Life Cycle Assessment of Marine Power Systems onboard Roll-on/Roll-off Cargo Ships: Framework and Case Studies

Thesis by
Janie Ling Chin

In Partial Fulfilment of the Requirements
for the Degree of
Doctor of Philosophy

Sir Joseph Swan Centre for Energy Research
Newcastle University
Newcastle upon Tyne
United Kingdom

6 October 2016

Abstract

A study into the environmental impact of marine power systems was performed in proximity with the defined research objectives: (i) present an overview on Annex VI *The International Convention for the Prevention of Pollution from Ships*, cargo ships, marine power systems and technologies; (ii) review life cycle assessment (LCA) methodology development; (iii) develop an LCA framework for marine power systems; (iv) carry out case studies to determine environmental impact, significant components and critical processes; (v) apply scenario analysis to investigate the sensitivity of the results to selected parameters; and (vi) compare power systems under study to verify their environmental benefits. Built upon literature and the proposed LCA framework, LCA case studies on conventional, retrofit and new-build power systems were performed using a bottom-up integrated system approach, where data were gathered and LCA models were created for individual technologies using GaBi software. Life cycle impact assessment was performed using CML2001, International Reference Life Cycle Data System (ILCD) and Eco-Indicator99 to estimate the environmental impact of the systems. It was found that disposing metal scrap of significant components was the principal cause of ecotoxicity potential, which was the impact category that showed the top two highest indicator results; and operating diesel engines and auxiliary generators or diesel gensets was mainly accounted for other impact categories. When compared with the conventional system, both retrofit and new-build systems consumed less fuels and released less emissions during operation but involved more materials and energy during other life cycle phases, leading to a decline in most impact categories to the detriment of a few burdens. The life cycle of marine power systems must be planned, managed and monitored appropriately for reduced environmental implications. Further research should address limitations presented in this study and explore other factors that might affect the environmental burdens of marine power systems.

Dedication

For my late mum, Agnes I T Sia.
I miss you so much from the bottom of my heart.

Acknowledgement

The thought of completing my PhD study had brought a warm glow of gratitude, excitement, satisfaction and relief to my heart. My first and foremost gratitude was directed to my husband, Stewart, and my family, in particular my sisters and brothers, Joyce, Jefferson, Jinny, Jerri, Jasmine and Jameson. Without their love, support and encouragement, I could never rise to the challenge. I could not express enough thanks to my main supervisor, Professor Tony Roskilly, for his offer of this golden chance to pursue my dream, his trust in my capacity and his patience with my style of being slow but conscientious rather than just ticking all the boxes. I had developed a lot and understood myself better over the years. I would also like to thank my second supervisor, Dr Oliver Heidrich, who challenged my ideas and approaches. Research presented in this thesis was delivered for a European Commission funded FP7 project 'INOvative Energy MANagement System for Cargo SHIP' (INOMANS²HIP, grant agreement no: 266082). Therefore, I was indebted to colleagues who were involved in the project, including Mr Hans van Vougt, Mr Tom Bradley, Mr Edward Sciberras, Mr Walter van der Pennen and Mr Alexander Breijs for sharing their technical knowledge and data. Without their data, the case studies would not be delivered. Knowing that I would revisit my thesis again and again for the rest of my life and probably would read it more frequently than anyone else, I would like to remind myself to remember this moment: if I could complete a part-time PhD study whilst having full-time employment, every challenge that I am undertaking the moment when I am reading this or will encounter in the future is achievable.

List of Papers

I Ling-Chin, J., O. Heidrich, and A.P. Roskilly, *Life cycle assessment (LCA) – from analysing methodology development to introducing an LCA framework for marine photovoltaic (PV) systems.* Renew Sustain Energy Rev, 2016. **59**: p. 352-378.

II Ling-Chin, J. and A.P. Roskilly, *Investigating a conventional and retrofit power plant on-board a Roll-on/Roll-off cargo ship from a sustainability perspective - A life cycle assessment case study*. Energy Convers Manag, 2016. **117**: p. 305–318.

III Ling-Chin, J. and A.P. Roskilly, *Investigating the implications of a new-build hybrid power system for Roll-on/Roll-off cargo ships from a sustainability perspective–A life cycle assessment case study*. Appl Energy, 2016. **181**: p. 416–434.

IV Ling-Chin, J. and A.P. Roskilly, *A comparative life cycle assessment of marine power systems*. Energy Convers Manag. 2016. **127**: p. 477–493.

V Ling-Chin, J. and A.P. Roskilly, *Life cycle assessment of a conventional power system on-board a Roll-on/Roll-off cargo ship*. Manuscript submitted to a journal for possible publication.

VI Ling-Chin, J. and A.P. Roskilly, *Life cycle assessment (LCA) framework for marine power systems on-board cargo ships*. Manuscript submitted to a journal for possible publication.

Contents

List of Figures

List of Tables

Abbreviation

A-HS	Auxiliary, high-speed
A-MS	Auxiliary, medium-speed
AC	Alternative current
ANN	Artificial neural network
AoPs	Areas of protection
BOD	Water biological oxygen demand
BOG	Boil-off gas
BTL	Biomass-to-liquid
$C_4H_8Cl_2$	1, 4-dichlorobutane
CML2001	Centrum Milieukunde Leiden
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Water chemical oxygen demand
CODLAG	Combined diesel-electric and gas propulsion
CODOG	Combined diesel or gas turbine propulsion
COSAG	Combined steam and gas turbine propulsion
CTUe	Comparative Toxic Unit for ecosystems
DALY	Disability-adjusted life year
DALYP	Disability adjusted life years per affected person
DC	Direct current
EAF	Electric arc furnace
ECAs	Emission Control Areas
EDIP97	Environmental Design of Industrial Products
EEDI	Energy Efficiency Design Index
EPS2000	Environmental Priority Strategies in Product Development
EVA	Ethylene-vinyl acetate
FloFlo	Float-on/Float-off
GES	General Energy Software
GHG	Greenhouse gas
GTL	Gas-to-liquid fuel
HC	Hydrocarbon
HCl	Hydrochloride acid
H_2S	Hydrogen sulphide

HF	Hydrofluoric acid
HFO	Heavy fuel oil
ILCD	International Reference Life Cycle Data System
IMO	International Maritime Organisation
IO	Input-output
IOT	Input-Output Table
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardization
LBG	Liquefied biogas
LB-CH_4	Liquefied bio-methane
LCA	Life cycle assessment
LCI	Life cycle inventory analysis
LCIA	Life cycle impact assessment
LIME	Life-Cycle Impact Assessment Method based on Endpoint Modelling
LNG	Liquefied natural gas
LWD	Lost work days
M-G	Main, gas turbine
M-HS	Main, high-speed
M-MS	Main, medium-speed
M-S	Main, steam turbine
M-SS	Main, slow-speed
MARPOL	International Convention for the Prevention of Pollution from Ships
MCFC	Molten carbonate fuel cell
MDO	Marine diesel oil
MGO	Marine gas oil
MSF	Multi-stage flash
NH_4	Ammonia
NMVOC	Non-methane volatile organic compound
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NRLVs	Noise-relevant life cycle variations
OCPL-LCA	Indoor occupational priority list for LCA
OH	Occupational health

OS	Occupational safety
PCB	Printed circuit board
PCTC	Pure car truck carrier
PDF	Potentially Disappeared Fraction
PEMFC	Proton exchange membrane fuel cell
PM	Particulate matter
$PM_{2.5}$	Particulate matter 2.5
PM_{10}	Particulate matter 10
PSO	Particle Swarm Optimisation
PTO/PTI	Power-take-off/power-take-in
PV	Photovoltaic
RME	Rapeseed methyl ester
RO	Residual oil
RoPax	RoRo passenger ship
RoRo	Roll-on/Roll-off
Rpm	Revolutions per minute
SCR	Selective catalytic reduction
SEEMP	Ship Energy Efficiency Management Plan
SEI	Solid-electrolyte-interphase
SOFC	Solid oxide fuel cell
SO_x	Sulphur oxides
TRACI	The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
UFs	Uncertainty factors
UNCTAD	United Nations Conference on Trade and Development
VFDs	Variable frequency drives
VLCC	Very large crude carrier
VOC	Volatile organic compounds
WE-CF	Work environment characterisation factors
WE-DALY	Work environment disability-adjusted life year
WHI	Workers affected by a particular hazardous item
WHRS	Waste heat recovery system
WMD	Workers diagnosed suffering certain magnitude of disability
YLD	Years of life lived with disability

YLDn	Number of years of life lived with disability
YLDP	Years of Life lived with a Disability per affected Person
YLL	Years of life lost
YLLn	Number of years of life lost
YLLP	Years of life lost per affected person

Chapter 1. Introduction

"*The most important and urgent problems of the technology of today are no longer the satisfactions of the primary needs or of archetypal wishes, but the reparation of the evils and damages by the technology of yesterday.*"

Dennis Gabor

Innovations: Scientific, Technological and Social, 1970

Among all modes of transport, marine has appeared to be paramount. In 2000, cargo shipped by marine transport accounted for 90% of world goods, and the quantity of goods shipped was projected to treble by 2030 [1]. The quantity of goods shipped in 2013 reached 9.55 billion tonnes, which was a 60% increase compared to the 5.98 billion tonnes shipped in 2000 [2], which made the projection plausible. Further evidence of marine transport as an important mode of conveyance could be seen in terms of capacity, in which marine transport facilitated more than 50% of trade outside Europe in 2008 [3] and more than 80% of worldwide trade in 2015 [4]. Accordingly, the quantity of greenhouse gas (GHG) emitted to the atmosphere by ships must be considered significant, if not increasingly substantial. In 2000, ocean-going ships emitted 638–800 Tg of carbon dioxide (CO_2) [5] and 52–56 Tg of sulphur dioxide (SO_2) [6, 7] whilst consuming approximately 20 Tg of marine diesel oil (MDO) [5]. Also, [8] reported that in 2005, marine transport released 651 Tg CO_2 equivalent GHG emissions. By comparing the results from 16 sources that used emission data between 1993 and 2005, [9] noted that global CO_2 emissions released by marine transport had increased from 453 Tg to 960 Tg. Marine transport in 2012 contributed 2.1–2.2% of global CO_2 and CO_2 equivalent GHG emissions, which translated to 938 Tg and 961 Tg respectively [10]. However, [11] noted that these figures were likely underestimated as documenting ship emissions in national inventories was not required but rather a voluntary act. Underestimating ship emissions seemed to have existed for some time. [12] claimed that the emissions of SO_2 'were greater than had previously been thought' as the emissions were not in agreement with the inventories published in Lloyd's 1995 Register of Ship.

Allowing for the variations in emissions, an important and recurring theme has emerged: emissions released by marine transport were not insignificant and seemed to be increasing and, without due care, it could exacerbate climate change. The seriousness of this issue was also emphasised by [13] who forecasted that taking no action at all, in this matter, could result in an increase of up to 250% in shipping emissions by 2050, compared to 2007. Concern for this matter provided the motivation for the research presented in this thesis, “Life cycle assessment of marine power systems onboard Roll-on/Roll-off (RoRo) cargo ships: framework and case studies”. The following sections describe the motivation and the scope of the study in detail.

1.1 Marine Regulation: the *International Convention for the Prevention of Pollution from Ships* (MARPOL)

As the agency of the United Nations which focused on shipping safety, security and pollution prevention, the *International Maritime Organisation* (IMO) had adopted the *International Convention for the Prevention of Pollution from Ships* (MARPOL) as the strategy to minimise and furthermore prevent damage on marine environment due to potential pollutants released during ship operation or accident. In total, six technical annexes (denoted as I–VI) were established in line with the sources of pollutants, including oil, noxious liquid substances, chemicals, sewage, garbage and air pollutants. Amongst all, Annex VI *Regulations for the Prevention of Air Pollution from Ships* was most commonly emphasised by maritime stakeholders, such as ship owners, operators, builders, classification societies, authorities, regulators and researchers. As detailed in [14], Annex VI covered 18 regulations from application to fuel oil availability and quality, as presented in Figure 1.1. As clearly stated in Regulations 13 and 14, a number of thresholds were proposed and enforced (or would be enforced in the near future) on shipping emissions released by marine diesel engines installed onboard ships, in particular nitrogen oxides (NO_x), sulphur oxides (SO_x) and particulate matter (PM). In addition, ships travelling in the Emission Control Areas (ECAs), including Baltic Sea, North Sea, North American and Caribbean Sea, had been subject to stricter requirements. Ships were obliged to meet the thresholds by switching to low-sulphur fuels or employing an alternative technique, as indicated in Regulation 4. In addition, the measure of *Energy Efficiency Design Index* (EEDI) for new ships and the implementation of the *Ship Energy Efficiency Management Plan* (SEEMP) for all ships became mandatory in 2013 [15], which presented a challenge to the maritime industry.

* **Regulation 1: Application**
The provisions apply to all ships unless otherwise stated.

* **Regulation 2: Definitions**
Glossaries commonly presented in the provisions are defined.

* **Regulation 3: Exceptions and exemptions**
Emissions due to equipment failure, ship safety/damage, life-saving at sea, trials for research on emission reduction and control technology, sea-bed mineral exploration, exploitation and production are exempted.

* **Regulation 4: Equivalent**
The use of any fitting/material/appliance/procedure/alternative fuel oil which is as effective in terms of emission reductions as that required by this Annex can be seen as an alternative solution.

* **Regulation 5: Survey**
The requirements include
- (a) for above 400 gross tonnage or a floating drilling rid/other platforms):
  - (1) an initial survey before the operation of the ship;
  - (2) an annual survey, once a year;
  - (3) an intermediate survey, 3 months around the 2nd or 3rd year of service;
  - (4) a renewal survey, as specified by the Administration every 5 years; and
  - (5) an additional survey together with important repairs/renewals'
- (b) for ships less than 400 tonnage: as requested by the Administration.

* **Regulation 6: Issue or endorsement of a certificate**
An International Air Pollution Prevention Certificate shall be issued after the initial or renewal surveys.

* **Regulation 7: Issue of a certificate by another party**
The certificate can be issued by a party requested by the Administration.

* **Regulation 8: Form of certificate**
The certificate shall be presented in English, French or Spanish using the set template.

* **Regulation 9: Duration and validity of certificate**
Less than 5 years.

* **Regulation 10: Port state control on operational requirements**
A ship is subject to inspection if there is a solid ground to believe that the owner/crew are less familiar with the prevention procedures of air pollution from the ship.

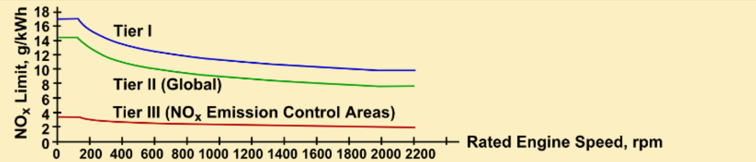
* **Regulation 11: Detection of violations and enforcement**
Co-operation is required in the detection and any law related to enforcement and safeguards of pollution prevention, reduction and control applies to this Annex.

* **Regulation 12: Ozone depleting substances**
The substances found onboard ship may include (and not limited to)
- (1) halon 1211 bromochlorodifluoromethane;
- (2) halon 1301 Bromotrifluoromethane;
- (3) halon 2402 1, 2dibromo-1, 1, 2, 2-tetrafluoroethane;
- (4) CFC-11 trichlorofluoromethane;
- (5) CFC-12 dichlorodifluoromethane;
- (6) CFC-113 1, 1, 2-trichloro - 1, 2, 2-trifluoroethane;
- (7) CFC-114 1, 2-dichloro -1, 1, 2, 2-tetrafluoroethane;
- (8) CFC-115 chloropentafluoroethane.

Installations containing
- (a) substances 1-8 are prohibited from 19 May 2005; and
- (b) hydro-CFC are to be prohibited from 1 January 2020.

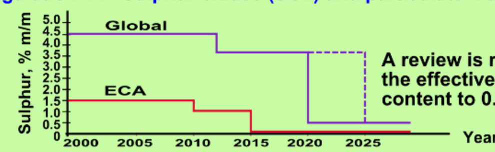
* **Regulation 13: Nitrogen oxides (NOx)**

Tier	Ship construction date	Total weighted cycle emission limit (g/kWh) for different engine rated speeds (rpm), n: n < 130	n = 130 -1999	n = 2000+
I	(a) Prior to 1 Jan 2000, minimum power engine cylinder displacement are 5000kW 90 litres (b) From 1 Jan 2000 onwards	17.0	$45\ n^{-0.2}$	9.8
II	(a) From 1 Jan 2011 onwards (b) From 1 Jan 2016, operate in ECA	14.4	$44\ n^{-0.3}$	7.7
III	From 1 Jan 2016	3.4	$9\ n^{-0.2}$	2.0



(Graph taken from http://transportpolicy.net/index.php?title=International:_Marine:_Emissions)

* **Regulation 14: Sulphur oxides (SOx) and particulate matter (PM)**



A review is required by 2018 to decide the effective date of limiting sulphur content to 0.5%, i.e. 2020 vs. 2025.

(Graph adopted from http://www.procal.com/marpol_regulation_14.htm)

* **Regulation 15: Volatile organics compounds (VOCs)**
Only apply to
- (a) tankers; and
- (b) gas carriers if safe retention of non-methane VOCs or safe return is allowed.

Tankers shall
- (a) employ a vapour emission control system; and
- (b) implement a VOC management plan.

* **Regulation 16: Shipboard incineration**
Shipboard incineration shall only be allowed in a shipboard incinerator. Substances which are prohibited include
- (a) cargo residues (subject to oil and chemical pollutions or garbage);
- (b) polychlorinated biphenyls (PCBs);
- (c) petroleum products containing halogen compounds;
- (d) sludge oil or sewage sludge; and
- (e) residues from exhaust gas cleaning system.

* **Regulation 17: Reception facilities**
Allow for the removal of ozone depleting substances and associated equipment and exhaust gas cleaning residues from ship.

* **Regulation 18: Fuel oil availability and quality**
The availability of fuel oils shall be promoted by all parties.
The fuel oil shall be blends of hydrocarbon processed from oil refinery and free of
- (a) inorganic acid; or
- (b) any substance that risking ship safety, harming the personnel, or resulting in additional air pollution.

Figure 1.1: Annex VI *Regulations for the Prevention of Air Pollution from Ships*.

1.2 Previous Work on Emissions, Energy Efficiency and Alternative Solutions

Some studies on marine transport had primarily focused on emissions. In the late 1990s, deep sea storage of CO_2 released from marine power systems were investigated. For instance, [16] estimated the environmental impact of CO_2 transport systems whilst [17] proposed a framework to select the options based on legal and socio-political perspectives. By conducting experiments, [18] showed that SO_2 and NO_x emitted from international shipping had a consequential scale of influence on local, regional and global air quality. By taking account of ship movements, energy and environmental aspects, [19] applied a model to estimate energy consumption and emissions released by ships within selected ports. Similarly, [20] claimed that shipping industries, which released CO_2, nitrogen dioxide (NO_2) and SO_2 in particular, could have significant impact on the environment. With exhaust samples, [21] analysed the correlation between sailing modes and emissions. [22] explored the relationship between CO_2 emission and other factors such as ship type, size and geographic setting. Focussing on SO_2 abatement techniques, [23] analysed both energy and emissions released by marine fuels due to crude oil production, processing, distribution, consumption and scrubbing. To assist ship owners in selecting the most suitable abatement technique, [24] developed a generic methodology. [25] analysed the composition of exhaust released from marine fuel combustion. [26] analysed to what extent efficient shipping could help reduce global CO_2 emissions. To estimate the contribution of shipping to global CO_2 emissions, [26] assessed global CO_2 reduction targets using marginal abatement cost curves developed for shipping and CO_2 abatement techniques. [27] studied emissions, cost and profit for the design of bulk vessels. To compare the use of marine gas oil (MGO) and scrubbers, [28] performed a cost-benefit analysis. Based on emission data collected from ships, [29] characterised PM in relation to particle size, mass, number of volatility. Also, [30] compared current methods used for estimating energy and emissions.

For the vast majority of vessels, marine diesel engines were the primary means of energy conversion and source of harmful emissions. Thus, a number of studies had focused on the correlation between diesel engine operation and emissions. For example, [31] explored how the temperature and pressure of charged air would affect NO_x emission whilst [32] attempted to reduce such emission via injection pressure correction. Meanwhile, [33] investigated how engine maintenance would affect NO_x and carbon monoxide (CO) emissions. In addition, [34] studied PM emitted by engines and possible reduction control strategies. [35] investigated the influence of EEDI on driving future propulsion system design for liquefied natural gas (LNG) carriers.

Considering that the propulsion and operation of cargo ships were made possible by power systems, it was believed that research on marine power systems onboard cargo ships was worth investigating. Marine technologies that were incorporated into a marine power system could be classified as conventional and innovative. The former was commercially and commonly applied whilst the latter was researched. Whilst diesel engines, shaft generators, boilers, economisers, gearboxes, propellers and bow thrusters represented conventional technologies, power take-off/power take-in systems (PTO/PTI), lithium-ion batteries, photovoltaic (PV) systems, cold ironing, flywheels, sails, fuel cells and super capacitors were examples of innovative technologies.

Alternative emission reduction strategies could be considered from technical, operational and multifaceted perspectives. Technical strategies included better vessel designs, more efficient engines and propulsion systems, use of advanced technologies, emission abatement systems and clean fuels. Based on a holistic approach, [36] investigated advanced computer-aided techniques for better ship designs. Recovering waste heat from diesel engine exhaust via the application of novel cycles had been investigated. For example, [37] designed a combined steam and organic Rankine cycle deployed by a diesel engine. [38] modelled and compared cooling systems powered by waste heat absorption and vapour compression cycles respectively. Although not as widely applied as diesel engines, alternative prime movers employing various cycles had been reported. In this matter, [39] discussed the design of combined cycles, including combined gas and steam turbines, combined gas turbine electric and steam, and heat recovery steam generators. [40] extended the study by covering the implications of combined cycles, followed by a comparison of emissions released by gas turbines and diesel engines. Also, [41] investigated a boil-off gas (BOG) reliquefaction system with cascade cycles designed for liquefied natural gas carriers. Whilst [42] presented marine power system designs which employed various types of fuel cells, [13] proposed a marine trigeneration system incorporating diesel generators, solid oxide fuel cell (SOFCs), a gas turbine and an absorption heat pump. Also, the use of sails to assist ship propulsion was explored. Using wind tunnel tests and computational analysis, [43] described the concept and analysed the performance. [44] modelled wind propulsion technologies including Flettner rotors and towing kites. [45] used sensors to measure strain and stress of a foremast by experiment. Based on performance and aerodynamic analysis, [46] proposed cascade hard sails for potential applications in marine transport. For cold-ironing technologies, [47] investigated the shore-side design and control aspects, and [48] examined electrical characteristics of the installation.

Operational strategies improved energy efficiency via effective operation, which adopted slow steaming and/or optimisation of speeds, schedules, weather routings and fleet planning. Ship speed had been scrutinised from different angles. For instance, [49] reviewed speed models and relevant parameters for marine transport. [50] investigated sailing speed optimisation for ships that transited across ECAs. Based on real-time operational profiles of two relevant ships, [51] explored the potential of improving energy efficiency via shorter waiting periods in port. Whilst [50] focussed on optimisation issues associated with fuel-switching, [52] developed a model which could be used to determine the optimal sailing route and speed. Based on operational data taking into account sailing speed, cargo capacity and time spent in port and at sea, [53] evaluated energy efficiency of feeders.

Multifaceted strategies presented wider scope which considered more than one factor covering technical, operational, decision-making, economic, environmental and legislative elements. [54] presented a review which covered technical (including propeller programming, fuel slide valves, oil consumption and retrofit) and operational aspects (in terms of business route, ship trim, hull, propeller and engine performance, slow steaming, speed and fuel consumption). Using a life-cycle energy management tool which considered configuration designs and operation profiles, [55] estimated energy efficiency of container ships. [56] analysed the efficiency and economic performance of a waste heat recovery system (WHRS) that deployed transcritical Rankine cycle. Whilst [57] developed a model for fuel consumption prediction using artificial neural network (ANN) to support decision making for energy efficient operation, [58] proposed a framework to assist ship owners in breaking down barriers to energy efficiency enhancement. In line with economic and environmental perspectives, [59] scrutinised the implications of speed reduction. To achieve optimum speed and fuel consumption at minimum cost, [60] proposed an algorithm for bunker fuel management. [61] reviewed the fundamental principles, technical designs and economic aspects of WHRS technologies. From technical and economic perspectives, [62] compared two propulsion options for ferries and RoRo cargo ships, i.e. a conventional diesel engine and a dual fuel engine employing a WHRS. [63] studied different optimisation possibilities that considered various control variables for a diesel engine integrating with a WHRS.

From a legal perspective, [64] assessed alternatives that might comply with future requirements. [65] investigated the relationship between marine technologies and legislation. [66] addressed the social-economic benefits of cold ironing. Using environmental governance mechanisms, [67] focused on the deployment of ‘green’ ship operation by shipping organisations. Besides, decision support tools were developed in relation to retrofitting a cargo ship in which [68] investigated the installation of an exhaust gas scrubber and fuel switching whilst [69] studied the option of connecting shaft generators to frequency converters. Also, [70] presented a decision-making framework for cleaner transportation which assessed the trade-off in all potential technologies and fuel sources. Meanwhile, [71] developed a process modelling framework for electric propulsion systems on-board large bulk carriers based on a system approach.

To date, the conventional power system design (i.e. diesel-mechanical systems) remained advantageous for vessels operating at a low speed applying slow steaming such as tankers, carriers and containers. However, all-electric was perceived as beneficial if additional cargo capacity was desired by these cargo ships in addition to RoRo cargo and passenger ships which required improved manoeuvrability and more electric power to meet high hotel loads [72]. Indeed, electric systems were not new. They had been researched and applied in cruise ships, as noted by [73, 74]. Literature examples included [72] which discussed design and control concepts, components, systems and future trends; [75] which presented the terminology and dependability theory of integrated power systems fundamentally required for electric propulsion; [76] which focused on challenges and novel trends of electric power generation schemes; [77] which proposed a control system for economic and environmental operation; [78] which discussed the benefits and challenges of marine electrical systems and how they were affected by the recent development in power conversion technologies; and [79] which overviewed the past, present and future of electric ships.

1.3 Previous Work on Environmental Impact Study

Implementing on-board technologies would also have an impact on the environment itself, negligible or significant. In this context, the environmental impact such as climate change, stratospheric ozone depletion, photochemical ozone formation, acidification, eutrophication (nitrification), human toxicity, ecotoxicity, depletion of abiotic resources and depletion of biotic resources as recognised by the International Organisation for Standardisation (ISO) [80] might or might not be relevant. According to [50], shipping was perceived to be environmentally friendly among all transportation modes, in terms of total energy consumption and emissions. On the contrary, [81] concluded that shipping had largely escaped from environmental scrutiny if compared to other transportation modes. One way to verify the claims was to look at existing Life Cycle Assessment (LCA) studies – a common tool used for environmental assessment – and the number of such studies which had been applied to this transport mode. Previously, relevant LCA studies focussed on marine vessels, structures, fuels, power technologies, emission abatement techniques, waste, software and framework development, as briefly reported here. To assess transport modes, [82] developed methodologies that could be applied, followed by [83] where a screening assessment was performed and [84] in which case studies on transport chain alternatives were presented. Building on the developed methodologies, screening assessment and case studies, [85] presented an overview. [86] compared materials used for constructing the structure of an inland ferry i.e. steel and fibre composite. Whilst [87] analysed the impact of fossil fuels, [88] investigated the pathways towards biofuel applications. Focussing on fuel cell technologies and engines, [89] compared molten carbonate fuel cells (MCFCs) with diesel engines; [90] compared SOFCs to diesel engines; and [91] compared fuel cells, gas and diesel engines. In addition, [23] assessed emission abatement techniques whilst [92] studied waste management options in port. Also, [93] attempted to develop a tool that could be used during the design phase. The work presented by [94] and [95] related to one another on software development, as did [96] which used commercial software. Whilst [97] presented an eco-design demonstrator that incorporating environmental element, [98] covered additional elements such as cost and safety aspects. How environmental impact was covered in these studies and their limitations are summarised in Table 1.1.

Table 1.1: Focus, coverage of environmental impact and limitation of existing LCA literature relevant to marine transport.

Focus, coverage [a]	Literature type [b]	Limitation
Emission abatement, III	I [23]	Only energy use and GHG emissions were assessed per nautical mile of distance travelled
Transport, II	II [82]	Data were not presented; it was reported that most data were available in SimaPro.
Transport	II [83]	Not publicly available.
Transport, IV	III [84]	The focus was on transport chains including railway, road, aviation and waterborne.
Transport, IV	I [85]	Transport chains of cargo vessels and trucks were studied but not fully reported.
Shipping, IV	II [86]	Data regarding emissions, engines and fuel combustion were from literature or Ecoinvent instead of primary data source.
Marine fuels, III	I [87]	No account for reference ship, as did real-time data and total fuel consumption by the engine.
Marine fuels, I	I [88]	Selective catalytic reduction, infrastructure, real-time operation and fuel consumption differentiation was not considered.
Auxiliary power, IV	I [89]	No information about the reference ship; only 1 diesel engine was assessed although 3 units were installed; reformer required for the MCFCs was not considered.
Auxiliary power, IV	I [90]	The lifespans of SOFCs and diesel engines were not considered; the comparison was made for 1kWh electricity generated without reporting the total impact.
Power technology, IV	IV [91]	The functional unit was not appropriately defined. It was not clear if the system was for main or auxiliary power.
Marine waste, IV	I [92]	Most data were not country specific and data for cement production plant were limited; all processes with a contribution less than 0.35% were excluded.
Shipping software, II	II [93]	Brief and limited to the selected components and data; neither impact assessment results nor the computer tool itself was available.
Shipping software, I	III [94]	The software and operational data e.g. fuel type and consumption were not available; emissions were reported as environmental impact.
Shipping software, III	I [95]	The manufacturing phase was not included in the scope.

Shipping software, II	I [96]	The software tool was not available; impractical as the environmental impact or emission reduction of a technology was required to calculate the index.
Shipping software, II	I [97]	Neither the demonstrator nor the tool was available; only very limited data and impact assessment results were presented.
Shipping software, II	I [98]	The tool was not available; data and details of environmental, economic and social assessments were mostly not reported.
Framework, I	I [99]	Limited to hull and machinery system, diesel oil and steel were the only resources under assessment, and no environmental impact was assessed.

[a] Coverage of the environmental impact: I No coverage; II Recognition without any estimate; III Assessment of 1–3 impact categories; and IV Assessment of more than 3 impact categories

[b] Literature type: I Journal article; II Report; III Conference proceeding/paper; and IV Thesis

1.4 Knowledge Gap

As implied by [100], some previous work focussed on emissions without elucidating environmental issues. The omission was commonly found on literature which was reported in the first paragraph of **Chapter 1.2**. A plausible explanation was that CO_2 emission had been adopted as a means to measure energy efficiency of marine power systems as in EEDI [35] whilst other GHG emissions were of lower magnitude and had less contribution towards climate change. However, estimating GHG emissions and climate change was not enough as it did not present a full picture of the impact of marine transport on the natural environment. Climate change only represented one of the attributes of natural environment from an LCA perspective. Any unnatural change in the attributes of human health and/or natural resources was indeed within the scope of environmental issues. Some examples of environmental issues included (i) ecotoxicity (on aquatic and terrestrial ecosystems), acidification, eutrophication and photochemical ozone formation in respect of natural environment; (ii) noise, odour, non-ionising radiation, thermal pollution and human toxicity (such as respiratory, cancer and non-cancer effects) in relation to human health; and (iii) freshwater consumption, depletion of fossil fuels and mineral resources relevant to natural resources. Despite being mature and widely implemented, conventional marine power systems had neither been scrutinised extensively in a single study nor covered substantially from an LCA perspective. Exploratory research questions therefore unfolded: What was the estimated environmental impact of a conventional marine power system onboard a cargo ship? What parameters might affect such impact?

By integrating different technologies, various power system designs would be possible. Therefore, the environmental impact of each design would be subject to change, in line with ship types, technology types, number of components and operational profiles. Different marine power system designs that could be employed onboard a cargo ship should be compared. Retrofitting existing cargo ships had been envisaged as a green and competitive route for marine vessels that were built prior to the enforcement of MARPOL Annex VI. Also, it was worth noting that the number of global vessels would be dynamic due to demolition of old ships and construction of new-build ships year by year. For instance, 22.4 million of gross tonnage was sold for demolition and more than 309.4 million of deadweight tonnage was ordered in 2014 [4]. Therefore, the opportunity of implementing innovative power systems onboard new-build ships was unlocked. Some advanced technologies had been rarely applied to marine transport despite being more commonly implemented for onshore applications (such as PV systems) and road transport (such as energy storage); both with a limited but increasing capacity. Neither had the integration of these emerging technologies in a retrofit/new power system nor their environmental performance been studied using an integrated system approach. For a specific research focus, a particular type of cargo ship should be selected. Altogether, more exploratory research questions were unfolded: What was the estimated environmental impact of a retrofit or a new-build power system onboard a cargo ship? Would integrating selected emerging technologies into an existing or a new-build marine power system add any environmental benefits and promote sustainability of the chosen ship type?

Concern in this matter had led to a research project funded by the European Commission where this PhD study was delivered as a part of research dissemination. As the study was of exploratory nature, it aimed to contribute to the conceptual understanding of LCA study on marine power systems. To achieve the aim, the following research objectives were defined:

- overview cargo ships, marine power systems and technologies
- review on LCA methodology development
- overview the end of life phase of relevant technologies and metallic scrap

- develop an LCA framework for marine power systems
- estimate environmental impact of selected power systems via LCA case studies
- identify significant components and critical processes
- investigate the sensitivity of life cycle impact assessment (LCIA) results to selected parameters
- compare power systems under study to verify the environmental benefits of innovative power systems

1.5 The Fundamental Concept of LCA as a Research Tool

Previously, LCA was referred to as a cradle-to-grave assessment. It had been practising since the early 1970s to assess the environmental impact of a product, either goods or service, throughout its life cycle [101]. The framework, principles and basic requirements of handling each LCA phase [102] was introduced by ISO in 1997, aiming to establish a universal technique which could be widely used to address the potential environmental impact associated with a product. This was extended in the late 1990s and beyond for the four LCA phases, including goal and scope definition and life cycle inventory analysis (LCI) [103], LCIA [104] and interpretation [105]. Then, they were revised and replaced by two shorter but more succinct documents, ISO 14040 and ISO 14044 [106, 107]. A more detailed elaboration of the historical development of the Standards was published in [108, 109], in addition to a summary of changes reported by [110].

When an LCA practitioner was interested in a particular product, either goods or service, and furthermore carried out an LCA study to estimate its potential environmental impact, the product was referred to as the product system or the system being studied. According to [111], the “areas the society seeks to protect” were the areas of protection (AoPs) in an LCA study. ISO 14044 had implicitly defined human health, natural environment (e.g. ecosystem and biodiversity) and resources (e.g. abiotic resources) as AoPs. A few commissioners/practitioners had fully received the definition, for instance [112], but others preferred to adopt different terminologies and/or extend the scope. To give a few examples, UNEP/SETAC Life Cycle Initiative [113, 114] recognised human health, resource depletion and ecosystem quality as the AoPs whilst [111, 115-117] recommended man-made environment (e.g. monuments and forest plantations) as the fourth AoP. However, [118] pointed out that man-made environment could not be considered as no scientific consensus had been reached in quantifying any impact on man-made environment. This study adopted the ISO's definition.

The LCA framework proposed by ISO is illustrated in Figure 1.2. In brief, the goal of an LCA study should tell why, for whom and for what. This could be done by clearly defining the reason to perform the study, the targeted audience, the intended application, together with a declaration of any plan to use the results in comparative assertions and disclose them to the public. The scope of the study should complement the set goal by defining what would be studied, what methodology or approach would be applied and what requirements should be met in the following phases. In principle, this included the product system, function, functional unit or reference flow, system boundary, allocation, assumptions, data quality, impact categories, LCIA methodologies, limitations, critical review (if any) and report format. At this stage, whether the LCA study was of gate-to-gate, cradle-to-gate, gate-to-grave or cradle-to-grave would be determined, as were processes and elementary flows to include in the study. Mass, energy and environmental relevance were recommended as the cut-off criteria used to exclude any insignificant inputs, outputs or unit processes from a study.

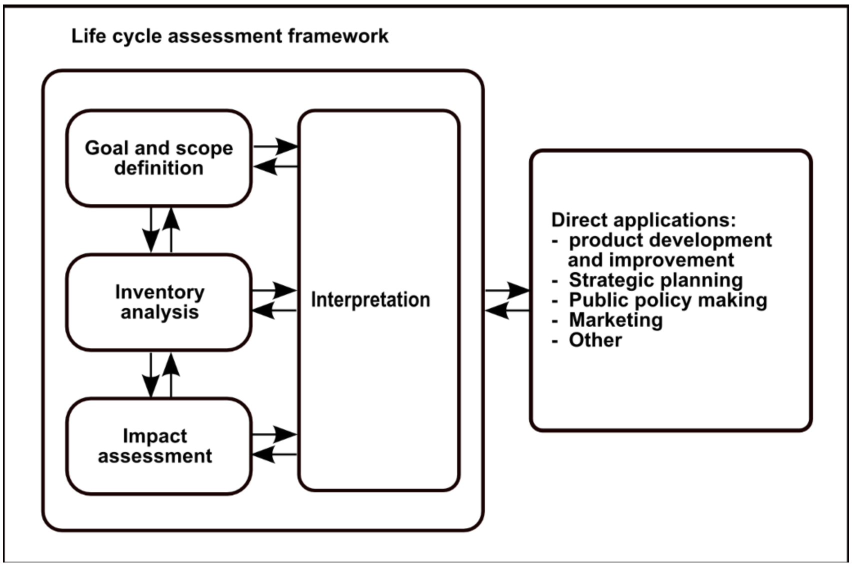


Figure 1.2: LCA framework as recommended by ISO 14040 [106].

During LCI, materials, energy flows and products involved throughout the life cycle of the product system under study were compiled from various data sources as inputs and outputs. In practice, LCI presented a persistent challenge, i.e. allocation in the cases of multi-functionality (involving two or more functions, co-products or systems) and recycling. The step-by-step approach from avoiding to applying allocation based on physical or other relationships was established by ISO 14044, as illustrated in Figure 1.3. In respect of recycling, ISO 14044 recommended avoiding allocation if material properties remained unchanged; else, allocating the inputs and outputs based on (and in the order of) physical properties, economic value or the number of use.

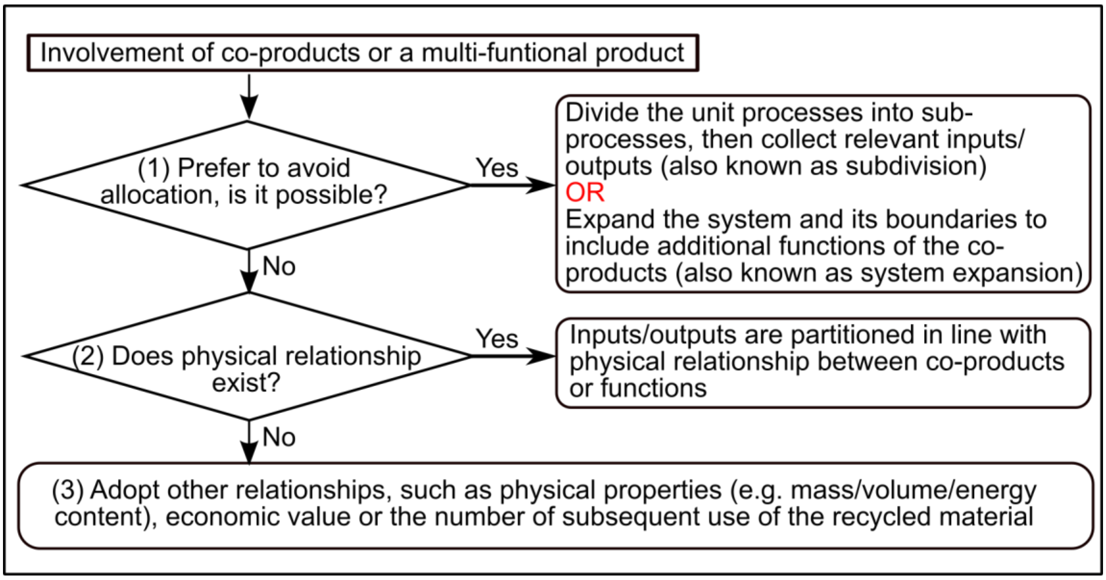


Figure 1.3: How to allocate inputs/outputs between co-products or functions.

In relation to of LCIA, ISO 14040 and 14044 had established *selection, classification and characterisation* together with *normalisation, grouping and weighting* as mandatory and optional elements respectively. Each element involved different technical tasks with some basic requirements:

- *Selection.* Impact categories, category indicators and characterisation models that were recognised internationally and related to the product system under study should be selected. As detailed in ISO 14044, the impact categories should be (i) named descriptively; (ii) identified with category indicators, endpoints and LCIs that could be assigned to as well as relevant characterisation factors and models that could be applied; and (iii) selected to comprehensively represent the environmental issues caused by the product system under study. The category indictor of an impact category must be environmentally relevant, i.e. able to show the consequences of LCIs on the category endpoint. Based on an identifiable environmental mechanism, the characterisation model should be (i) technically and scientifically sound where the extent of validity was reported; (ii) linking the LCIs to the indicator and endpoint of selected impact categories, and (iii) deriving characterisation factors for relevant substances to allow for an aggregated impact for each impact category. During selection, it was required to involve minimal value choice and be free of double-counting.

- *Classification*. LCI results were assigned to appropriate impact categories. Some LCI results would lead to only one single impact category whilst others could result in more than one impact category. The latter involved either parallel or serial mechanism.
- *Characterisation*. For each impact category, a category indicator result (i.e. LCIA result) was calculated in a common unit. The indicator result was the aggregated product of the LCI results and the characterisation factors.
- *Normalisation*. Category indicator results were compared to a reference. This could be useful for checking inconsistency, determining the significance of an indicator result and preparing for the following stages. If normalisation was applied, the technical tasks must be carried out diligently, as explicitly pointed out by ISO 14044, "the normalisation of the indicator results can change the conclusions drawn from the LCIA phase".
- *Grouping*. Impact categories were organised based on indicator results and value choice. Impact categories were (i) descriptively sorted based on inputs/outputs, spatial dimension from local to global scales, AoPs or the scientific degree of the model used; and/or (ii) hierarchically, normatively ranked in the order of certainty or reversibility degrees, or based on policy priorities.
- *Weighting*. Indicator results or normalised results were converted to an aggregated score across impact categories. For all impact categories under study, weighting factors were derived from value choice and applied to the indicator results or the normalised results.

Life cycle interpretation involved the identification of significant issues and evaluation of LCI and LCIA results in terms of consistency, completeness and sensitivity. Sensitivity of the results was subject to uncertainty and methodological choice; both issues could be dealt with using scenario analysis. Alternatively, uncertainty could be addressed with additional data collection from further research or other approaches for uncertainty analysis. It was essential to recognise that the results could only provide an estimate on the environmental burdens where absolute accuracy was impossible in any case. Therefore, explaining limitations, making recommendations and drawing conclusions should be included.

1.6 In Need of an LCA Methodology Review

The following conclusion made by [109] deserved further investigation:

> *…critiques of the ISO 14040 series has markedly dropped off since its redrafting and consolidation in 2006. Indeed, some recommendations are merely repetitions of similar arguments made previously or remain unsuitable…*

The nonexistence of persistent critique, even if it was the case, did not necessarily indicate acceptance or satisfaction. A possible explanation was that neither new ideas nor solutions had been proposed whilst the research community had become tired of the persistent problems. Indeed, some issues associated with the ISO 14040 series had been reported by [111, 112, 119, 120] after the revision, including its overly flexible nature, the absence of step-by-step guidelines, the unequal level of detail, the legitimacy of the results as well as the lack of consistency and quality assurance, to name but a few. If recommendations were repeated, did they not imply a possibility of unresolved issues? Also, it was unclear which recommendations were 'unsuitable' in this context as no elaboration was provided. If the claim (that the critiques had dropped off after revision) was true, it would be intriguing to find out if LCA, as the focus of the Standards, had also become mature and free of critiques.

A number of previous LCA reviews were published, which focussed on

- principles, challenges and opportunities [108, 111, 115, 116, 121-130];
- materials [131, 132];
- buildings and construction [133-138];
- food [139];
- transport [140, 141];
- bioenergy [142-149];
- solar energy [150-153];
- wind energy [154-157];

- geothermal energy [158]); and
- electricity generation [159-161].

This did not repudiate but intensify the need of a new review because an up-to-date analysis on LCA methodology development embracing all life cycle phases was still lacking whilst it was intriguing to find out if LCA had become mature. Prior to this study, no one had ever attempted to review existing review articles. Also, integrating concepts/approaches proposed for a particular topic and clearly showing the latest research development trend were missing. Therefore, an up-to-date analysis on LCA methodology development covering the four life cycle phases was required for better understanding.

1.7 In Need of an LCA Framework for Marine Power Systems

It was worth noting that product systems assessed in LCA studies were generally like chalk and cheese; and even in compliance with ISO Standards with a similar research focus, each application would be case specific. Therefore, transferring from theories to applications remained one of the greatest challenges faced by LCA researchers, in particular to those who were new to the topic. Such a challenge had inaugurated the development of LCA frameworks for product systems. Previously, a number of LCA frameworks were proposed, as summarised in Table 1.2. Each framework had distinct scope such as life cycle phases, specific inputs/outputs/materials/processes, LCI methodologies, LCIA impact categories and analysis, life cycle interpretation, social, national and sectoral focus, or combined with other disciplinary approaches. In this matter, research gaps existed as the coverage was not all-embracing yet where LCA frameworks for other scope were still missing. The LCA framework proposed by [99] covered how to estimate emissions of a sea-going ship attributable to hull and machinery systems. The scope was limited as it took into account engines and boilers only without addressing the impact of such emissions on the environment. In addition, component construction was limited to engines which considered diesel oil and steel only whilst boiler construction was not covered. As such, it intensified the need for an LCA framework that would focus on power systems onboard ships, in particular, addressing resource consumption and environmental impact throughout the life cycle.

Table 1.2: Scope of existing LCA frameworks.

Scope	Literature
Life cycle phase	• Resource supply, demand and use [162] • Material selection [163] • Manufacture [164]
LCI for specific input, output, material or process	• Green water flows [165] • Nanomaterials [166] • Recycling [167] • Topsoil erosion, transport and deposition [168]
LCI methodology	• Database [169] • Allocation [170] • Consequential approach [171] • Input-output based evaluation [172] • Hybrid approach [173] • Dynamic approach [174] • Temporal discounting [175]
LCIA─impact category and analysis	• Resource depletion [176] • Land use [177] • Traffic noise [178] • Freshwater resource depletion [179] • Noise impact [180] • Indoor environmental quality [181] • Noise, ecological light pollution and radio-frequency electromagnetic fields [182] • Indoor nanoparticle exposure [183] • Decision analysis [184, 185]
Interpretation	• Uncertainty analysis [186]
Social focus	• Social LCIA [187] • Working environment [188] • Concept [189] • Methodology [190]
National focus	• Malaysia [191] • Singapore [118]
Sectoral focus	• Agriculture [192, 193] • Tourism [194] • Food processing i.e. fish products [195] • Food production chain [196] • Biofuel [197] • Electric cars [198, 199] • Ocean going ships [99] • Manufacturing [200]
Wider scope	• LCA and multi-criteria analysis [201] • Sustainability assessment [202] • LCA and urban metabolism [203] • LCA and land planning [204] • LCA and data envelopment analysis [205] • LCA, economic and energy performance [206]

1.8 In Need of LCA Case Studies on Marine Power Systems

As explained in **Chapter 1.3,** knowledge gaps existed as previous LCA studies had not assessed the environmental performance of marine power systems which selectively integrated advanced technologies. To recap, research questions were unfolded in **Chapter 1.4**: What was the estimated environmental impact of a marine power system? Would advance technologies add any environmental benefits? One way to address these questions was to perform LCA case studies on conventional, retrofit and new-build power systems onboard the chosen ship type, in which the environmental impact of individual systems was analysed and compared. In relation to LCA studies, many LCA practitioners claimed that representative data which were time and space specific were required for a more accurate LCA result. However, such data were expensive and the process of data collection would be time-consuming. It was argued that the impact of individual data on the overall result could be insignificant particularly if the product system study had a massive system boundary. If the argument was true, time and space specific data would not be necessary and average data could be used instead. Case studies presented in this study would verify the appropriateness of using average data to produce reliable estimates of environmental impact, in addition to the identification of significant parameters and impact.

1.9 Research Methodologies

The main research methodologies applied in this study steered from background information and understanding towards research, application and completion. The background of the topic (which covered marine regulations, previous work, knowledge gaps, tools and approaches) formed the motivation and scope of the study. The fundamental understanding was acquired through an overview on cargo ships, marine power systems and technologies, and followed by literature review on LCA methodology development, which are presented in **Chapters 2** and **3** respectively. As the end of life was important, the study was extended to research into the current practice of ship dismantling and end of life management of some technologies and metallic scrap. The understanding of these subjects, altogether, led to the development of an LCA framework for marine power systems. Both end of life management and LCA framework are presented in **Chapter 4**. To expand existing knowledge, the work was continued with the application of the research, in which LCA case studies on selected power systems were performed (covering material and energy acquisition, manufacture of components, operation and maintenance of the systems, dismantling and end of life management). In applying LCA, background data were collected and standardised from various sources, and supplemented by commercial database, Ecoinvent, provided background data from other sources were not available. Real-time operational data provided by the ship owner were used by the research consortium to simulate optimised operation profiles on a daily basis. The simulation results were used to estimate the primary data required for this study including fuel consumption and emission release. Using GaBi software, LCA models were created to estimate the environmental impact attributable to individual components. Based on a bottom-up integrated system approach, the environmental impact estimated for individual components incorporated into a particular system was summed up to present the total environmental burdens estimated for individual power systems. For each case study, the results were analysed to identify significant components and critical processes. The case studies were supplemented by scenario analysis to investigate the sensitivity of selected parameters and determine the appropriateness of using average data in assessing the environmental impact of a massive system. The case studies and analysis enabled a comparison among power systems under study to determine the system that was more environmentally friendly—all are presented in **Chapter 5**. The study was completed and closed with an overall summary of the work, which is presented in **Chapter 6**. Built upon the research methodologies, the overall structure of the study is illustrated in Figure 1.4.

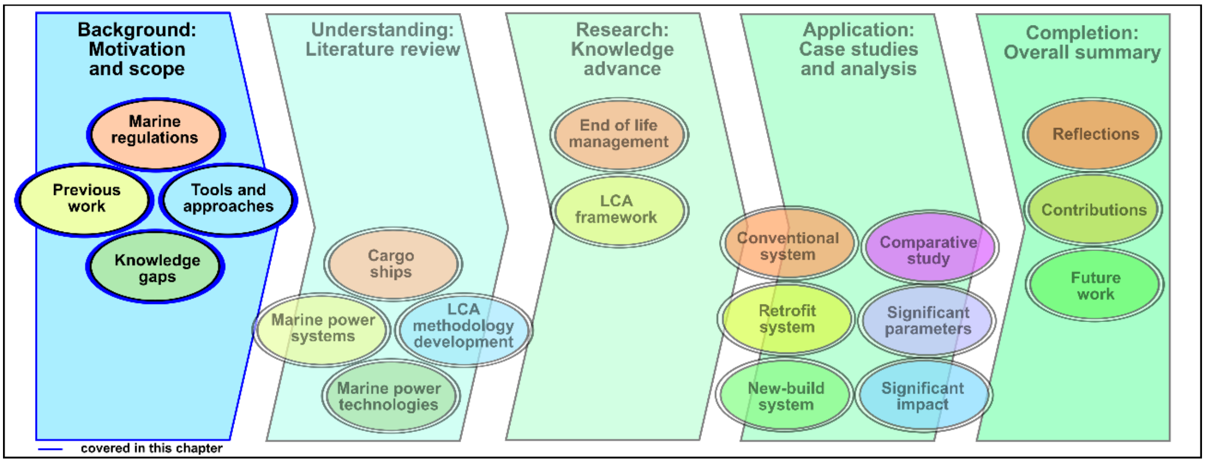


Figure 1.4: The structure of the study.

1.10 Summary

Marine transport played a crucial role in modern life. However, emissions released by marine transport were also significant, and would aggravate environmental issues rapidly provided no due care was taken immediately.

The business, by its very nature, was complex as it had been constantly affected by legislative (e.g. Annex VI and EEDI enforced by IMO), economic (e.g. capital investment of technologies and fuel cost), technical (e.g. choice of technologies and vessel types) and operational factors (e.g. efficiency, sailing routes and speed). To address the challenge of complying with stricter regulations, recent research had extended to cover emissions, energy efficiency, alternative solutions and environmental studies. Knowledge gaps existed as the environmental impact of conventional and innovative power systems onboard cargo ships had not been assessed, neither had the significant causes nor the parameters that affecting such impact. Annex VI enforced by MARPOL, previous work on emissions, energy efficiency, alternative solutions and environmental impact study, LCA concept, the need to review LCA methodology development, develop an LCA framework and perform LCA case studies on marine power systems, and research approach applied in the study were explained in this chapter. The literature journey continues in **Chapter 2** to explore cargo ships, power systems and technologies.

Chapter 2. Overview of Cargo Ships, Marine Power Systems and Technologies

"*There is not a discovery in science, however revolutionary, however sparkling with insight that does not arise out of what went before. 'If I have seen further than other men,' said Isaac Newton, 'it is because I have stood on the shoulders of giants'.*"

Isaac Asimov

Adding a Dimension, 1964

Marine power system designs differed from ship to ship [207] and more than one system design could be technically employed for most ship types. Prior to assessing the environmental impact of any marine power system, a basic understanding of cargo ship types, power systems and technologies was necessary to ensure comprehensibility of the study, which presented the focus of this chapter as illustrated in Figure 2.1. The knowledge of innovative technologies was crucial to support the selection of the power systems under study and interpretation of the results at a later stage in **Chapter 5**.

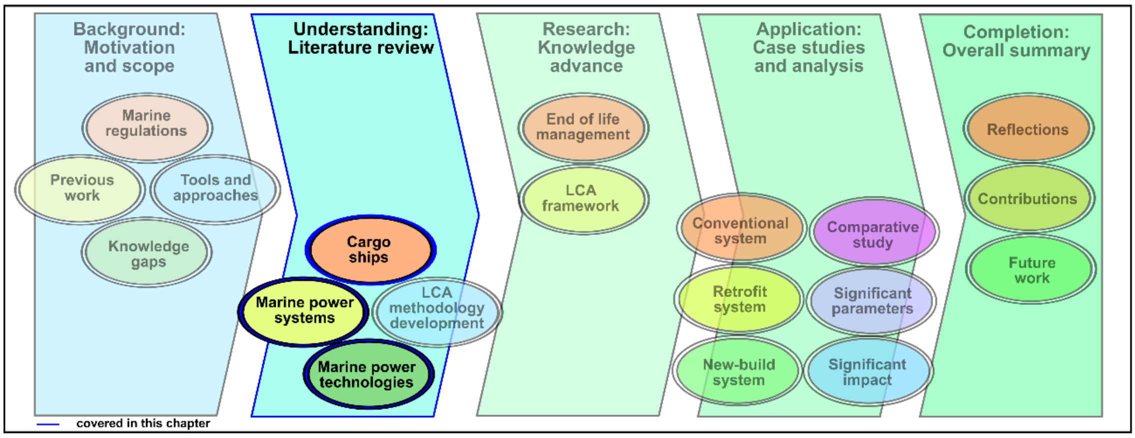


Figure 2.1: The focus of **Chapter 2**.

The following sub-objectives were set:

- overview cargo ship categories in terms of ship propulsion type, voltage, total onboard power and deadweight (**Chapter 2.1**);
- overview marine power systems (**Chapter 2.2**); and
- discuss a selection of power technologies (**Chapter 2.3**).

The chapter was closed with a short summary to set the scene for **Chapter 3**.

2.1 Overview of Cargo Ships

Merchant ships, also referred to as civil ships, were of a variety of designs and could be classified as cargo, industrial, technical and service ships. Cargo ships could be further distinguished as general, liquid and specialised. Tankers, LNG, liquefied petroleum gas (LPG) and chemical cargo ships exemplified liquid cargo ships. Reefers, containers, barge-carrying ships, bulk carriers, RoRo and Float-on/Float-off (FloFlo) were common examples of specialised cargo ships. Whilst cargo ships transported freights and passengers, industrial ships including trawlers, seiners and whalers were operated primarily for fishing purpose. Technical and service ships, as indicated by their names, were respectively in operation for specific purposes. Floating houses (which functioned as hotels, hospitals or workshops), research ships and training ships were examples of technical ships. Service ships, such as rescue ships, fireboats and icebreakers were run respectively for emergency or navigation against severe weather.

Different cargo ship categories had been proposed by a number of organisations, for example IMO [208], Eurostat [209] and *United Nations Conference on Trade and Development* (UNCTAD) [210]. By carrying out a comparison, it was evident that some ships might fall within more than one type and moreover, some ship types might be appropriate in more than one category. To gain insights into this matter, data regarding 245 ships covering a wide range of ship types as published in Significant Ships from 2008 to 2012 [211-215] were collected to build up a database. As the ships were ordered in that period which were to be delivered in subsequent years, they presented the latest trend of new-build designs. Data, such as name, year of build, IMO number, deadweight, speed, model and make of main and auxiliary engines, total power, type of propellers and thrusters employed onboard the vessels were initially gathered. In addition, information with respect to voltage of the power system installed onboard some ships were also available. Although not exclusive, such data were beneficial enough to offer an idea in this matter. Due to missing data, some ships were eliminated and consequently, only 191 ships were included in the database.

Among the ships, the following 4 types of propulsion systems had been employed:

I Diesel engines driving fixed pitch propellers (FPPs) i.e. diesel-mechanical systems

II Diesel engines with reduction gear connected to screw shafts to drive controllable pitch propellers (CPPs) i.e. mechanical systems with reduction gear

III Diesel engines driving alternators connected to electric motors i.e. diesel-electric systems

IV Steam turbines, either with reduction or reverse gear connected to screw shafts to drive FPPs

These propulsion systems are labelled as I–IV in relevant tables and figures in this section for brevity and consistency.

Seven categories were defined through data analysis, namely container ships, tankers, liquefied gas carriers, bulk carriers, passenger and cargo ships, general cargo (without passenger) ships and support vessels. The generic structure of a few ship types is illustrated in Figure 2.2. The findings of data analysis are summarised in Table 2.1.

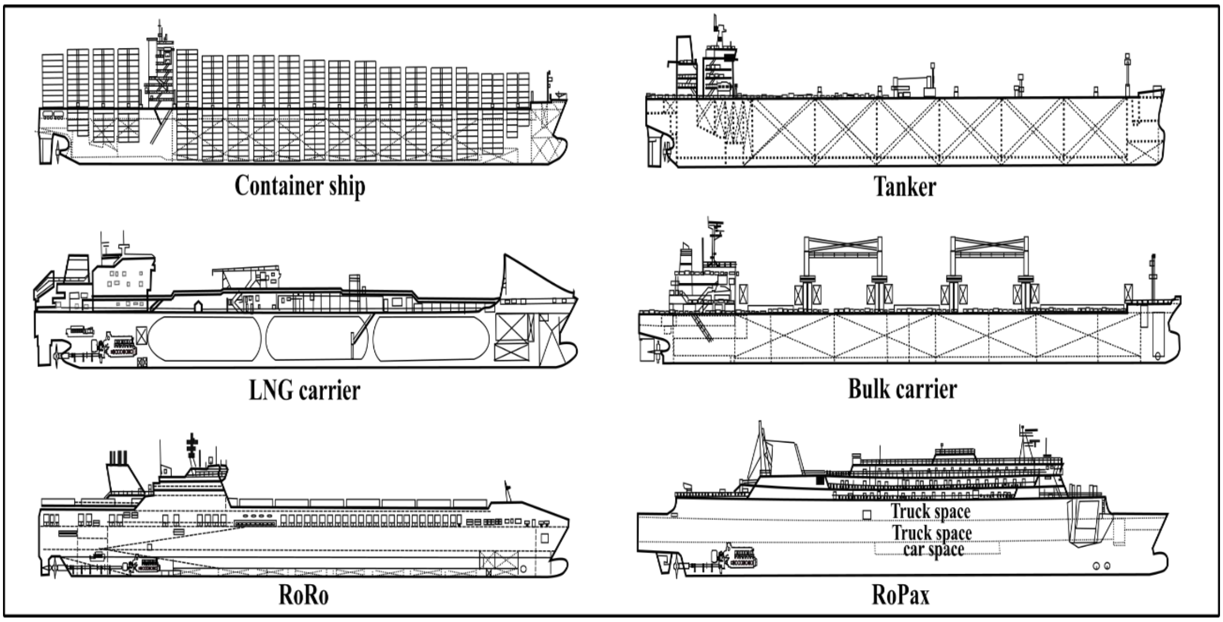


Figure 2.2: Generic structure of some marine vessels (adopted from [213]).

Table 2.1: Summary of the database, in terms of ship categories, types, propulsion systems and voltages.

Ship categories	**Ship types as published in Significant Ships** [211-215]		**Types of propulsion, voltage**
Container ship	• Container ship • Post Panamax container ship		I, 450V or 6600V II, 450V
Tanker	• Oil/chemical carrier • Oil/chemical tanker • Chemical tanker • Oil tanker • Oil carrier • Liquefied gas tanker	• Aframax oil tanker • Aframax oil/chemical carrier • Suezmax oil tanker • Suezmax crude oil tanker • Very large crude carrier (VLCC)	I, 440V, 450V or 6600V II, 440V
Liquefied gas carrier	• Liquefied gas carrier • Liquefied gas tanker • Dual-fuel liquefied gas carrier	• 3-fuel liquefied gas carrier • Diesel-electric LNG • Regasification tanker	I, 445V, 450V or 6600V II III, 6600V IV, 6600V
Bulk carrier	• Bulk carrier • Self-unloading bulk carrier • Self-unloading wood chip carrier • Fruit juice carrier • Ore carrier • Coal carrier	• Supramax bulk carrier • Kamsarmax bulker • Kamsarmax bulk carrier • Post panama bulk carrier • Dunkerque-max bulk carrier	I, 440V, 450V or 480V II
Passenger and cargo ship	• RoRo • RoRo, passenger and vehicle ferry • RoRo vehicle carrier • RoRo cargo ship • Multipurpose RoRo • Multipurpose dry cargo ship, RoRo • Heavy-lift multipurpose RoRo cargo • RoRo cargo and passenger ship	• Passenger ship • RoRo passenger • RoRo passenger ship (RoPax) • Cruise ship • (Diesel-electric) cruise ship • Passenger and vehicle ferry • RoRo cargo/pure car truck carrier (PCTC) • Solar power car carrier	I, 440V, 450V or 600V II, 400V, 415V, 440V or 450V III, 6600V
General cargo (no passenger) ship	• General cargo • Dry cargo • Hopper dredger	• Heavy load carrier • Heavy-lift cargo ship	I II, 450V or 6600V III, 6600V
Support vessel	• Special purpose ship (research) • Diving support vessel	• Offshore construction vessel	I III, 660V or 6600V

	• Wind turbine vessel • Subsea construction vessel • Drillship	• Deepsea intervention vessel • Floating production, storage and offloading (FPSO) vessel	

For each ship category, the relationship between total onboard power and deadweight is illustrated in Figure 2.3 where the range of deadweight and total onboard power are shown in Figure 2.4. Table 2.2 also presents the breakdown of each range as per type of propulsion system. A few key points to note:

- Among 191 vessels, diesel-mechanical systems appeared as the most common propulsion system employed onboard vessels, followed by mechanical systems with reduction gear and diesel-electric systems, as illustrated in Figure 2.5.
- For ships with diesel-mechanical systems, more than 98% of them employed a FPP.
- Steam turbines with gear reduction connected to screw shafts was only employed onboard liquefied gas carriers.
- Focussing on vessels operating with diesel-electric systems, the upper limit of deadweight established was found to be 100000 tonnes.

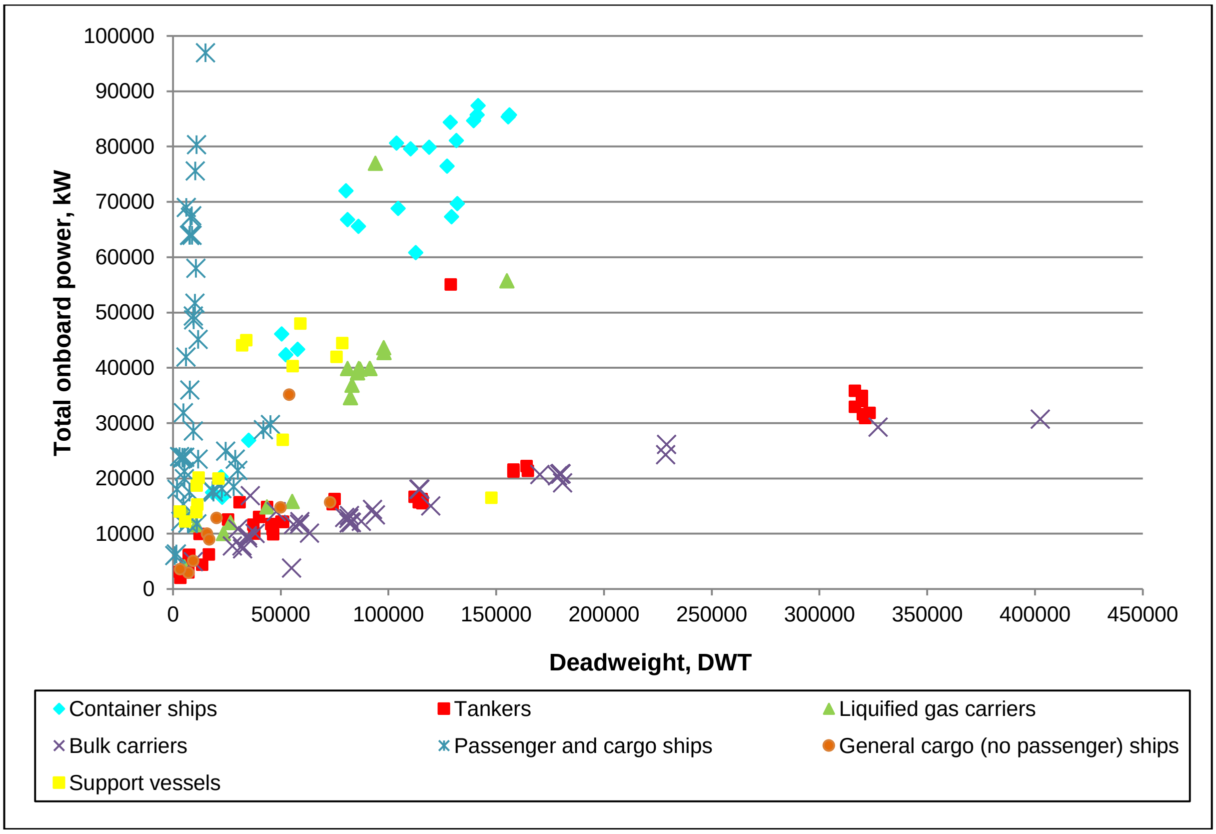


Figure 2.3: Total onboard power vs. deadweight of vessels for each category.

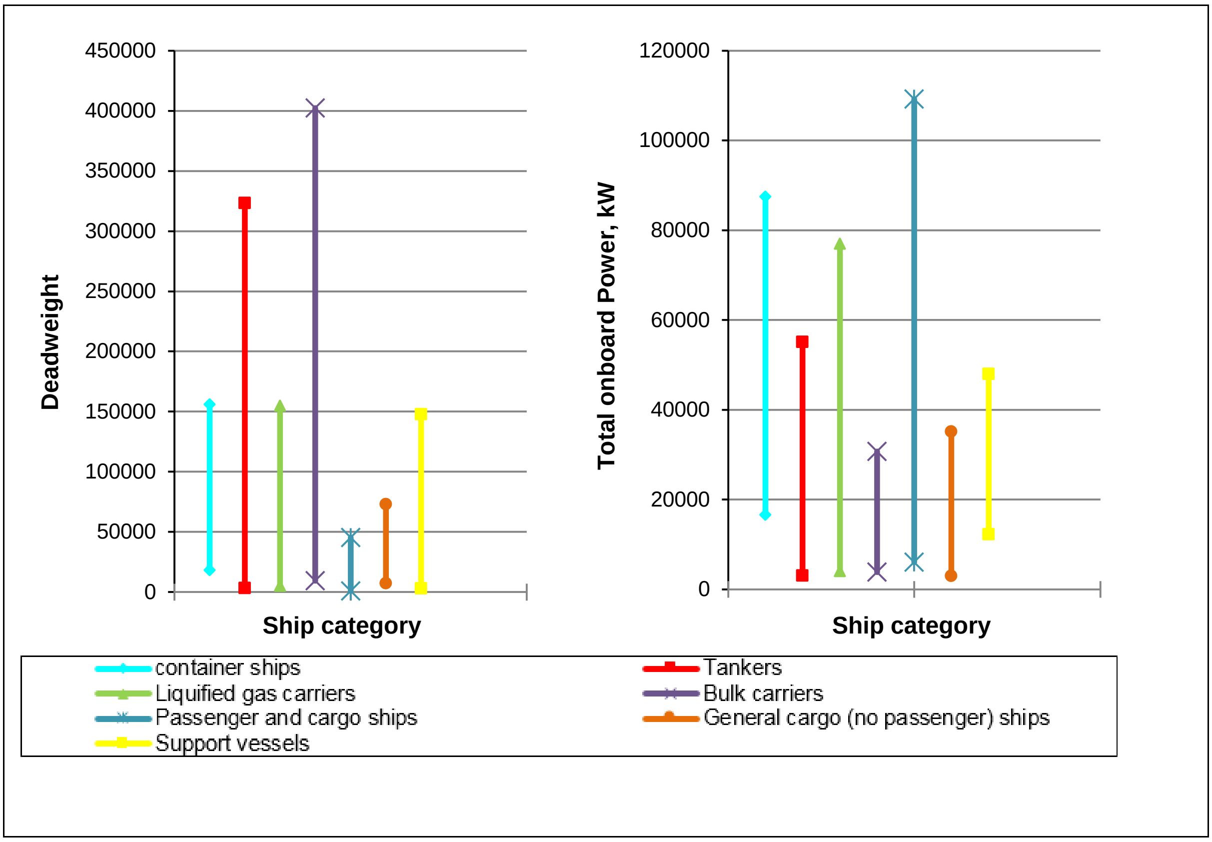


Figure 2.4: Ranges of deadweight (left) and total onboard power (right) for each ship category.

Table 2.2: Ranges of deadweight and total onboard power for each propulsion type.

	Deadweight (DWT), tonnes				Total onboard power, kW			
Ship Category \ **	I	II	III	IV	I	II	III	IV
Container ship	22314–156085	18299–127170			16608–87440	17520–76474		
Tanker	3150–323190	7103–43593			3140–55080	3048–15728		
Liquified gas carrier	5202–154940	10630	6150–97730	82308–97931	4050–55740	11630	13300–77000	34660–42790
Bulk carrier	27454–402347	9386–55000			7800–30760	3820–4990		
Passenger and cargo	815–45200	1853–11600	1441–15000		6072–69000	11810–67540	6400–109200	
General cargo (no passenger)	7147–72863	9303–53829	3200		2984–15725	5100–3516	3600	
Support vessel	32100–147700		3070–78500		16500–44080		12240–48000	

** Type of propulsion system

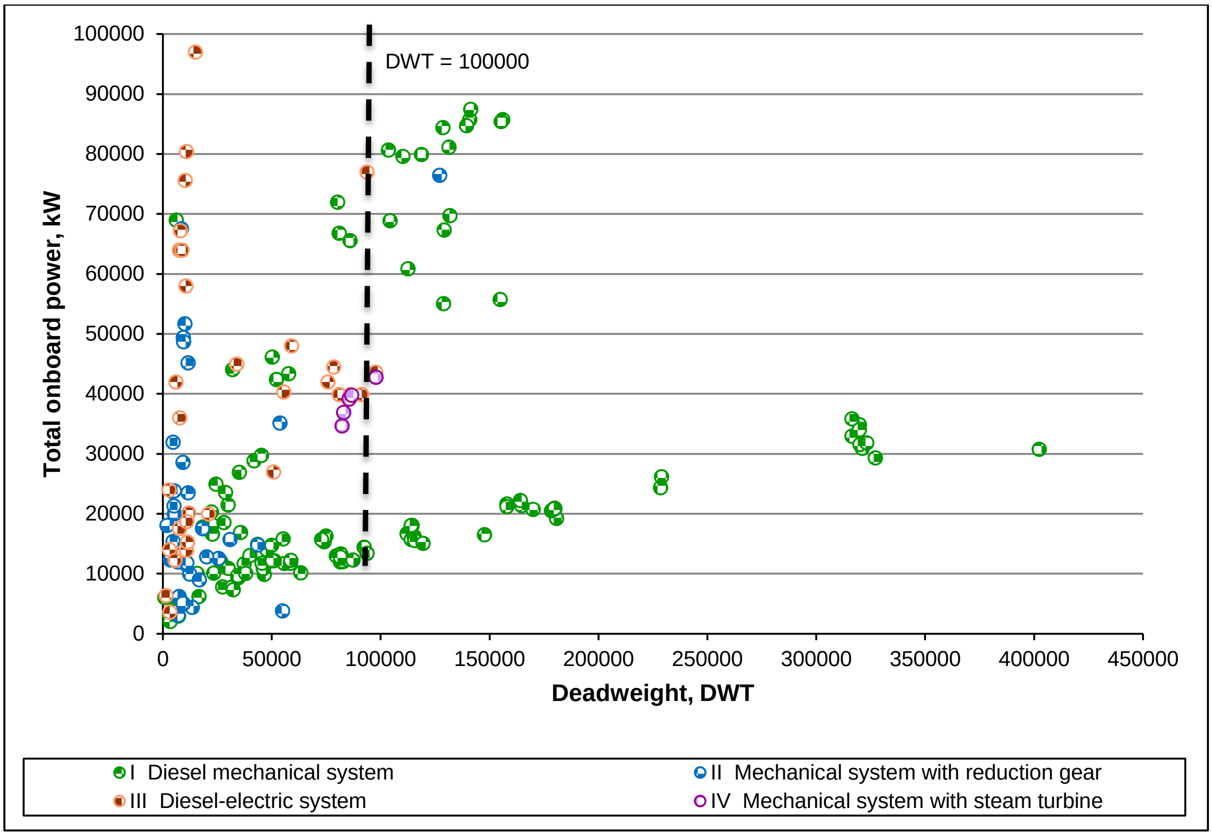


Figure 2.5: Total onboard power versus deadweight of vessels for each type of propulsion system.

The data also showed that vessels currently operating with diesel-electric systems included liquefied gas carriers, passenger and cargo ships, general cargo ships with no passenger and support vessels, as illustrated in Figure 2.6. Bearing the deadweight of each vessel in mind, the application of diesel-electric propulsion onboard these vessels showed the following trend:

- Liquefied gas carriers: mainly for those between 75000 and 100000 tonnes.
- Passenger and cargo ships: spread out evenly up to 15000 tonnes.
- General cargo (no passenger) ships: only one application was reported, below 15000 tonnes.
- Support vessels: evenly applied for those below 80000 tonnes.

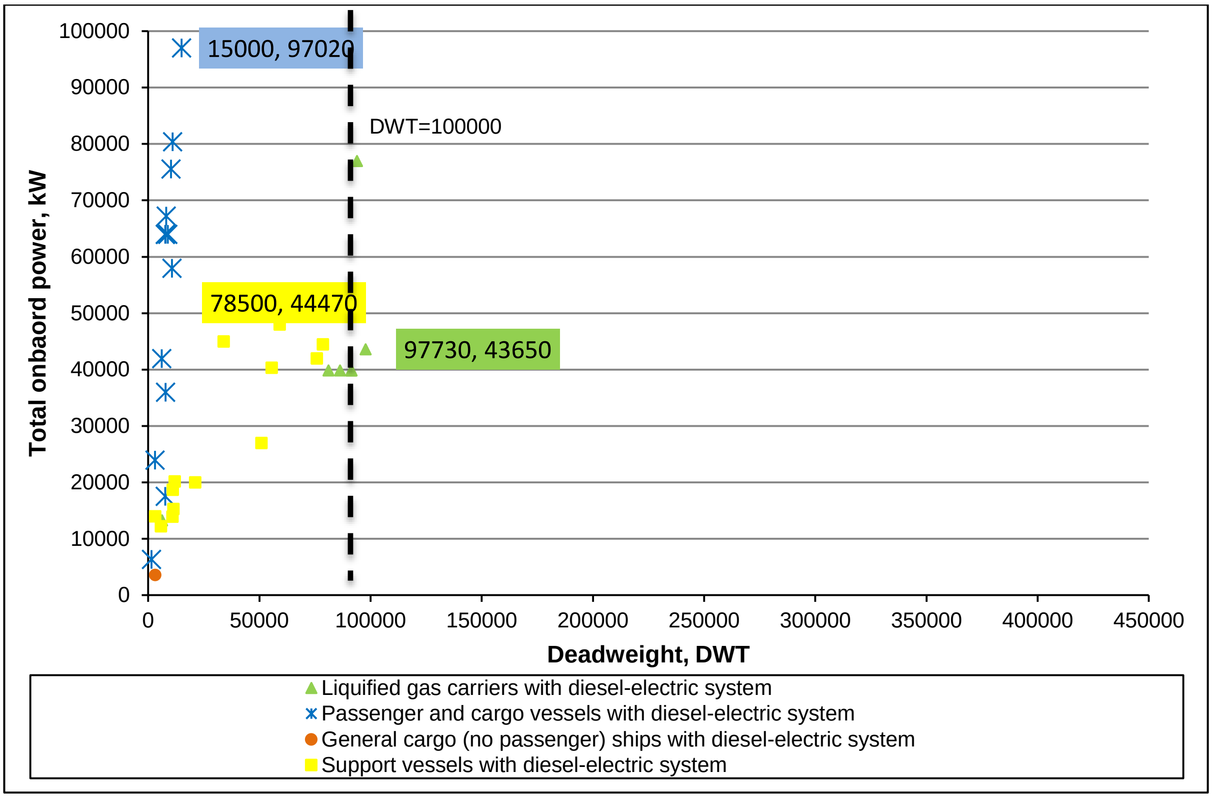


Figure 2.6: The application of diesel-electric propulsion among vessels in the database.

2.2 Marine Power Systems

As shown in **Chapter 2.1**, marine power systems could be recognised in accordance with its prime movers and transmission. To date, conventional technologies including diesel engines, gas and steam turbines were still the primary choice of prime movers for cargo ships. Nuclear powered systems had been explored and experimented with a few ships but not commonly commercialised. The connection between prime movers and propellers distinguished between mechanical and electrical transmission. According to [216], the transmission of propulsion power was of

(i) direct-mechanical if the prime movers, in particular any low-speed engine, were connected directly with the propellers;

(ii) mechanical with speed-reduction gear if reduction gearboxes were employed between the prime movers and the propellers;

(iii) direct-electric if the prime movers were connected by cables to electric motors that driving the propellers; and

(iv) all-electric (also known as full-electric, integrated electric or integrated full-electric which was a speed controlled electric drive) if the prime movers were connected to a switchboard where power electronics were employed in distributing electricity to the electric motors that driving the propellers.

How marine power was supplied was a decisive factor. Depending on the end users, it was commonly distinguished as main and auxiliary power supplies. The former enabled ship propulsion and the latter provided electricity for ship services, e.g. heating, refrigeration, fresh water, lighting, ventilation, pumps, cranes for cargo handling etc. In terms of energy, the operation of a marine power system involved chemical, thermal, mechanical and electrical energy conversions from fuel supply to ship propulsion and services which involved various power technologies as presented in Figure 2.7. Examples included here were not exhaustive but for explanatory purposes. Nevertheless, it indicated the massive scope of a marine power system which involved a broad selection of fuels and technologies applied in various processes during daily operation. An in-depth understanding of marine power systems as well as technologies was therefore important to ensure efficiency, safety and sustainability.

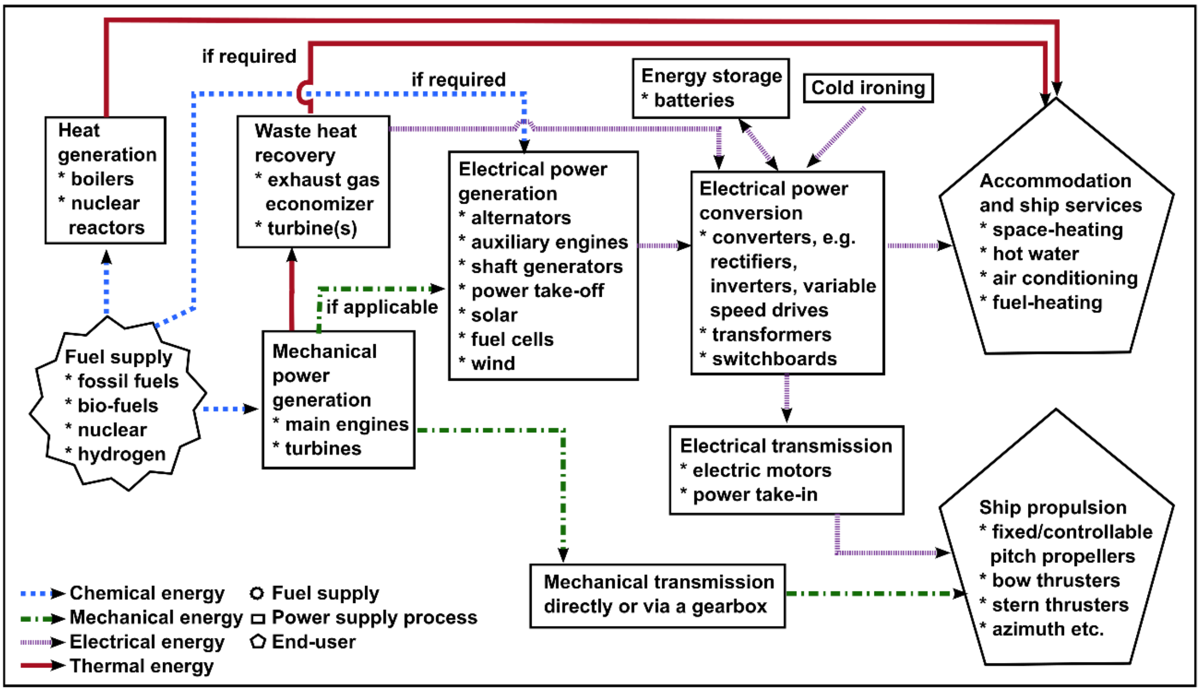


Figure 2.7: The energetic transformations and possible power technologies for ship propulsion and services.

Examples of power systems which were commonly mentioned in literature included diesel-mechanical, steam turbine mechanical, nuclear-powered steam turbine mechanical, gas turbine electric, diesel-electric, full-electric, combined and hybrid power systems. As the most widely applied design for cargo ships, a mechanical power system generated power separately from different prime movers for propulsion and hotel loads respectively. A range of marine power technologies had been employed as the prime movers of mechanical power systems onboard cargo ships, including diesel, gas and dual-fuel engines, steam and gas turbines as well as nuclear reactors. Amongst all, diesel engines were most widely applied for most cargo ships whilst steam turbines were mainly employed onboard LNG carriers. Applications of other technologies were relatively limited for cargo ships but common for other ship types. For example, gas turbines were commonly used in combined power systems for naval ships, nuclear was by and large for warships and icebreakers, and electric motors were mainly adopted by submarines. Propellers (and reduction gearboxes, if required) were employed in addition to enable ship propulsion. Generally speaking, one to four prime movers of the same or different technologies could be and were usually employed for power generation, separately or in an integrated system.

A diesel-electric system employed prime movers to run electric generators (also known as alternators) which connected to electric motors that coupling with the propellers, and at the same time supplied electricity to auxiliary and hotel loads. The prime movers [217, 218] would generally consist of 2 to 4 diesel engines of the same output rate. Gas engines, gas turbines, steam turbines or combined cycle turbines could be employed as alternative prime movers [219], if required. Mechanically coupled with the prime movers, the electric generators were connected to a common bus bar system. During operation, all electric generators fed the bus bar system to power the electric motors which would consequently turn the propeller shafts directly or via reduction gearboxes [220]. The rotation speed of the electric motors (and consequently that of the propellers) was low but with high torque, which was regulated via frequency and voltage control by transformers and converters [220]. Both diesel engines and electric generators continuously operated at the same rotation speed [219].

Similar but more advantageous than diesel-electric power systems, all-electric power systems (also known as full-electric, integrated electric or integrated full-electric) would generate three-phase electricity based on power demand for optimal performance in supplying electricity to both propulsion drives and all auxiliary systems simultaneously [218]. Diesel engines and gas turbines of different capacities were commonly adopted as the prime mover(s) with the use of power electronics where gearboxes were eliminated. All-electric power systems could involve alternating current (AC) and/or direct current (DC) distribution. When AC distribution (which was more common) was considered, an all electric propulsion consisted of prime movers, synchronous generators, switchgears, transformers, power electronics converters (i.e. DC/AC, AC/DC and DC/DC), electric motors and propellers. The prime movers employed for an all-electric power system could be of various sizes of conventional propulsion technologies, including internal combustion engines [221], gas turbines [222] or diesel engines combined with gas turbines [223]. The synchronous generators would be coupled with and powered by the prime movers to generate AC power [221], which was then adjusted by transformers and converted by converters before being used (i) by the electric motors to drive the propellers and (ii) for auxiliary and hotel loads. The speeds of the prime movers and electric motors were strategically and respectively controlled for optimal power output [222]. In a DC distribution system (which was of growing interest), switchgears and transformers were removed and rectifiers were used to convert AC power generated by synchronous generators into DC power, leading to the elimination of multiple stages of power conversion that were required by AC distribution systems. Electric podded drives (i.e. azipod, where an electric engine was installed inside a pod) could be used for better flexibility in propulsion. An all-electric power system was demand-based as different (and only the necessary) prime movers would be selectively operated based on dynamic demand for optimal efficiency [218].

A combined power system, for example combined diesel or gas turbine propulsion (CODOG), combined diesel-electric and gas propulsion (CODLAG) and combined steam and gas turbine propulsion (COSAG) as encapsulated by [224], employed any conventional power technologies to supply propulsion power at low and high speeds. As combined power systems were more commonly applied onboard naval vessels but not for cargo ships, they were not further discussed.

2.3 Marine Power Technologies

Although marine engines were proven and mature, it was harder to achieve efficiency improvement and emission reduction [61] via engine technologies alone. For these purposes, alternative means for future ship propulsion and power supply had been recently identified and proposed as possible measures to be taken. Examples of these proposals included [9, 225, 226]. According to [9], 10–30% of CO_2 could be individually reduced via the uptake of CPPs, pulling thrusters, reduced waiting periods in port, and implementation of cold-ironing and WHRSs, in addition to diesel-electric, all-electric and improved machinery. [226] recognised the emergence of low-energy, green-fuelled and electric ships, and therefore proposed alternatives that would be suitable for each. [225] perceived gas turbines, hybrid propulsion, renewable sources for large ships' augmentation power, water injection and selective catalytic reduction (SCR) as well as diesel and dual-fuel engines as technologies to be implemented in short-to-medium term whilst other alternatives were also recommended for medium-to-long and long terms. These recommendations were integrated in terms of ship design, propulsion, machinery and operation as illustrated in Figure 2.8.

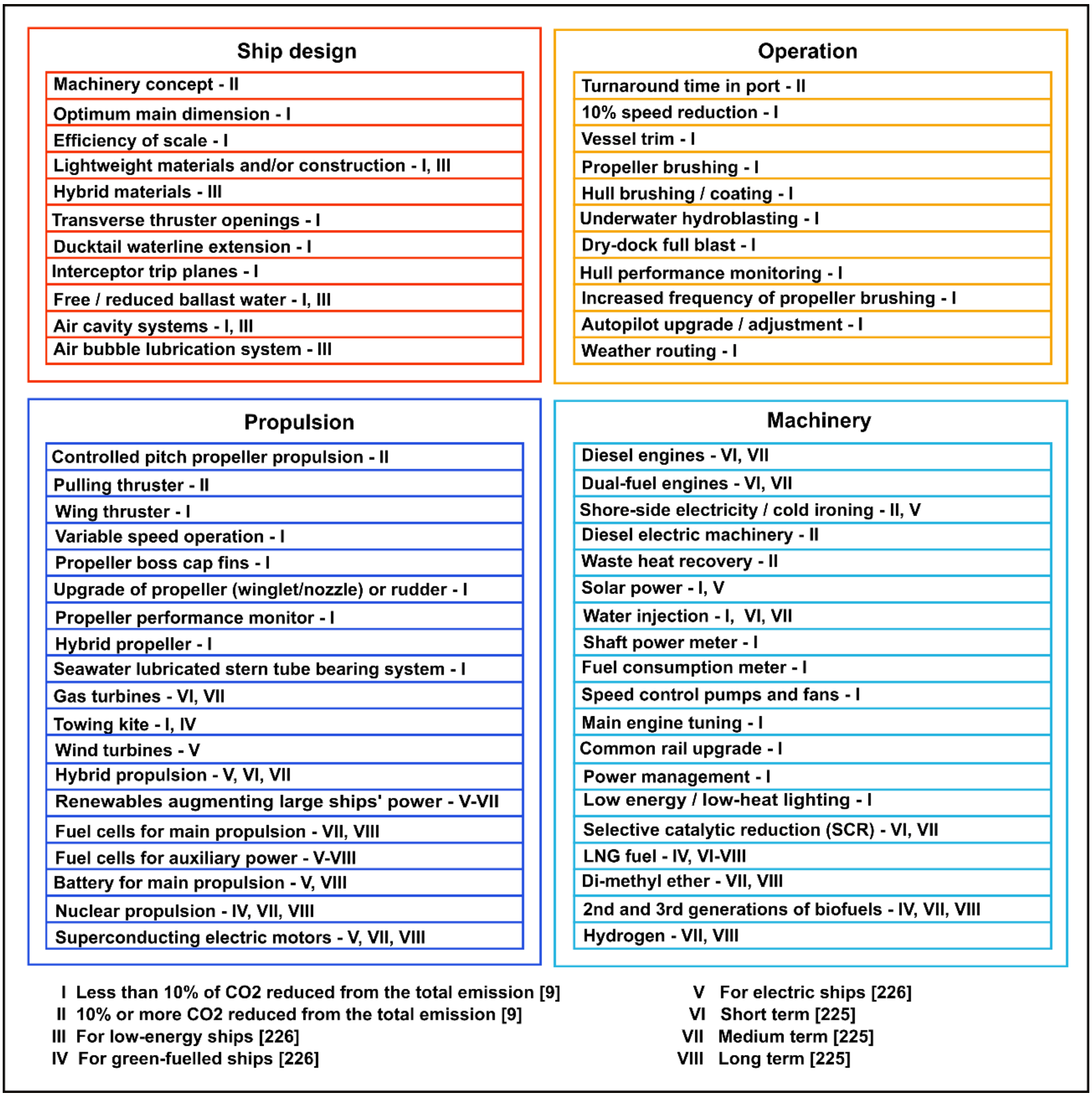


Figure 2.8: Future technologies for ship propulsion and auxiliary power.

Research on innovative advances was still on-going, for example, to adopt fuel cells and/or batteries for full-load requirement as substitutes for diesel engines or implement a hybrid system which could offer partial propulsion benefits from fuel cells, batteries, WHRSs, solar energy, wind energy and/or cold-ironing whenever available. Existing literature had mainly focussed on one or two particular technologies, whether conventional or innovative. Due to the lack of a single study addressing marine power technologies comprehensively from fundamental concept to state-of-the-art development, a knowledge gap existed, which motivated the presentation of this overview.

In the following section, the fundamental working principle of marine power technologies including diesel and gas engines, steam and gas turbines, fuel cells, batteries, WHRSs, shaft generators, PTO/PTI, wind, solar and cold-ironing was presented. For each technology, the state-of-the-art development, advantages, disadvantages, suitable applications and fuel types, and any additional remark were also illustratively summarised.

2.3.1 *Diesel, gas and dual-fuel engines*

Engines could be classified in accordance with the method used to ignite fuel, crankshaft speed, working cycle, the acting combustion gases and fuel types required for combustion, as below:

- Whilst spark ignition engines applied Otto cycle and relied on a spark plug to ignite, compression ignition engines worked on Diesel cycle to self-ignite by compressing the air in the cylinders to high pressure, high temperature [62, 227].
- Engines were of low-, medium- and high-speed when the crankshaft speeds, for example, for diesel engines were less than 140 revolutions per minute (rpm), between 400 and 1000 rpm, or more than 1000 rpm, respectively. Generally speaking, a low-speed engine would drive a propeller directly whilst a medium-to-high-speed engine would be connected to a reduction gearbox to drive the propeller.
- Engines were of 2- or 4-stroke respectively if their pistons were required to perform a complete power cycle in 2 or 4 piston strokes whilst the crankshaft completed 1 or 2 complete revolutions [227].

- Engines were of single- or double-acting in line with their combustion gases acting on one or both sides of the pistons.
- Depending on marine fuels required for internal combustion, existing engine types included diesel, gas and dual-fuel engines.

The working principles of 2- and 4-stroke diesel engines [228] were based on Diesel cycle as briefly explained here. For a 2-stroke engine, the first stroke was known as ‘compression and power’, in which the piston in each engine cylinder would move upwards to compress air-fuel mixture whilst air ports were covered up to result in combustion. In the second stroke i.e. ‘exhaust and intake’, pistons moved downwards and air ports were opened to enable rapid blow-down. Exhaust was discharged whilst fresh air and fuel refilled the combustion chamber. In contrast, a 4-stroke engine involved ‘intake’, ‘compression’, ‘power’ and ‘exhaust’ strokes. During the ‘intake’ stroke, both inlet and exhaust valves would open for the inflow of fresh air whilst the pistons were located at the bottom of engine cylinders. The second stroke took place where pistons moved up and compressed the air. In the next stroke, atomised fuel was sprayed finely by an injector in each cylinder, self-ignited and burned whilst pistons moved downwards. During the ‘exhaust’ stroke, the exhaust valves opened and pistons moved upwards to release exhaust gases. Additional information about diesel engines in relation to advantages, disadvantages, suitable applications, fuel types, state-of-the-art development and additional remarks is shown in Figure 2.9.

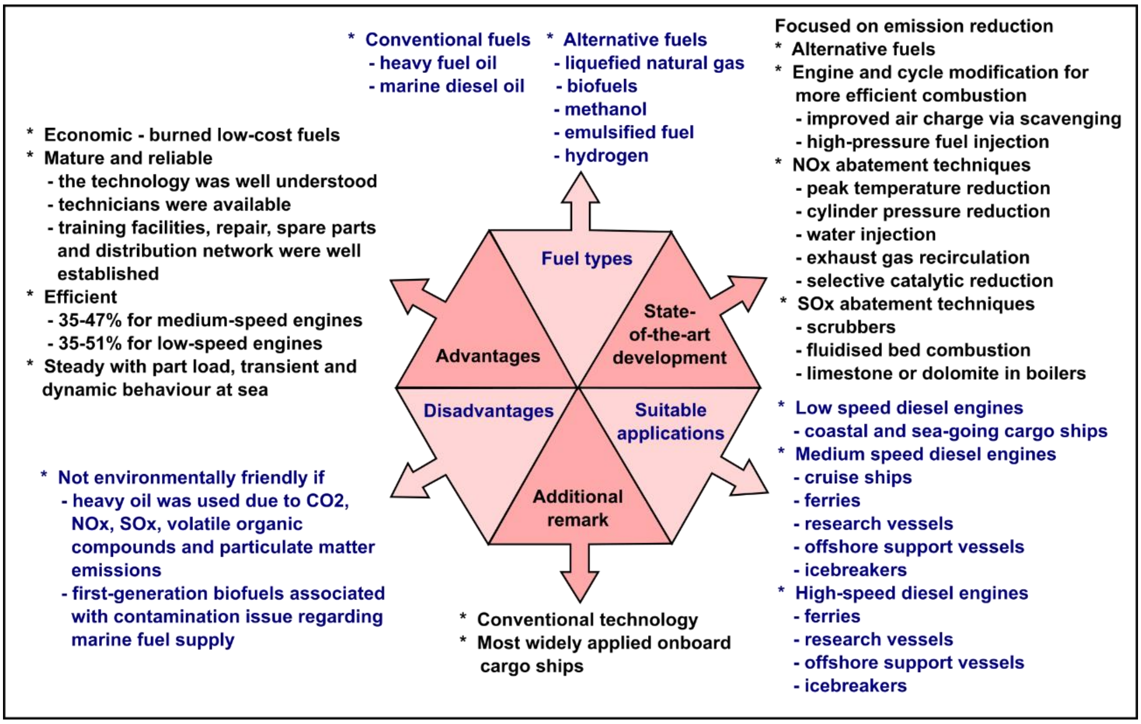


Figure 2.9: Additional information about diesel engines.

Gas engines [228], which run exclusively on gas, were also known as single gas fuel engines. Each complete working cycle of a gas engine involved 4 strokes based on the Otto cycle principle. In brief, the combustion air supplied by the turbocharger mixed with gas injected by a mechanical valve in each cylinder to form a lean mixture. The mixture was then compressed and partially pushed into the pre-combustion chamber to mix with pure gas. The rich mixture was ignited by a spark plug which successively triggered the combustion of the lean mixture in the cylinder. Additional information about gas engines is presented in Figure 2.10.

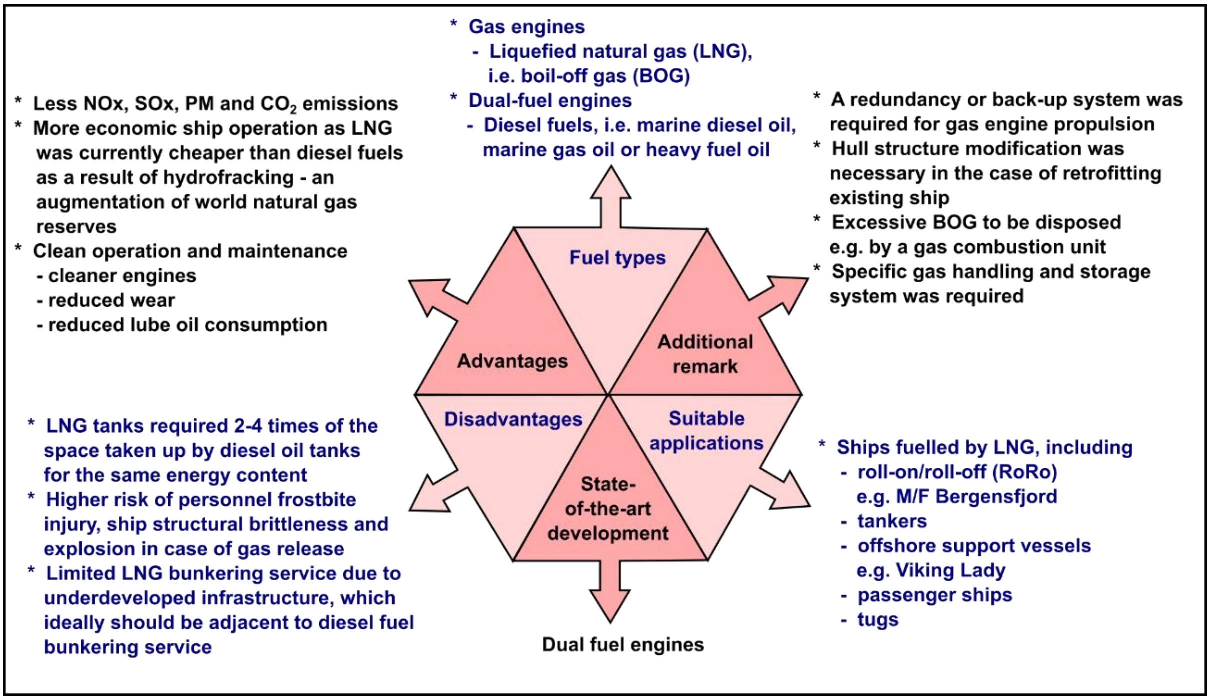


Figure 2.10: Additional information about gas engines.

As the state-of-the-art development of gas engines, dual-fuel engines [227] were also of 4-stroke. They combined Otto and Diesel cycles and operated in gas mode or liquid-fuelled diesel mode. During gas mode, the engine worked on lean-burn Otto principle where the air-fuel mixture was compressed and ignited by a pilot fuel i.e. a small quantity of diesel fuel (i.e. approximately 1–15% of total fuel input) injected into the combustion chamber. Whilst working on diesel mode, the engine applied Diesel cycle concept where diesel fuel, i.e. MDO, MGO or heavy fuel oil (HFO), was injected into the chamber at high pressure to ignite and burn. The pilot fuel was maintained to ensure reliable pilot ignition when gas mode was resumed. Therefore, dual-fuel engines could operate with mixtures of gas and diesel fuels at various portions or 100% diesel fuels but not pure gas.

2.3.2 *Steam and gas turbines*

The use of steam turbines as marine power technologies was in proximity to boilers, condensers and feeding pumps. The boiler burned BOG to generate high-temperature, high-pressure steam which entered the steam turbine and expanded. The potential energy of steam was transformed into mechanical energy to gear the propeller shaft coupled with the steam turbine [229]. After leaving the steam turbine, the low-pressure steam condensed in the condenser to form saturated liquid, which was then compressed in the feeding pump before circulating back to the boiler.

Using a vaporiser to generate additional BOG and burning a liquid fuel were 2 possible fuel options for boilers in case BOG was insufficient [207]. Additional information about steam turbines is illustrated in Figure 2.11.

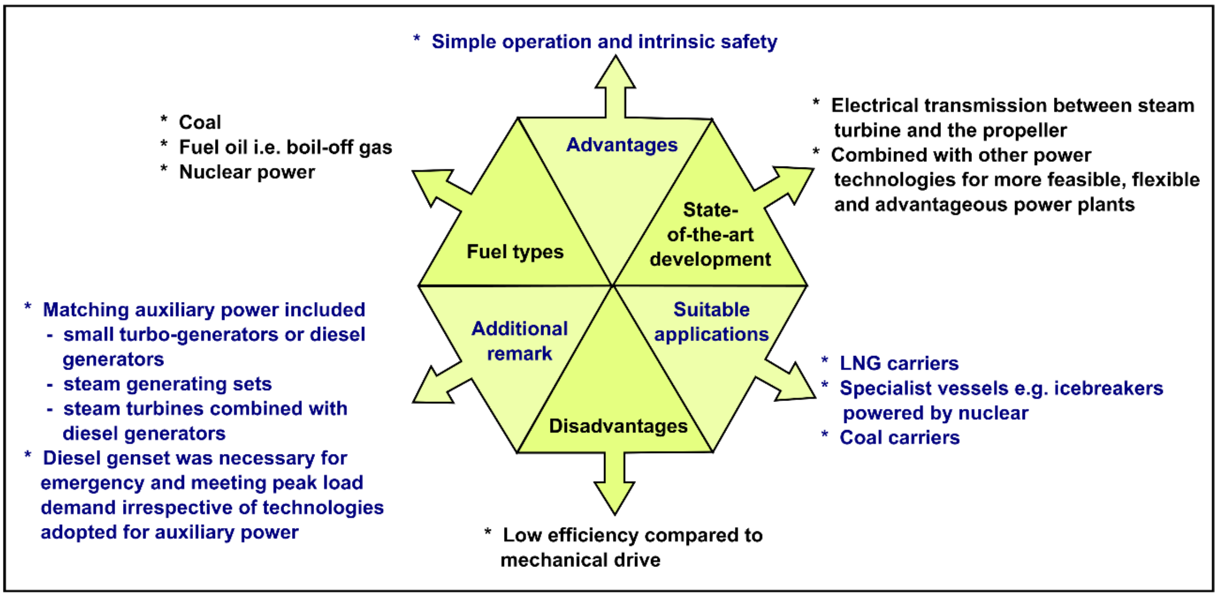


Figure 2.11: Additional information about steam turbines.

With different components, gas turbines [224, 228] functioned based on similar working principles. Typically, a gas turbine had one or more built-in compressors, combustors/heat exchangers, compressor turbines and power turbines. In a simple open/close cycle, atmospheric air/the working fluid was compressed by the compressor and became high-pressured. The high-pressured compressed air/working fluid was then delivered to the combustor/the high-temperature heat exchanger so that fuels could be burned in compressed air/working fluid. The hot air/working fluid from the combustor/high-temperature heat exchanger expanded in the compressor turbine before it was released to the atmosphere/the low temperature heat exchanger. The potential energy of the hot air was converted into mechanical energy to drive the power turbine which was coupled directly with a propeller for mechanical transmission or an electric motor in the case of electrical transmission. In some cases, additional components, for example regenerators, intercoolers, recuperators and reheat combustors, to name but a few, were incorporated into the simple cycle to form regenerative, intercooling, intercooling recuperated, reheat and intercooling reheat cycles, respectively. Additional information about gas turbines is presented in Figure 2.12.

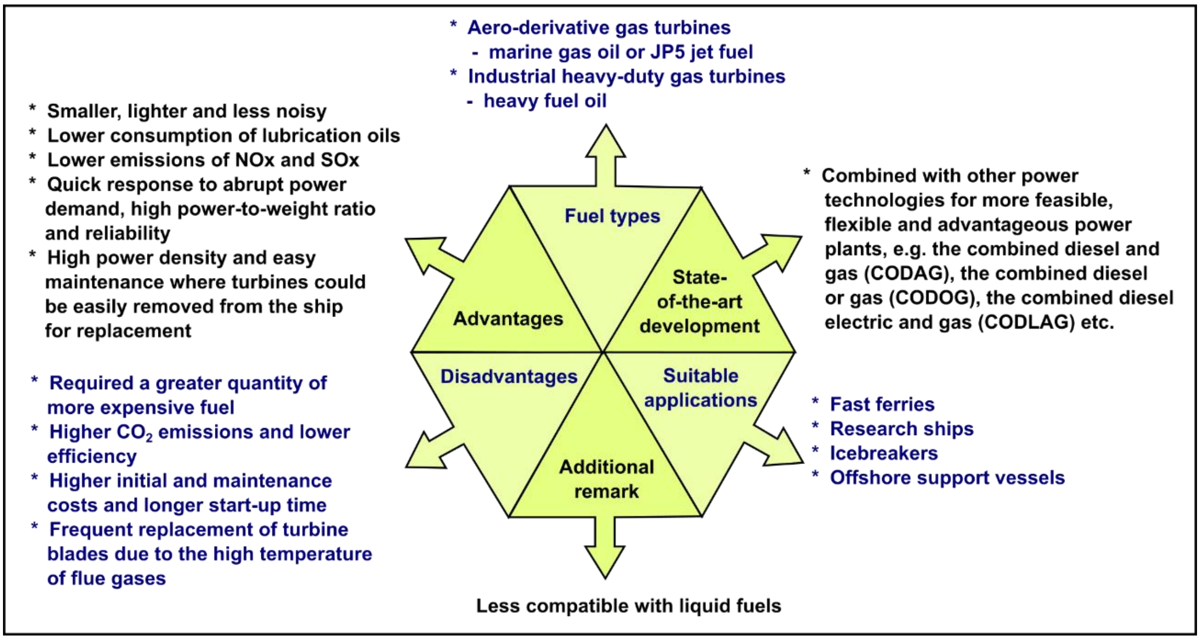


Figure 2.12: Additional information about gas turbines.

2.3.3 *Fuel cells*

Despite the fact that numerous types of fuel cells were available in the market or undergoing development, as reported by [230, 231], only 3 types of fuel cells were suitable for marine applications. These included MCFCs and SOFCs for marine propulsion in small vessels and proton exchange membrane fuel cells (PEMFCs) for auxiliary power in large vessels [232]. The basic design of a fuel cell consisted of an electrolyte located between an anode and a cathode. The anode was also known as a fuel electrode where a hydrogen flow was supplied; likewise, the cathode was also referred to as an oxidant electrode where an air flow was supplied. Hydrogen and the air were stored in external storage tanks and supplied to the fuel cell during operation [225]. Additional information about fuel cells is presented in Figure 2.13.

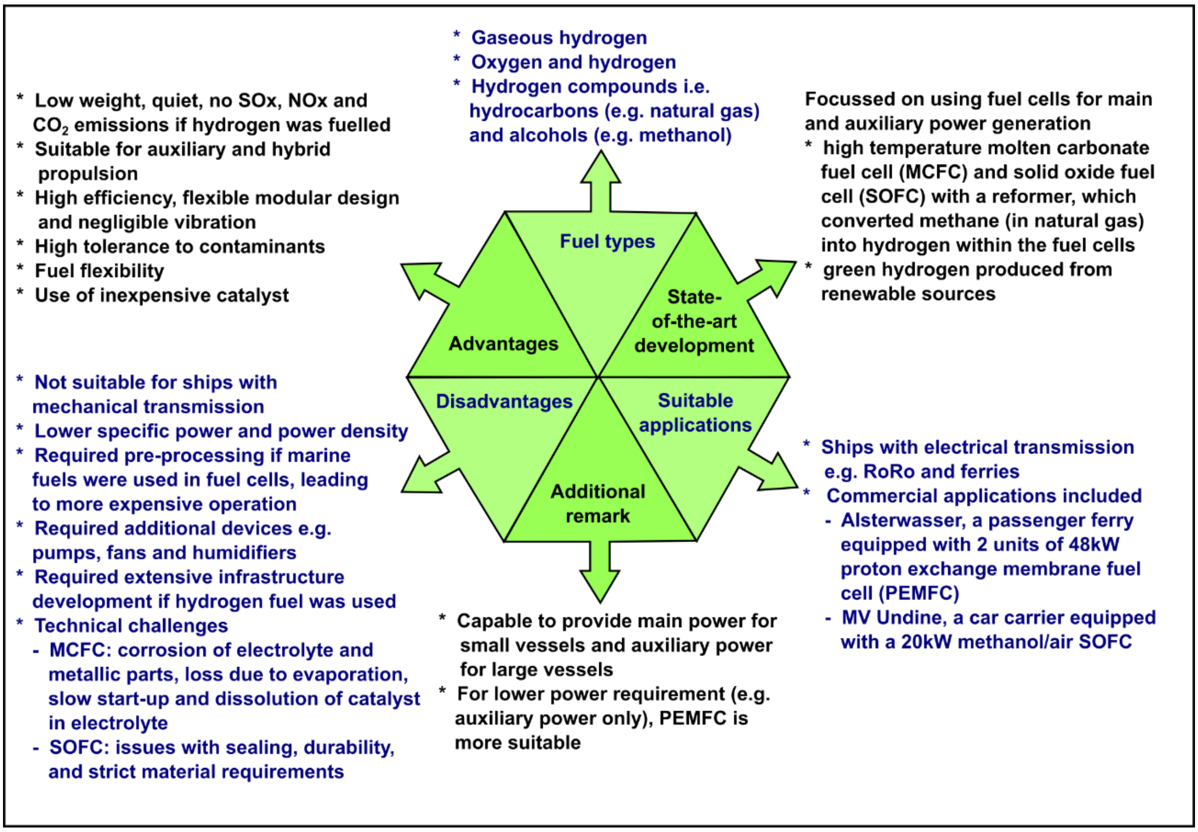


Figure 2.13: Additional information about fuel cells.

The fundamental principles applied to MCFCs, SOFCs and PEMFCs were based on electrochemical reactions where oxidation and reduction processes took place at the anode and the cathode of the fuel cells respectively to produce water, heat and electricity. The latter was generated in all cases following the movement of electrons along an external circuit connecting the anode and the cathode. Electrochemical reactions taking place in these fuel cells were briefly explained:

- MCFCs [233]: Acting as electrolyte, the molten carbonate salt conducted carbonate ions. At the anode, hydrogen molecules reacted with carbonate ions to produce water, carbon dioxide and electrons. Carbon dioxides proceeded through molten carbonate whilst electrons travelled along an external circuit to reach the cathode. At the cathode, oxygen molecules in the air reacted with carbon dioxides and electrons to result in carbonate ions, which maintained the quantity of electrolyte in MCFCs.
- SOFCs [231]: At the anode, hydrogen fuel was burned and resulted in difference in oxygen concentration across the electrolyte, i.e. hard ceramic. Oxygen molecules at the cathode were attracted to travel through the electrolyte and reached the anode to react with hydrogen

molecules where water, electrons and heat were produced. Electrons travelled along an external circuit to reach the cathode where oxygen molecules in the air were reduced to oxygen ions after acquiring these electrons. The same process repeated.

- PEMFCs [230]: At the anode, hydrogen gas was oxidised to produce hydrogen ions and electrons. Hydrogen ions proceeded through an acidic electrolyte whilst electrons travelled along an external circuit to reach the cathode to react with oxygen molecules. Likewise, water and heat were produced.

2.3.4 *Batteries*

The basic structure of batteries comprised one or more electrochemical cells in which each cell consisted of a negative electrode (i.e. anode), a positive electrode (i.e. cathode) and a solid, molten or liquid electrolyte [234]. Batteries were constantly in charging or discharging mode [234]. During discharging mode, oxidation took place in anode where positive ions (cations) and electrons were released whilst reduction happened in cathode and resulted in negative ions (anions). Cations and anions would flow to the opposite electrodes through the electrolyte. Meanwhile, electrons would travel from the anode to the cathode along an external load to provide the required power. To charge the batteries, an external power source was supplied. Two processes involving electrons happened simultaneously, i.e. electrons at the negative terminal of the power source were injected in the anode whilst electrons at the cathode were attracted to the positive terminal of the power source. Reduction and oxidation took place in the anode and the cathode respectively to enable both electrodes to regain their previous states. As soon as the batteries were fully charged, their discharging mode resumed. Additional information about batteries is presented in Figure 2.14.

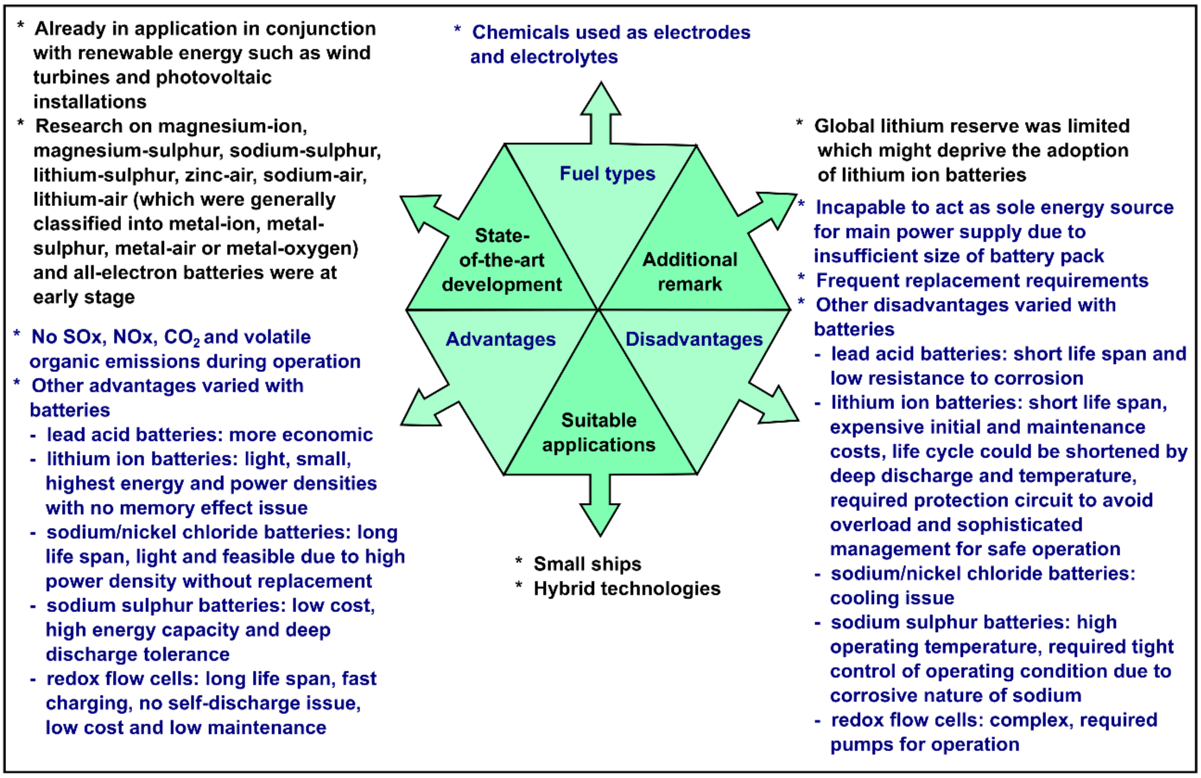


Figure 2.14: Additional information about batteries.

A wide range of batteries had been developed, for examples lead-acid, nickel-cadmium, sodium-nickel chloride, zinc-air, sodium-air, lithium-air, magnesium-ion, magnesium-sulphur and lithium-sulphur, to name but a few. High energy density, long discharging time and consistent voltage drop over time were three characteristics required by batteries for marine propulsion applications [235]. Lithium-ion, sodium-sulphur and flow cells which showed such characteristics were anticipated as the potential candidates, and were therefore further discussed here.

- Lithium-ion batteries [234, 236, 237]. The electrolyte of lithium-ion batteries was commonly a mixture of 2 to 4 lithium-based salt solutions which was electronically not conductive but capable to transport lithium ions. To enhance the power density of lithium-ion batteries, the distance travelled by ions was kept as short as possible, either by placing the electrolyte in a polymer or absorbing the electrolyte with thin fleece. Inside lithium-ion batteries, small particles were covered by a surface film known as solid-electrolyte-interphase (SEI). A binder was used to attach the particles to a current collector of each electrode, i.e. lithium-metal-oxide particles (with increased conductivity by graphite) to aluminium foil for the positive electrode and lithium-graphite particles to copper foil for the negative electrode, as illustrated in Figure 2.15.

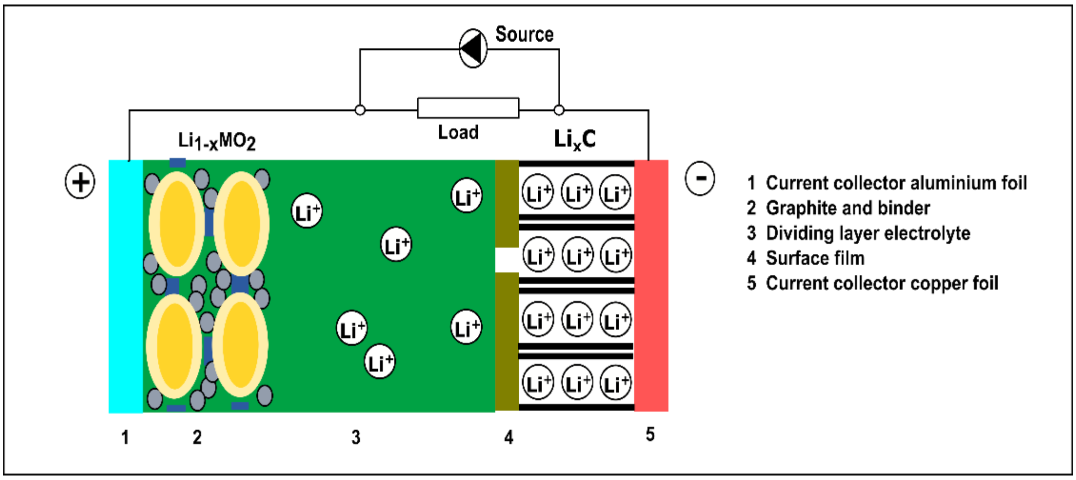


Figure 2.15: The structure of a lithium-ion battery cell [236].

During discharging mode, lithium ions travelled from lithium-graphite particles in the negative electrode, through electrolyte, and entered lithium-metal-oxide particles next to the positive electrode whilst electrons also moved from the negative to the positive electrodes via an external circuit. To avoid permanent damage to lithium-ion batteries, charging process generally started when the batteries were nearly 80% discharged where lithium ions took a reverse path and electrons were injected from an external source.

- Sodium-sulphur batteries [237-239]. In contrary to conventional batteries, sodium-sulphur batteries operated at high temperatures between 300 ^oC and 350 ^oC. They were made of liquid electrodes (i.e. molten sulphur and molten sodium as positive and negative electrodes respectively) which were physically isolated from each other by a solid electrolyte (i.e. beta-alumina ceramic tube), as illustrated in Figure 2.16.

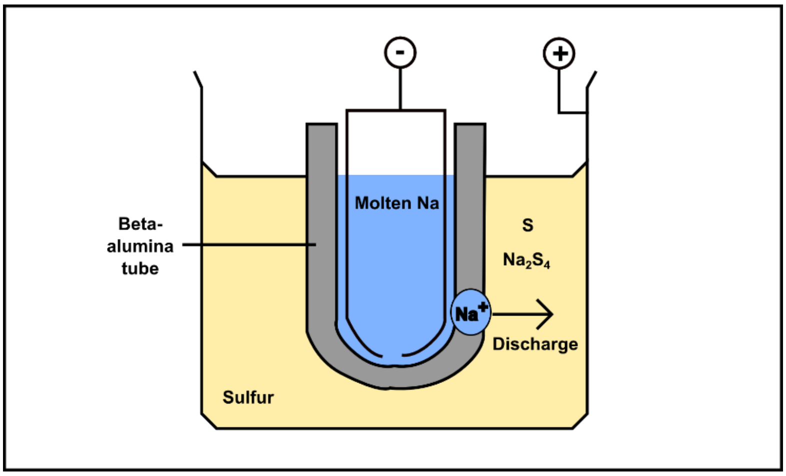


Figure 2.16: The structure of a sodium-sulphur battery [237].

During discharging mode, sodium ions migrated through beta-alumina to combine with sulphur and form sodium poly-sulphides, i.e. Na_2S_4. Meanwhile electrons travelled from the negative to the positive electrodes along an external circuit. During charging mode, the processes reversed: electrons were supplied to the negative electrode by an external source whilst sodium ions released from sodium poly-sulphides resumed their former form, i.e. sodium. The operating temperature of sodium-sulphur batteries was maintained by the heat produced throughout the processes during charging and discharging or by an external heat supply during stand-by mode.

- Flow batteries, also known as redox batteries [239], flow cells [234], regenerative fuel cells [240] or redox flow cells [239]. In addition to generic components such as anodes, cathodes and electrolytes, the basic structure of flow batteries also included an ion-exchange membrane and pumps as necessary constituents, as illustrated in Figure 2.17. Inside an electrochemical cell, the membrane used to separate the anode and the cathode was permeable to anions (more commonly) and cations. Externally stored in separate tanks, 2 liquid electrolytes were recirculated to the cell by pumps through recirculation loops during charging and discharging mode. To acquire useful power capacity, more than 1 anode and cathode could be employed in series in a flow battery unit based on the ‘plate-and-frame’ principle [240]. Flow batteries functioned based on reversible reduction and oxidation processes taking place at the cathode and the anode respectively. Zinc-bromine batteries and vanadium redox batteries were two common examples of flow batteries. The electrolytes of these batteries were zinc bromide liquid and vanadium of different valence states in a sulphuric acid medium, respectively.

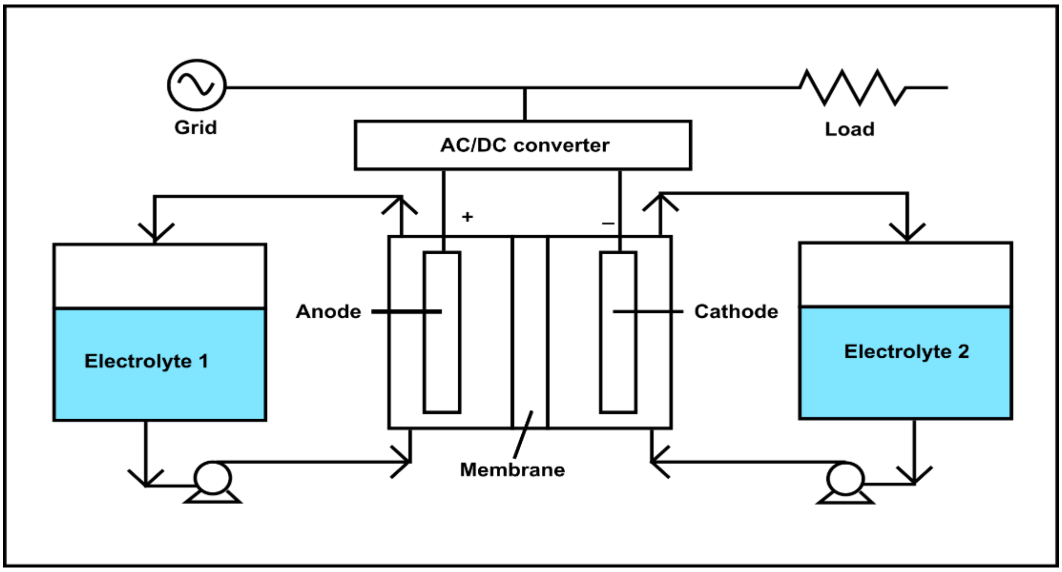


Figure 2.17: The structure of a flow battery [234].

2.3.5 *Waste heat recovery systems (WHRSs)*

When marine fuel was burnt by a two-stroke diesel engine onboard a sea-going ship, approximately 50% of the input energy was used for power output whilst the rest was released as waste heat, i.e. 25% from exhaust (between 250 ^oC and 500 ^oC), 16.5% from air coolers, 5.2% from jacket water coolers and 2.9% from lubricating oil coolers [61, 241]. Depending on the system configuration, the waste heat, if recovered, could be used to produce [61]

(i) saturated steam using an evaporator or an exhaust gas boiler (i.e. economiser) to meet heating demand;

(ii) both saturated and superheated steam which was fed to a compressor, and/or a turbine (commonly known as turbocharger, power turbine and turbo-compounding) for electricity generation to enable ship propulsion;

(iii) chilled effect for refrigeration using a refrigerant and an absorbent; and

(iv) fresh water by flashing (due to a sudden pressure drop), cooling and condensing sea water in a multi-stage flash (MSF) system supply.

The first two applications were more common [242], evidencing the potential of WHRSs for overall energy efficiency improvement and fuel consumption reduction. Additional information about WHRSs is shown in Figure 2.18.

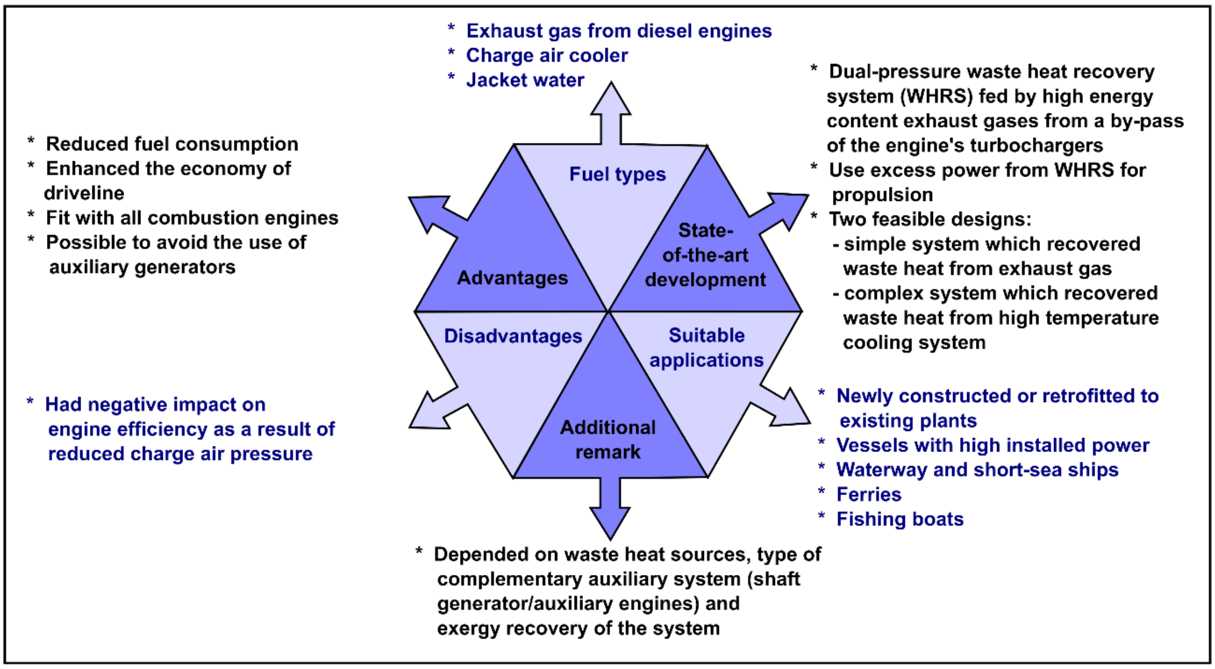


Figure 2.18: Additional information about WHRSs.

A number of WHRS configurations had been reported, for example:

- A simple WHRS with a basic Rankine cycle [61] for heating purpose, as illustrated in Figure 2.19.

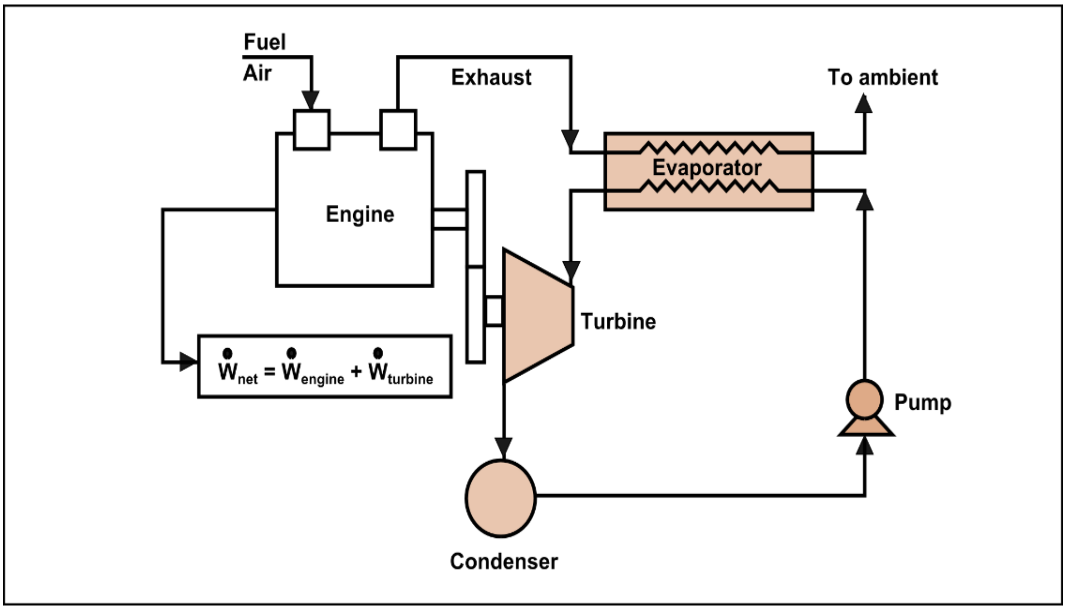


Figure 2.19: The simple WHRS with a basic Rankine cycle [61].

The simple WHRS based on a Rankine cycle [61] was a typical application, which composed an evaporator/economiser, a turbine, a condenser and a feed pump. The working fluid, e.g. water or organic fluid, was pumped by the feed pump to enter the evaporator where steam was produced and further heated by waste heat. The high-temperature steam reached the turbine, expanded and produced power which was then transferred to the electric generator or shaft propeller. The turbine outlet was condensed in the condenser and the resulting liquid was pumped back to the evaporator where the processes repeated.

- A single steam pressure WHRS [242] for electricity generation. A single steam pressure WHRS consisted of an exhaust gas boiler, a water/steam drum, a heat exchanger, a turbogenerator, 2 condensers and 4 pumps, as illustrated in Figure 2.20.

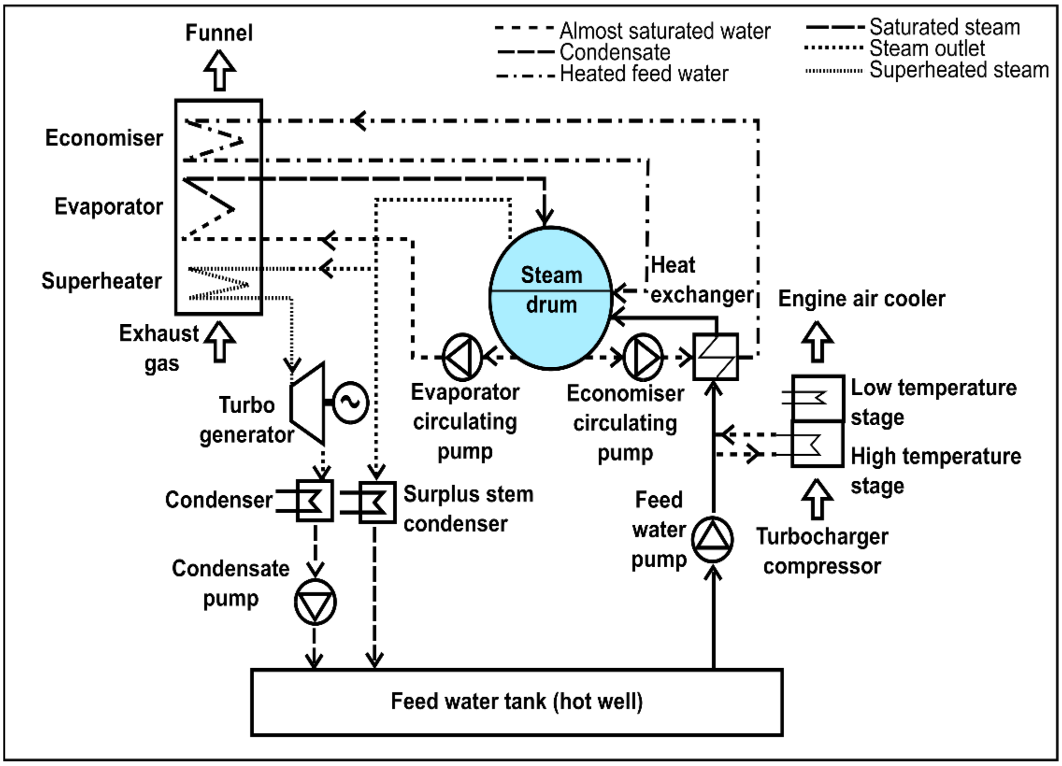


Figure 2.20: The single steam pressure WHRS [242].

The exhaust gas boiler consisted of economiser, evaporator and superheater sections which dealt with heated feed water, water at a temperature close to the saturation point, and saturated steam respectively. The (preheated) feed water from the feed water tank and the saturated water from the water/steam drum were respectively pumped by a feed water pump and an economiser circulating pump to enter the heat exchanger. From there, the heated feed water entered the economiser section of the boiler, and reached a temperature close to the saturation point before returning to the water/steam drum. With an evaporator circulating pump, the almost saturated water left the drum, entered the evaporation section of the boiler and became saturated. The saturated water/steam mixture returned to the drum and got separated. The saturated steam left the drum, went through the superheater section of the boiler and became superheated before heading to the turbogenerator. The superheated steam expanded in the turbogenerator to produce power output. The steam outlet from the turbogenerator was condensed by sea water in a condenser, and sent back to the tank by a condensate pump. The surplus quantity of saturated steam generated in the drum, if any, was condensed by a surplus steam condenser and sent back to the tank. The processes repeated until the required quantity of electricity was generated. It was worth noting that the use of engine air cooler for preheating purpose should not be considered for single pressure WHRS as it could not result in any significant efficiency improvement, although it did work well for dual steam pressure WHRS [242].

- A dual steam pressure WHRS [241] for electricity generation, as illustrated in Figure 2.21 consisted of steam and power turbines, an economiser, a condenser, a separator, a preheater and a few feed water pumps. Both steam and power turbines connected to a turbocharger via a speed reduction gearbox to drive the alternator of the engine. The steam turbine was of dual-pressure and multi-stage. Similarly, the economiser had low- and high-pressure evaporators and separators. Engine exhaust gas was fed to the economiser and the power turbogenerator whilst the jacket cooling water was employed to preheat the feed water to 85 ^{o}C. Some feed water entered the low-pressure evaporator where saturated steam was generated, then superheated by the low-pressure superheater before heading to the steam turbogenerator. The shaft power generated by both power and steam turbogenerators would drive the alternator via reduction gearboxes where the generated power was used for propulsion. During the process, some feed water was further preheated by the scavenge air cooler to reach a temperature of 150–170 ºC before being supplied to the high-pressure evaporator. The resulting high-pressure saturated steam was then used for ship services. The dual steam pressure WHRS could run on 4 modes with different electrical power sources: (i) motor mode powered by the WHRS; (ii) alternator mode by the motor/alternator system; (iii) booster mode by the WHRS and auxiliary engines; and (iv) emergency mode (where engines were disengaged) by auxiliary engines.

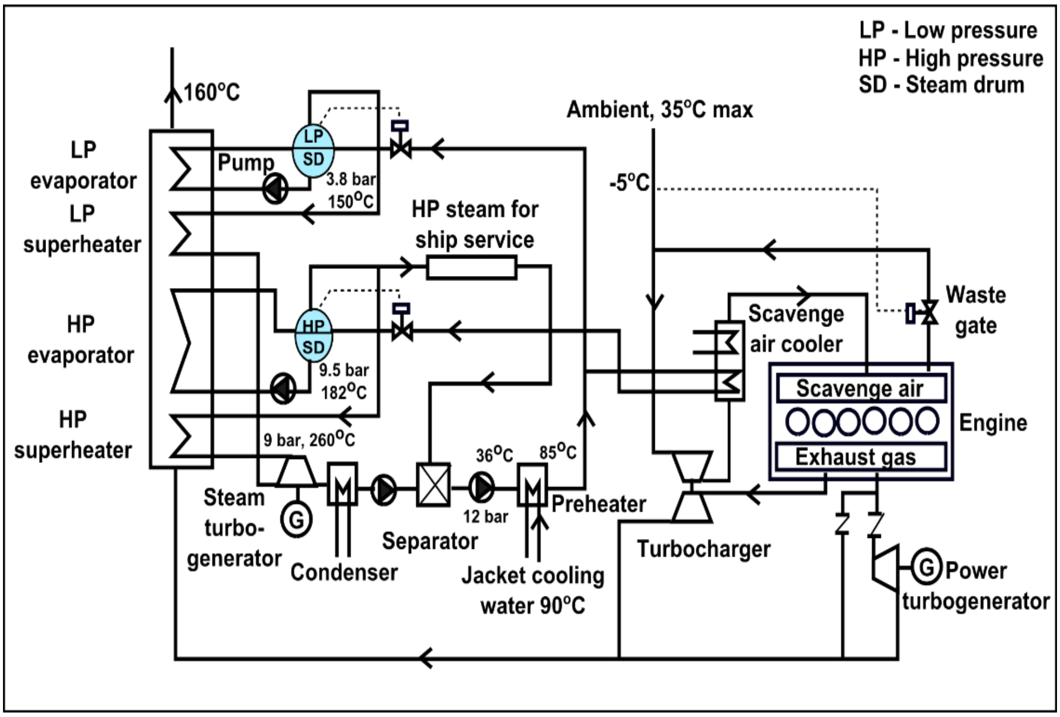


Figure 2.21: The dual steam pressure WHRS [241].

2.3.6 *Shaft generators and power take-off/power take-in (PTO/PTI) systems*

Traditionally, a shaft generator functioned as an AC generator to assist ship propulsion. Electricity was generated when the armature conductors of the shaft generator were cut by the magnetic field created by the rotation of the propeller shaft or the crankshaft of the main engine [243]. The shaft generator was mechanically driven by a main engine directly or via a reduction gearbox to drive the propeller. It was also known as power take-off (PTO), and its voltage and frequency varied with the changing speed of the engine in correspondence to sailing profiles [244]. As power distributed by the main switch board was of constant voltage and frequency, the presence of a frequency control system (e.g. bi-directional converters) was essential to maintain the voltage and frequency of PTO at any engine speed. If an alternative power source (e.g. batteries or auxiliary generators) was employed to supply electricity to the shaft generator, it worked as a motor. It was referred to as power take-in (PTI) and it would drive the propeller at a reduced speed [243]. During emergency, when the main engines failed, the shaft generator would be powered by auxiliary generators to function as a take-me-home device. Additional information regarding shaft generators is shown in Figure 2.22.

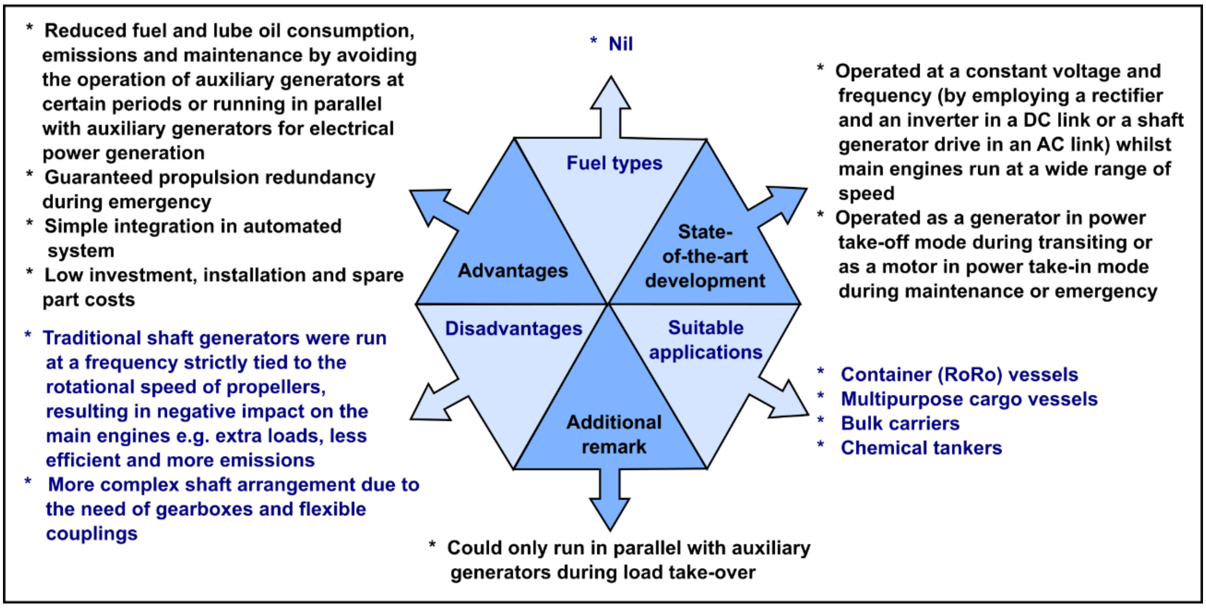


Figure 2.22: Additional information about shaft generators.

2.3.7 *Photovoltaic (PV) systems*

Solar cells, modules (also referred to as solar panels) and arrays were the components of a PV system which differed in terms of size and arrangement. As the basic unit, the solar cell comprised positive and negative semiconductor layers i.e. a PN junction [245]. Two common types of solar cells were crystalline cells and thin films which were made of silicon and amorphous silicon respectively [246]. Figure 2.23 illustrated how solar cells generated electricity from sunlight. In brief, the solar cell absorbed photons from sunlight and as a result, electrons in the negative layer were released. These electrons were naturally attracted to the positive layer and their movement across an external circuit would create voltage difference that resulted in an electric current [245].

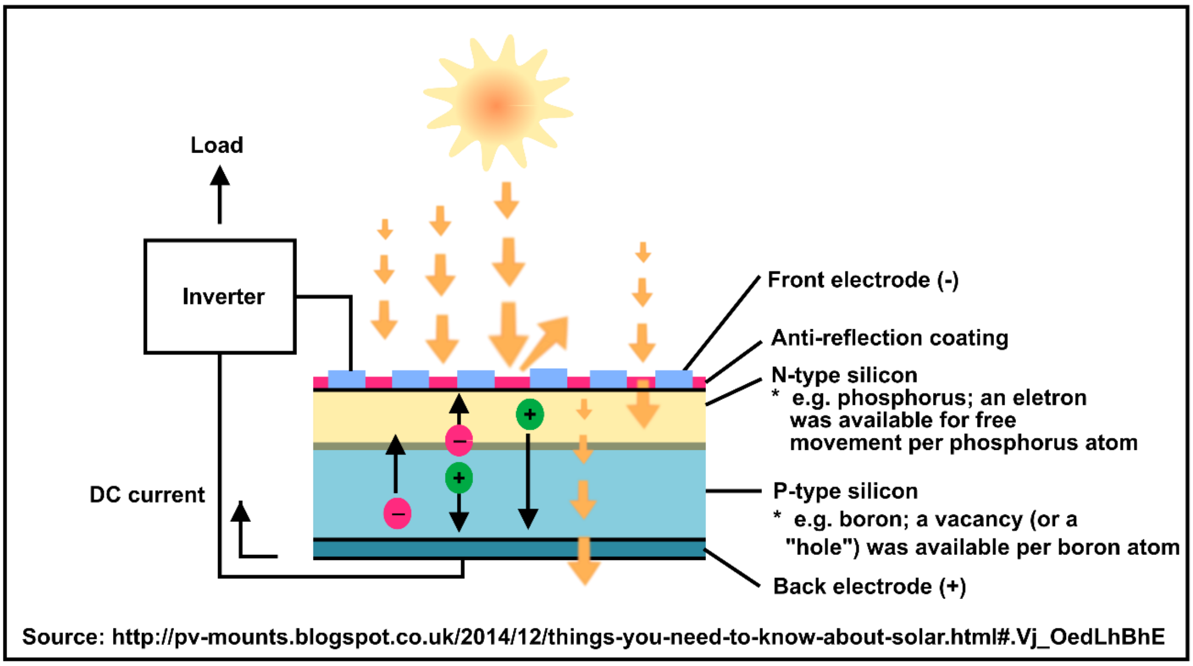


Figure 2.23: How solar cells worked.

As the structure of solar cells connected in series, modules could be arranged in series and/or parallel to build up a single or multiple arrays. A number of arrangements had been designed for existing PV systems [245], including:

- string technology i.e. only one string of parallel panel to one converter;
- centralised technology i.e. strings of parallel panels connected to a converter;
- multistring technology i.e. strings of parallel panels, each with individual converter, connected to a common converter; and
- module-integrated converter technology i.e. only one single panel to a converter.

Additional information about PV systems is presented in Figure 2.24.

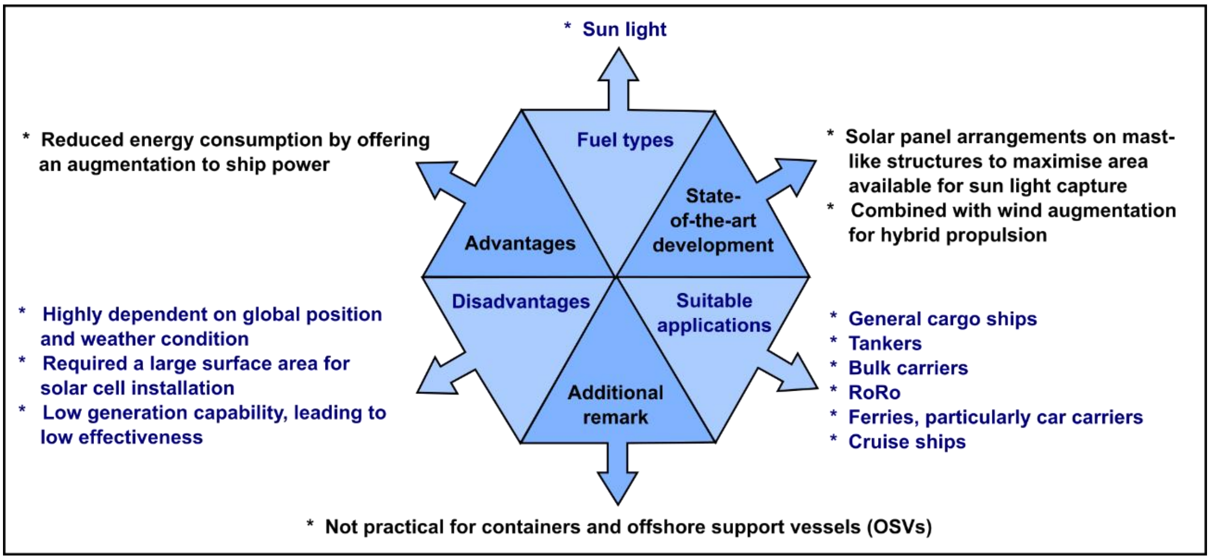


Figure 2.24: Additional information about PV systems.

2.3.8 *Technologies that harnessing wind energy*

Being identified as one of the future maritime technologies [225, 226] which could partially cover loads on the prime movers and consequently reduce fuel consumption, harnessing wind energy seemed to be coming back into fashion for ship propulsion. The pertinent technologies included a variety of sails (namely rigid, dynarigs, telescoping and turbosails), towing kites, and Flettner rotors, as illustrated in Figure 2.25.

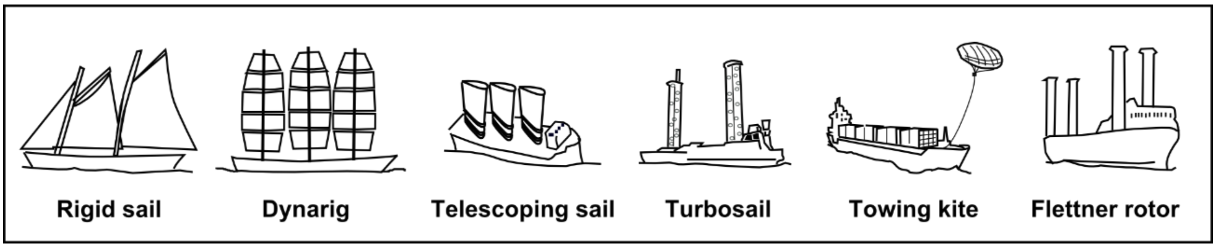


Figure 2.25: A variety of sail types.

The working principle of each sail type was briefly explained as follows:

- A rigid sail, also known as traditional sail or wing, consisted of a piece of fabric stretching over the mast [43]. When travelling in the same direction, ships with rigid sails were accelerated by wind. Otherwise, a rigid sail acted like an airfoil corresponding to airflow. Wind from one side proceeded along the sail towards the rear, resulting in a higher air pressure at the rear of the vessel. Due to the pressure difference of the air flow, a lift was created at the other side of the sail, which pulled the vessel forwards.

- A dynarig [247, 248] consisted of sails which were set to the yard camber and rigidly attached to a freestanding mast on a square rig. The mast rotated freely in corresponding to wind direction so that sails could work effectively to assist ship propulsion.
- A telescoping sail [249] consisted of curvy, hollow, identical, retractable and automatically-controlled parts which were made of aluminium and fibre-reinforced plastic. The sail could be expanded or contracted in accordance with weather and operational conditions, for example, contracted when the ship was in the port or during bad weather.
- A turbosail [43] consisted of metallic, hollow but perforated cylinders which rotated when wind passed through. Based on Savonius principle, turbosails were installed at fixed points. A fan was placed above each turbosail. Operated by engines, the fan accelerated the airflow and resulted in increased lift for ship propulsion.
- Directly attached to the bow of the ship, a towing kite [226], also known as skysail, created a thrust force from wind that assisting ship propulsion.
- A Flettner rotor [43, 44] was a rotating cylinder built on the Magnus effect. When wind impacted the rotating rotor from one side, it dispersed around the rotor, resulting in a forward lift and a turbulent wake, i.e. aerodynamic drag, at the opposite side.

Additional information in relation to the use of wind energy was presented in Figure 2.26. It was important to stress that wind propulsion technologies were still undergoing development [248] at this stage and their employment would require the presence of conventional power technologies to guarantee full ship propulsion.

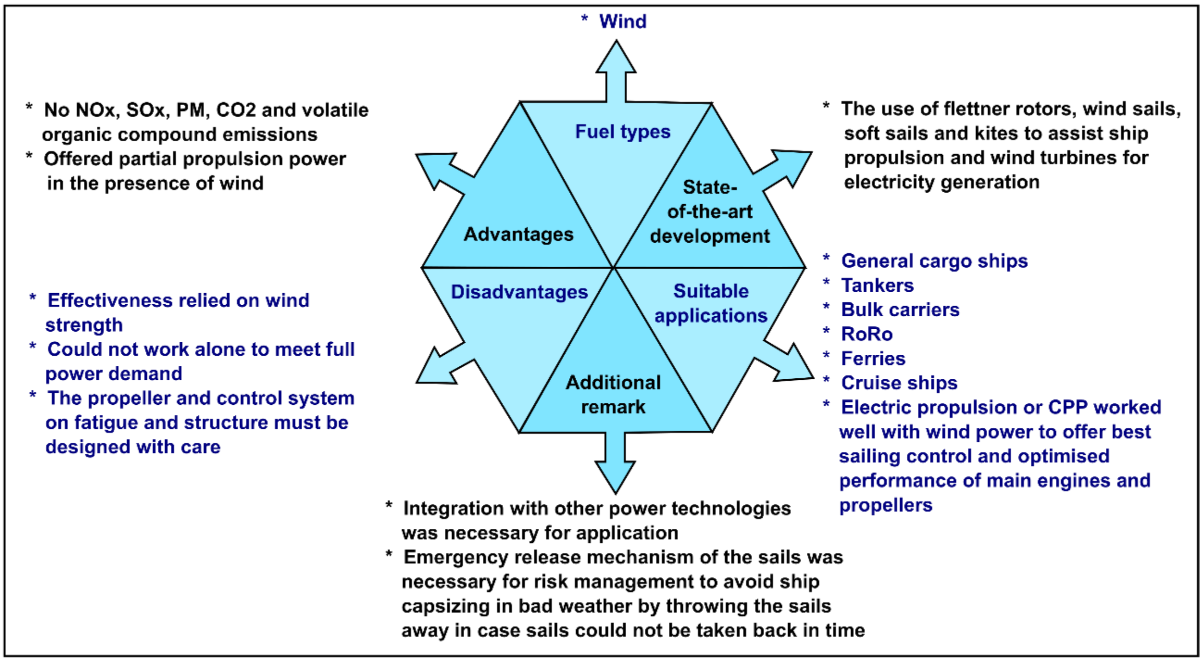


Figure 2.26: Additional information about technologies that harnessing wind energy.

2.3.9 *Cold-ironing*

Cold-ironing, as illustrated in Figure 2.27, was also referred to as shore-side electricity [250], shore-side power [251], shore connection or on-shore power supply [252]. Traditionally, when a ship berthed, its auxiliary engine and boilers stayed in operation to provide hotel services. In contrast, cold-ironing allowed for meeting hotel loads without any disruption by plugging the ship into local power supply whilst the auxiliary engines were turned off [252]—a pretty straight-forward working principle.

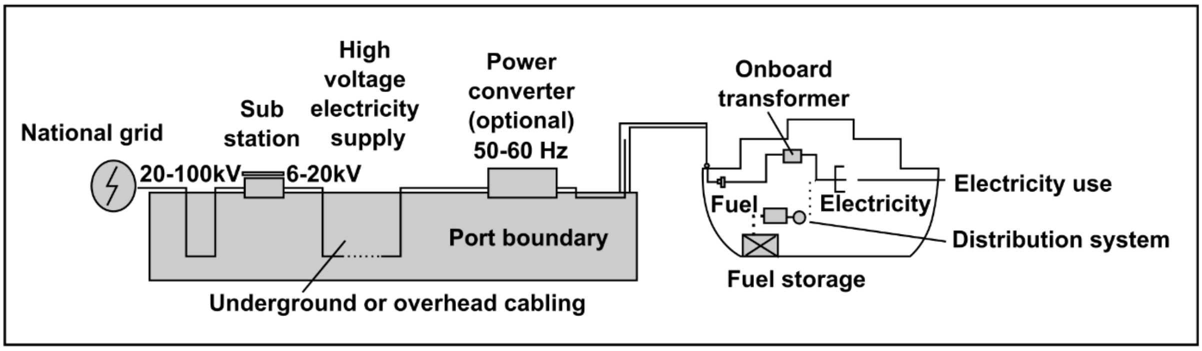


Figure 2.27: Cold ironing for marine vessels in port [250].

Nevertheless, the electrical infrastructure development in port and onboard ships involved not only massive financial investment but also technical barriers. In addition to the diversity of voltage, frequency and power requirements and inconsistency of connectors and cables used onboard different ship types, the expensive cost of on-shore electricity in some regions also hindered the uptake of this technology [252]. Recent studies [251, 253] also concluded that the benefits of cold-ironing were greatly dependent upon the way on-shore electricity was generated: only if renewable energy sources e.g. hydroelectric, nuclear, solar etc. were primarily employed, would the cold-ironing be promising and advantageous in emission reduction. Therefore, countries which relied on fossil fuels for power generation would not be able to take any advantage. Additional information about cold-ironing is presented in Figure 2.28.

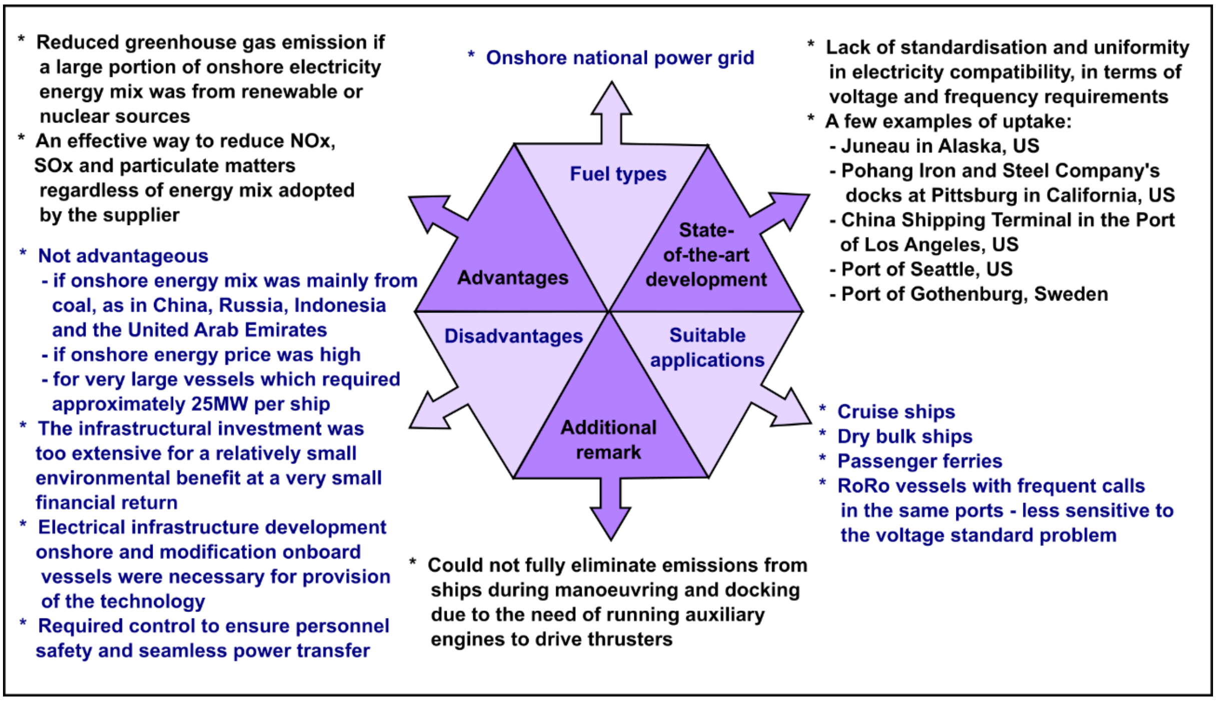


Figure 2.28: Additional information about cold-ironing.

2.4 Summary

An overview on cargo ships, marine power systems and technologies was presented in this chapter. In short, the prime movers of cargo ships were, to date, primarily selected from conventional power technologies including engines, turbines and nuclear power, which were capable to meet full range and peak power demands independently. At present, focus had been steered towards innovative technologies, such as fuel cells, batteries, WHRSs, cold-ironing, PV systems and technologies that harnessing wind energy, which showed the potential to augment auxiliary power onboard cargo ships. Whilst mechanical systems were most common at present, intensive interest had been shown on diesel-electric, all-electric and hybrid systems.

Particularly in relation to auxiliary power supply, auxiliary generators were required in the case of mechanical systems whilst alternative sources were employed by hybrid systems. Neither auxiliary generators nor alternative sources were necessary for diesel-electric and all-electric power systems. Whilst marine power system designs differed from ship to ship and more than one system design could be technically employed for most ship types, diesel engines remained as the conventional practice. The innovative technologies could not eliminate conventional technologies but only supplement them by acting as an augmentation to partially cover the power demand, unless a major breakthrough occurred. The operation of a marine power system involved energy conversion from chemical to mechanical, thermal and electrical. The broad selection of fuel types, technologies and the involvement of various energy types and processes, altogether, increased the complexity of a marine power system. For safety and sustainability, care was required in proposing advanced power system design integrated with any innovative technology. It was therefore important to compare these technologies from an environmental perspective. For this reason, LCA was selected in this study as a tool to estimate the environmental impact of selected marine power systems, which is covered in **Chapter 5**. To enhance understanding, a review on LCA methodology development is presented in **Chapter 3**.

Chapter 3. Literature Review of Life Cycle Assessment Methodology Development

"*Science, like life, feeds on its own decay. New facts burst old rules; then newly divined conceptions bind old and new together into a reconciling law.*"

William James

The Will to Believe and Other Essays in Popular Philosophy, 1910

In addition to LCA concept (as presented in **Chapter 1**) and an overview on cargo ships, power systems and technologies (as presented in **Chapter 2**), an understanding on LCA methodology development was another prerequisite knowledge required for the study. The focus of this chapter is illustrated in Figure 3.1. The literature review was crucial for the selection of LCIA methodologies and impact categories in LCA application at a later stage in **Chapter 5**.

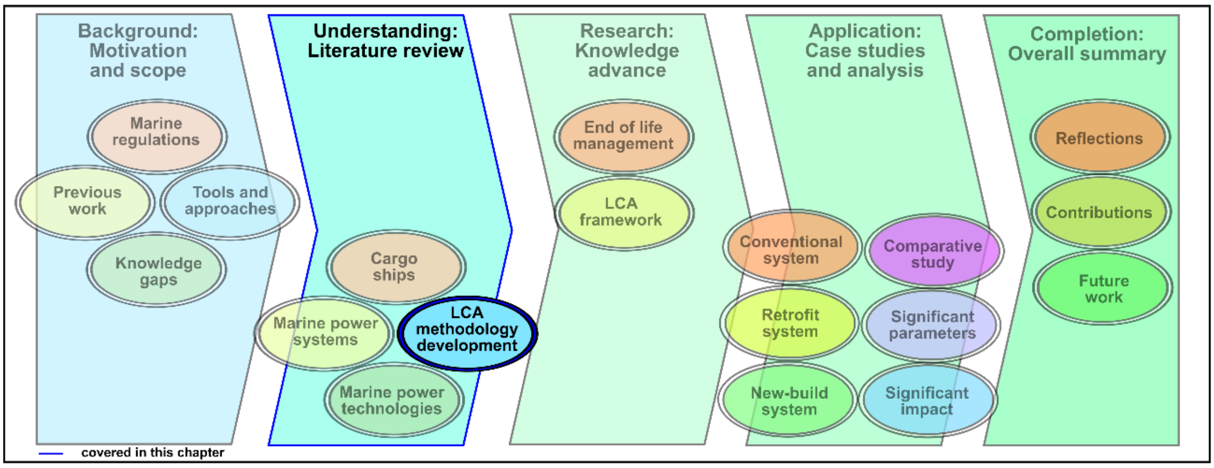


Figure 3.1: The focus of **Chapter 3**.

Methodology approach applied in delivering this analysis is explained in **Chapter 3.1**. Covering the four life cycle phases, the following sub-objectives were set:

- scrutinise LCA methodology development to compare and integrate the proposed concepts or approaches (**Chapter 3.2**);
- clarify environmental aspects, environmental impact and impact categories (**Chapter 3.3**), goal and scope definition (**Chapter 3.4**) and LCI analysis (**Chapter 3.5**);
- discuss LCIA methodologies for impact categories that had recently shown substantial development (**Chapters 3.6–3.8**); and

- detail methodology development with respect to life cycle interpretation (**Chapter 3.9**).

The chapter closes with a short summary to set the scene for **Chapter 4**.

3.1 Methodology used in This Literature Review

The literature review covered three levels of discussion from recognition to clarification and extensive discussion, as presented in yellow, orange and black boxes respectively in Figure 3.2 in the form of a mind map. It was carried out in line with the core of the LCA framework recommended by ISO 14040 [106] and extended to the associated components and/or elements. Other types of LCA study based on exergy, emergy, embodied energy or sustainability concept (see [137, 254-257]) had been emerging but not included in this analysis, mainly because they were neither covered by ISO 14040 nor ISO 14044. They were excluded from this analysis so that the review could direct attention towards conventional LCA only. Literature on LCA methodology development available on ScienceDirect and Google Scholar was identified for the analysis. The literature included review articles, research articles, technical reports, guidelines and conference papers. To uncover research trends shown in the literature, a threefold analysis (instead of a one-off approach) was developed in 3 stages. In the first stage, generic terminologies were used to search for relevant literature. Review articles published in the last decade, 15 in total, were categorised into Sample Group A and analysed to determine their literature coverage in terms of topic and level of detail. In the second stage, the remaining literature was filtered based on the contents presented in their abstracts and conclusions. Literature on conventional LCA study (95 pieces in total, of which 83% were journal publications) were selected to form Sample Group B and analysed to reveal the research trend. Upon completion of this stage, topics requiring clarification or recently being substantially developed were determined. In the third stage, literature in Sample Groups A and B was checked. Using specific keywords, additional literature materials (38 in total which were necessary for complementing an in-depth discussion) were found. These materials were categorised into Sample Group C and analysed. Sample Group C was deliberately not added to Sample Group B to avoid any bias in the research trend. Separate disclosure and a comparison of the topics covered by both review and other literature types were made possible through this threefold analysis to determine if they were in agreement. Based on the findings, research needs in the area of LCA were identified.

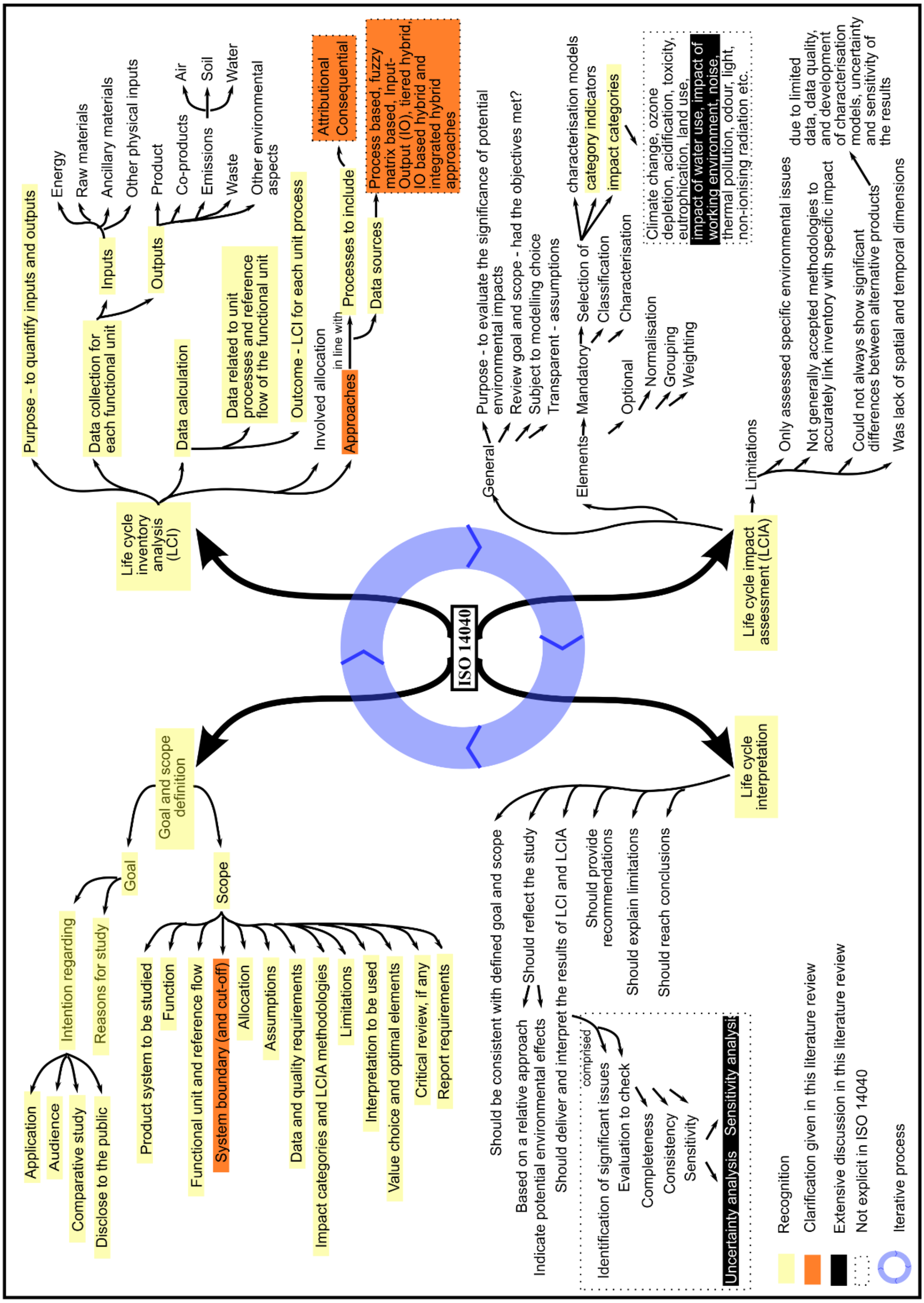


Figure 3.2: A mind map illustrating the focus of this LCA review.

3.2 Findings of Literature Analysis: the Current Research Trend

3.2.1 *Analysis of review articles (Sample Group A)*

The outcome of analysing 15 review articles [108, 109, 111, 115, 116, 121-130] is summarised in Table 3.1 where a scale of I–VI was adopted to describe the levels of discussion (from recognition to extensive and integrated discussion). The articles showed a research trend in accordance with the life cycle phases. With the identification of research needs and challenges [108, 129], the focus had steered from an overarching LCA concept of all-embracing life cycle phases [115, 116, 121, 123, 124] to single phase of LCI [122] and LCIA [111], followed by the sole engagement with a specific topic, e.g. consequential LCI [125], weighting [127], ISO Standards [109] and recently researched impact categories [126, 128, 130]. In relation to LCIA, the scope had become more specific in a similar manner, shifting from a wide range of common impact categories [116] and characterisation models [111] to a coverage of a few less developed impact categories [115], followed by concentration on individual impact categories [126, 128, 130]. Among all, [115] presented the most comprehensive coverage, although transparency, documentation, temporal differentiation and sensitivity analysis were barely recognised whilst ISO Standards, double counting, cut-off, serial and parallel mechanisms, and dynamic of environment were missed out. Conversely, [122, 126] showed the most limited scope with an emphasis on LCI and LCIA respectively. Whilst data availability, source or database and uncertainty were most frequently recognised, characterisation and relevant methodologies were most intensively discussed. A continuous coverage was found for most topics with the exception of process-based and hybrid LCI approaches, selection of impact categories, characterisation models and factors, and dynamic of environment, which had been exclusively unattended to since 2010. Meanwhile, some topics which were briefly mentioned in ISO Standards were not at all or sporadically discussed e.g. serial and/or parallel mechanisms, recycling, future scenario modelling and grouping. Other topics which were not included in ISO Standards were brought up e.g. rebound effect, renewability of resources, dynamic of the environment and consensus building or harmonisation. In addition, some topics, e.g. transparency, consensus building and harmonisation, were broadly recognised but not intensively discussed. Altogether, these findings revealed potential topics for further investigation.

Table 3.1: Topics presented in review articles (Sample Group A) and the levels of discussion.

Topic	Resource															Frequency (brief discussion: in-depth discussion)
	[121]	[116]	[122]	[111]	[123]	[124]	[115]	[108]	[125]	[126]	[109]	[127]	[128]	[129]	[130]	
ISO Standards	IV	II	V	III	II			III			VI	III	I			9 (6:3)
Transparency	III			III	I		I	I				III	I	I		8 (8:0)
Phase I: Goal and scope definition																
Goal and scope	IV	III		I	IV	II	III	I			III			I		9 (7:2)
Functional unit	IV	III		I	IV	III	III				III				I	8 (6:2)
System boundary	VI		V		V	I	V		III	III	III		I	III		10 (6:4)
Phase 2: LCI																
Allocation	I				IV	III	V		I		III	I				7 (5:2)
Multi-functionality	IV				V	I	II				I					5 (3:2)
Double counting			III		I	V									I	4 (3:1)
Recycling	III	I			VI		III	I	III		III			II	II	9 (8:1)
Rebound effect**							II		VI					I		3 (2:1)
Renewability of resources **							III						III		IV	3 (2:1)
Cut-off	I				VI	I					I					4 (3:1)
Attributional vs. consequential	IV				I		IV		IV				I			5 (2:3)

Data																
Availability/ source/database	I		III	III	III	III	IV	III	I	III	I		IV	II		12 (10:2)
Quality	I	II	II	I	III	IV	III	IV			I			I		10 (8:2)
Documentation	IV			I	I		I						III		I	6 (5:1)
LCI approach																
Process-based	IV		V		V		V									4 (0:4)
Input-Output (IO) based	IV		V		V		V						I			5 (1:5)
Hybrid	IV		IV		V		V									4 (0:4)
Phase 3: LCIA (mandatory)																
Selection of																
Impact categories		I		VI	I	IV	II	III								6 (4:2)
Category indicator		II		I	I	V	II	III		IV		I	III			9 (7:2)
Environmental mechanism[+]				III		I	V[+]	I					IV[+]			5 (3:2)
Characterisation models/factors		I		V		V	VI	III								5 (3:2)
Classification		I			I	V	III	IV			I	I	III			8 (6:2)
Serial mechanism																0
Parallel mechanism																0
Characterisation		IV		VI	III	VI	VI	IV	II	III		I	VI		IV	11 (4:7)
Methodology		IV[a]		IV[b]		II[c]	VI[d]	VI[e]		IV[f]			IV[g]		IV[h]	8 (1:7)
Midpoint vs. endpoint		VI		IV		III	IV	III		III			IV		III	8 (4:4)
Spatial differentiation		IV		III	I	V	IV	III	I	VI			III	II		10 (6:4)

Temporal differentiation		IV		III	I	IV	I	III	II	VI			I	II		10 (7:3)
Dynamic of environment**					I	V										2 (1:1)
Future scenario modelling*					V		IV							I		3 (1:2)
Consensus building/harmonisation**	I	I		III	I	III	III	III	I				III	I	I	11 (11:0)
Phase 3: LCIA (optional)																
Normalisation		IV		V		III	II	IV			I	III		I	I	9 (6:3)
Grouping		IV					III	V								3 (1:2)
Weighting		IV		V	I	IV	IV	V			I	VI	I	I	I	11 (5:6)
Phase 4: Interpretation																
Uncertainty	I	IV		I	III	IV	IV	III			III	I	II	I	I	12 (9:3)
Sensitivity analysis	I				I	VI	I				I		I			6 (5:1)
Uncertainty analysis	I					IV	VI	III				I		I		6 (4:2)
Frequency	20	19	8	20	29	26	34	22	10	8	15	10	20	15	12	

+ Environmental mechanism was shown in the literature
* Implicitly included in ISO
** Not included in ISO
I Recognition; mentioned once or twice throughout the literature
II Brief discussion; presented in a few sentences or a paragraph
III Brief discussion; mentioned dispersedly 3 times or more throughout the literature
IV Extensive discussion; in one stand-alone subsection
V Extensive discussion; combined with other relevant topic(s) in one subsection
VI Extensive discussion; integrated with other relevant topics throughout the literature.
■ A grey box denoted extensive discussion with a scale of IV, V or VI.

[a] Existing models and corresponding indicators were summarised for climate change, stratospheric ozone depletion, acidification, aquatic eutrophication, terrestrial eutrophication, human toxicological effects, ecotoxicological effects, photo-oxidant formation, biotic resources, abiotic resources, land-use impact, ionisation damage and nuisance from odour and noise including traffic noise.

[b] The characterisation approaches of Centrum Milieukunde Leiden (CML2001), Eco-Indicator99, Ecoscarcity, Environmental Design of Industrial Products (EDIP97), Environmental Priority Strategies in Product Development (EPS2000), IMPACT2002+, Life-Cycle Impact Assessment Method based on Endpoint Modelling (LIME) and The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) in assessing the damage of corresponding impact categories on 3 AoPs (i.e. human health, natural resources and natural environmental quality) were compared at midpoint, endpoint, damage and weighting levels.

[c] Existing models including CML2001, Eco-Indicator99, EDIP97 and TRACI were briefly discussed.

[d] Current LCIA development assessing abiotic resource depletion, impact of land use, water use, toxicity and indoor air were presented.

[e] Existing characterisation models and research needs respectively for global warming, ozone depletion, acidification, eutrophication, smog formation, land use, water use, human health and ecotoxicity were briefly presented.

[f] Existing LCA approaches on soil-related impact were briefly discussed.

[g] Existing LCIA approaches which assessed the impact of freshwater use at midpoint and endpoint levels were evaluated with established criteria.

[h] The methodology approach adopted by Exergy, CML2001, Eco-Indicator99, EDIP97, EPS2000, IMPACT2002+ and ReCiPe for assessing the impact of natural resource depletion at midpoint and endpoint levels were discussed.

3.2.2 *Analysis of other literature types (Sample Group B)*

In addition to ISO Standards, overview, comparison and consensus building, literature in Sample Group B [101, 106, 107, 110, 114, 117, 118, 170, 177, 178, 180, 258-341] were organised into 23 topics (representing the main focus of each) in accordance with the life cycle phases, as illustrated in Figure 3.3.

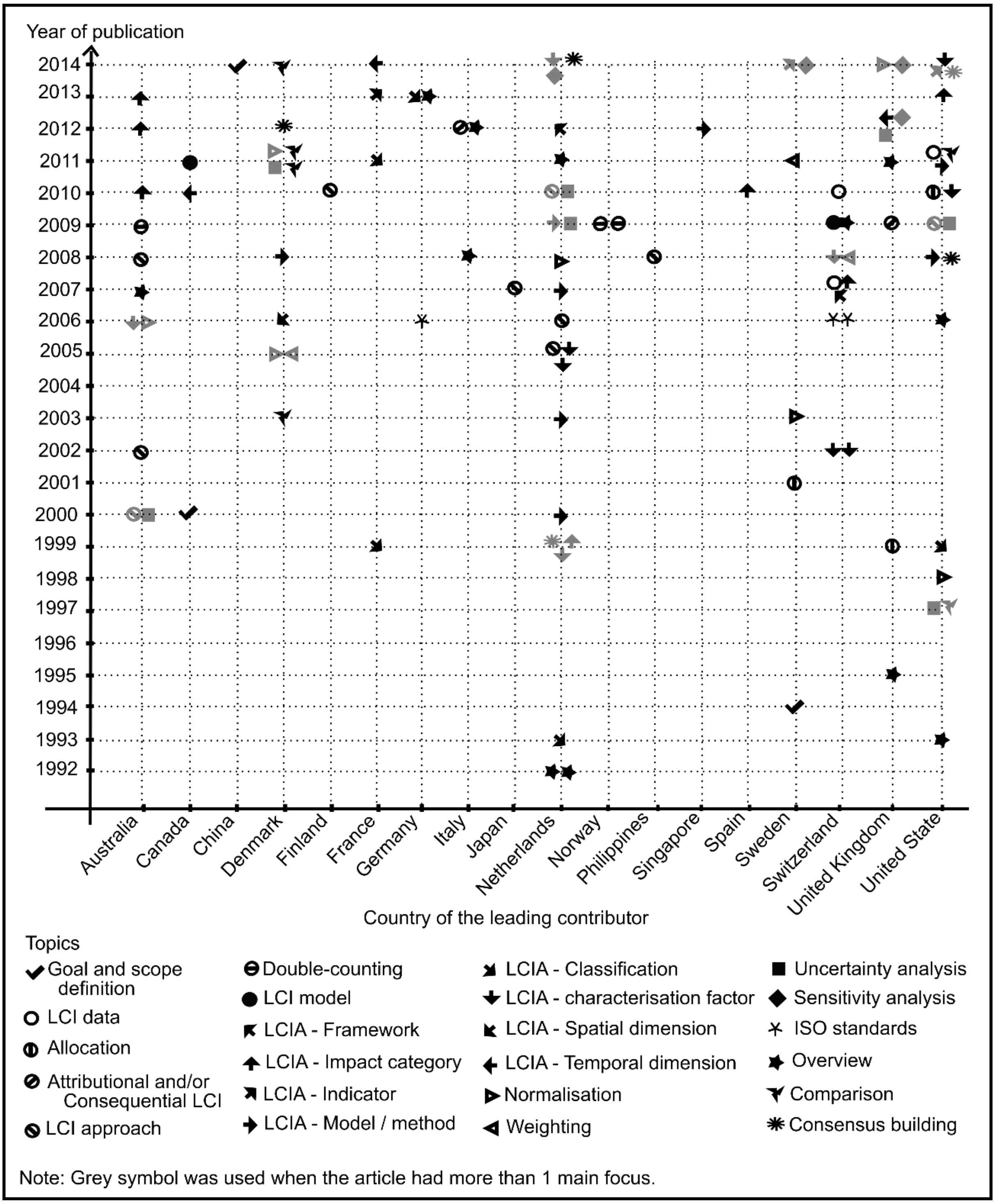


Figure 3.3: Distribution of literature materials in Sample Group B.

The country of the institution with which the leading contributor was affiliated and the year of publication were both disclosed. For literature which covered 2–3 main focuses, they were included under the relevant topics. A slightly different approach was adopted for those presenting an overview. Instead of breaking down into subtopics, they were categorised under the umbrella of ‘overview’. Among all, 10 pieces of literature were published before 2000; 12 between 2000 and 2004 and the rest followed afterwards. Irrespective of literature presenting an overview, the majority were devoted to one main focus whilst approximately 16% covered 2–3 main focuses. There were a few points worth-noting. Netherlands, US and Switzerland were found as the top 3 countries producing approximately one half of the literature in this sample group. In contrary, LCA appeared to be a comparatively new research topic in Asia where only 1 publication was from China, Japan, Philippine and Singapore each. Taking all into account, overview was the most common focus, followed by LCI approaches and LCIA methodology development for characterisation factors. The least attended subtopic in this part was not identified as those providing an overview were not broken down into subtopics. Research advance on LCI had expanded gradually where new ideas such as water categorisation, consideration of capital goods, dealing with traffic noise, handling double-counting inherent in the tiered hybrid approach, and the use of fuzzy numbers, physical Input-Output Tables (IOT) and non-local data for LCI development were reported. Among all life cycle phases, the scientific endeavour on LCIA was relatively more prominent in which 44% of literature presented the development of frameworks, impact categories, indicators, characterisation factors, characterisation models and methods, classification, spatial and temporal dimensions, normalisation and weighting, respectively. The development of some characterisation models i.e. ReCiPe, IMPACT2002+, TRACI, UNEP-SETAC Toxicity Model (USEtox) and USES-LCA were reported, which was crucial to not only guarantee transparency but also enable full understanding and appropriate practice among the users. Examples of recently addressed impact categories included soil quality, land as a resource, traffic noise, impact of work environment, impact of water use (freshwater ecotoxicity) and impact of resource scarcity. Research on sensitivity and uncertainty analysis, normalisation and weighting for LCA studies was slowly but steadily developed particularly in recent years. In relation to rebound effect, consensus building, serial and parallel mechanisms relevant to classification, recycling, future scenario modelling and grouping, the findings were in agreement with those of Sample Group A.

3.2.3 *Overall findings*

From the results, one could interpret that methodology development of each LCA phase was not evenly balanced. From goal and scope definition to life cycle interpretation, there was an increase in complexity which came along with diminishment in methodological advance. As the most straight-forward phase, goal and scope definition received criticism to the minimal extent compared with the other LCA phases. Methodologies for LCI were more established than those of LCIA and life cycle interpretation. Extensive discussion on goal and scope definition as well as LCI was therefore not the focus of this review but only a few points requiring clarification to enhance the understanding of existing LCA knowledge. In relation to LCIA, attention was given on the methodology development of impact categories being substantially developed recently, including the impact of water use, noise and working environment. Other impact categories were not covered not only because of the word constraints, more importantly, they were either hitherto more developed (e.g. climate change, ozone depletion, particulate matter formation, acidification, photochemical oxidant formation, human toxicity, ecotoxicity and resource depletion, in which impact categories applicable to the maritime context are briefly described in **Chapter 4**) or were not substantially investigated (e.g. space use, odour, light, non-ionizing radiation and thermal pollution). Normalisation, grouping and weighting (i.e. the optional LCIA elements) were excluded from discussion in this chapter due to the same reasons. In respect of life cycle interpretation, uncertainty analysis was extensively covered in line with its steady development in recent years, together with a discussion on sensitivity analysis for potential methodology development in the context of LCA due to its increasingly important role.

3.3 Clarification on Environmental Aspects, Environmental Impact and Impact Categories

As previously reported in **Chapter 1.5**, ISO established ISO14040 and ISO 14044 [106, 107] as the international standards which focussed on LCA. Both environmental aspects and impact categories were included in the lists of “terms of definitions” of ISO14040 and ISO 14044, as follows:

- *Environmental aspect: element of an organisation’s activities, products or services that can be interact with the environment*
- *Impact category: class representing environmental issues of concern to which life cycle inventory analysis results may be assigned*

Whilst the definition of environmental impact was missing from the lists of ISO14040 and ISO 14044, environmental aspects were not further elaborated. Impact categories were covered by these two standards in relation to LCIA during *selection*, as explained in **Chapter 1.5**. To enhance understanding, a general description of common impact categories is presented in Table 3.2.

Table 3.2: Description of common impact categories

Impact categories	**Description**
Climate change	• Any change in the climate over time as a result of greenhouse gas emissions due to human activity or natural processes [342]
Ozone layer depletion	• Also referred to as 'stratospheric ozone depletion' or simply 'ozone depletion' • Ozone was damaged by chlorine and bromine which were released by chlorofluorocarbons and halons [342]
Eutrophication	• An aquatic environment, e.g. a lake or a stream, which became overly rich in nutrients due to human sewage and animal waste, and consequently, the environment became lifeless as aquatic plants used up water and oxygen during the processes of overgrowth, death and decomposition [342]
Acidification	• In the air, sulphur dioxide, nitrogen dioxide and/or ammonia reacted with other compounds and turned into sulphuric and nitric acids, which changed the chemical composition of the soil and water [342]
Toxicity	• The degree of danger posed by a substance to human beings, animals and/or plants [342] • Toxicity could be further classified as human toxicity and ecotoxicity • It was also common to distinguish the latter as terrestrial, freshwater and marine aquatic ecotoxicity
Photochemical oxidant formation	• Also referred to as 'respiratory organics effect' or 'respiratory (organics) for human health' • At high concentration, photochemical oxidants (i.e. the ozone that appeared in the lower troposphere) could be harmful to human beings, materials and plants [342]
Ionising radiation	• Alpha, beta or gamma radiation could ionise particles such as ionising atoms within DNA and consequently would result in biological changes [342]
Desiccation	• Environmental problems related to water shortage e.g. lower water table and change in the natural vegetation [343] • As a result of water extraction for various purposes (including industrial and residential use) and water supply from other areas
Depletion of biotic resources	• Environmental concern on living resources e.g. rainforests and animals [343]

Depletion of abiotic resources	• Depletion of non-living natural resources e.g. minerals, crude oil, water etc. which took place because of excessive extraction and consumption [343]
Land use	• Environmental issues concerning the consequences of land used by human beings for various activities on resources, biodiversity etc. [343]
Waste heat	• Also referred to as 'thermal pollution' • Waste heat was generally discharged into atmosphere or surface waters from power stations and production plants • It might increase the local temperature of the atmosphere and aquatic systems (but not on a global scale) [343] • It was regarded as an impact category although no characterisation model had been developed yet
Odour	• Was classified as airborne and waterborne • Also referred to as 'malodorous air' and 'malodorous water'[343] • When the concentration of an odorous substance was high, it became unpleasant and consequently resulted in health issues • The acceptable level of odour, however, varied among individuals
Noise	• Also referred to as 'noise nuisance' • Noise was of universal concern in relation to sound [343] • Similar to odour, individuals would tolerate sound differently: some might perceive a particular source of sound as acceptable or negligible whilst others might be irritated
Casualties	• Mainly related to casualties caused by accidents [343] • It was common that casualties and the impact of exposure to substances at workplace (also known as the impact of working environment) were perceived as relevant to one another

In addition, ISO published ISO 14001 [344] and ISO 14004 [345] which covered environmental management from an organisational perspective. As recommended by ISO 14004, LCA was one of the approaches that could be applied to understand the environmental impact of an organisation "when identifying environmental aspects and determining their significance". Environmental impact was defined by ISO 14001 and ISO 14004 as *any changes to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's environmental aspects.* With relatively broader scope, environmental aspects and environmental impact were detailed in ISO 14001 and ISO 14004, as summarised in Figure 3.4.

	Environmental aspects	Environmental impact
Relationship	The cause of environmental impact	The effect of environmental aspects
Examples	Discharge, emissions, consumption or reuse of materials, generation of noise etc.	Depleted natural resources, improved water/soil quality, polluted air, decreased productivity etc.
Use	To assist an organisation in determining * environmental aspects that could be influenced * implications on its environmental performance * the need of control and improvement * priorities for management action	Necessary in identifying environmental aspects and their significance
Characteristics	Dependent on the activities, products and services of an organisation * natural resource extraction and distribution * design and development * manufacture * transportation * use * waste management	Scale: * geographical: local, regional or global * temporal: short, medium or long term * significance level: varying
How to determine	Qualitative and/or quantitative data, considering * emissions to air * release to water * use of natural resources * release to land * use of raw materials * use of energy * energy emitted (e.g. heat and radiation) * waste and by-products	Possible approaches: * life cycle assessment * environmental impact assessment * cause-and-effect diagram * input-output flowchart * mass/energy balance

Figure 3.4: The concept of environmental aspects and environmental impact as described in ISO 14001 [344] and ISO 14004 [345].

3.4 Clarification on Goal and Scope Definition: Cut-off and System Boundary

Goal and scope definition was of unquestionable importance as the primary phase of an LCA study. As summarised in Table 3.3, these topics had been broadly covered from recognition, discussion to application. As it was unlikely to know in advance which data was insignificant and could be excluded, additional dimensions were distinguished by [115, 123, 279, 309, 321, 334] for cut-off and system boundary selection, as shown in Figure 3.5.

Table 3.3: Literature coverage on goal and scope definition, system boundary and cut-off.

Topic	Coverage level
Goal and scope definition	I [108-111, 122, 127, 258-262, 265, 270, 272, 279, 280, 295, 298, 302, 305, 314-316, 322, 340] II [116, 124, 129, 309, 326, 329, 332, 333] III [106, 107, 114, 115, 121, 123, 263, 274, 284, 285, 310, 339] IV [292, 317]
System boundary	I [128, 180, 258, 261, 272, 279, 283, 286, 292, 312, 315, 331, 333, 337, 338, 341] II [109-111, 125, 126, 129, 271, 306, 316, 332] III [101, 106, 107, 114, 115, 121-124, 269, 274, 284, 285, 304, 305, 309, 310, 321, 328, 334, 339, 340] IV [323, 327]
Cut-off	I [109, 121, 124, 125, 260, 281, 290, 291, 312, 339] II [106, 261, 279, 284] III [107, 114, 122, 123, 309, 321]

I Recognition where the topic was brought up once or twice
II Brief discussion where the topic was mentioned 3–5 times, discussed slightly without much detail
III Noticeable discussion where the discussion of the topic was either in a dedicated section or integrated with other topics throughout the literature
IV Case study

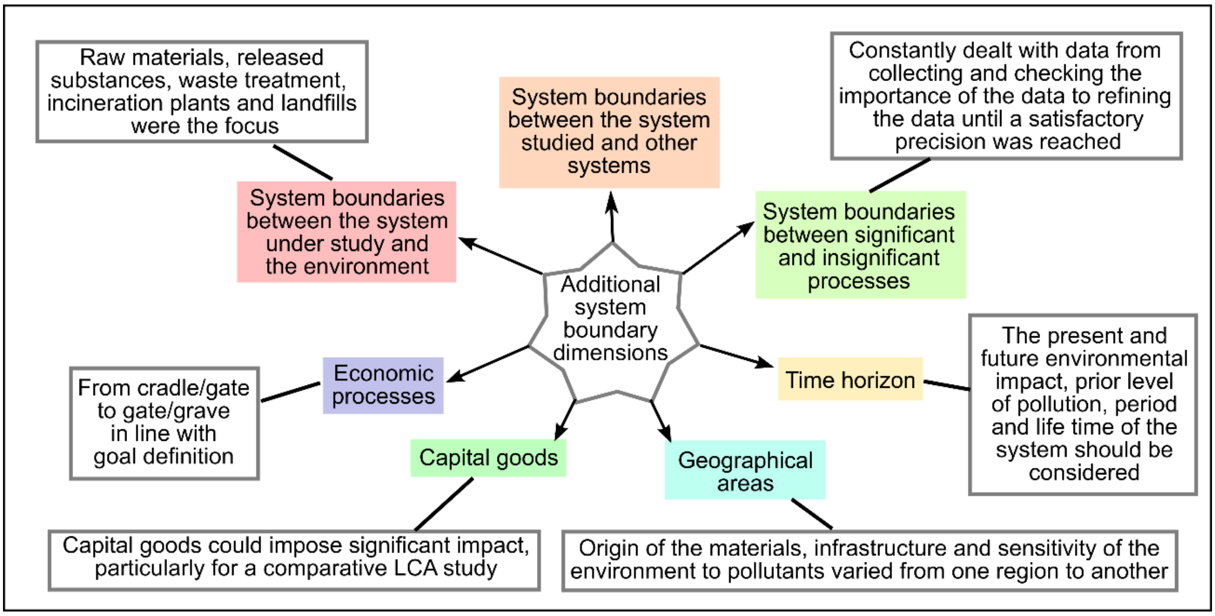


Figure 3.5: Additional dimensions for cut-off and system boundary selection.

Particularly for boundary selection between different systems, a few methods were reported as follows:

- The contents of the system were defined either using process tree system [309], technological or social-economic whole system [334]. The process tree system should only consider processes and transport which were directly involved in the life cycle of the system under study. The technological whole system would account everything affected by the choice between comparative systems except economic and social forces, which were included by the socio-economic whole system.

- Only the 'main' life cycle stream was considered [321]. The method did not allow boundaries to be repeatedly selected, nor did the selection of similar boundaries for different systems.
- A percentage of the total mass, generally 5–10%, of unit processes in the system under study was considered as the cut-off ratio to eliminate any input below the rate. The method did not consider the impact of an input on its system from an entire life cycle perspective.
- Only readily available inputs were included [321]. The method could result in a false sense of completeness and bias analysis.
- Alternative cut-off criteria were used by taking weight, energy, toxicity and price into account in defining the contribution of an input to the system as negligible, small or large [321]. Issues regarding unrepeatable boundaries remained unsolved.
- Relative contribution of mass, energy and economics to the functional unit which allowed similar boundaries to be selected for different studies [122, 321]. Any non-energy-non-combustion related air emission was beyond the scope of this method.

Selecting appropriate system boundaries generally would require a large quantity of data which resulted in additional cost and time [123]. Due to its considerable impact on "the depth and the breath of LCA" [106, 107], goal and scope definition (including system boundary and cut-off) was a decisive factor to determine the credibility of LCA results. Without due care, any omission or flaw at this fundamental phase would result in an absolute divergence due to a sort of snowball effect, leading to misinterpretation and inappropriate decision.

3.5 Clarification on LCI: Attributional and Consequential Approaches—What Processes to Include

Without much detail, ISO 14040 [106] presented the following remark in its annex:

> *Two possible different approaches to LCA have developed during the recent years. These are*
>
> *a) One which assigns elementary flows and potential environmental impact to a specific product system typically as an account of the history of the product, and*
>
> *b) One which studies the environmental consequences of possible (future) changes between alternative product systems.*

A few terminologies were adopted for these approaches. The former was referred to as attributional, descriptive, accounting or retrospective LCA whilst the latter was known as consequential, prospective, change-oriented, decision- or market-based LCA [112, 115, 340]. Similar to goal and scope definition, attributional and consequential LCA had been broadly studied, from recognition [123, 128, 291, 309, 341] to brief [263, 283, 338] and noticeable discussions [114, 115, 121, 125, 170, 269, 310, 339, 340]. The core subjects of discussion in this regard were presented as the following:

(i) The use of average or marginal data. A distinction was presented in accordance with attributional and consequential approaches, see [114, 121, 125, 269, 274]: attributional LCA used average data (which were measured, historic or fact-based) to account for inputs and outputs that were directly involved in production, consumption and disposal of the product system under study at a specific time and a particular production level which would deliver a certain quantity of functional unit without considering market and non-market effects, in which the inputs and outputs would be generally allocated based on mass, energy content or economic value. In contrast, consequential LCA used marginal data (which involved a generic supply-demand chain built upon a decision) to account for all inputs and outputs that significantly, directly and indirectly affected by a change in the production of the product system due to the substitution or use of constrained resources by taking into account both market and non-market effects (e.g. policies and impact of research and development), in which allocation was avoided via system expansion.

(ii) Deciding between attributional and consequential approaches. According to [340], the choice could be made by answering some questions, as listed in the following:

- How was system boundary of the study defined?
- What were the processes to be included?
- What were the causal chains to be used?
- How were questions framed to identify the exact problem to be tackled?
- What were the derived questions?
- What were the technological options?
- What was the scale of the expected change(s)?
- What was the time frame of the question?
- Could a ceteris paribus assumption be held?
- Was the system under study replacing another system on a small scale?
- Was the technology used in the new system expected to extend to other applications on a larger scale?

Considering the equivocal and wearisome nature of this method which indeed presented an evident shortcoming, one might alternatively consider a three-question provisional scheme proposed by [310] as illustrated in Figure 3.6. However, as according to [310], the scheme was immature and a further in-depth testing would be required as it was merely the first step towards building a consensus among LCA community. In this matter, [115, 125, 339] reported that no consensus was reached among LCA community on the appropriateness of one approach compared to the other, relevance of the knowledge generated by both approaches and their practicability.

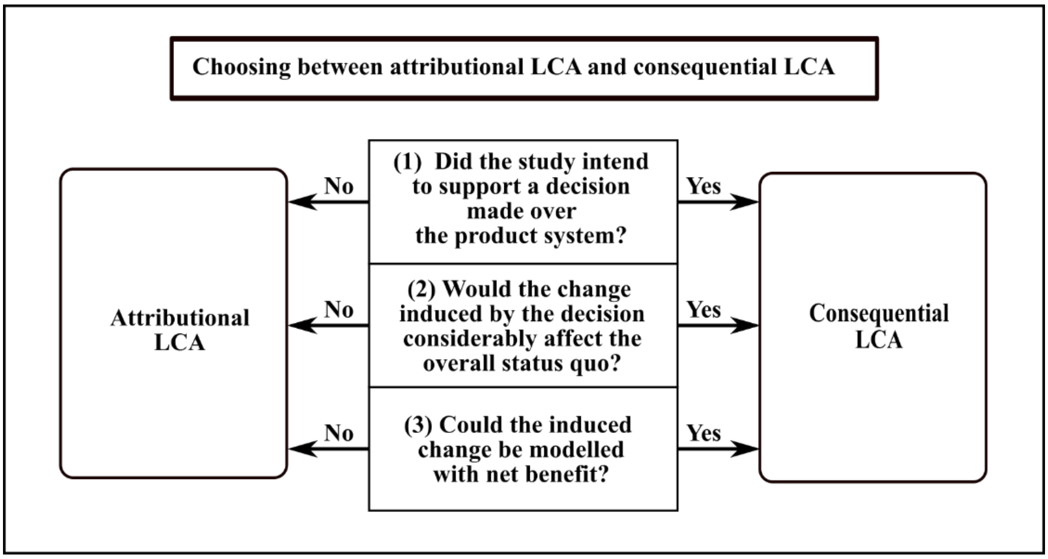


Figure 3.6: The 3-question scheme provisionally used for choosing between attributional and consequential LCA, as proposed by [310].

(iii) Whether to combine attributional and consequential approaches. Whilst [340] noted that consequential LCA had always been inconsistently performed and misinterpreted as 'the state-of-the-art methodology', [269] strongly claimed that both approaches must stand alone where a combination was not allowed. Dissimilar recommendations were given by [115, 121, 340], leading to a confusing situation. An emphasis should be made on the fact that both approaches served different purposes, as implied by [106] (as mentioned earlier). To reiterate, attributional LCA aimed to identify environmental burdens throughout the life cycle of a product system whilst consequential LCA estimated the change in environmental burdens incurred by a decision made in line with a marginal change in the production of the system. A clear-cut solution was therefore incontrovertible to the question of whether to combine attributional and consequential approaches if one referred to this very fundamental concept in practice based on the reason(s) of carrying out the LCA study. Such a simple but decisive approach was appropriate from a pragmatic point of view in line with the purpose of LCI (i.e. to collect and quantify data). As clearly pointed out by [340], the difference between both approaches was the type of processes to be taken into account (i.e. attributional approach considered processes which would significantly contribute to environmental burdens; consequential approach accounted for processes which were affected by decisions) whilst their LCIA modelling principles remained unchanged. In addition, both approaches could be applied one after the other separately if an LCA study aimed to serve more than one purpose for different levels of understanding, for instance, to compare the environmental impact of a product system with an alternative system before and after implementing some technical improvements using generic and marginal data. In this case, attributional approaches should be applied for a comprehensive picture if the LCA practitioners were new to the topic whilst consequential approached could be adopted if prerequisite knowledge of the environmental performance of the product system under study and marginal data which involved supply-demand chains were in place.

3.6 Clarification on LCI Approaches: What Data Sources and Principles to be used for Quantity Computation

The purpose of LCI was to calculate and analyse the quantities of inputs and outputs involved in delivering a specific functional unit of the product system under study [121], which typically produced a list of substances with identified quantity as the outcome. Based on data sources and fundamental principles used for computation involved in LCI compilation, a number of methods were developed, including process (using process flow diagram and matrix), fuzzy matrix, IO, tiered hybrid, IO based hybrid and integrated hybrid approaches. These methods were respectively recognised [263, 267, 283, 321, 327, 328, 333, 341]), briefly [291] or noticeably discussed [114, 115, 121-123, 170, 271, 274, 284, 285, 290, 291, 306, 307, 309, 310, 312, 313, 330-333, 338, 339] and applied [271, 294, 312].

Figure 3.7 presents an overall idea how these methods could be integrated with one another in line with the fundamental principles, data sources and life cycle phases from energy and material acquisition to the end of life. [332] compared these methods (except fuzzy matrix-based approach) in terms of data requirements, uncertainty of data source, system boundaries, software tools and requirements, simplicity, time and labour intensity. Based on [115, 121-123, 271, 274, 290, 291, 294, 305, 306, 309, 310, 312, 313, 330, 332, 333, 338, 339], Table 3.4 briefly described the methods and extended the comparison to cover strengths and limitations of each method. The use of structural path analysis in a hybrid LCA [306], although interesting, was excluded from this comparison because the analysis did not compile LCI but rather preliminarily identify the most important input paths. Along with the criteria proposed by [121, 332] such as goal and scope, requirements on accuracy, completeness, time, budget and data availability, the strengths and limitations of each approach should also be taken into consideration in choosing an LCI method in practice.

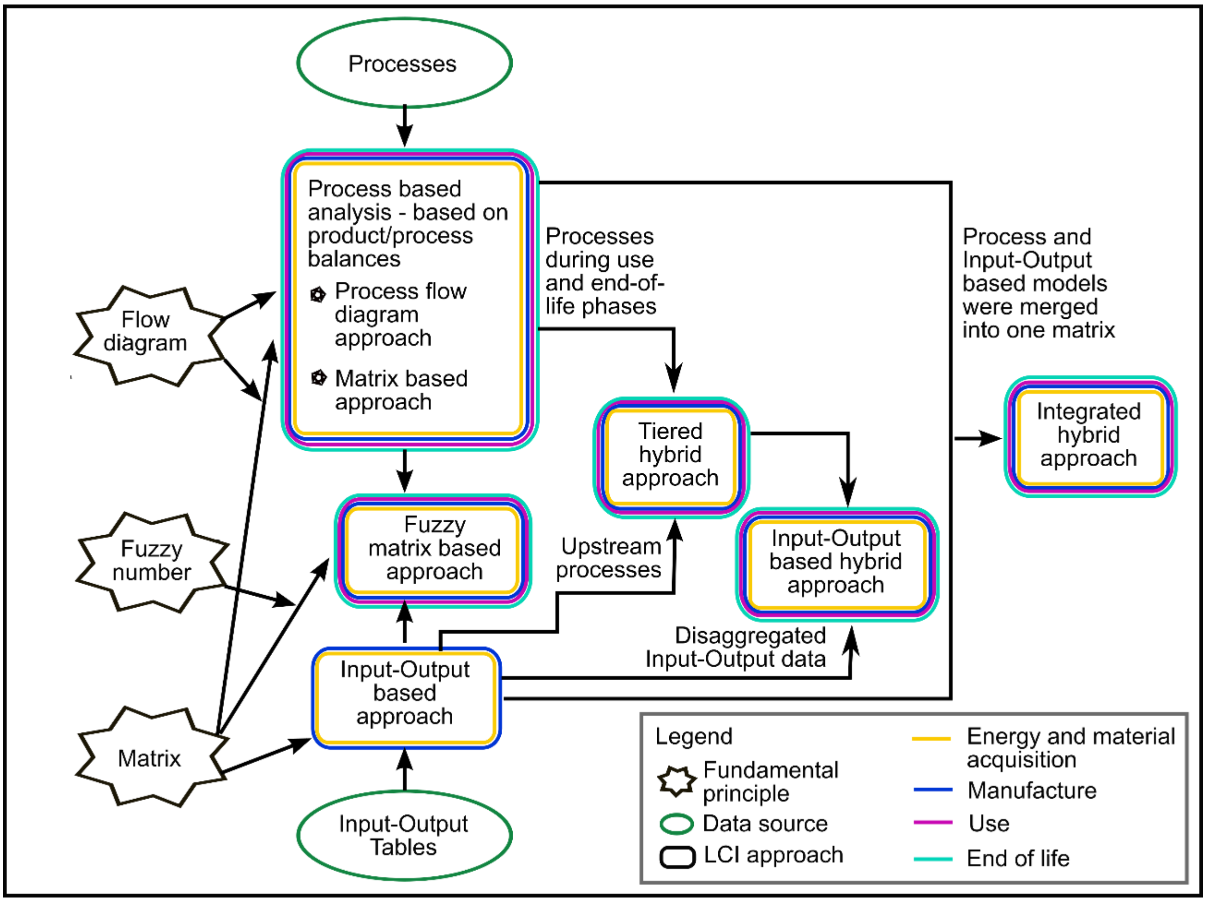


Figure 3.7: Outline of existing LCI approaches in line with the fundamental principles, data sources and life cycle phases.

Table 3.4: Brief description, strengths and limitations of LCI approaches.

Approach	Brief description	Strengths	Limitations
Process flow diagram approach [115, 122, 294, 305, 306, 309, 312, 332, 338]	• Based on process and product balance models where bottom-up process analysis was applied • Inventory was calculated with algebra; when required, infinite geometric progression could be applied to simplify the calculation	• Case-specific and more accurate • Most common form of LCI approach	• Time-consuming and expensive to collect empirical data or from other sources • Underestimate any truncation error occurred when capital goods and upstream processes were cut off • Calculation could be complicated when the system involved multi-functionality or interconnecting inputs between processes • Subject to use outdated data
Matrix based approach (simplified model) [122, 290, 338]	• Similar to process flow diagram approach where simultaneous equations were created based on bottom-up process analysis using product balance or process balance. The equations were then solved by matrix	• Powerful • Was able to solve endless regression problems associated with system and support advanced analysis, such as connections with IOT	• Restricted to single-output processes • Not clear if process balance could deal with multi-functionality issue • The number of processes to be included was still limited and capital goods were generally excluded
Fuzzy matrix based approach [291, 333]	• Fuzzy number was integrated into matrix-based LCI at different possibility levels • Material composition matrix was derived based on resources, materials and products, and data from IOT	• Data uncertainty due to vagueness could be modelled at different possibility levels • Computational time was considerably short compared to Monte-Carlo model	• Could not model correlated uncertainties • Determining fuzzy distributions of the inputs was complicated • Limited to inverse-positive matrices only

IO based approach [115, 121-123, 274, 305, 338, 339]	• Matrixes were formed based on top-down monetary transactions among industry sectors as published in IOT, which were national data on the supply and consumption of goods and services	• Easy to perform • Eliminated the need to estimate data for each process • Took account of capital goods • Transparent because only publicly available data and standard calculations were used	• Resolution was too coarse for detailed studies involving raw material selection, process redesign and any comparison at the regional/ international level • Data were old, inconsistent (due to compilation variation) and of high aggregation level, leading to aggregation error • Could not provide LCIs for the use and end of life stages • Could not correctly reflect the environmental burdens as process data were not used for modelling
Tiered hybrid approach [115, 122, 271, 305, 310, 313, 330, 332]	• Direct inputs to main processes were calculated with detailed process analysis whilst upstream flows that were indirectly connected to the main processes were estimated via IO based approach	• Combined the strengths of process and IO based approaches • LCI compilation was quick • Capital goods were included • Results were more comprehensive	• Suffered from double-counting unless material flow analysis was incorporated • Process and IO based approaches could not be assessed together systematically

IO based hybrid approach [122, 271, 332]	• Also known as hybrid LCI method based on IO data • To improve process specificity, IO data on industry sectors were disaggregated and solved by tiered hybrid approach; process based approach was applied for main processes during use and end of life phases	• Consistent • Higher resolution for detailed applications • Avoided double-counting	• Issues with process data and IOT remained the same • Difficult to model the relationship between life cycle phases of a product
Integrated hybrid analysis [122, 310, 332, 339]	• Detailed information at the unit process level was fully incorporated into IO model by linking process-based system (represented in a technology matrix by physical units) and the IO system (in monetary units) through flows crossing the border of both systems • Process and IO based approaches were integrated consistently into one matrix	• Double-counting was avoided as tiered hybrid approach was not applied • Consistent and complete for upstream processes • Interactions between processes and industries were fully modelled	• Complex • Time-consuming • Required intensive data

3.7 Recent LCIA Methodological Development: the Impact of Water Use

Water was considered as an abiotic resource at the early stages of LCA development. Somehow, the perspective evolved to recognise water as an impact category due to its use and depletion. [111, 115, 116, 124, 128, 130, 268, 299, 322] were the articles in Sample Groups A and B which, at different levels of detail, considered water use as an impact category. In brief, [111, 116, 124, 130] did not give much focus whilst [115] left out some important development. Focussing on LCI and LCIA phases, [128] fully dedicated to the topic of existing approaches for freshwater use at the expense of other LCA elements. Research articles were limited to [268, 322] and a case study was reported by [299]. The investigation revealed that additional resources, i.e. [179, 346-353] (in which some were respectively built based on [176, 343, 354-360]) were necessary to present a more comprehensive scope. Definitions of some terms, e.g. water source, flow, use, return and depletion, were partially proposed by [179, 268, 346-348, 350] and these were integrated for water classifications as illustrated in Figure 3.8.

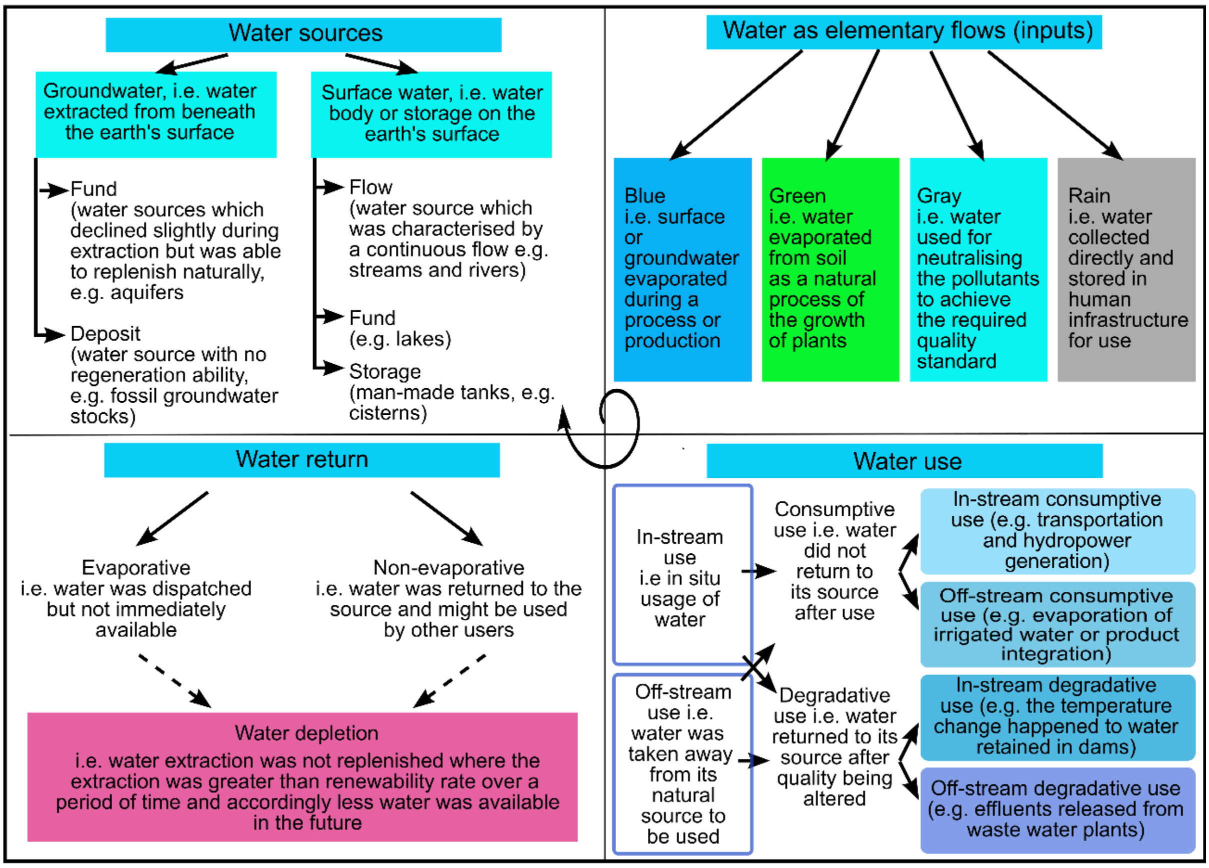


Figure 3.8: Water classifications as sources, elementary flows, use and return.

A few points were worth noting:

- In respect of water quality, 3 proposals were reported, respectively based on un-usable to excellent quality levels [268], distinction approaches (i.e. distance-to-target method or water functionality) [179] and quality indicators [346]. As complexity increased from quality levels, distinction approaches to quality indicators, the incorporation of any quality indicators proposed by [346] into impact assessment methodology was not achieved yet, except thermal factor being assessed by [351].
- Although approaches recommended by [348, 349, 360] were applied by [299] in a case study to assess the impact of water use, [299] did not point out that the indicator results from these approaches were not in agreement. Despite dissimilar result patterns and magnitude orders (as evidenced by the results reported by [299]), existing methods did not receive any criticism. This was uncommon compared to the cases of other impact categories (e.g. acidification, eutrophication and ecotoxicity) generally assessed by different LCIA methods e.g. CML2001, ReCiPe, the methodologies recommended by the International Reference Life Cycle Data System (hereafter "ILCD") etc. What was more, it remained a challenge to decide which concept to apply among existing methods.
- Although not elaborated here, research developed for other relevant subject areas (but not directly within LCA context), e.g. virtual water by [354, 357], surplus energy concept by [176], water indices as recognised by [128] (e.g. water resource per capita, basic water needs, withdrawal- and consumption-to-availability, water poverty and groundwater sensitivity indices) and those for natural resources in LCA context, e.g. eco-factors applied in Ecological Scarcity by [360] and exergy by [359], had been or could be applied for LCA methodological development. The supporting information presented by [128] detailed the findings of scientific comparison among existing methods, covering completeness, robustness, relevance to environment, transparency, documentation and reproducibility, applicability and stakeholder acceptance.
- Data regarding quality requirements, use, availability, demand, vulnerability, scarcity, conflict, poverty index and future of water, if available, would be useful for developing and performing LCIA for this impact category.

- Research was required to further develop LCIA methods which could fully address water quality, temporal and spatial factors─a challenge to the LCA community.

3.8 Recent LCIA Methodological Development: the Impact of Noise

From cradle to grave, the life cycle of a product system involved an extensive number of processes. As pointed out by [284], “a process produces a certain amount of noise”. The impact of noise in LCA context had been conveyed in literature over the past 2 decades, and possibly earlier, from simply recognising it [115-117, 121, 265, 270, 295, 329] and commenting on its standing [111, 124, 129, 259, 281, 287, 295, 341] to briefly discussing it [267, 284, 339] and fully developing a methodology for its impact assessment [178, 180, 273, 278, 361-366] (where [361-366] were literature included in Sample Group C to complement the discussion). Methodologies to assess the impact of noise were developed rapidly [341] and become available [129]; still, it was neither included in LCI database [267] nor applied in most LCA studies [281, 287]. By the means of additional tools (e.g. noise emission models, national databases, surveys, questionnaires and experiments), various concepts covering physics (e.g. sound energy), mathematics (fuzzy numbers/intervals and variation in noise level), social science (e.g. disturbance, nuisance and health damage) and demographics (e.g. population density) were applied selectively in developing these methodologies. The concept of each methodology was summarised and a comparison is presented in Table 3.5.

1. Sound energy concept [284] which was also referred to as CML guide [361]. The method claimed that noise was linearly generated with the process of manufacturing a product system. Therefore, noise production (in the square of sound pressure second, Pa^2s) could be determined by taking account of sound energy (in Pa^2, derived from sound pressure level in decibel, dB) and the duration in which noise was generated, together with hearing threshold and the quantity of required materials or products produced in a year.
2. Disturbance and equivalent traffic concept [365], also referred to as Ecobilan method [361]. The method determined the noise thresholds for day- and night-time in accordance with legislation and measured disturbance which was expressed as the total number of people disturbed. Data on population density, existing noise propagation model (based on

equivalent traffic concept which assumed that the potential noise impact of the traffic mode under study and that of a reference mode on the environment were the same) and mapping were used to measure the disturbance as per specific transport means.

3. Environmental scarcity factors or Swiss FEDRO method [361], also referred to as Doka methodology [364]. Although [361, 364] both claimed that the method was adapted from the earlier work of Muller-Wenk (which was inaccessible), a variant of methodological concept was reported. According to [361], the Swiss FEDRO method determined the environmental scarcity factors by defining actual and critical flows based on people who were highly annoyed by the noise emission. The former was the number of highly annoyed people (derived from Swiss EPA method and the effect curves from Swiss survey) whilst the latter was set as 20% of Swiss population. According to [364], Doka claimed that a non-linear relationship would exist between noise emission and its effects on human health; and therefore, to calculate the damage caused by noise emission in disability-adjusted life year (DALY) per vehicle-kilometre, noise emission that was measured in dB could be substituted into a simplified formula which incorporated regression parameters.
4. Total nuisance caused by a specific process, also known as Nielsen and Laursen methodology [364] or Danish LCA guide [361]. In this method, information such as background noise and noise level (both in dB; the former was set via interviews and the latter was simulation results from noise emission and propagation models), process duration and the number of people (based on average population density) exposed to the noise produced in a process (in which transport was selected for the study) were required to determine the total noise nuisance caused by the process (in person-second).
5. Fate-exposure-effect-damage model [366], also known as Swiss EPA [361] or Muller-Wenk methodology [364]. The method involved the following analysis via different approaches:
   - Fate analysis which determined the average noise level per year, L_{eq} and the increase in noise level, ΔL_{eq} resulting from increased vehicle numbers per year by taking account of vehicle types,

speeds and gradient of a road and the use of the existing noise emission model i.e. SAEFL.

- Exposure analysis which extrapolated the number of people exposed to the increased noise level from the figures estimated by Kanton's road noise emission model.
- Effect analysis which determined the relationship between communication disturbance at day-time (or sleep disturbance at night-time) and the noise level based on the outcome of social surveys.
- Damage analysis which estimated health damage due to traffic noise, in DALY per 1000 vehicle-kilometre, by taking account of disability weight for communication and sleeping disturbances (based on responses collected from 41 physicians via questionnaire).

6. Fuzzy-set approach [362]. After defining the quality of the sound environment i.e. types of land use (urban, residential or rural), population densities and noise level intervals in the form of fuzzy numbers, the overall noise level of a process could be calculated, which was necessary for the (dimensionless) impact assessment of noise based on nuisance felt by the population under study. In addition, the fuzzy-set approach could be incorporated with semantic distance concept to perform pairwise comparison upon the LCIA results of different impact categories across a range of scenarios, as demonstrated by [363] in assessing electricity generation processes.
7. New framework to extend Swiss EPA method to specific vehicles, tires and situations [178]. The method was built on the earlier work of Muller-Wenk to calculate the additional noise level resulted from an increased number of vehicles, where vehicle and tire types (using a noise emission model, i.e. SonRoad and TUV measurements respectively) as well as time and space were distinguished. The approach also took into account population densities and differentiated road classes based on noise effects upon the population.
8. Self-reported annoyance [278]. The method used existing noise emission model i.e. IMAGINE to model traffic flows at 2 situations so that the variation in noise level (known as noise-relevant life cycle variations,

NRLVs) could be determined. The number of highly annoyed persons was estimated by applying polynomial approximation to the dose-response functions. Based on the increased percentage of annoyance due to NRLVs, the impact could be estimated as the product of difference in the percentage of annoyance and the total number of people exposed to noise.

9. Fate-effect model [180]. After pointing out the common deficiency of previous methodologies (i.e. failure to focus on the process that producing noise emissions rather than the situation in which noise took place), [180] proposed a new methodology which defined the characterisation factors for noise impact category in LCA context as the product of fate and effect factors measured in person-Pascal per Watt. Fate factor, in Pascal per Watt, was determined at the background level as the small increase of sound pressure due to a marginal change of sound power at a compartment where directivity and attenuation (in line with a frequency scale defined by 8 octave bands) were taken into account. Similarly, effect factor, measured in person, was defined as the small increase in person-pressure due to a marginal change in sound pressure of an octave band at a compartment based on the number of people living in that compartment, the day-night weighting and the A-scale weighting (for the octave band). [273] complemented the fate-effect model by not only presenting characterisations factors but also distinguishing the fate model for noise impact upon the internal occupational and external environments.

Table 3.5: Comparison of existing methodologies for the impact of noise.

Concept (unit)	Source of noise	Spatial differen-tiation	Temporal differen-tiation	Type of data required for calculation	Strengths	Limitations
Sound energy concept (the square of Pascal) [284]	Process [284]	No [361]	No [361] (although the time of sound production was rele-vant [284]	Quantity required to meet the functional unit and annual production [284]	Complied with ISO 14040 and was applicable to all situations [361]; simple and straight-forward calculation	Only considered the aggregation of sound at midpoint level [111]; less useful and not suitable for comparison [361]
Disturbance and equivalent traffic concept (Number-of-people-hour/ passenger-kilometre or number-of-people-hour/ goods-kilometre) [365]	All transport modes or production plants [365]	No [361]	No [361]	Areas affected by noise above thresholds; distance of the source of noise from the ground and the presence of any obstacle between the source and the observer [365]	The results might be used as models to assess traffic noise in European countries with similar population density along the road under study [365]	Did not comply with ISO 14040 and the indicator was very rough [361]; could not differentiate the sources of noise in the assessment as all were treated as 1 single source
Environmental scarcity factors [361] (DALY /vehicle-kilometre) [364]	Road traffic [361]	No [361]	No [361]	Noise measured in decibel [364]	Quite practical [364]; allowed for intermodal comparison; complied with ISO 14040 [361]	Only addressed traffic noise
Total nuisance caused by a specific process	Process when goods were being	Yes [361]	No [361]	Number of persons and noise level within/at a distance	Simple [364]; allowed for intermodal comparison [361]	Did not comply with ISO 14040; not suitable for inclusion

(person-second) [364]				from the source; duration and noise level [364]		in LCI databases, and overestimated the noise effects [361]
Fate-exposure-effect-damage model (DALY/1000-vehicle-kilometre) [366]	Traffic [361]	Yes [361]	Yes [361]	Traffic (i.e. average number of vehicles per type, speed and road gradient etc.) and demographics (i.e. population being exposed to the noise) [366]	Applicable to different countries [364]; complied with ISO 14040 where impact categories measured in DALY could be compared easily [361]	The noise emission model was obsolete [364]; might over-estimate noise effects [361]; inaccurate due to simplifications; only addressed traffic noise
Fuzzy sets approach (dimensionless) [362]	Any process (for conceptual discussion using coal mining and combustion processes) [362]	Yes	No	Quality of site, (i.e. existing noise level; types of land use included rural, urban and residential; population density); nuisance felt by individuals and exposed time [362]	Uncertainty was accounted for by the fuzzy numbers [363]; could be applied to any process	Sophisticated and required expert judgement for determining variables of the assessment [362]
Guidelines for incorporating the effects of noise into LCA (DALY) [364]	Road traffic [364]	No	No	Noise maps, demographics data [364]	Potential reference for methodology development in the future	Methodology had not been developed for the impact assessment; limited focus on traffic noise
Requirements for methods used to incorporate	Traffic [361]	Yes	Yes	–	Potential reference for methodology development	Methodology was not developed for the impact assessment; limited to traffic noise

noise into LCA [361]						
New framework to extend Swiss EPA method (dB(A)) [178]	Traffic	Yes	Yes	Measurements of real traffic situations [178]	The results could be implemented in LCI databases for other LCA study [178]	Noise from mixed sources was not considered yet [178]; limited to traffic noise
Self-reported annoyance (Number of annoyed persons) [278]	Traffic [278]	Yes	Yes	Traffic data (e.g. vehicle speed and flow) and receiver data (e.g. demographics and noise exposure) [278]	Results were more accurate due to the state-of-the-art noise emission model; more intelligible for decision making [278]	Required intensive data, was limited to variation assessment where the impact of noise was not assessed [278]
Fate-effect model (person-Pascal/Watt) [180]	Processes [180]	Yes	Yes	Sound emission, weighting factors and number of people living in the compartment [180]	Noise effects related to functional unit; methodology focussed on the process causing the noise [180]	Characterisation factors were not presented and therefore could not be included into existing LCIA models
Fate-effect model [273]	Processes [273]	Yes	Yes	Directivity of sound; sound power and sound power level [273]	Complement [180], provided characterisation factors for future LCA study; distinguished fate factors for noise emissions in internal and external environments [273]	–

3.9 Recent LCIA Methodological Development: the Impact of Working Environment/Impact Related to Work Environment

The impact of working environment on human health had also been recognised since 2 decades ago as an impact category in LCA context. For instance, in the early 1990s, [284] already affirmed that there was no quantitative method developed to address such impact. Some similar and relevant aspects were briefly set forth by [108, 115, 117, 124, 265, 287, 326, 327, 339, 341] which adopted different terminologies such as “accidents”, “working condition”, “working environment”, “indoor air”, “indoor air pollution”, “indoor and occupational exposure” etc. In brief, accidents were recognised as an impact category which was less developed with neither inventory nor characterisation factors being available [287]; related to work environment (caused by accidents or non-toxic substances) and should be taken into account comparatively to human toxicity category [117]; indecisive whether the impact of casualties attributable to accidents should be seen as an individual impact category because of the absence of standards, and consequently, impact attributional to work environment was generally out of consideration [124]; and therefore being omitted due to the difficulty in making prediction and the negligible effect as perceived [265]. In this matter, [108] indicated that indoor air pollution had already been included as a special application of LCIA where [115] claimed that human exposure to indoor chemicals could be significant and LCIA was already available to assess such impact on internal environment in line with the report of 2 relevant case studies. In terms of indoor and occupational exposure, [339] projected that it was to be considered as a part of human toxicity impact category despite the fact that it had been developed as a new impact category. The latter was in agreement with [341] who highlighted the expeditious LCIA development for indoor and occupational exposure as a new impact category, which could be exemplified by [326] and [327].

Despite the recognition of the impact related to work environment, none of the above mentioned literature defined this impact category, as did [188, 367, 368]. This might explain the use of a variety of terminologies. However, it was commonly accepted that emissions were generally released to both internal and external environments, and any measure to reduce the impact of a product on the external environment might result in negative effects on the working environment at the expense of human health [188, 326, 367]. To define, the relevant phrases as presented in the literature were referred. Compared to short and simple phrases adopted by other literature, [327] presented a more detailed remark, which could be adopted. The impact of working environment could be defined as the effects on human health as a result of occupational exposure to biological, physical and/or chemical hazards at working environment during the life cycle of a product system. A comparison of literature is presented in Table 3.6, distinguished by sample groups. The concept of existing methodologies was summarised as follows, in chronological order:

1. Direct-quantitative-and-qualitative approach by [367] where (i) death due to work related accidents; (ii) workdays lost due to wok related accidents and diseases; (iii) workdays lost due to illness; (iv) hearing loss; and (v) allergies, eczemas and similar diseases were identified as quantitative impact categories estimated based on organisational statistics data, together with carcinogenic impact and impact on reproduction identified as qualitative impact categories and estimated based on a semi-quantitative approach.
2. A method to assess occupational health impact was proposed by [369] based on DALYs, which took account of the number of morbidity, disability and mortality cases as well as the severity and duration of the incidents in terms of years of life lost (YLL) and years of life lived with disability (YLD). How to calculate DALYs per industry sector was outlined as a five-step approach: (i) find out how many morbidity, disability and mortality cases there were; (ii) quantify how long each morbidity/disability case had been since the incidence; (iii) determine how severe each case was; (iv) determine what the upstream impact associated with the sector was based on IO model; and (v) match the data on morbidity, disability and mortality with IO data.
3. Built on EDIP methodology, a sector-based working environment assessment was proposed by [368] where a number of impact categories were identified, including total number of accidents, fatal accidents, musculoskeletal disorders, central nervous system function disorders, cancer, hearing damage, skin diseases, airway diseases (allergic and non-allergic) and psycho-social diseases. A five-step approach was suggested to calculate the number of injuries and accidents per unit weight of production: (i) identify sectors which showed substantial rate of injuries and accidents; (ii) identify the corresponding products produced in these

sectors; (iii) aggregate the number of all products; (iv) account for the work-related damages and injuries for the production activities based on statistics; and (v) determine the impact of working environment per functional unit, i.e. by dividing the outcome of (iv) by that of (iii).

4. An impact assessment method for external and working environments was proposed by [188]. In relation to working environment, 2 impact categories i.e. occupational health (OH) and occupational safety (OS) were recommended where lost work days (LWD) was introduced as the category indicator for both. Data regarding the number of workers (i) affected by a particular hazardous item (WHI) and (ii) diagnosed suffering certain magnitude of disability (WMD) were required to estimate LWD for OH and OS impact categories, taking account of exposure, effect and damage factors whenever applicable. DALY and potentially affected fraction (PAF) were adopted to assess the damage caused by the external environment to human health and ecosystem quality.

5. The methodological framework developed by [370] aimed to assess human health effects due to indoor and outdoor exposure to pollutants. The one-box model based on mass conservation and concentration homogeneity was selected as the default approach compared to the other 4 existing indoor air exposure models i.e. one-box model with mixing factor, multi-box model, two-zone model and eddy-diffusion model which were all compatible to USEtox model. The latter was used for assessing outdoor exposure assessment. In this case, characterisation factors for human toxic effects were calculated by determining the product of intake and effect factors.

6. Two methods, i.e. Methods 1 and 2, were proposed by [371] to rank and identify chemicals to be included in LCA study. Based on USEtox model, Method 1 took into account the concentration and severity of exposure, effect factors and the exposed population where the number of exposed personnel was applied as a weighting factor. Acting as a quality control tool, Method 2 was based on the risk quotient as applied in occupational risk assessment, i.e. the ratio of exposure concentration to occupational exposure limit. Data required for the assessment was collated from literature, toxicity report and databases. Characterisation factors in terms

of DALY were then calculated by determining the sum of cancer and non-cancer effects.

7. Work environment disability-adjusted life year (WE-DALY) was introduced by [326] which could be used to calculate the characterisation factors for the impact on human health attributable to hazardous exposure in working environment. Using published statistics data for each industry, WE-DALY estimated the sum of the number of years of life lost (YLLn, representing the difference between the average lifespan of the workers and the actual age at death of the deceased worker) and the number of years of life lived with disability (YLDn, representing the duration of suffering certain injury or illness due to working environment).
8. Work environment characterisation factors (WE-CF) by [327] was a continuation of the WE-DALY method by [326] to complement LCIA for the impact on human health attributable to work environment. WE-CF was determined as the ratio of WE-DALY to the physical output (e.g. mass and volume) produced by the industry.

An additional remark was that [188] and [327] had respectively classified existing approaches in line with chemical use/screening, work process and sector/compartment model; however, most of the literature were inaccessible (and therefore not further discussed here), which presented a possible reason why the impact of working environment had been rarely included in LCA study.

Table 3.6: Comparison of literature on the impact of work environment.

Phrase used	Proximity *	Level of detail**	Highlight of the literature [Resource]
Accidents; workplace exposure; working conditions	C	II, III	Working conditions were recognised as an environmental problem; accidents and working conditions were respectively discussed as process data and an impact category [284].
Accidents; work environment; impact from the work environment	A, B	I	Toxic impact of the work environment should be assessed as a part of human toxicity impact category whilst non-toxic impact of the work environment and those caused by accidents should be further considered as separate impact categories [117].
Accidents	D	I	The impact category of accidents was usually not covered due to perceived marginal threat and difficulty in making any prediction [265].
Casualties due to accidents; impact in work environment; chemical exposure at the workplace	A	I	The lack of standards led to (i) indecisive situation if “casualties due to accidents” should be considered as an independent category; and (ii) exclusion of “impact in work environment” from further assessment [124].
Indoor and occupational exposure; injuries related to working environment accidents	B	II	Indoor and occupational exposure, including injuries (casualties) related to working environment accidents, was recognised as a new and separate impact category undergoing characterisation model currently but would become a part of human toxicity in future [339].
Indoor air; indoor chemical exposure; impact to the working environment	A	III	A short summary was presented in relation to a few selected literature published between 1998 and 2009 in this context. It was noted that LCIA was available to assess human exposure to indoor chemicals as 2 relevant case studies were reported [115].
Indoor air pollution	D	I	As an area of concern to many building occupiers, indoor air had become a special application of LCIA [108].

Indoor and occupational exposure	D	I	Rapid development of indoor and occupational exposure was noted [341].
Accidents	D	I	The development of some impact categories like accidents was poor as neither inventory data nor characterisation factors were available [287].
Work-related impact; impact to human health attributable to work-related exposures to workplace hazard; occupational health impact from the work environment	A	IV and V	The "impact to human health attributable to work-related exposures to workplace hazards" were expressed in terms of WE-DALY, and calculation was shown in a case study [326].
Working conditions	D	I	"Working conditions" was recognised as a social impact category of a product system [129].
Impact to human health attributable to the work environment; the work environment impact category; impact from the work environment	A	IV and V	WE-DALY of an industry was calculated with workplace data. Then, WE-DALY was used to determine WE-CF [327].
Additional literature materials, i.e. Sample Group C:			
Impact of the work environment; work-related accidents	A	IV	5 quantitative and 2 qualitative work environment impact categories were proposed. Data collection, reliability and relevance of these impact categories were discussed [367].
Occupational health impact; health impact due to hazardous work environments; workplace injuries; workplace-related illnesses	B	IV and V	A method to assess occupational impact was proposed based on DALYs and an example was provided to show how the results of the model could be applied [369].
Working environmental impact; Occupational exposure; work-related damage; occupational accidents; occupational diseases and occupational injuries	A	IV and V	A method to calculate impact of working environment per functional unit was proposed and its application was presented [368].

Impact on the working environment; occupational health and safety; occupational health; occupational safety; occupational accidents; occupational diseases; occupational disabilities	A	IV and V	A new methodology was developed to assess the total impact on the working and external environments and its applicability was shown in a case study [188].
Health effects from indoor pollutant emissions and exposure; human-health effects from indoor exposure; occupational exposure	C	IV and V	In line with existing model used for assessing outdoor emissions, the one-box exposure model was selected to determine the characterisation factors for human toxic effects due to indoor exposure [370].
Indoor occupational exposure; occupational health effects; occupational diseases; human-health impact from indoor exposure	C	IV and V	In line with USEtox model, the indoor occupational priority list for LCA (OCPL-LCA, referred to as Method 1) was developed, which could be used for assessing human-health impact attributable to indoor occupational exposure to solvents [371].

* Proximity to impact of/from/in/to the work environment
A Explicitly, if impact of/from/in/to the work(ing) environment was mentioned
B Implicitly, if work(ing) environment was mentioned
C Loosely, if workplace was mentioned but not directly connected with the impact
D Indistinctively, if neither work environment nor workplace was mentioned
** Level of detail
I Recognition only, without discussion at LCI/LCIA level
II Brief discussion at LCI level
III Brief discussion on LCIA methodology
IV In-depth discussion on LCIA methodology
V Application/case study

3.10 Life Cycle Interpretation: Uncertainty and Sensitivity Analysis

In estimating potential environmental impact, LCA, by its very nature, associated with uncertainties. Uncertainty was defined as the quantity discrepancy between the real values and the data used in the study [115] generally obtained from experiments, calculations, assumptions or estimations. Also, uncertainty could be defined quantitatively and qualitatively. The former was a measure which determined the spread of values attributed to a parameter. The latter referred to the lack of precision in data and methodologies due to incomplete data, lack of transparency, unrepresentative methods and the choice made [114]. According to [124], uncertainty was the 'lack of knowledge' with respect to true quantity value and model form, appropriateness of modelling and methodological decision, and therefore, its effects could be addressed by uncertainty and sensitivity analysis. This was in agreement with [107, 114] in which uncertainty and sensitivity analysis appeared to be coupled together. Accordingly, uncertainty analysis was defined as a systematic technique which quantified the uncertainty in LCI results due to variability and inaccuracy of data and model whilst sensitivity analysis was defined as a systematic technique which assessed the effects of methodological choice and data on the results [106, 107].

To get a grasp of the state-of-the-art methodological development in this context, literature in Sample Groups A and B were analysed and the findings are presented in Table 3.7. In contrast to the vast number of literature recognising the inherent uncertainties in LCA (and the need to address them by performing uncertainty and sensitivity analysis), the methodological concept in LCA context was not covered widely. A few publications had attempted to explicitly classify the types of uncertainty; however, a common drawback was found as each list was limited to a few uncertainty types among many. Built on [106, 107, 109, 111, 114, 115, 124, 286, 303, 305, 319, 320, 331, 338, 339], all uncertainty types were integrated as illustrated in Figure 3.9 to present an overarching scope.

Table 3.7: The coverage of uncertainty, uncertainty and sensitivity analysis in literature.

Subtopic	Resources
1. Uncertainty	
• Recognition of uncertainty inherent in LCA [a]	[106-109, 111, 114-117, 121-124, 126-129, 178, 180, 259, 261, 264, 265, 267-269, 274, 276, 278, 280, 281, 288, 293, 295, 296, 298, 302, 303, 305, 306, 310, 312, 314, 318-321, 324, 328, 329, 333, 338-341]
• Definition [b]	[114, 115, 124]
• Types [c]	Explicitly: [111, 114, 115, 124, 286, 319, 338, 339] Implicitly: [106, 107, 109, 303, 305, 320, 331]
• Sources [b]	[115, 122, 305]
• Problems [b]	[124]
2. Uncertainty analysis	
• Recognition of (the need for) uncertainty analysis [a]	[106-109, 111, 114-117, 122, 124, 127-129, 180, 259, 265, 272, 275, 281, 283, 293, 295, 298, 303, 306, 309, 310, 314, 318, 321, 325, 326, 328, 329, 333, 338-341]
• Definition [b]	[106, 107, 114]
• Methodologies [d]	[115, 124, 295]
• Methodologies specifically for LCI [d]	[107, 114, 286, 291, 305, 333, 338]
• Methodologies specifically for LCIA [d]	[286, 297, 302, 324]
• Methodological concept [e]	[286, 291, 297]
• Application [f]	[286, 297]
3. Sensitivity analysis	
• Recognition [a]	[106, 115, 116, 121-124, 127, 180, 261, 265, 290, 295, 305, 310, 319, 320, 329, 333, 338-340]
• Methodological concept [e]	[107, 114, 284, 285, 289]
• Application [f]	[101, 106, 107, 114, 284, 285, 289]

[a] Uncertainty (as well as the need for uncertainty and sensitivity analysis) was recognised if it was only cursorily mentioned.

[b] Definition, sources or problems commonly associated with uncertainty was reported when discussion on the corresponding topic was unambiguously presented.

[c] The types of uncertainty were explicitly included if they were organised appropriately; or implicitly presented if one or more uncertainty type was mentioned unsystematically.

[d] Methodologies for uncertainty and sensitivity analysis were covered if a suggestion was made (without detail). In the case of uncertainty analysis, the suggestion could be general or specific for addressing uncertainty at LCI/LCIA level.

[e] A methodological concept was proposed if the fundamental principle was discussed.

[f] Application was performed if the methodology was implemented and/or the results were shown.

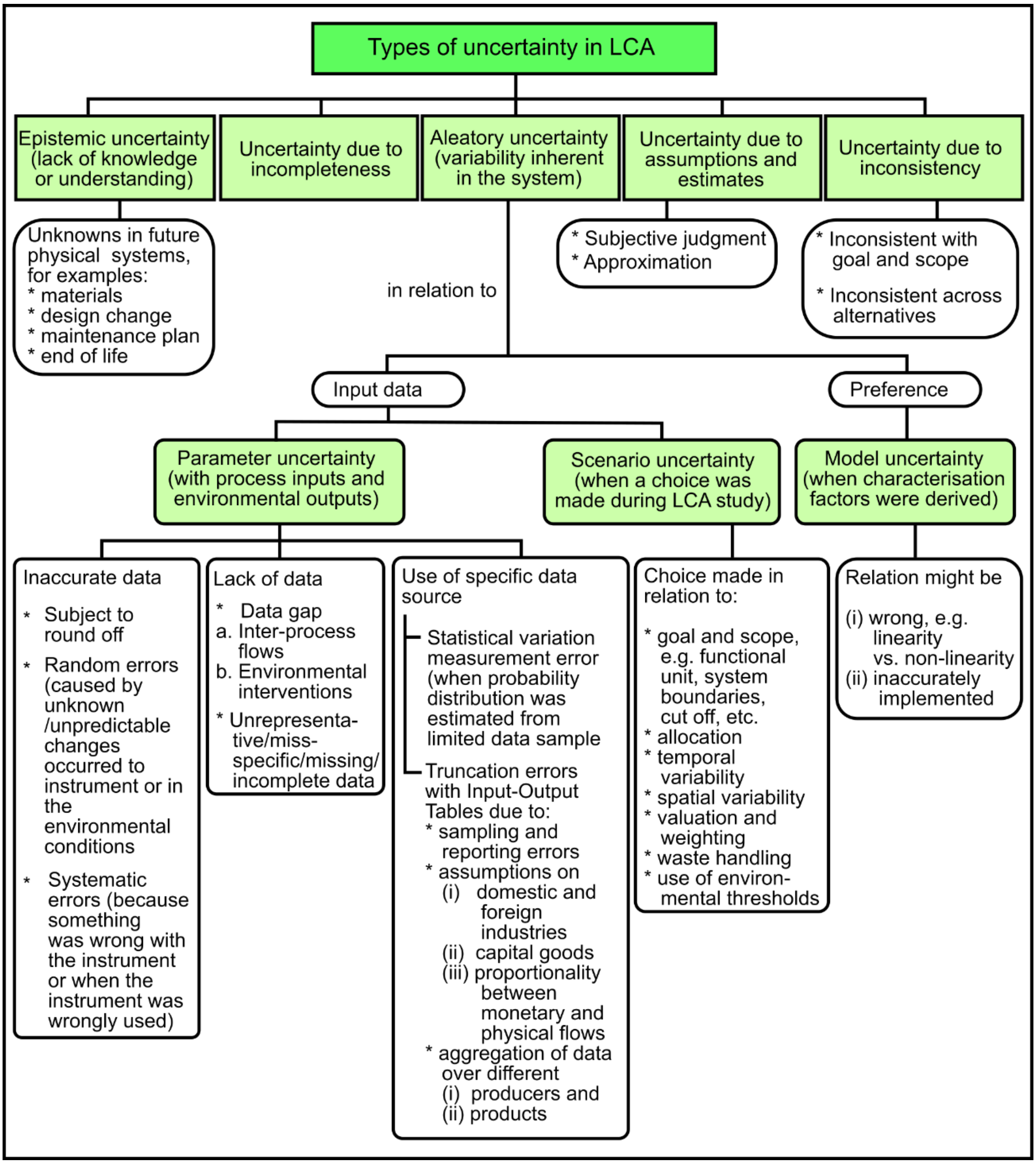


Figure 3.9: Types of uncertainty inherent in LCA.

As reported by [115, 124, 295], a range of approaches had been proposed for uncertainty analysis. [363, 372-377] were included in Sample Group C to complement the analysis. The fundamental concept and application of the statistical, scientific, social/constructive and graphical approaches of uncertainty analysis in the context of LCA were discussed:

1. Statistical approach
   i. Stochastic modelling, used to propagate uncertainty due to inaccurate data [377], input and output parameter uncertainty

[373] and model uncertainty [295]. Stochastic modelling involved the use of

(a) a probability distribution for different conditions [374]:
- uniform for less studied and/or more debated parameters
- normal if the input data were the average values of the data collected
- lognormal for skewed data limited to positive values only
- triangular for less studied and/or more debated parameters
- beta generally for several shapes of distribution bounded on both positive and negative sides where no prior knowledge was required
- gamma for model developed from real world samples

(b) a sampling technique, where the parametric sampling technique, e.g. bootstrapping as recognised by [115], was not included in this review as its methodological concept in LCA context for uncertainty analysis application was not found. Random and non-parametric sampling included
- Monte Carlo [295, 376, 377]. Within a defined range, all parameters were varied and selected randomly by employing a computer. To deal with inaccurate data, all key input parameters were specified and applied one by one in the calculation. To deal with model uncertainty, characterisation factors were repeatedly calculated with all possible uncertainties. After an extensive number of repetitions, the results formed a probability distribution where the statistic properties of the distribution were investigated. Monte Carlo was technically valid and widely recognised.

- Latin Hypercube [373, 376]. This was a special type of Monte Carlo simulation which segmented the uncertainty distribution into non-overlapping intervals (with equal probabilities). From each interval, a value was randomly chosen and substituted into an equation to obtain an output variable. The output variables generated a distribution with a representative frequency chart. The complex mathematic model of this sampling method presented a drawback and hindered its application.

ii. Non-parametric good-of-fit test, e.g. Kolmogorov-Smirnov (K-S) test and Chi-Square test [286], used to choose the best hypothesised distribution. The frequency distribution of inventory data (with multiple parameters collected from industries or via simulation) and the probability density function of a hypothesised distribution (normal, lognormal, gamma, beta etc. generated by Maximum Likelihood Estimation based on the characteristics of parameters, i.e. mean, standard deviation etc.) were assessed by K-S and Chi-Square tests. A null hypothesis was set, i.e. both distributions were in consistency. A critical value was assigned to K-S and Chi-Square tests to decide if the null hypothesis was true at the significance level of 0.05. When the results of K-S and Chi-Square tests were in conflict (very uncommonly), K-S test for a small sample (with 30 data or less) and Chi-Square test for a relatively bigger sample should be applied. The lowest values of results from both tests indicated the best distribution of the inventory data.

iii. Analytical method [374-376], used to propagate uncertainties due to input data on the model outputs. The relationship between input and output variables was evaluated by estimating the moments, i.e. variance or standard deviation of the distribution based on Taylor series. Although the analytical method required less information regarding the distribution and was computationally efficient compared to the sampling method, its application was practically hindered by the complexity of Taylor series.

iv. Fuzzy number [291, 333], used to propagate epistemic uncertainty inherent in matrix-based inventories by applying upper and lower limits to emission and resource flow inventory vectors to create a number of matrices. For the defined degrees of belief, i.e. α-cuts = 0,…,1, the matrices were solved. The inventory results at all α-cuts were combined to form a fuzzy distribution. The approach was advantageous as it was more informative and computationally efficient. It was claimed that a comparison between alternatives of epistemic uncertainties could be made by ranking the fuzzy numbers; however, no methodological concept was provided.

v. Bayesian [372], used to estimate model uncertainties which propagated parameter uncertainties. A probability distribution was generated by applying stochastic modelling, i.e. a prior distribution type of uncertainties was selected and Monte Carlo was employed to calculate the indicator results of an impact category repeatedly. To measure the importance of each parameter uncertainty, the correlation coefficient between the input parameter and its output was calculated. A posterior probability was then formed by applying Bayesian update procedure. For each parameter, the ratio of standard deviation to means (known as the coefficient of variation) could be calculated to determine how much uncertainty was reduced.

vi. Interval calculation [376]. A 95% confidence interval was calculated by using standard deviation in the analytical method and the non-parametric good-of-fit test.

2. Scientific approach

   i. More research [295], used to reduce model uncertainty. More scientific research was carried out for better measurements and more accurate data.

   ii. The scale of uncertainties [338], used to manage uncertainties at LCI level. After performing a hybrid LCI, uncertainties due to data, cut-off, aggregation, temporal and spatial factors were estimated to identify ways for improvement by comparing the scale of uncertainties. Then, data of low relevance were replaced by data of high quality, followed by estimation and comparison of the uncertainty scales. The processes were repeated until the results were sufficiently certain. A critical issue with this approach existed as detail on estimating uncertainties was not provided.

   iii. Scenario comparison [295, 375, 376], used to investigate the effect of data and model uncertainties on the results via parameter variation (also known as scenario analysis). All parameters remained unchanged whilst one specific parameter (or a number of consistent scenarios of parameter e.g. best, worst and average cases) was varied. In addition, model uncertainty could also be dealt with by comparing the characterisation factors calculated from a few strategically manipulated uncertainty parameter values.

   iv. Uncertainty factors (UFs), used to deal with

      - unrepresentative input data due to future technology, temporal and geographical factors [377]. Based on empirical analysis of technological development, time series and cross-sectional data on process inputs and environmental releases, the UFs were estimated and applied to the unrepresentative input data.
      - uncertainties due to parameters and choice [297, 373]. UFs were used to characterise the parameter uncertainty of input data whilst stochastic modelling (i.e. Monte Carlo or Latin Hypercube simulation) was applied to quantify and propagate parameter uncertainty of the output variables into a particular distribution type. A comparison indicator could be used to compare the choice between 2 products.

- pairwise comparison of alternatives [363]. Based on the LCIA results for 2 scenarios for an impact category (in the form of crisp number, probability distribution function or fuzzy membership function), the preference relationships between scenarios (i.e. one scenario was preferred, strongly preferred, not preferred or strongly not preferred to the other) were evaluated and aggregated. The aggregated results of the preference relations for each couple of scenarios were used for the calculation of the classical entropy measure and an index; and accordingly, all scenarios under study could be ranked from the worst to the best or vice versa.

3. Social/constructive approach [375, 377]. Pedigree matrix was applied to qualitatively deal with uncertainties due to unrepresentative or unavailable data. This was done by identifying relevant data quality indicators, e.g. temporal, spatial and future technology correlations, at different levels. Accordingly, a score was assigned to each level, e.g. for temporal indicator, levels 1, 2 and 3 represented data age groups 0–3, 4–10 and 11–15 years respectively etc. Expert judgment and/or inputs from stakeholders were required in defining the pedigree matrix and furthermore assigning the scores to indicate the level of each indicator applicable to the case under study.
4. Graphical approach [374]. Some graphic tools including error bars, histograms, box-and-whisker plots (Tukey boxes), cumulative distribution functions and graphs of mean outcome versus the number of iteration for modelling were used to visually show how certain/uncertain the results were.

In short, scientific approach by more research directly would reduce uncertainties; scenario comparison and graphical approaches showed the effects of inputs (e.g. parameters and choice) on the results; stochastic modelling, scale of uncertainties and UFs dealt with data uncertainties whilst analytical method, fuzzy number, Bayesian and scale of uncertainties by nature propagated uncertainties to a combination of variables defined in the functions.

Sensitivity analysis also applied mathematics concepts (in addition to scenario analysis) to investigate the influence of methodological choice such as input data and assumptions on the results. Compared to ISO 14040 [106] which suggested sensitivity analysis as one of the reasons for the difference in LCIA results for alternative products, ISO 14044 [107] had put more emphasis on the use of sensitivity analysis to (i) check input and output data for significant environmental burdens and/or further system boundary refinement; (ii) obtain additional information for the reference choice during normalisation; (iii) assess the consequences of value choice during weighting; (iv) check for sensitivity and limitations of the study during interpretation; and (v) include mass, energy and environmental significance criteria in sensitivity analysis for a comparative study. Among review articles of Sample Group A as presented in Table 3.1, [109, 115, 121, 123, 124, 128] embraced the role of sensitivity analysis in LCA studies. Meanwhile, a constantly gradual (but not sufficiently detailed) development could be observed in the literature of Sample Group B from a very brief recognition [106, 115, 116, 121-124, 127, 180, 261, 265, 290, 295, 305, 310, 319, 320, 329, 333, 338-340] to a short discussion on the basic concept covering the use of reliability and validity analysis [284, 285], percentage of change or the absolute deviation [107], and temporal sensitivity [289] as measures for sensitivity analysis, possibly supported by the application of qualitative method (i.e. expert judgement) or quantitative methods including spreadsheet, linear and non-linear programming [114]. In addition, sensitivity analysis was performed in some LCA studies [101, 106, 107, 114, 284, 285, 289] but the applied methodology was not detailed. Sensitivity analysis was not new and had been commonly applied in other fields, e.g. weather forecast, decision making and risk assessment, to name but a few. A number of common methodologies were preliminarily but not exclusively identified partially in accordance with [378, 379] and categorised with a brief description as illustrated in Figure 3.10, which could be seen as a connecting point for stimulating research development of sensitivity analysis in the context of LCA.

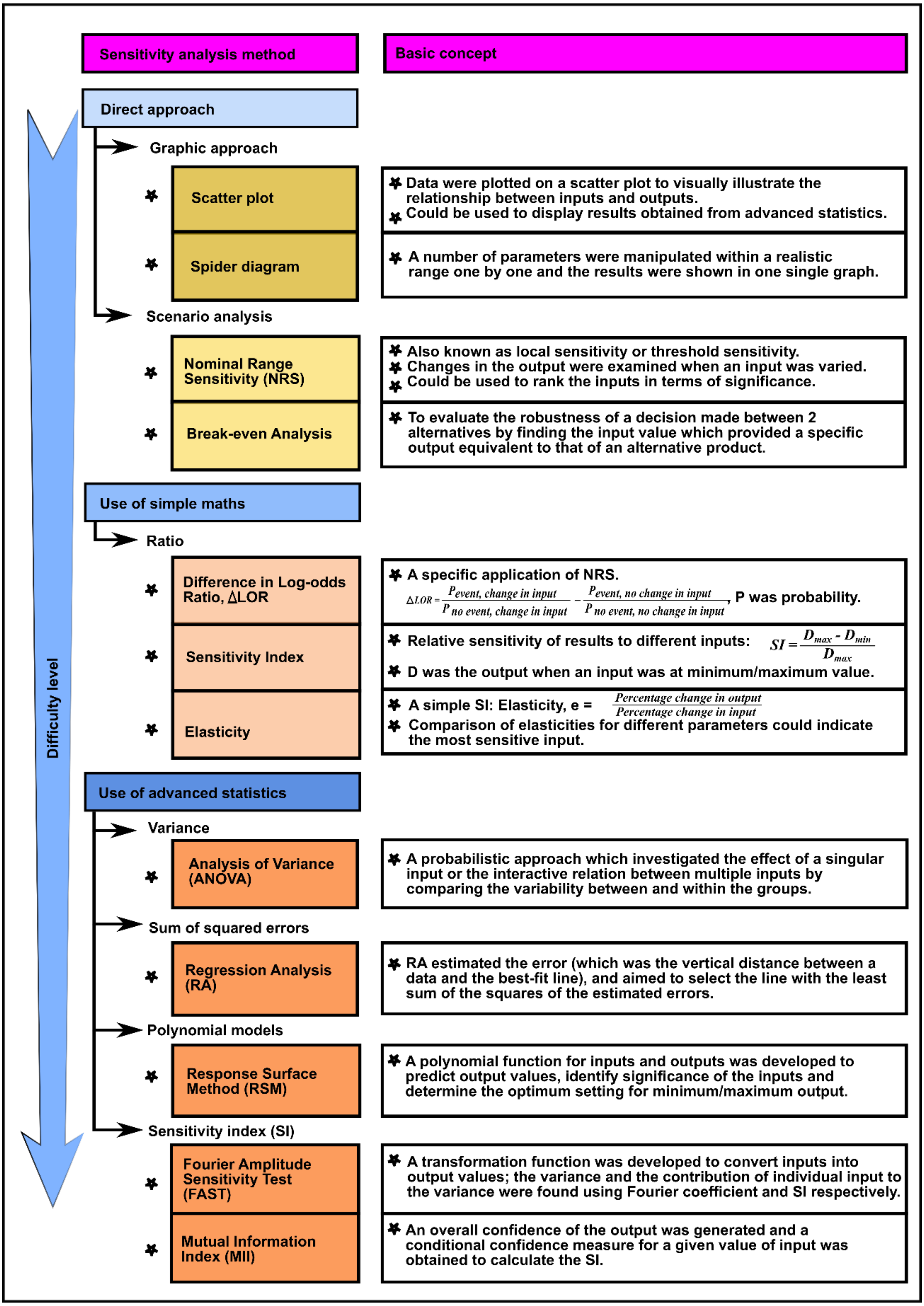


Figure 3.10: The basic concept and difficulty level of some common sensitivity analysis methods.

3.11 Research Needs and Areas for Future Development

Probably in response to a particular remark presented in ISO 14040 [106], there were '*no generally accepted methodologies for consistently and accurately associating inventory data with specific potential environmental impact*' (page 16), selecting the best practice or recommended approach via comparison, harmonisation or consensus building had become common recently. In respect of this, [296] pointed out that consensus building was not practical due to the fact that existing methods under evaluation might have less scientific ground whilst new methodologies were constantly being developed, which would be excluded from such evaluation. As advocated by [296], LCA research should focus on meeting the major challenges e.g. integrating global scale and spatial differentiation. Other unremittent challenges for future LCA development were identified via this analysis:

- LCI data. Whilst LCI approaches were well developed, unavailable, missing, out-of-date and unrepresentative data remained a major obstacle to deliver reliable LCA results. Research into developing robust and representative inventory was required.
- Classification involving series and parallel mechanisms. Some elementary flows were attributional to more than one impact categories which were likely to be assessed in an LCA study. Relevant examples included, first, SO_2 which generally resulted in acidification, human toxicity and aquatic ecotoxicity [270]; and second, water which resulted in water deprivation [349] due to consumption and furthermore the depletion of water as a natural resource [130]. How to appropriately classify such elementary flows in series and parallel mechanisms should be explored and developed.
- LCIA methodology. Research on the impact of water use, noise and working environment was still ongoing and should be further expanded to cover comprehensive scope and took into account spatial and temporal dimensions. Other impact categories including space use, odour, non-ionizing radiation (i.e. electromagnetic waves) and thermal pollution [284, 341] were noted but their characterisation model had not yet developed. At present, there was no environmental mechanism, indicator, characterisation factor and model available for these impact categories.
- Uncertainty and sensitivity analysis. In relation to uncertainty analysis, methodology that could be applied to address uncertainties due to

incompleteness and inconsistency had not been explored. Also, how to incorporate existing methodologies for sensitivity analysis, for example advance statistics, into LCA study should be further studied.

- Any other relevant topics. Other elements which were not explicitly included in ISO Standards, for example rebound effects, renewability of resources, dynamic of environment and future scenario modelling, were of increasing importance from a pragmatic perspective. Indeed, dealing with rebound effects or renewability as well as modelling dynamic environment or future scenario were challenging and required extensive research engagement to overcome its complex nature.

3.12 Summary

A literature review on LCA methodology development embracing all life cycle phases was reported. The literature was categorised into Sample Groups A, B and C, comprising 15 review articles published in the last decade, 95 pieces of other literature types (with 83% journal articles), and 38 additional materials necessary for complementing an in-depth discussion respectively. A threefold analysis was performed to scrutinise and compare the literature in these sample groups. The analysis showed that for Sample Group A, the focus had steered from overarching LCA of all-embracing life cycle phases to single phase and then sole engagement with a specific topic. For Sample Group B, 44% reported the scientific endeavour on LCIA compared to other life cycle phases. Following clarification on environmental aspects, impact, impact categories, system boundary, cut-off and existing LCI approaches including attributional, consequential, process based, IO based etc., the methodology development of impact categories (covering impact of water use, noise and working environment), uncertainty and sensitivity analysis was discussed. Classification involved series and parallel mechanisms, LCIA development for space use, odour, non-ionising radiation and thermal pollution, rebound effects, renewability of resources, dynamic of environment and future scenario modelling in LCA context were identified as research needs and areas for future development. The end of life of ships and metallic scrap and an LCA framework applicable to marine power systems is reported in **Chapter 4**, followed by case studies in **Chapter 5**. Both **Chapters** are built around environmental aspects (such as emissions and resources) and relevant impact categories, in which LCA was applied as an approach to determine the environmental impact of the marine power systems under study.

Chapter 4. Development of a Life Cycle Assessment (LCA) Framework for Marine Power Systems

"*It would be possible to describe everything scientifically, but it would make no sense; it would be without meaning, as if you described a Beethoven symphony as a variation of wave pressure.*"

Albert Einstein
Paraphrased words as given in Ronald William Clark, *Einstein*, 1984

LCA was a widely recognised tool used for estimating potential environmental impact of a product system throughout the defined life cycle phases. In addition to ISO 14040 and 14044, LCA methodologies had been broadly developed, and the endeavour was still ongoing which had gradually steered from LCI and LCIA methodologies to less developed impact categories, uncertainty and sensitivity analysis [380], as reported in **Chapter 3**. However, LCA applications were case-specific. Transferring from theories into applications was challenging, in particular if one had no experience and was not familiar with the subject, i.e. marine power systems in this study. An LCA framework for marine power systems which set a step-by-step structure would provide guidance by outlining a standardised approach on how to apply and what to do at each stage. An understanding on the end of life management, which was perceived as a significant life cycle phase of marine power systems, was a prerequisite to the applications in **Chapter 5**. Both the end of life management and LCA framework in the marine context were the focus of this chapter, as illustrated in Figure 4.1.

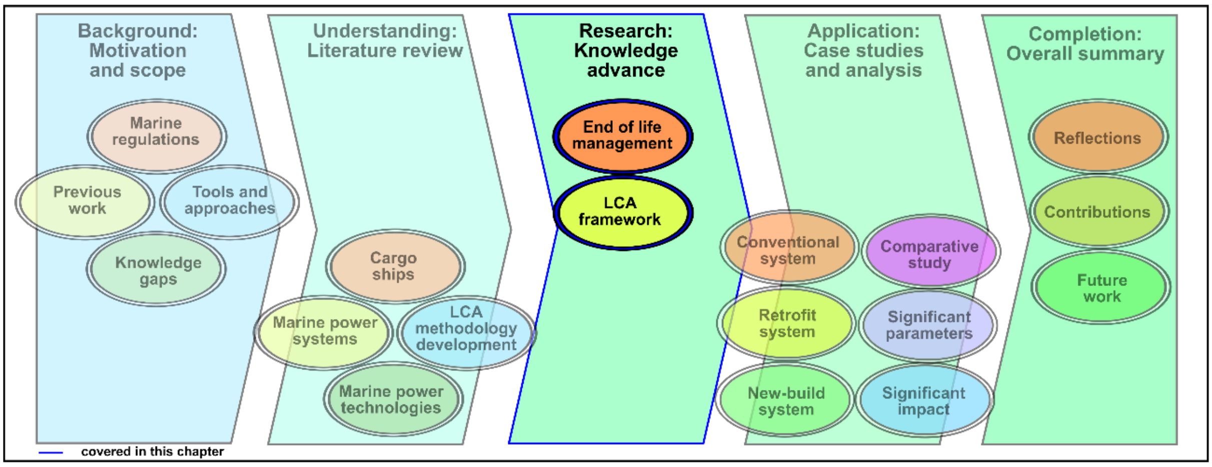


Figure 4.1: The focus of **Chapter 4**.

The following sub-objectives were defined:

- understand end of life management plans for ships, power systems and metallic scrap (**Chapter 4.1**); and
- provide life cycle phase by phase guidelines which specified information that was required for relevant applications, and give helpful hints on resource consumption, processes, emissions and environmental impact (**Chapter 4.2**).

The chapter was closed with a short summary to set the scene for **Chapter 5**.

4.1 End of Life Management

In the context of ship dismantling in Europe, a number of conventions and guidelines had been in place since 1989, including the *Green Paper on Better Ship Dismantling*, *Safety and Health in Shipbreaking*, *The IMO Guidelines on Ship Recycling*, *Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal*, and *Technical Guidelines for Environmentally Sound Management of the Full and Partial Dismantling of Ships* [381-385]. Efforts made throughout the quarter-century had led to the enforcement of European regulation on ship recycling i.e. [386] to mandatorily require

- ship owners to (i) document the quantity and location of hazardous materials in an inventory throughout the life cycle; (ii) ensure that the ship was to be recycled in an approved recycling yard (which was included in European List); and (iii) provide a ready-for-recycling certificate and relevant information to the recycling yard;
- recycling yards to prepare a ship recycling plan prior to hazardous material removal and clean the ship to ensure it was gas-free for hot work;
- local authorities to assess ship recycling yards located in Europe and provide recommendations to the European Commission; and
- the European Commission to maintain the European List of approved recycling facilities.

At present, ships were mainly dismantled in India, Bangladesh, Pakistan, China, America and Turkey. In addition to the recycling yards in Aliaga, Turkey, examples of other ship recycling facilities in Europe included Simont S.p.a. in Italy; Van Heygen Recycling S.A. in Belgium; Scheepssloperij Nederland B.V. and Gdansk shipyard in Poland; Fornaes, Jatop and Smedegaarden in Denmark; Bacopoulos and Savvas

Pireus in Greece; Undoris JSC in Lithuania; Desguaces de la Arena in Spain and Aker-Kvaerner in Norway [114].

Beaching, slipway, alongside and drydock [114] were the four approaches practised at recycling yards. When a ship arrived at the recycling yard, she was

- driven up the beach and chained where oxygen cutting was applied to reclaim steel and other valuable scrap. The approach was known as beaching and had been applied by 95% of recycling facilities worldwide.
- tightened by a concrete slipway or on shore where valuable components were removed by mobile cranes. The approach was known as slipway and had been applied in Turkey.
- stopped alongside sheltered waters where ship dismantling would begin from top to bottom i.e. superstructure to engine room and lastly double bottom. The approach was known as alongside and had been applied in China.
- directed to a dry dock to be dismantled piece by piece. The approach was known as drydock and had been applied in the United Kingdom.

Among power technologies discussed in **Chapter 2**, the following information about the end of life management plans of diesel engines, batteries and PV systems were found:

1. **Main diesel engines**. Existing business dealing with used Sulzer spare parts, for example Pescar Shipping and Logistics [387] showed that components of diesel engines could be reconditioned for further use. The components included the crankshaft, cylinder covers, cylinder liners, pistons, connecting rods, injectors, safety valves, injector valve bodies and fuel pumps, to name but a few. Reconditioning would be required prior to reuse [388] as summarised below in the case of an automotive engine, which was perceived to be applicable to marine diesel engines:
    - straighten, regrind, polish and recondition the crankshaft, connecting rods and cylinder heads
    - bore and hone the cylinder block
    - install new piston rings, camshaft, lifters and timing components, bearings and oil pumps
    - rebalance the engine components

- inspect the engine components
- assemble the engine and carry out pressure test
- paint the remanufactured engine.

In general, how many times an engine could be reconditioned depended on the condition of the components and availability of spare parts. An engine which was in good condition could be remanufactured 2–4 times; the cylinders could be refitted with cast iron or steel sleeves not more than 2 times and pistons could be reconditioned up to 4 times. [388] claimed that the remanufactured engine could result in 26–90% less raw material consumption and 68–83% energy saving as well as reduction in CO_2 (73–87%), CO (48–88%), SO_2 (71–84%) and non-methane hydrocarbon (50–61%). According to [389], materials used for manufacturing a diesel engine could be refurbished and recycled during engine remanufacturing, which involved engine disassembly, cleaning, refurbishment and reassembly. The elementary flows (i.e. materials and energy) and emissions involved in component refurbishment and material recycling were reported by [389], as summarised in Table 4.1, indicating that several components of used engines would be refurbished whilst a small proportion would be recycled.

Table 4.1: Elementary flows and emissions involved in handling used diesel engines [389].

Elementary flow and emission	Component refurbishment	Material recycling
Materials, %*		
(i) steel	15.32	5.88
(ii) cast iron	67.69	0.48
(iii) aluminium	3.90	0.8
(iv) alloy	1.23	2.64
Electricity consumption, kWh per engine	71025.88	1837.893 **
Resources, kg		
(i) coal	52866.56	3309.95
(ii) crude oil	6123.46	383.58
(iii) natural gas	497.36	31.20
Total emissions, kg		
(i) CO	824.05	51.39
(ii) CO_2	93418.31	5850.00
(iii) SO_2	943.34	58.73
(iv) NO_x	360.64	22.94
(v) Methane, CH_4	333.11	21.11
(vi) Hydrogen sulphide, H_2S	40.38	2.53
(vii) Hydrochloride acid, HCl	22.94	1.44
(viii) Dust	873.60	55.06
(ix) Water biological oxygen demand (BOD)	75.25	4.59
(x) Water chemical oxygen demand (COD)	86.26	5.51
(xi) Ammonia, NH_4	0.92	0.06

* 100% mass of an engine

** Electricity consumed by a metal melting furnace for recycling

2. **Lithium-ion batteries**. Recycling and appropriately disposing lithium-ion batteries was necessary to avoid the formation of corrosive substances such as hydrofluoric acid and lithium hydroxide on the negative electrodes as well as fire caused by flammable materials in the batteries. Indeed, battery recycling was mandatory as required by European Directive 2006/66/EC [390]. The following three recycling methods for lithium-ion batteries were reported:

- Pyrometallurgical recycling [389, 391-393]. Lithium-ion batteries were dismantled and burned in a high temperature shaft furnace with the presence of a slag-forming agent, such as sand, limestone or slag. During the process, electrolytes, carbon anodes and plastic were burned whilst valuable materials such as copper, cobalt, nickel or iron were recovered in the form of alloys.

Lithium, aluminium and any other materials presented in the cathodes could be found in slag. To recover these metals, solvent extraction and leaching using a leaching agent (such as sulphuric acid, chloride acid and nitric acid) could be applied but the processes were not economical.

- Intermediate recycling [392, 393]. Lithium-ion batteries were pulverised in a hammer mill. The mixture of metals and plastic was then separated in a shaker table whilst the aqueous stream from the hammer mill was filtered. The filtrate was then mixed with soda to form lithium carbonate. The metals and lithium carbonate could be reused. Similar to pyrometallurgical recycling, the method was not economical.
- Direct recycling [393]. Lithium-ion battery cells were placed in a container where CO_2 was added and turned into supercritical (by increasing pressure and temperature of the container). The supercritical CO_2 would extract the electrolyte from the cells. The electrolyte could be reused after processing. The electrolyte-free cells were then pulverised and all components were separated from one another. Re-lithiation (i.e. charging) was required for cathode materials prior to reuse.

3. **PV systems**. A number of LCA studies on onshore PV systems were available, as summarised in Table 4.2. Although not common at present, it was anticipated that recycling PV systems would be implemented in the near future, as suggested by [394]. The process involved breaking down PV systems into individual components where waste was treated and recycled separately [395].

Table 4.2: Literature on the LCA studies of onshore PV systems.

Literature	Key points
[150]	• A 30-year life cycle of inverters and transformers was expected. • For Balance of System (BOS), 526–542 MJ/m^2 of total primary energy was required where 29–31 kg CO_2 equivalent/m^2 of GHG emissions were released. • Primary energy of 1000 MJ and 3000 MJ were respectively required for materials and processes to manufacture 1 PV module (Type: KC120). The life cycle CO_2 emission rate was 54.6 g CO_2 equivalent/kWh$_e$.
[394]	• Real experience of recycling PV systems was not available. • Small quantity of panel scrap was treated in incineration plants or disposed to landfill. • Recycling silicon cells, aluminium frames, glass and electronic scrap was expected in future.
[395]	• PV modules and BOS were separated; broken down into individual components to be treated separately. • First scenario: PV modules and BOS were disposed to the landfill where disposing plastic waste was most burdensome whilst environmental impact from BOS was trivial. • Second scenario: glass, plastic and metallic scrap were recycled separately where BOS and transporting waste by lorry were respectively the smallest and largest contributors to the total environmental impact. • Energy required for the recycling process was 26% of that of manufacturing process.
[396]	• PV systems were landfilled where neither material nor energy was recovered.
[397]	• More than 99% of the environmental impact was from the production of PV systems. • Recycling PV modules was not considered as it was not in practice *although LCA data were available*.
[398]	• Negative contribution due to reusing wafers, glass and metallic scrap outweighed the environmental burdens resulted by recycling process itself.

After dismantling, the scrap was categorised and stored appropriately before being transported to individual recycling or disposal sites, according to [399] as summarised in Table 4.3.

Table 4.3: Storage approach for a selection of scrap types.

Scrap type	Storage approach after dismantling
Residue oil and fuels	In separate storage tanks
Stainless steel	In containers or piles
Steel	Segregated into different areas in accordance with steel grades
Non-ferrous metals such as copper, brass, lead, zinc and aluminium	Stored in separate containers, preferably covered up
Cables	Plastic coating and wires were collected together in one area and stored separately
Chemicals	Acids or alkalis were identified and stored separately
Asbestos	Handled by a licensed contractor where removed asbestos was double-bagged and stored before delivered to a licensed landfill site
Paint containing triethyl- or trimethyl-tin	Removed by blasting before disassembly; Washings needed to be stored and handled as hazardous waste
Re-useable items	Stored in an appropriate place

According to [400], a total emission of 0.047–0.057 kg and 0.011 kg of CO_2 equivalent would be released respectively in collecting and sorting 1 kg of scrap. Waste sorting, as reported by [401-404], started with physical separation where useful parts were preliminarily distinguished from mixed scrap. Shredding or fragmenting was then applied in a shredder to break the scrap into smaller pieces prior to being tumbled in a large drum to eliminate dust. Magnet, air, eddy current, heavy metal separator, acid, x-ray and thermal methods could be applied in line with scrap types to meet the following purposes:

- Magnetic separation dissociated ferrous (i.e. iron and steel) from non-ferrous scrap.
- Air suction retrieved plastic, paper and textiles.
- Eddy current and heavy metal separator recovered non-ferrous metals e.g. magnesium, aluminium, copper, zinc and lead from waste and shredder residue.
- Spark, magnetic, chemical and spectroscopic testing differentiated alloys using magnets, acids or x-ray spectrometers.
- Thermal methods, for instance de-coating, de-tinning and de-zinning, removed paints, grease, tin, zinc etc.

After categorisation, the scrap was stored and once a sufficient quantity was accumulated, it was packed, for example being baled, bundled or briquetted before shipping to recycling plants, smelters, foundries and manufacturers where the scrap was melted (if required) and processed to produce secondary materials or new products. The following sections described how various types of metallic scrap were recycled.

4.1.1 *Iron and steel scrap recycling*

Pig iron, cast iron, wrought iron, mild steel, carbon steel and high carbon steel were alloys of iron and carbon. Although Tatasteel, which was the only steel producer in the UK, had claimed that the make-up of these alloys could not be defined precisely, a rough idea is illustrated in Figure 4.2. At the end of the life cycle of an alloy product that contained iron, the alloy scrap could be recycled for secondary steel production. Both basic oxygen furnace (BOF) and electric arc furnace (EAF) were common smelters applied by steel industry. The former was mainly used for primary steel production and the latter was more widely used for secondary production [403, 405]. The scrap was mixed with lime (acting as a flux to ease the soldering process) and loaded in baskets. The furnace anodes were submerged in the scrap. Energy was applied to melt the scrap and form liquefied steel. During the process, oxygen gas was constantly supplied so that impurities such as aluminium and silicon could be oxidised into slag. Additional substances were added to liquefied steel in a ladle for alloying purpose before being cast into final products. According to [403], 9.1–12.5 GJ of energy was required to produce 1000 kg of secondary steel whilst 82.4–180.7 kg of CO_2 would be emitted.

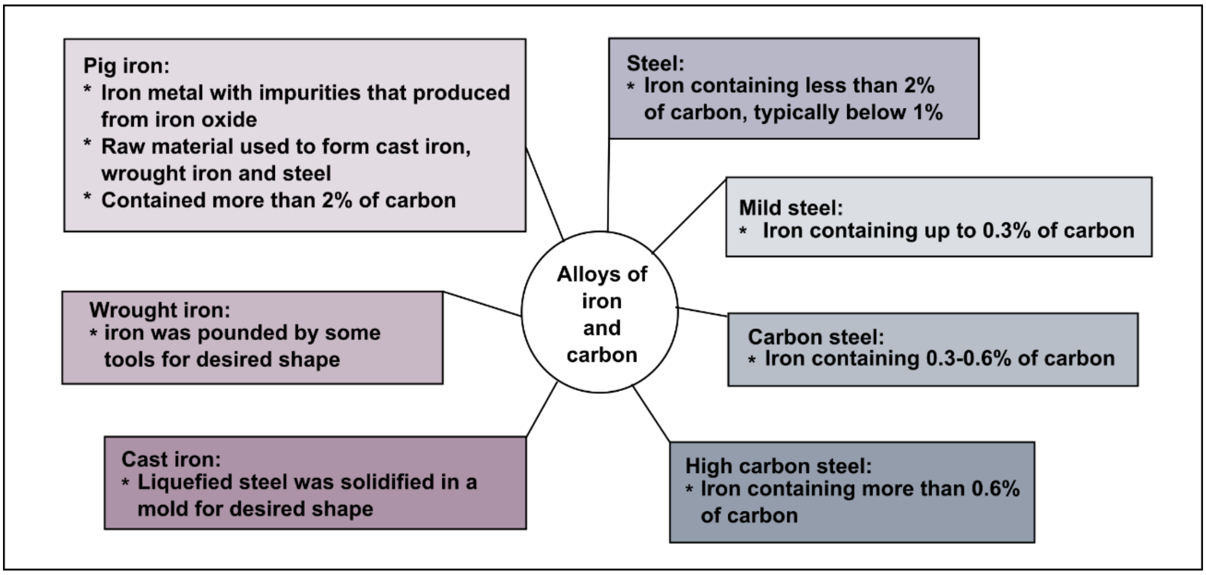


Figure 4.2: Alloys of iron and carbon.

4.1.2 *Stainless steel scrap recycling*

The process of recycling stainless steel with EAF as described by [406, 407] was in the same manner with that of recycling steel scrap discussed in **Chapter 4.1.1**. To keep carbon content below 0.03% and remove impurities, the molten stainless steel was further processed in an argon-oxygen decarburising furnace prior to adding alloying substances. It was reported by [408] that on average, (i) 6.8 kW of electricity was consumed every hour to pre-prepare 1000 kg of scrap, which involved pressing, shearing, cutting, bundling and crushing; (ii) in the scenario of 100% recycling, 23000 MJ of energy was required for the process of 1000 kg secondary stainless steel production where 68 MJ and 2200 MJ were respectively used for scrap preparation and transportation; and (iii) 1016 kg of scrap, i.e. 182 kg of chromium, 80 kg of nickel and 754 kg of iron, was required to produce 1000 kg secondary stainless steel.

4.1.3 *Aluminium scrap recycling*

Depending on the quality of aluminium scrap and the desired outcome, numerous ways could be applied to recycle aluminium scrap, as reported by [402, 405, 409-411]. According to [410], open-loop recycling was applied for aluminium scrap due to changes in the inherent properties of aluminium. This was in agreement with [402] who claimed that ‘diluting’ aluminium scrap with primary aluminium or ‘down-cycling’ aluminium scrap to form aluminium products of lower quality were two common but economically destructive approaches practised for aluminium recycling. Other alternatives should be implemented in long term for a better economic value.

Secondary aluminium production included transportation of aluminium scrap from manufacturing plants and consumers to recycling plants. Whilst aluminium scrap from manufacturers was re-melted directly for new products, the scrap from other sources was preheated and treated to remove contaminants, coating and grease before being melted in a rotary furnace [405]. Filtering, fluxing and floating which respectively removed alumina, impurities (such as calcium, magnesium and lithium) and hydrogen were common examples of chemical treatment in practice. The molten aluminium was then cast as secondary ingots or turned into alloys.

Similar to primary production, ingots from secondary production were used in (i) shape casting to produce semi-fabricated aluminium components; (ii) extruding to produce semi-fabricated or finished extruded aluminium components; and/or (iii) hot or cold rolling to produce coils. [409] recommended to assume a secondary aluminium composition of 35% and 85% respectively for realistic and future scenarios. The LCIs for ingot casting reported by [409] indicated that primary production would consume 211 kWh of electricity, 18 kg of fuel and 52 m^3 of natural gas whilst secondary production would require 115 kWh of electricity and 126 m^3 of natural gas. The LCIs for secondary aluminium ingot production is shown in Table 4.4. In this matter, [405] claimed that energy required for recycling aluminium scrap would be only 5% of that consumed in primary aluminium production.

Table 4.4: Materials, energy and emissions involved in producing 1000 kg of aluminium ingots from secondary production, based on LCI of ingot casting presented in [409] where data for recycling stages prior to ingot casting were not reported.

Stage	Ingot casting
Materials	
Metal, kg	1000
Alloy additives, kg	17.4
Grain refiners, kg	2.27
Water, l	3509
Energy	
Electricity, kWh	115
Fuel oil, kg	0
Diesel, l	0
Natural gas, m^3	126
End product	
Ingots, kg	1000
Emissions	
PM, kg	
CO_2, kg	66
CO, kg	23
SO_x, kg	0.001
NO_x, kg	0.2
Cl_2, kg	0.06
HCl, kg	0.17
Hydrofluoric acid (HF), kg	0.01
Non-methane HCs, kg	0.09
Residue, kg	80

4.1.4 *Copper and brass scrap recycling*

A closed-loop recycling plan had been practised for copper scrap as implied by [401], which pointed out that 'some elements would be reprocessed to their elemental form (e.g., copper)'. How copper scrap was recycled depended on its chemical composition, as reported by literature on copper recycling which is summarised in

Table 4.5. Whilst pure copper scrap could be used directly, copper scrap with 92–95% was smelted in an anode furnace and then oxidised by air to remove impurities. To recycle copper alloy scrap with less than 70% of copper content (including brass scrap), the scrap was smelted in a blast furnace and oxidised in a converter prior to electrolysis. If copper content was low, e.g. approximately 3% as in pewter alloy, the scrap was recycled to its alloy form.

Table 4.5: A summary of literature on copper recycling.

Resource: [407]					
Copper content	Less than 60%	61.3%	92-94%	94%	100%
Name	Copper bearing materials	Refinery grade brass	Light copper	-	Pure copper scrap
Sequential recycling approach	Shearing, magnetic separation, cleaning and degreasing	Being smelted in a blast furnace and refined via electrolysis	Being cast into anodes and refined with electrolysis		Being reused directly to form wire bars

Resource: [411]			
Copper content	Less than 30%	75%	95%
Smelter type	Blast furnaces	Converters	Anode furnaces
Materials	Copper scrap, iron scrap, limestone, sand and coke	Black copper from blast furnaces	Converter copper, copper raw material and oil/coal dust
Sequential recycling approach	The mixture was changed at the top of the blast furnace; air was blown through tuyeres; coke was burned for smelting process	Black copper was added to primary copper production for temperature control. Alternatives include (i) hydrometallurgical treatment using ammonia leaching to produce copper powder; or (ii) solvent extraction treatment fed to copper-winning cells	Smelting; removal of impurities via oxidisation by blowing air on the bath
Outcome	Black copper and slag	Converter copper	Copper

[412] and [413] had respectively reported that 4.62–4.95 MJ and 6.3 MJ of energy would be required to smelt, convert and electro-refine 1 kg of copper scrap. In relation to emissions, [411] reported that 260 g of particulate matter 10 (PM_{10}), 190 g of particulate matter 2.5 ($PM_{2.5}$), 110 g of lead, 2.3 g of cadmium, 1.4 g of arsenic, 28 g of copper, 0.13 g of nickel, 3.7 g of polychlorinated biphenyl (PCB) and 50 µg 1-Toxic Equivalent Quantity (TEQ) of polychlorinated dibenzodioxins (PCDD) were released when 1000 kg of secondary copper was produced.

4.1.5 ***Zinc scrap recycling***

Different approaches could be applied to recycle metallic scrap that contained zinc, as described by [407, 411, 414]. Depending on scrap type and the desired outcome, zinc recycling approaches could be differentiated as summarised in Table 4.6. Closed-loop recycling was only applied for metallic scrap from alloys that contained zinc, e.g. brass and bronze, where the scrap was melted with other metals to produce the alloys [414]. To recover zinc coat from galvanised steel scrap, leaching i.e. immersing the scrap in a caustic solution was applied, followed by electrolysis. In practice, steelmakers preferred to smelt galvanised steel scrap in an EAF to recover steel instead of zinc. As a result, dust and slurry that containing zinc were commonly formed in EAFs. To recover zinc from galvanised steel scrap, the scrap could be heated in a rotary or reverberatory furnace at 364 ^{o}C in which zinc was melted and collected at the bottom of the furnace. Similarly, if it was aimed to recover other metals in the process in addition to zinc from the scrap, the scrap could be heated in a basket and placed in a molten salt bath where liquid metal was collected at a sequence of temperatures.

Table 4.6: Zinc recycling approaches.

Scrap type	Desired outcome	Approach	Remark
Metallic alloy scrap e.g. brass and bronze scrap	Recycled metallic alloy e.g. recycled brass	The scrap was re-melted within alloy group	Zinc was not separated from copper
Galvanised steel scrap	Recycled zinc	Leaching and electrolysis	In practice, recycled steel in EAF was more common and preferred
	Recycled steel	Direct melting in EAF	
Dust and slurry of EAF	Waelz oxide with 55% zinc content	Waelz process resulting in Waelz oxide that was fed into primary zinc production	Other metals with low boiling points, e.g. lead, cadmium and silver, were also recovered
Raw materials with 40% zinc content	Zinc content of 97.5–98%	Thermal zinc refining by fractional distillation using retorts	–

To deal with dust and slurry from EAFs and drosses (referred to as oxidic substances), Waelz process was recognised as the best available technology. In a steelmaking plant, metallic scrap containing zinc and lead was mixed with the oxidic substances and turned into pellets. Together with coke and fluxes, the pellets were charged to a rotary kiln where air was injected as combustion gas at one end. Throughout the process, zinc and lead were reduced, vaporised and re-oxidised to form Waelz oxide (containing 55% zinc and 10% lead), which was then used in primary zinc and lead production.

To produce zinc with high purity, fractional distillation using retorts could be applied. Scrap containing zinc was pre-treated, for example, via comminution, sieving, magnetic separation and de-chlorination. The oxidic substances were mixed with bituminous coal and the pre-treated scrap before being briquetted, coked in a coking furnace at 800 ^{o}C and charged to retorts, together with a small quantity of pure metallic materials [411]. By heating the retorts, zinc was reduced from the scrap, vaporised and condensed. The resulting liquefied zinc was transferred to the foundry where it was cast into ingots.

According to [412], 13.65 MJ of energy would be required to produce 1 kg of secondary zinc. [411] reported that without abatement, 340 g of PM_{10}, 255 g of $PM_{2.5}$, 65 g of lead, 35 g of cadmium, 0.006 g of mercury, 5.9 g of arsenic, 150g of zinc, 0.0031 g of PCB and 100 µg 1-TEQ of PCDD would be released when 1000 kg of secondary zinc was produced.

4.1.6 *Tin scrap recycling*

Literature on tin recycling was limited to [401]. Similar to recycling zinc coat from galvanised steel scrap, leaching and electrolysis could be applied to recover tin coat from tinplate scrap (i.e. steel sheet coated with tin). Examples of tin alloys included solder (2–35% tin and lead), bronze (5–10% tin and copper) and pewter (1–8% antimony and 0.25–3% copper). The scrap of these alloys was recycled in the alloy form; therefore closed-loop recycling was applied in practice. LCI for tin recycling process was not available from literature.

4.1.7 *Lead scrap recycling*

Literature on lead scrap recycling included [401, 407, 411, 412, 415]. In line with sources of the scrap, lead scrap could be classified as lead-acid battery scrap (representing the majority), industrial lead scrap (e.g. skimmings and drosses) and others (e.g. solder, cables and bearings). Lead-acid battery scrap was first crushed by a hammer mill into smaller pieces. Physical separation took place in hydro-separators where small pieces of metals, paste and organic substances found in lead scrap were washed and separated. This was followed by gravity separation for impurity removal. Lead compounds were then reduced to lead elements via smelting at 1200–1260 ^{o}C in a blast, rotary, reverberatory or electric arc furnace with/without desulphurisation. The resulting by-product, i.e. slag, containing 20–40% of lead, could be further reduced in the furnaces to recover more lead. Alternatively, slag could be used as materials for cement industry or disposed to landfill as solid waste. To further enhance the level of purity and remove impurities, raw lead produced from smelting process could be refined via electrolysis or melting using refining kettles. Industrial and other lead scrap was generally in small quantity and was commonly used for the production of alloys or new batteries.

Energy ranging 7–11.2 MJ and 5–11.86 MJ would be required to produce 1 kg of secondary lead, as reported by [412] and [415] respectively. According to [411], 11800 g of PM_{10}, 8800 g of $PM_{2.5}$, 5800 g of lead, 15 g of cadmium, 47 g of arsenic, 35 g of zinc, 3.2 g of PCB and 8 µg 1-TEQ of PCDD would be released when 1000kg of secondary lead was produced without abatement.

4.1.8 *Nickel scrap recycling*

Literature on nickel scrap recycling included [406, 412, 416, 417]. In addition to being used as catalysts in hydrogenation e.g. production of margarine from vegetable oils, nickel was primarily used as a constituent of alloys. Intermediate products that contained nickel included stainless steel, alloy steel, copper- nickel alloys, superalloys, nickel-plating compounds, nickel-cadmium batteries and nickel-metal-hydride batteries. These intermediate products were made of primary and secondary nickel. According to [417], 57% of nickel scrap would be recycled as stainless steel scrap, 14% as carbon and copper alloy scrap and 21% would be disposed to landfill. The scrap including swarf (e.g. fine chips or fillings of metal produced by machining operation during manufacture), if recycled, would be reprocessed as alloys. The process started by degreasing the scrap before mixing with any virgin material. The mixture was melted in an induction furnace (i.e. an electric furnace that supplies heat via induction heating) and then cast under vacuum or with an argon blow to form solid ingots. Slag and solid waste formed respectively during melting and casting processes were either refined in an electric furnace or sold to a third party.

Relevant LCI data included 2.17 MJ of energy required for collecting and transporting 1kg of nickel scrap [416]. According to [412], secondary nickel production would consume only 10% of energy required for primary production i.e. 194 MJ for leaching or 114 MJ for smelting and refining.

4.1.9 *Other metallic scrap*

Other alloy scrap, for instance, manganese and magnesium, was generally not recycled. Possible reasons included (i) technical challenges due to small quantity e.g. solder, chemical binding and similar thermodynamic behaviour between alloying metals; and (ii) economic consideration due to the need of investment for the machines/processes whilst market prices for the scrap were relatively low [407]. Additional data regarding emissions released during some processes were found in [400], as summarised in the following:

- Secondary production of materials i.e. the conversion of recovered materials into new products: 0.31–1.26 kg CO_2 per 1 kg of corrugated cardboard, 0.07–0.86 kg CO_2 per 1 kg of glass, 0.21–0.53 kg CO_2 per 1 kg of high density polyethylene (HDPE) plastic, 0.19–0.89 kg CO_2 per 1 kg of low density polyethylene (LDPE) plastic, 0.85–1.90 kg CO_2 per 1 kg of polystyrene (PS) plastic, 0.02–2.94 kg CO_2 per 1 kg of steel and 0.40–8.37 kg CO_2 per 1 kg of aluminium.

- Landfill: 26 kg CO_2 equivalent per 1000 kg of materials landfilled in US.
- Combustion: 324–480 kg CO_2 equivalent per 1000 kg of materials burned in combustion.

4.2 The LCA Framework for Marine Power Systems in Accordance with ISO 14040 and ISO 14044

The framework was developed in line with the literature review in **Chapters 2–3** and a number of case studies as presented in **Chapter 5**. In developing an LCA framework for marine power systems, the following factors were taken into consideration:

- Coverage. The framework should comply with the International Standards on LCA i.e. ISO 14040 and ISO 14044, covering all phases which presented challenges to LCA practitioners.
- Relevance. Whilst the concept was built on the Standards, the contents should have a specific focus i.e. marine power systems onboard cargo ships.
- Originality. The framework should offer something new to advance existing knowledge.
- Practicality. The framework should provide insights on how to carry out LCA studies on marine power systems in which relevant guidelines should be detailed phase by phase and supported by sufficient examples.

The framework laid down a step-by-step guideline in accordance with ISO 14040 and ISO 14044 on how to conduct a cradle-to-grave LCA study of a marine power system. For each life cycle phase, the framework would tell where to start, what the key elements were and what should be done, and supported by illustrative graphics and examples. For practicality and better understanding, the framework would also illuminate background information and expected results, as presented in a number of tables. As LCA studies on marine power systems were case specific and complicated, the presentation of this framework was by no means exhaustive; still it could help transfer from theories to practice, in particular to those who had no prerequisite knowledge about marine power systems, LCA or both.

4.2.1 *Phase 1: goal and scope definition*

"The depth and the breath" of an LCA study was fundamentally delineated by the elements recognised for goal and scope definition, as illustrated in Figure 4.3.

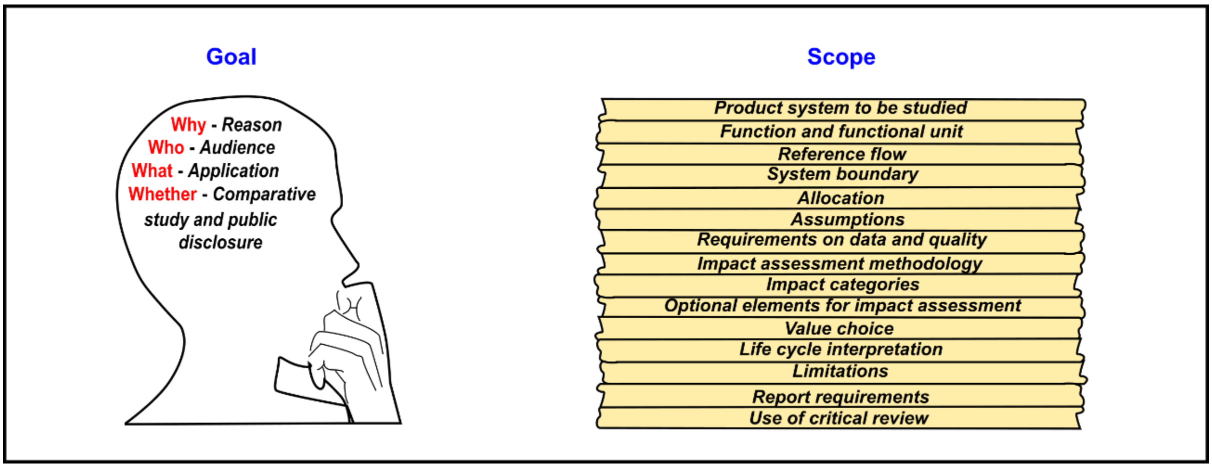


Figure 4.3: Elements recognised by ISO 14040 and ISO 14044 for goal and scope definition.

In compliance with ISO 14040 and ISO 14044, the goal of an LCA study of the power system onboard a marine vessel could be defined appropriately by answering four wh-questions, as follows:

- Why was the study undertaken?
- Who were the targeted audience?
- What did the study apply for?
- Whether the results were used for a comparative study and furthermore disclosed to the public?

For example, the reason for the study was to estimate the potential environmental impact from an LCA perspective applied to the power system onboard a marine vessel (e.g. passenger and cargo ships, container ships, tankers, bulkers, liquefied gas carriers, support vessels etc.). The targeted audience would include regulators and agencies (e.g. IMO), ship builders, owners, operators, marine engineers, LCA researchers and the public. The results would be either/neither used in a comparative LCA study and/or/nor disclosed to the public.

The study was shaped by scope definition where the key elements were provisionally outlined, as follows:

- The product system to be studied was the power system of the chosen vessel, which integrated a range of technologies in accordance with power system design. It was worth noting that a marine vessel, as well as her power system, was generally designed as requested by the ship owner for a particular sailing profile, for example short or deep sea shipping, crossing or within ECAs, receiving regular calls in the same ports or engaging with tramp trade. Diesel engines, auxiliary generators, gas or steam turbines, boilers, economisers, shaft generators, gearboxes, propellers and shafts, thrusters and electric motors were components that commonly integrated into conventional designs. PTO/PTI, fuel cells, batteries, WHRS, PV systems, power electronic components such as converters and variable frequency drives (VFDs), use of sails, cold ironing and emission abatement systems were examples of emerging technologies for innovative designs.

- The function of the product system was to supply power required for propulsion and ship services including hotel loads and cargo handling of a marine vessel.
- Defining a functional unit was technically challenging as there was neither unanimity nor a concrete approach. For product systems which were used for different applications, their functional units would be distinct from each other. For example, for a diesel engine operated in a power plant, the functional unit could be *total power generated over the lifespan* whilst for a diesel engine used in a truck, the functional unit would be *total distance travelled by the truck*. Even if the product systems under study shared a common function, the functional units, still, would not be the same but case specific (depending on the goal and the scope of the study). For instance, aircrafts, road vehicles, trains and ships were used to transport goods and people. When any aircraft, road vehicle, train or ship was assessed in an LCA study, the functional unit could be (i) quantity of cargo shipped; (ii) number of passengers transited; (iii) quantity of cargo and passengers transported; or (iv) distance travelled by the vehicle. As such, there was no definite functional unit for an LCA study but it was always defined based on the goal and the scope of the study. For LCA studies on marine power systems, it was less advantageous and not ideal to adopt *one kilowatt-hour of electricity generated by the power system* or *one tonne of cargos over one kilometre* (in short, *one tonne kilometre*) as the functional unit. This was because a marine power system would employ

numerous technologies and components with diversified lifespans and power capacity involving mechanical, electrical and/or thermal energy. Also, the environmental burdens of a marine vessel would vary with vessel types, power system designs, technologies, fuel types and sailing profiles, to name a few. The variation could be profound, moderate or trivial, which required an in-depth investigation prior to drawing any conclusion. Therefore, the functional unit should be more comprehensive at the system level, for example, the operation of the power system throughout specific life cycle phases of a marine vessel in business i.e. 25–35 years.

- In a comparative study, the number of product system required to fulfil the intended function should be defined as the reference flow. When the operation of marine power systems over specific duration was defined as the functional unit, a straight-forward reference flow would be 1 power system required to fulfil the function over the specific period. In a case where power generated by the power system or distance travelled by the vessel was defined as the functional unit (which presented a more complicated nature for the study), an equal quantity of the power generated by the systems under study or distance travelled by selected vessel types throughout the same period of life cycle could be designated as the reference flow. The conventional designs, i.e. diesel-mechanical systems for most cargo ship types or steam turbine mechanical systems for LNG carriers, were likely to be used as the reference case. For the vessels under study, a straightforward comparison could be made if the sailing profiles were similar; if not, the subject could be explored to a greater extent.
- The system boundary of an LCA study should characterise the study by denoting the life cycle phases and components to be studied. Depending on the life cycle phases to be covered, the study was either cradle-to-gate, gate-to-gate, gate-to-grave or cradle-to-grave. Apart from the cradle-to-grave study, other alternatives might consider one or more phases from engineering and design approval, resource exploration and processing for energy and raw materials, manufacture, installation, operation and maintenance to the end of life of the product system, inclusive of transport wherever relevant. Configuration of the power system with specific technologies, component models and quantities was designed and

determined by naval architects in line with the request of the ship owners, taking power demand, availability, space, efficiency, reliability, lifespan and other technical requirements into account. LCA practitioners would decide which life cycle phases, components, elementary flows and processes were beyond the system boundary, and therefore to be cut off based on the preliminarily established criteria. Exclusion of certain phases (e.g. engineering and design approval) and components (e.g. auxiliary machinery, cables, distribution bus and others) that were not in use or perceived as less significant was common due to time and resource constraints. To decide when to stop seeking more data and proceed to LCI and LCIA, cut-off criteria such as data availability, energy, mass, toxicity, economic and social values that would contribute to fulfilling the functional unit could be applied.

- As the study would involve various technologies and numerous components of diversified life spans, subdivision and system expansion should be exercised to avoid data allocation. In applying subdivision, inputs and outputs involved in each process and life cycle phase were gathered for individual components, and added together as the total flows of the product system i.e. the power system. Throughout the life cycle of the power system, replacement of components with shorter lifespans would be necessary to fulfil the functional unit. System expansion should be applied when additional components were included in the study.
- Making assumptions was unavoidable in an LCA study mainly because of missing information, incomplete data and uncertain parameters. The broader the system boundary, the more assumptions the study would involve. In all cases, assumptions should be explicitly detailed to ensure transparency of the study and allow for further research as well as comparison.
- Requirements on data and quality were provisionally set for data sources, types, spatial and temporal differentiations, technological coverage, representativeness, reproducibility, completeness, consistency and uncertainty. Although it was challenging and expensive to acquire reliable and complete data, still, such good quality was preferable to present a more reliable outcome.

- It was essential to preliminarily define which LCIA methodologies and impact categories would be applied. The underlying characterisation models, impact categories, environmental mechanisms and/or category indicators would vary from one LCIA methodology to another. When one or more characterisation models and impact categories were applied in an LCA study, the environmental mechanisms and category indicators were chosen by default.
- Normalisation, grouping and weighting were optional in an LCA study. Whether or not they were performed should be determined as a part of scope definition. Normalisation was the process where indicator results were compared to a reference, which could be (but not necessarily) chosen from input or output data in a base case or on a local, territorial or international scale. Grouping was the process of sorting or ranking impact categories using a nominal value or a previously established scale. Weighting was the process to multiply indicator results (normalised or not) by weighting scores which were predetermined. Weighting results could be presented as individual scores per impact categories or a single score aggregated across all impact categories. The indicator result of each impact category should be reported together with the outcome of grouping or weighting, if applied.
- Value choice was typically applied in an LCA study based on expert judgement, experience, technical knowledge and preference due to time and resource constraints. Value choice was involved in the study in selecting a power system design, choosing an option where two or more alternatives were available to fulfil the purpose and meet the required quality under the same working condition, deciding which characterisation methodology to apply, whether normalisation, grouping and/or weighting was performed or not, for example. The outcome of an LCA study was therefore subject to value choice. To ensure appropriate interpretation, the study should be transparent in which available options and reasons for a particular decision were conveyed.
- Exclusion of some particular aspects of the product system under study (e.g. life cycle phases, processes, transport, resources, emissions, impact etc.) was common. The decision was made at this early stage mainly because too much or too little was known. The former would result in a

perception that the environmental burdens caused by such aspect was negligible whilst the latter would lead to an attitude that no additional information could be acquired due to limited knowledge and resources. The exclusion implied limitations of the study, which should be reported for transparency.

- A hypothetical plan on life cycle interpretation should be proposed by outlining how LCI and LCIA results would be presented and what assumptions, value choice, limitations and significant issues could be involved.
- The study could be documented in the form of soft and/or hard copies and disseminated via various media. For instance, oral presentation or poster exhibition in a seminar/conference, technical writing in a report or thesis, and professional publication in a handbook or a journal. During scope definition, an initial plan on report format and contents was required.
- A critical review was prefered if the study intended to assess two or more alternatives and make a public assertion. The process was vital to ascertain consistency throughout the study, including goal and scope definition, LCI and LCIA, data quality, life cycle interpretation and documentation.

4.2.2 *Phase 2: LCI*

Figure 4.4 illustrates the life cycle of a marine power system from engineering design and approval to the end of life. Both attributional and consequential approaches were technically applicable, and the choice should be made in line with the defined reason of the study. The former gathered historic or measured data relevant to life cycle processes that were directly involved in delivering the functional unit; the latter accounted for market and non-market marginal data that were significantly affected by the change in producing the product system. An existing LCI method, including process based (using process flow diagram with/without matrix application), fuzzy matrix based, IO based, tiered hybrid, IO based hybrid and integrated hybrid approaches could be applied, as discussed in **Chapter 3**, depending on data sources and the fundamental principles to be applied. As an LCA study of a marine power system was case specific, the process based approach was recommended for a cradle-to-grave study, as proposed in this section.

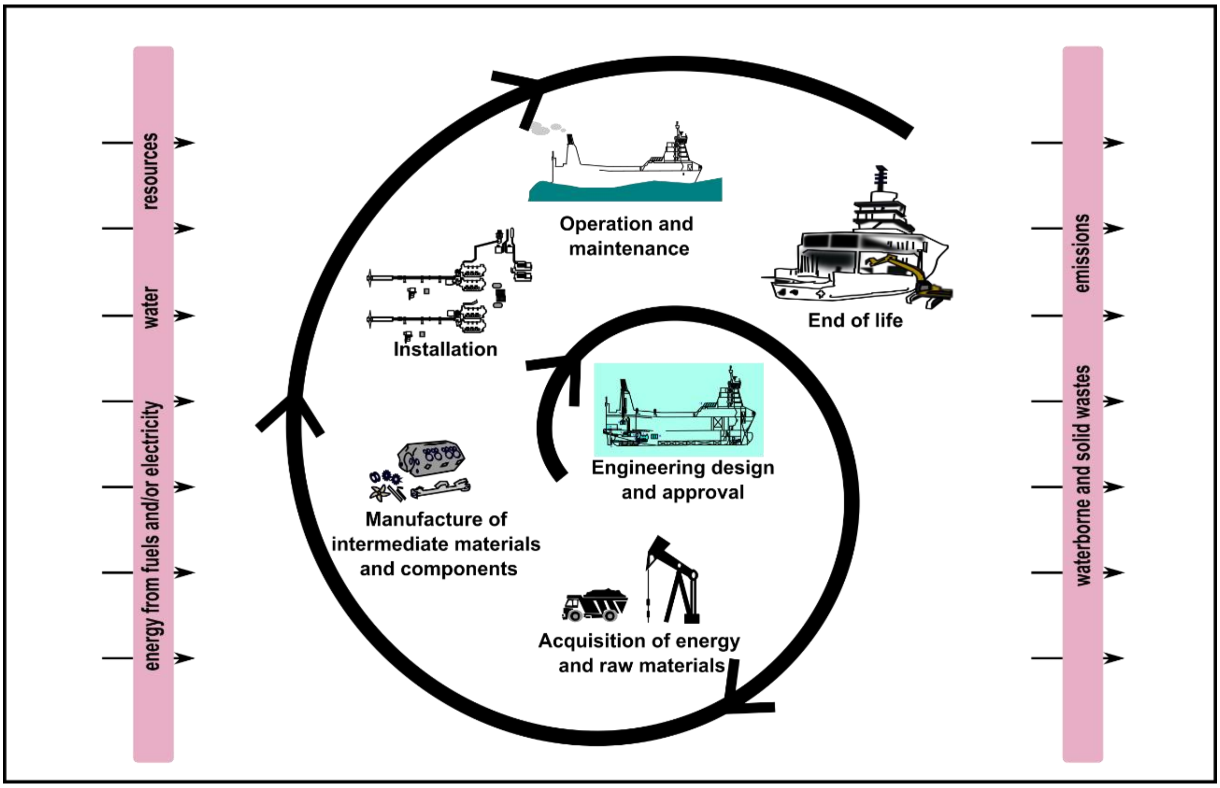


Figure 4.4: Life cycle of a marine power system.

Upon selection of the vessel type, technical data such as system design, technology type and make, power range and lifespan were to be provided by naval architects, manufacturers and/or the ship owner. Figure 4.5 illustrates 2 examples of marine power system configurations, i.e. diesel-mechanical and diesel-electric designs in which diesel engines and gensets were the prime movers respectively. For both designs, a substitution could be made by employing gas and/or steam turbines as the prime movers. For all-electric systems, power augmentation could be achieved via the incorporation of emerging technologies. Background information such as manufacture, mass breakdown, energy and material consumption, emissions and wastes involved during the life cycle phases under study was to be gathered from literature, technical reports, industrial annual reviews, conference proceedings, textbooks and existing databases e.g. Ecoinvent. Examples are presented in Tables 4.7–4.8.

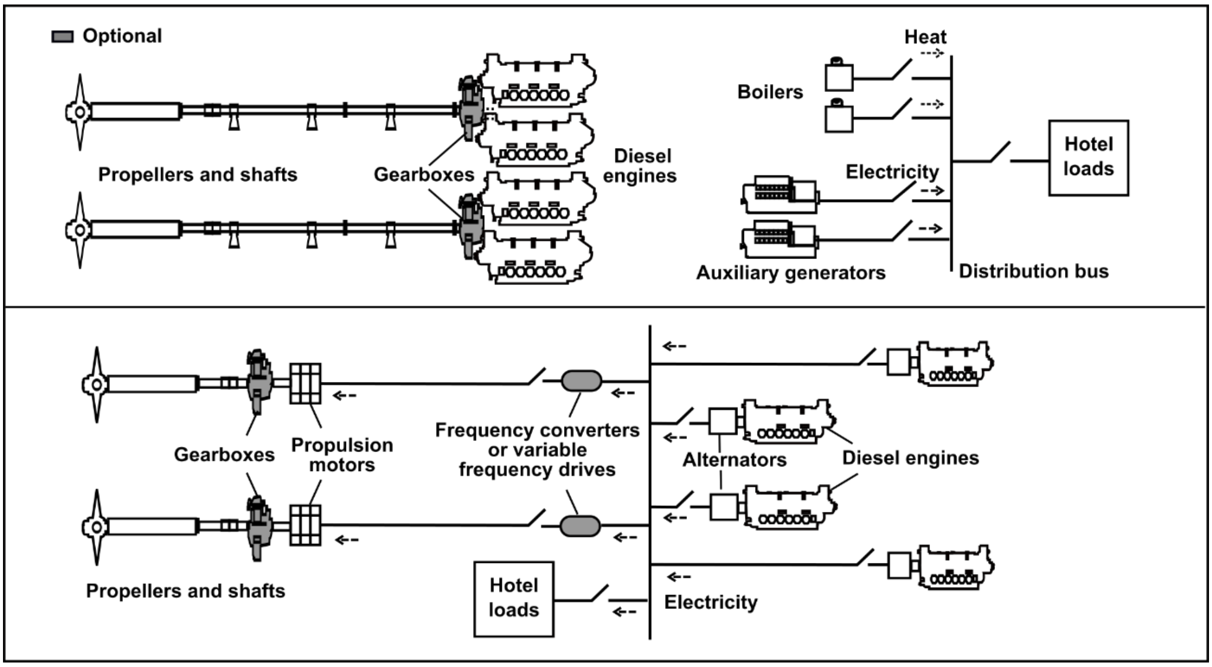


Figure 4.5: Examples of marine power system configurations for cargo ships: diesel-mechanical (top) and diesel-electric designs (bottom).

Table 4.7: Processes and materials used in manufacturing common and emerging components which could be (but not necessarily) incorporated into a marine power system.

Component and function	Manufacturing process [a]	Material [b]
Main diesel engines or diesel gensets supplied power for ship propulsion	1 Machining and testing of engine block, crankshaft, camshaft and connecting rods 2 Manufacture of other components e.g. pistons, cylinders, cylinder heads etc. 3 Incorporation of pistons, connecting rods, crankshaft, camshaft; cylinders and cylinder heads (in sequence) into engine block with smart tooling 4 On-site testing and painting	69.5% cast iron, 21.3% steel, 2.7% aluminium, 2.2% carbon and 1–4% chromium and tin
Auxiliary generators generated auxiliary power for hotel loads		83.2% cast iron, 15.2% steel, 0.2% stainless steel, 0.4% aluminium and 0.9% copper
Shaft generators acted as asynchronous alternators and assisted ship propulsion		With cast iron bearing plates: 46–55% steel, 7–12% copper, 35–45% cast iron, 0–2% aluminium, less than 1% of stainless steel, and 1–2% plastic or rubber for insulating materials
Gearboxes enabled the operation of main engines and propellers at optimum speed	1 Manufacture of components 2 Connection of input, output and transmission shafts 3 Assembly of components 4 Sealing, inspecting and painting	10% aluminium, 20% cast iron and 70% steel
Propellers and shafts propelled the	1 Engineering design 2 Cast mould preparation 3 Mix of molten raw materials	3.84% aluminium, 32.32% copper, 0.01% lead, 0.35% manganese,

ship during transiting	4 Impurity removal and casting 5 Finishing and assembly of blades and hub	1.70% nickel, 0.04% silicon, 61.66% steel and 0.04% zinc
Thrusters and built-in motors navigated the ship during manoeuvring		6.75% aluminium, 59.52% copper, 0.02% lead, 3.38% nickel, 0.08% silicon, 28.60% steel, 0.08% tin and 0.75% zinc
Electric motors turned propellers and thrusters	1 Producing metal sheets laminations and welding 2 Machining the stator core, rotor and housing 3 Forming electromagnetic circuit for the stator and final assembly	82% steel, 11% copper, 3% cast iron, 1% stainless steel, 1% aluminium and 2% plastic
Boilers provided auxiliary power for heating and hot water supply	1 Boiler shell construction from flat plate 2 Welding, inspecting and testing 3 Incorporation of burner, combustion chamber, coils and smoke tubes into the boiler shell 4 Hydraulic testing and painting	82.4% steel, 4.2% chromium steel and copper each, 3.2% rock wool, 2.6% aluminium, 1.7% corrugate board and 0.4% paint
Economisers recovered exhaust waste heat to preheat the working fluid of boilers		
PV systems augmented power supply	1 Silicon production, purification and growth 2 Solar cell fabrication including surface preparation, p-n junction formation, coating and metallisation for electrical conductivity 3 Module encapsulation (i.e. soldering and laminating tempered low iron glass, EVA, solar cell, EVA and back sheets in series) prior to fitting with aluminium frame and junction box	74.16% glass, 10.3% aluminium, 6.55% ethylene-vinyl acetate (EVA), 3.48% silicon, 3.60% plastic back sheets, 0.57% of copper, 0.08% of silver, 0.14% of tin and 0.035% of lead
Lithium-ion battery systems augmented power supply	1 Lithium carbonate formation (from lithium rich brine water and soda crystals), washing, drying and mixing with a solvent to be used in a press 2 Cathode and anode formation from pressing aluminium sheet with lithium ink and copper winding respectively 3 Battery system construction by arranging cathodes,	15–30% lithium iron phosphate cathodes, 10–25% lithium intercalation in graphite anodes, 10–20% electrolyte, 3–5% ethylene or propene separator, 1–20% aluminium cathode foil, 1–30% copper anode foil and 20–40% steel case

	anodes, separators and electrolytes systematically	
Power electronic such as inverters, rectifiers and converters controlled voltage, current and/or frequency of electrical energy	1 Electronic component and printed circuit board (PCB) production, which involved lapping, diffusion, photolithography, alloying, evaporating, passivation and encapsulation 2 Electronic component installation on PCB, soldering and final assembly	6.69% aluminium, 26.34% copper, 46.85% steel, 6.48% inductor, transistor, capacitor and diode, 1.20% corrugated board, 1.43% polystyrene and 0.3% polyethylene
VFDs controlled voltage and frequency input of electric motors	1 Diode, capacitor and transistor production, which involved lapping, diffusion, photolithography, alloying, evaporating, passivation, encapsulation and epoxy filling (whichever relevant) 2 Component installation and soldering 3 Final assembly	50.52% aluminium, 10.94% steel, 9.97% copper, 2.31% epoxy resin, 2.76% glass, 1.74% butyrolactone, 1.04% nylon, 1.07% polypropylene, 0.71% polyvinylchloride and 18.95% corrugated board
Three-phase transformers ensured voltage compatibility between propulsion/ thruster drives and the main switchboard	1 Engineering design 2 Core cutting, stacking, laminating and formation, followed by winding and drying 3 Tank production, accessory assembly and testing	44.64% ferrite or aluminium, 9.37% copper, 0.44% steel, 33.02% epoxy resin and 12.51% plastic
Transformers for power distribution ensured voltage compatibility between supply and end use		9.37% copper, 0.44% steel, 33.02% epoxy resin, 44.64% ferrite and 12.51% plastic
Transformers for cold ironing supplied power from onshore network		

[a] All processes began with proposing and approving engineering design and ended with testing, painting and shipping.

[b] Data were standardised based on inputs from various sources including industrial consortium members.

Table 4.8: Resource consumption, with estimated order of magnitude, at each life cycle phase of a marine power system onboard a RoRo cargo ship over 30 years in business.

Life cycle phases	Resources		Orders of magnitude*
Manufacture	Materials, kg	Aluminium	4
		Brass	0–2
		Carbon	3
		Cast iron	5
		Copper	4–5
		Lead	1
		Manganese	2
		Nickel	3
		Silicon	1–2
		Steel	5
		Stainless steel	3
		Tin	3
		Zinc	2
		Epoxy resin	0–4
		Fleece	0–2
		Glass	0–4
		Nylon	0–2
		Phthalic anhydride	0–2
		Plastic	1–3
		Polyethylene	2
		Polyvinyl fluoride	0–2
		Polypropylene	0–2
		Polystyrene	0–1
		Polyvinylchloride	0–2
		Rockwool	2
	Energy, MJ	Electricity	5
		HFO	3
		Light fuel oil	5
		Natural gas	5
Operation and maintenance	Fuels, kg	HFO	0–7
		MDO	8
		Lubricating oil	4
Dismantling	Energy, MJ	Electricity	5–6
		Natural gas	3
	Fuels, kg	Coal	5
		Light fuel oil	4
End of life: oil waste treatment and recovery	Energy, kg	Diesel	2
		Light fuel oil	2
		LPG	2
	Fuels, MJ	Electricity	5–6
		Natural gas	5
	Materials, kg	Hydrogen	1
		Propane	1
		Sodium hydroxide	2
		Sulphuric acid	2
End of life: metallic scrap	Energy, kg	Coal	3
		Coke	3

handling, recycling and disposal	Fuels, MJ	Crude oil	2
		Blast furnace gas	4–5
		Diesel	5
		Electricity	6
		HFO	2
		Natural gas	4–5
	Materials, kg	Argon	1–2
		Dolomite	2–3
		Graphite	2
		Lime	3
		Nitrogen	3
		Oxygen	3

* Based on LCA case studies in **Chapter 5**

Operational data could be (i) modelled based on energy balance analysis and optimised using simulation by marine engineers or (ii) estimated based on real-time, historical measures recorded by the ship operator over a period. Examples of energy balance analysis and modelling were available, see [418, 419]. Throughout the lifespan, fuel consumed by diesel engines, generators, gensets, boilers and incinerators (if any, in kg) could be estimated using the following formula:

$$Fuel\ consumption = n\left(\sum \frac{P_i\ x\ LF_i\ x\ SFC_i\ x\ t}{1000}\right)$$

in which

n = total number of trips throughout the lifespan;

i = diesel engines, generators, gensets, boilers or incinerators

P_i = maximum power output, kW;

LF = load factor i.e. percentage of maximum power output;

SFC = specific fuel consumption, g/kWh, as presented in Table 4.9;

t = average time required for a voyage, hours.

The average time required for a voyage, *t*, if unavailable, could be estimated:

$$\frac{Distance, nautical\ mile}{Speed, nautical\ mile\ per\ hour}$$

The load factors of prime movers ranged between 75% and 85% at sea [30] and 20% during manoeuvring or in the port [420]. Emissions, kg, released from burning 1000 kg of MGO, MDO or residual oil (RO) could be estimated as follows:

$$Emission_i = \frac{1000\ x\ Emission\ Factor_i}{SFC_i},$$

in which *i* represented CO_2, SO_2, NO_x, CO, hydrocarbon (HC) or PM, where emission factors and SFC are presented in Table 4.9. During operation, technologies employed for power supply, fuel types and sailing modes, as in the following, were factors that affecting emissions released into the environment:

- Common prime mover types: slow-, medium- or high-speed main diesel engines; medium- or high-speed auxiliary generators, gas and/or steam turbines;
- Conventional fuel types: MGO, MDO and RO such as HFO; and
- Sailing modes: transiting at sea, manoeuvring or berthing in port.

Table 4.9: Emission factors for prime movers supplying main (M) and auxiliary (A) power onboard cargo ships, classified as slow-speed (SS), medium-speed (MS) and high-speed (HS) diesel engines, gas (G) and steam (S) turbines, adopted from [30, 420].

Classification	Fuel type [a]	SFC [b], g/kWh	Emission factors [b], g/kWh				
			CO_2	SO_2	NO_x	HC	PM
M-SS	I	185:204	588:647	0.9:1.0	17.0:13.6	0.6:1.8	0.9
	II	185:204	588:647	3.7:4.1	17.0:13.6	0.6:1.8	0.9
	III	185–221:215	603.6–620:682	10.5:11.6	18.1:14.5	0.6:1.8	1.46–1.5:2.4
M-MS	I	203:223	645:710	1.0:1.1	13.2:10.6	0.5:1.5	0.9
	II	203:223	645:710	4.1:4.5	13.2:10.6	0.5:1.5	0.9
	III	185–221:234	659.3–677:745	11.5:12.7	14.0:11.2	0.5:1.5	1.46–1.5:2.4
M-HS	I	203:223	645:710	1.0:1.1	12.0:9.6	0.2:0.6	0.9
	II	203:223	645:710	4.1:4.5	12.0:9.6	0.2:0.6	0.9
	III	213:234	677:745	11.5:12.7	12.7:10.2	0.2:0.6	2.4
M-G	I	290:319	922:1014	1.5:1.6	5.7:2.9	0.1:0.5	0.5
	II	290:319	922:1014	5.8:6.4	5.7:2.9	0.1:0.5	0.5
	III	305:336	970:1067	16.5:18.1	6.1:3.1	0.1:0.5	1.5
M-S	I	209:319	922:1014	1.5:1.6	2.0:1.6	0.1:0.3	0.9
	II	290:319	922:1014	5.8:6.4	2.0:1.6	0.1:0.3	0.9
	III	305:336	970:1067	16.5:18.1	2.1:1.7	0.1:0.3	2.4
A-MS	I	217	690	1.1	13.9	0.4	0.3
	II	185–221	661.4–690	2.2–4.3	13.9	0.4	0.35–0.38:0.3
	III	185–227	702.6–722	12.3	14.7	0.4	1.46–1.5:0.8
A-HS	I	217	690	1.1	10.9	0.4	0.3
	II	217	690	4.3	10.9	0.4	0.3
	III	227	722	12.3	11.6	0.4	0.8

[a] Fuel types: I MGO; II MDO and III RO
[b] Emission factors: at sea:manoeuvring, if differentiated by sailing modes; and in a range, if different values were reported

The end of life processes of ships and metallic scrap are presented in **Chapter 4.1**. How metallic scrap was processed and relevant inventory data including energy consumption and emissions are summarised in Table 4.10. Data for end of life treatment of non-metallic scrap was available in Ecoinvent database.

Table 4.10: Recycling processes and life cycle inventory data of metallic scrap.

Scrap types	Recycling processes	Energy and emission data involved in handling 1 kg of each scrap type as standardised from literature
Iron and steel scrap	The scrap was mixed with lime (to ease the soldering process) and loaded in baskets [403]. In an EAF, anodes were submerged and energy was applied to melt the scrap and form liquefied steel. Oxygen gas was constantly supplied to oxidise impurities such as aluminium and silicon into slag.	Energy was provided by electricity and burning natural gas i.e. 1.705 MJ and 0.618 MJ respectively, requiring 0.015 kg pig iron and 0.0399 kg liquid oxygen, which released 0.000102 kg SO_2, 0.00024 kg NO_x, 0.105 kg CO_2, 0.0024 CO, 0.0159 kg $PM_{2.5}$ and 0.000201 kg PM_{10} [403, 412].
Stainless steel scrap	In a similar manner to recycling steel scrap, stainless steel scrap was melted in an EAF. The molten stainless steel was further processed in an argon-oxygen decarburising furnace to remove impurities [406, 407].	Energy was provided by electricity and burning natural gas i.e. 7.175 MJ and 2.6 MJ respectively in which the process required 0.063 kg pig iron and 0.167 kg liquid oxygen, which released 0.000428 kg SO_2, 0.00000827 kg NO_x, 0.441 kg CO_2, 0.0101 kg CO, 0.0671 kg $PM_{2.5}$ and 0.000846 kg PM_{10} [408, 412].
Aluminium scrap	Open-loop recycling was applied in which aluminium scrap was preheated and treated to remove contaminants, coating and grease before being melted in a rotary furnace. Other common chemical treatments in practice included filtering, fluxing and floating which removed alumina, impurities and hydrogen respectively. The molten aluminium was then cast as secondary ingots or turned into alloys. [402, 410]	Energy provided by electricity and burning natural gas i.e. 0.0953 MJ and 10.223 MJ was required respectively to produce 0.883 kg aluminium ingot, which released 0.00441 kg SO_2, 0.00265 kg NO_x, 0.545 kg CO_2, 0.000883 kg CO and 0.000883 kg PM [409, 411, 421].
Copper and brass scrap	Copper scrap with 92–95 % was smelted in an anode furnace and then oxidised by air	4.95 MJ of energy provided by burning blast furnace gas was involved, which released

	blow to remove impurities. To recycle copper alloy scrap with less than 70 % of copper content (including brass scrap), the scrap was smelted in a blast furnace and oxidised in a converter prior to electrolysis. [407, 411]	0.00002 kg SO_2, 0.00007 kg NO_x, 0.2 kg CO_2, 0.000015 CO, 0.00019 kg $PM_{2.5}$, 0.00026 kg PM_{10} etc. [411-413]
Zinc scrap	Closed-loop recycling was only applied for metallic scrap from alloys that contain zinc, e.g. brass and bronze, where the scrap was melted with other metals to produce the alloy [414]. If it was aimed to recover other metals in addition to zinc from the scrap, the scrap could be heated in a basket placed in a molten salt bath where liquid metal was collected at a sequence of temperatures. To recover zinc coat from galvanised steel scrap, electrolysis and leaching could be applied.	Energy provided by electricity, burning natural gas and coal i.e. 0.733 MJ, 0.335 MJ and 1.455 MJ was required, which released 0.00367 kg SO_2, 0.00157 kg NO_x, 0.0000394 kg $PM_{2.5}$ and 0.00000756 kg PM_{10} [411].
Lead scrap	Slag containing lead could be used as materials for cement industry or disposed to landfill as solid waste [415]. To further remove impurities, raw lead produced from smelting could be refined via electrolysis or melting in refining kettles. Industrial and other lead scrap, which were in small quantity, was generally used in alloy or new battery production.	7 MJ of energy provided by burning blast furnace gas was required, which released 0.00002 kg SO_2, 0.00007 kg NO_x, 0.2 kg CO_2, 0.000015 kg CO, 0.0079 kg $PM_{2.5}$, 0.0106 kg PM_{10} etc. [411, 412, 415]
Nickel scrap	57 % of nickel scrap was recycled as stainless steel scrap, 14 % as carbon and copper alloy scrap and 21 % was disposed to landfill [417]. If recycled, the scrap would be degreased and mixed with virgin material, melted in an induction furnace and then cast under vacuum or with argon blow to form solid ingots.	Energy was required by electricity, heavy fuel, coal and natural gas i.e. 1.920 MJ, 0.215 MJ, 2.298 MJ and 1.709 MJ respectively, which released 0.0119 kg CO_2, 0.000295 kg $PM_{2.5}$, 0.0000429 kg PM_{10} etc. [411, 412]

4.2.3 *Phase 3: LCIA (mandatory and optional elements)*

Aiming to understand and estimate the potential environmental impact of a marine power system, LCIA should be performed in accordance with ISO 14040 and ISO 14044, which established *selection*, *classification* and *characterisation* as the mandatory elements, as illustrated in Figure 4.6.

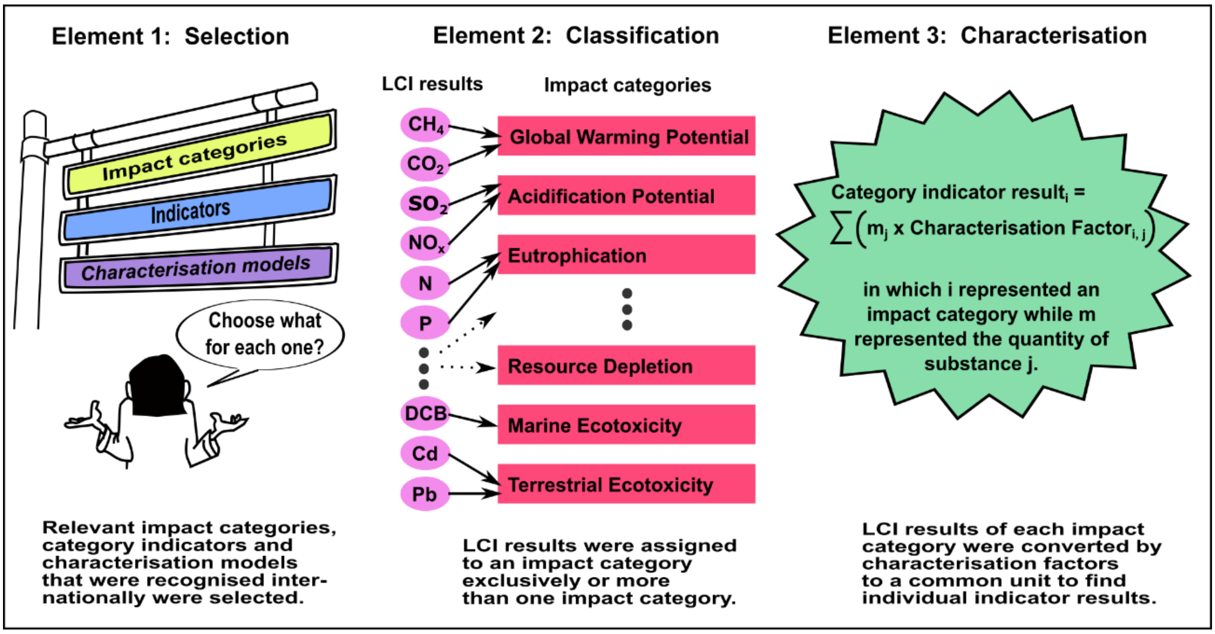


Figure 4.6: Mandatory LCIA elements.

The *selection* element involved the process of choosing impact categories, indicators and characterisation models that were to be applied in the study. To give a few examples, existing characterisation models included (i) midpoint-oriented approach e.g. CML2001 and TRACI; (ii) endpoint-oriented approach e.g. Eco-Indicator99; and (iii) midpoint-endpoint approach e.g. IMPACT2002+, Stepwise2006, ReCiPe and ILCD. Examples of common impact categories (not exhaustively) included climate change, depletion of abiotic resources, ozone layer depletion, eutrophication, acidification, human toxicity, (freshwater and marine aquatic, terrestrial, freshwater and marine sediment) ecotoxicity, photochemical oxidant formation, impact of ionising radiation, depletion of biotic and abiotic resources etc., as previously reported in **Chapter 3**, Table 3.2. Some impact categories were applicable to marine context, as shown in Table 4.11. It was worth noting that each characterisation model had established its own set of impact categories. Whilst a few impact categories could be similar from one characterisation model to another, not any two single characterisation models would be exactly the same. Impact categories that appeared similar could be different, due to the difference in the underlying mathematic relationships, environmental mechanisms, reference substances, exposure routes and reference information used for normalisation.

Table 4.11: Environmental issues differentiated as per impact categories in marine context and their readiness for assessment.

Impact categories	**Relevance to marine context ***	**Already included in existing methods ***
Climate change	Yes	Yes
Ozone layer depletion	The impact was at a minimal level after the ban on halons	Yes
Eutrophication	Yes	Yes
Acidification	Yes	Yes
Toxicity	Yes	Yes
Photochemical oxidant formation	Yes	Yes
Ionising radiation	Not significant	Yes
Desiccation	No	No
Depletion of biotic resources	Yes	Yes
Depletion of abiotic resources	Yes	Yes
Land use	Yes	Yes
Waste heat.	Yes	No
Odour	Limited to engine rooms and engineering decks	No
Noise	Yes	No
Casualties	Not very common	No

* Based on the author's understanding of the literature review

During *classification*, the LCI results generated from the previous step were assigned accordingly to relevant impact categories. For each impact category, the LCI results were converted into a common unit based on characterisation factors. The process was referred to as *characterisation* and the results were known as *category indicator results* or *indicator results*. The mandatory elements were supplemented by 3 optional elements namely *normalisation*, *grouping* and *weighting*, as illustrated in Figure 4.7, which were only applied in line with goal and scope definition.

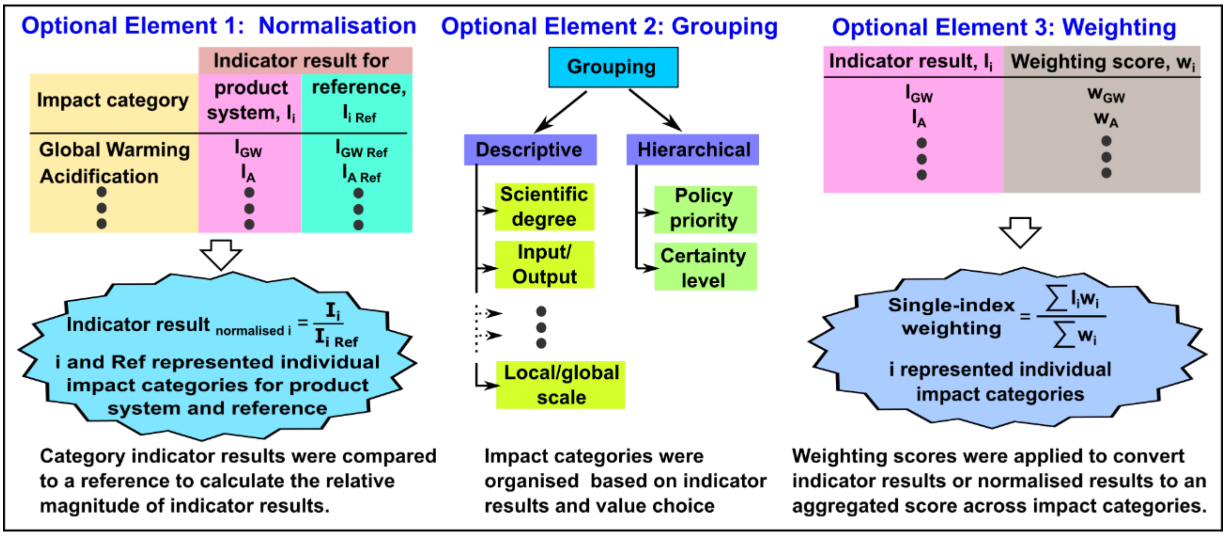


Figure 4.7: Optional LCIA elements.

The environmental issues had been distinguished as per impact categories and some of them were readily incorporated into most characterisation models. Therefore, LCIA could be performed by either applying existing characterisation models or developing a new model, if necessary. In the former case, characterisation methodologies for individual impact categories would be chosen by default when a particular characterisation model was applied using commercial software such as SimaPro and GaBi. In applying a midpoint-oriented characterisation model, the product of inputs/outputs (i.e. resources and emissions) and their corresponding characterisation factors for each impact category was calculated one by one, summed up and expressed as the category indicator results at endpoint level with/without value-based aggregation. The latter was a further step of LCIA which assigned weighting scores to indicator results for a single index. An endpoint-oriented characterisation model multiplied the mass of an emission and characterisation factor one by one for all emissions, followed by aggregating the results to give an impact score at the level (or close to the level) of AoPs. In this framework, classification of significant materials and emissions attributable to marine power systems in line with relevant impact categories and indicators are illustrated in Figures 4.8–4.10, respectively for CML2001, ILCD and Eco-Indicator99 methodologies, which presented the first step towards conducting LCIA for an LCA study on marine power systems.

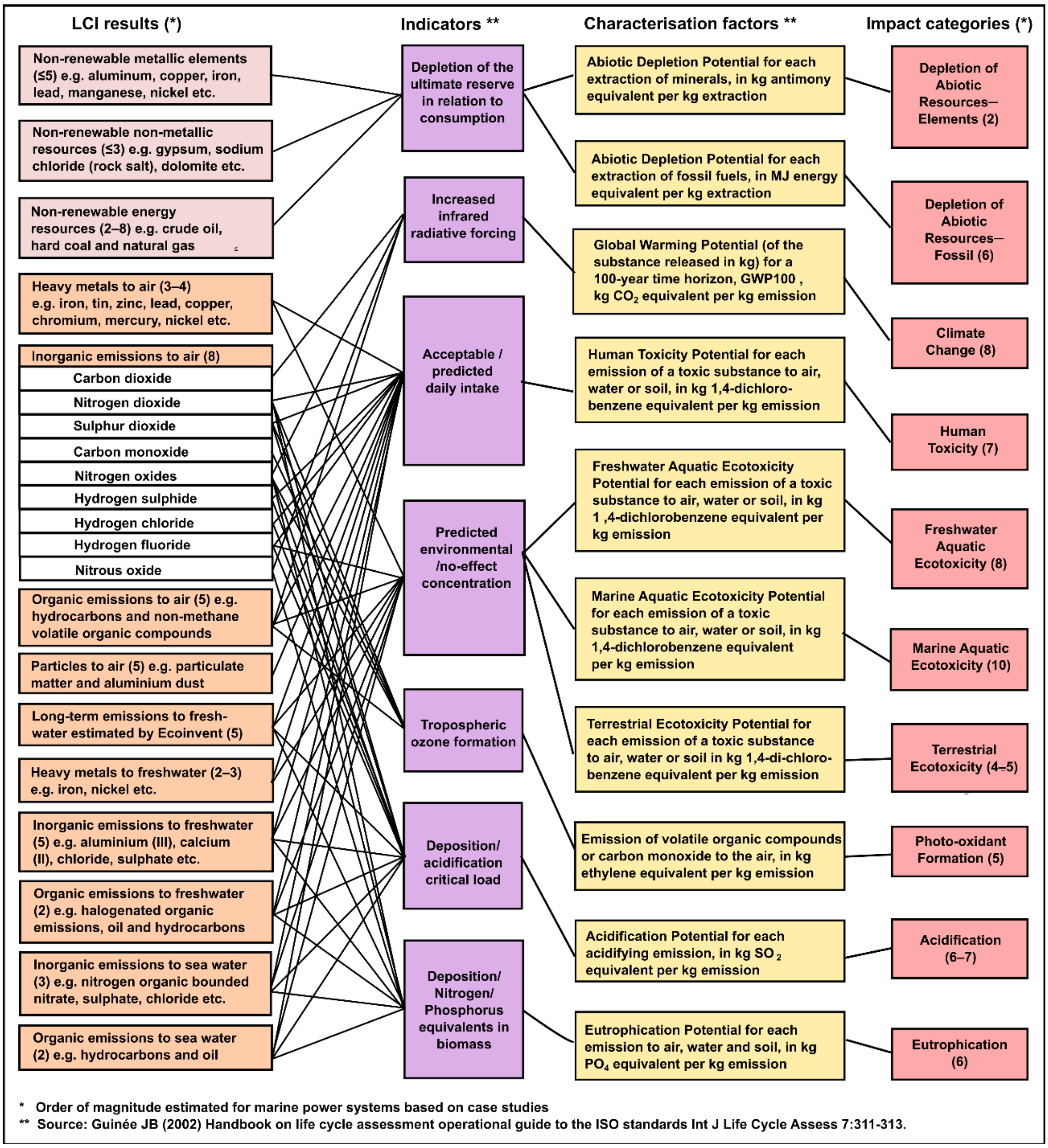


Figure 4.8: Significant LCI results and relevant indicators, characterisation factors and impact categories if CML2001 methodology was applied in performing LCIA of a marine power system.

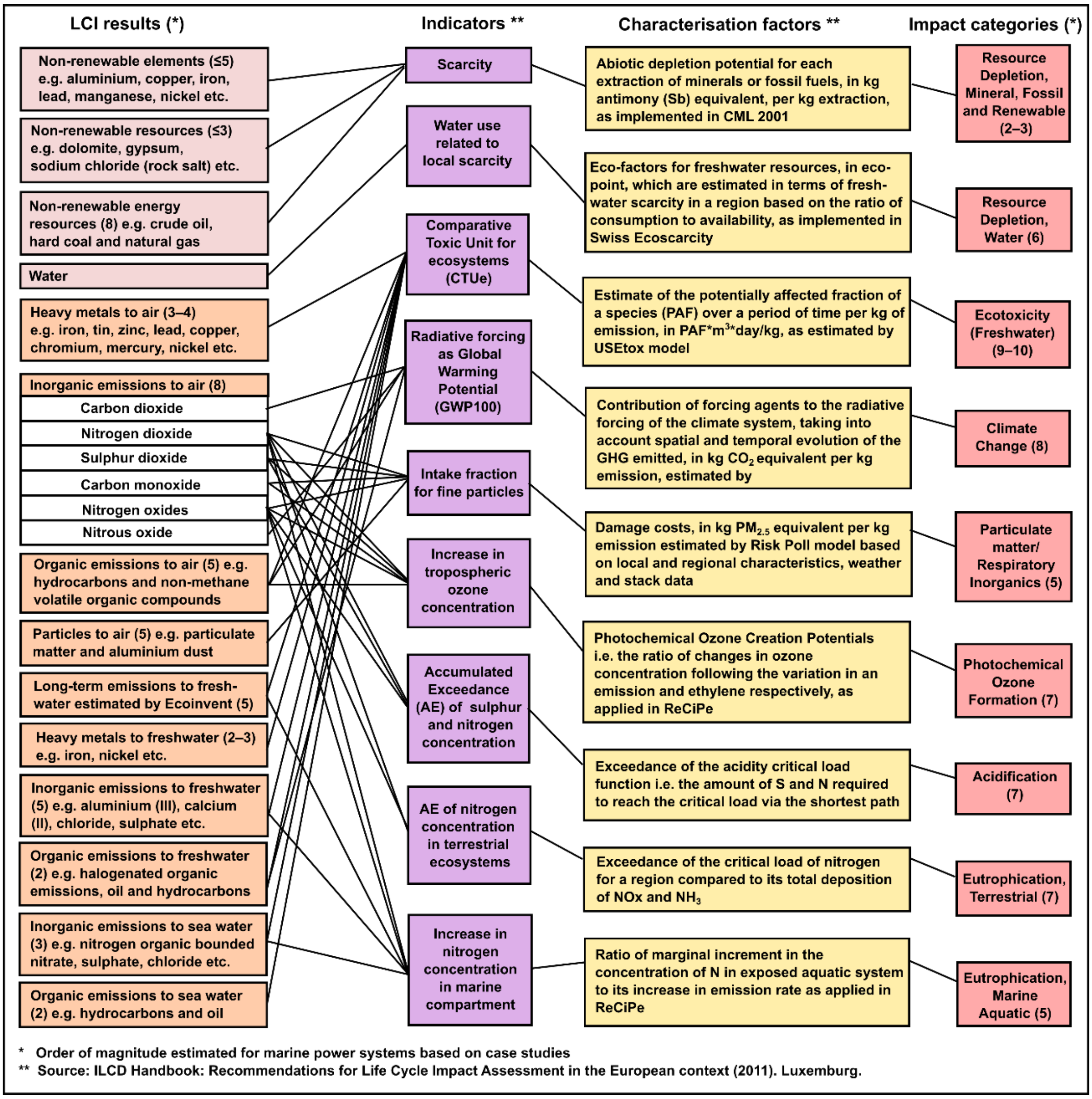


Figure 4.9: Significant LCI results and relevant indicators, characterisation factors and impact categories if ILCD was applied at midpoint level in performing LCIA of a marine power system.

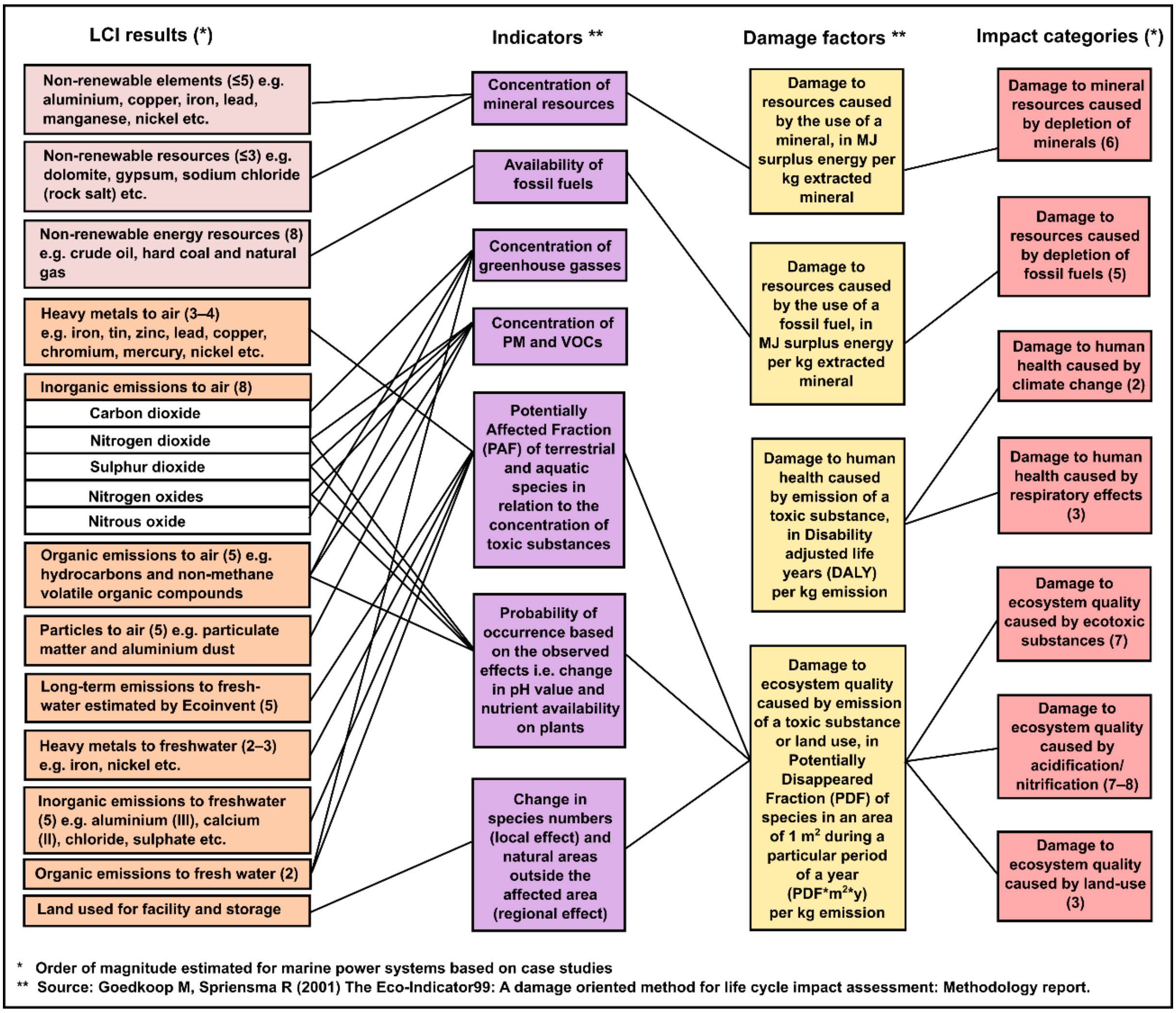


Figure 4.10: Significant LCI results and relevant indicators, damage factors and impact categories if Eco-Indicator99 was applied in performing LCIA of a marine power system.

If a new characterisation model was to be developed, characterisation could be modelled based on fate, exposure, effect and damage analysis (whichever relevant), as detailed by [111, 297], using the following formula:

$$I_i = \sum_{xmn} F^i_{xmn} \, P^i_{xn} \, M_{xm},$$

where *i* represented an impact category assessed in the study; M_{xm} was the quantity of a substance, *x*, i.e. resource or emission that was extracted from or released to an environmental compartment, *m*, e.g. air, water or soil along an exposure route, *n*; F^i_{xmn} denoted the fate and exposure pathways whilst P^i_{xn} showed the potency of the substance, *x*.

Fate analysis was used to describe how a particular substance would shift or distribute in the environment based on mass conversation principles by calculating the concentration of the substance resulting from resource consumption or emission release in a particular environmental compartment, and determining the marginal change in resource availability or human intake. Transport, dispersion and deposition were listed as three stages of pathways to be considered during fate analysis [281]. A characterisation model included an exposure analysis to calculate exposure factors, if relevant. In the analysis, the model took into account the intake and absorption of a substance, in particular chemicals, by human beings via different exposure routes, i.e. inhalation, food consumption, liquid intake and dermal uptake. Another terminology, i.e. intake factors which combined fate and exposure factors [324, 336], could be adopted to directly tell how much the exposure of the population to an emission would be. Examples of effects included atmospheric temperature, human health problem, potentially disappeared fraction, ecological toxicity, severe hereditary etc. [281]. The effect analysis assessed the increase of an effect in terms of 'potency' and/or 'severity' in correspondence to the depletion of a resource or concentration increase of an emission. The potency-based factor estimated the potential risk or the likelihood of a substance imposing an effect on human beings and the environment based on an exposure dose-effect response (also referred to as dose-response relationship [320] or concentration-response relationship [335]). The dose-response potency-based factor could be further distinguished into linear and non-linear. The former firstly predicted a no-effect concentration baseline (also known as low hazardous concentration for impact that was relevant to emission release), let say x%, and assumed that the response would change linearly at a concentration below the baseline affecting x% of the population. The latter measured the marginal change corresponding to every small change in the concentration based on a non-linear dose-response function. The damage factor, also referred to as the severity-based factor, was used to qualitatively or quantitatively derive the effect (or damage) due to resource consumption or emission release based on laboratory data, as reported by [281]. In relation to emission release, damage factor was calculated as per disease or incident and could be defined in different units, i.e. years of life lost per affected person (YLLP) or years of life lived with a disability per affected person (YLDP) [325]. When the results in YLDP were weighted against a reference, new outcome in disability adjusted life years per affected person (DALYP) was presented.

4.2.4 *Phase 4: life cycle interpretation*

In accordance with ISO 14040, interpreting LCI and LCIA results during life cycle interpretation involved four interactive steps as illustrated in Figure 4.11.

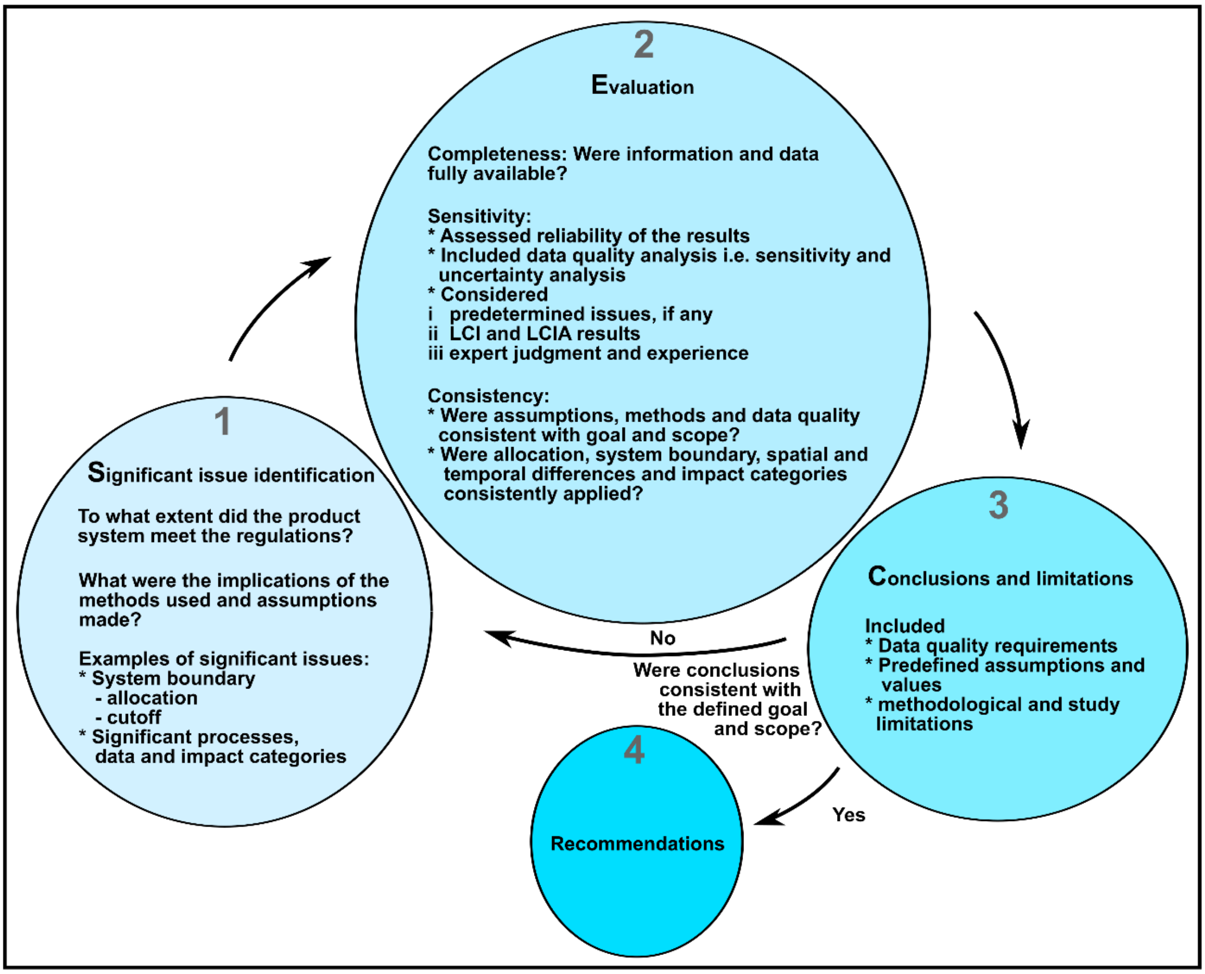


Figure 4.11: The four interactive steps of life cycle interpretation in accordance with ISO 14044.

As LCA studies indicated neither impact thresholds nor safety margins but only estimated relevant burdens without explicitly assessing their risks, to what extent the indicator result of an impact category should be considered as harmless or fatal remained unclear. Thus, interpretation must be done with reasonable care to avoid misleading conclusions. In the context of LCA study on marine power systems (hereafter “LCA study” or “the study” for brevity), the following points were worth noting:

- Identification of significant issues. In general, marine power systems were complex and involved a wide range of technologies. The scope of a cradle-to-grave study was massive due to the number of components and processes involved. The technical designs (i.e. technologies and components), operational profiles and end of life scenarios were factors affecting the overall environmental impact of the power systems. Although the studies were case specific, it was expected that

(i) the operation of marine power systems would be the most significant life cycle phase and the major source of emissions whilst the end of life scenarios i.e. recycling of metal scrap could play a noticeable role in improving the environmental friendliness;

(ii) steel, cast iron, aluminium and copper were likely the most common metals required for the manufacturing phase whilst operating the prime movers would be the most significant process;

(iii) SO_2, NO_x and CO_2 (in ascending order with 6–8 orders of magnitude) were the most significant emissions; and

(iv) acidification, climate change and ecotoxicity were the three most burdensome impact categories.

The LCIA results varied with methodological options and assumptions made (within the same orders of magnitude as indicated in Figures 4.8–4.10).

- Evaluation of completeness, sensitivity and consistency. A close look at the availability of information and data, reliability of the results and consistency in assumptions, methods and data quality with the defined goal and scope would help ensure confidence in the findings.
- Contribution towards the environmental impact. Considering the large number of components incorporated and processes involved throughout the full life cycle of a marine power system, a parameter e.g. input/output, material/component choice, process, scenario etc. might contribute negligibly, moderately or significantly towards the overall environmentally burdens. Whether or not the overall results were sensitive with a particular parameter and uncertainty inherent in the study was a significant issue should be verified by applying sensitivity and uncertainty analysis in analysing the quality of data. Existing approaches were based on

(i) graphics (e.g. scatter plots and spider diagrams), scenarios, ratios (such as sensitivity index), variances, sum of squared errors, polynomial models etc. for sensitivity analysis; and

(ii) scientific methods (e.g. more research, scenarios, uncertainty factors and scales), statistics (e.g. intervals, fuzzy numbers, analytical methods and sampling techniques or probability distributions applied in stochastic modelling), constructive measure (e.g. pedigree matrices) and graphics (e.g. histograms, error bars, Tukey boxes etc.) for uncertainty analysis (see **Chapter 3** for detailed discussion).

If commercial software was used for the LCA study, scenario analysis which addressed both sensitivity and uncertainty was the most suitable approach due to the massive scope of the study. The outcome would help verify significant issues which were identified in the previous step.

- Report of conclusions and limitations. After analysing LCI and LCIA results, identifying significant issues, and evaluating completeness, sensitivity and consistency of all relevant elements, one should draw conclusions in line with the defined goal and scope, in particular the reason of conducting the study. Limitations should be specified to avoid misleading interpretation and enhance understanding of the audience.
- Recommendation for future work. Factors, parameters and aspects that might affect the findings but had not been addressed in the study due to time and resource constraints should be considered and recommended for future work.

4.2.5 The developed framework: a simplified version

The LCA framework described in **Chapters 4.2.1–4.2.4** was developed based on the understanding of the literature review (as reported in **Chapters 2–3**) and end of life management presented in **Chapter 4.1**. To enhance conciseness, the developed framework was illustratively simplified as shown in Figure 4.12 for the case of performing LCIA using commercial software.

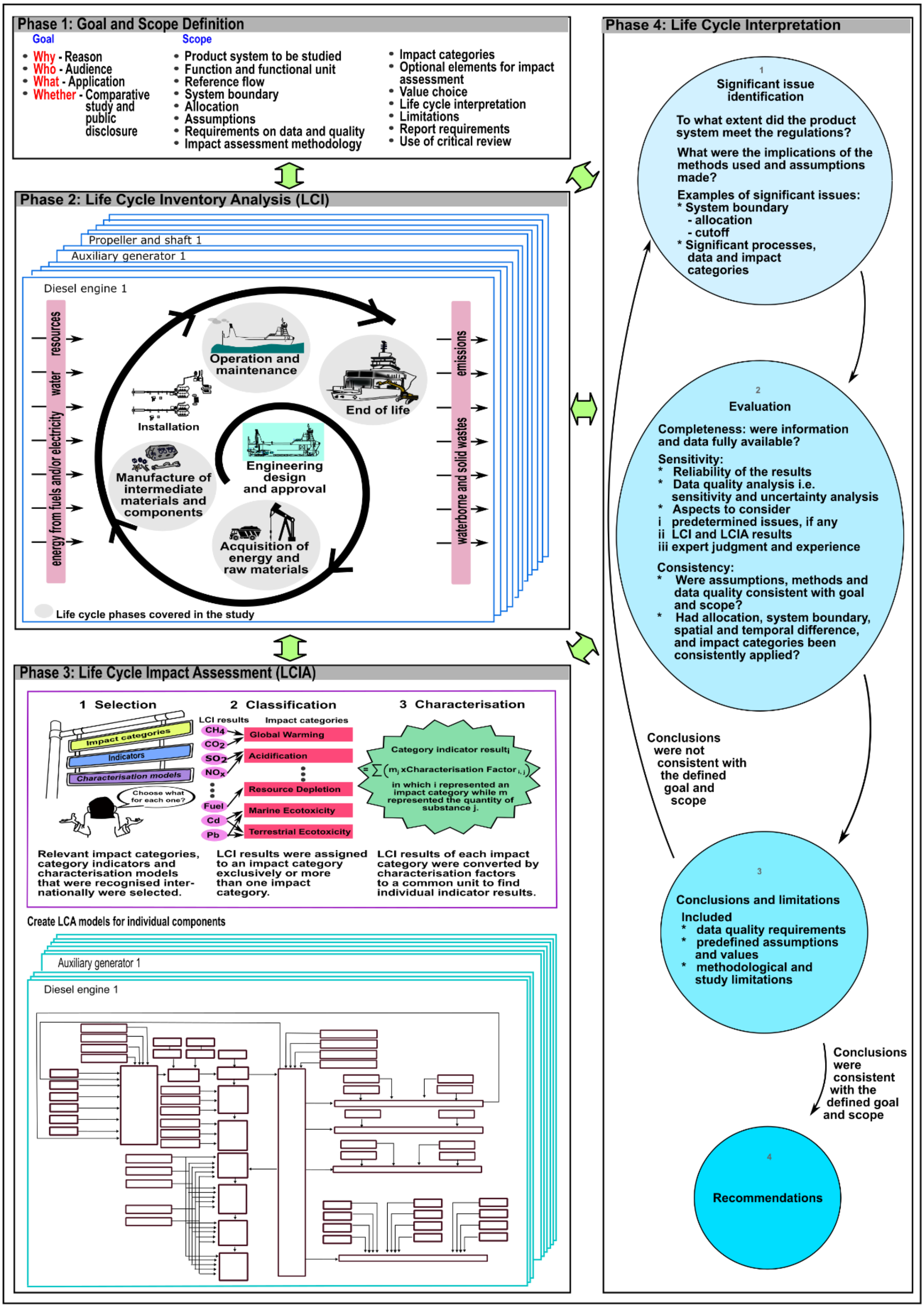


Figure 4.12: LCA framework developed in this study and applied in the LCA case studies.

4.3 Summary

A number of LCA frameworks covering different scope were available; still, a customised LCA framework for marine power systems was missing. The need for such framework was necessitated by the growing concern over shipping emissions, the proposal of IMO to reduce shipping emissions via efficient energy and advanced technologies, and the current interest of maritime stakeholders. The end of life management of ships, relevant components (limited to diesel engines, PV and battery systems) and metal scrap was reported, followed by the presentation of an LCA framework for marine power systems. The proposed framework overcame the limitations of the standard method established by ISO in terms of practicality and benefits to LCA practitioners. Unlike the standard method, the proposed framework had a specific focus on marine power systems, as detailed in **Chapters 4.2.1–4.2.4**. As such, the main contribution of the proposed framework was to assist LCA practitioners in assessing the environmental impact of marine power systems by presenting guidelines, phase by phase, on

- the key elements of goal and scope definition in relevant LCA application;
- manufacture of a range of marine power technologies, materials, energy and fuel consumption, and recycling processes for LCI;
- classification of significant materials and emissions to relevant impact categories and indicators if commercial software was applied, and the concept of fate, exposure, effect and damage analysis if a new characterisation model was to be developed for LCIA; and
- some key points relevant to life cycle interpretation.

Based on this framework, 3 case studies were performed to assess the environmental impact of conventional, retrofitting and new-build marine power systems, as presented in **Chapter 5**. The proposed framework had practical implications for future research work in this subject area as it offered a starting point, in particular to those who did not have prerequisite knowledge about LCA and/or marine power systems, described relevant elements and requirements phase by phase, and illuminated background information and expected results by presenting examples, illustrative graphics and tables. The work was important as it filled the research gaps by customising the LCA framework established by ISO Standards to fit the context of marine power systems. LCA studies on marine power systems were case specific because of the wide range of power system designs, operational profiles and end of life scenarios in addition to more than one methodological choice available for individual LCA elements. The circumstances led to the limitation of this proposed framework, in which it could by no means offer a definite solution for all technical options and methodological choices but a comprehensive idea of selected approaches. Future work should focus on extending the proposed framework to cover more technical options of marine power systems with different operational profiles for various vessel types as well as addressing transportation, spatial and temporal difference.

Chapter 5. Life Cycle Assessment (LCA) Case Studies of Marine Power Systems

"*I like the scientific spirit—the holding off, the being sure but not too sure, the willingness to surrender ideas when the evidence is against them: this is ultimately fine—it always keeps the way beyond open—always gives life, thought, affection, the whole man, a chance to try over again after a mistake —after a wrong guess.*"

Walt Whitman

Walt Whitman's Camden Conversations, 1973

In line with the focus of this chapter, as illustrated in Figure 5.1, methodology applied in this study is explained in **Chapter 5.1**, followed by Case Study 1 on a conventional power system in **Chapter 5.2**, Case Study 2 on a retrofit power system in **Chapter 5.3**, Case Study 3 on a new-build power system in **Chapter 5.4**, and a comparative study in **Chapter 5.5**. The chapter closes with a brief summary highlighting the key findings of the work.

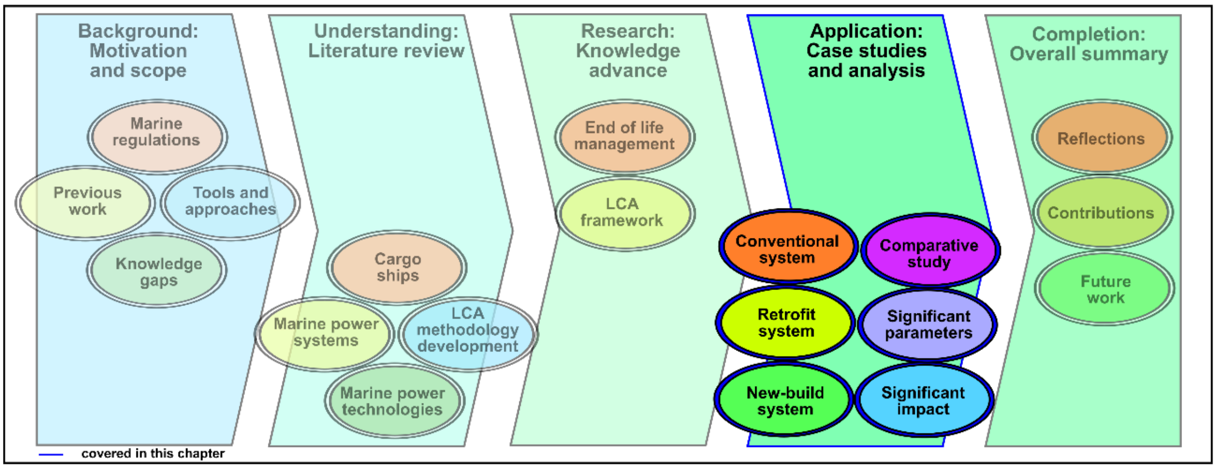


Figure 5.1: The focus of **Chapter 5**.

5.1 Methodology/Research Approach

LCA case studies applied in this work involved massive system boundaries. A bottom-up integrated system approach was adopted in the case studies in accordance with the developed framework, as illustrated in **Chapter 4,** Figure 4.12. After defining goal and scope of the studies, a reference ship was selected and components **integrated** into each power **system** under study were identified. In total, three power systems i.e. conventional, retrofit and new-build designs were investigated in Case Studies 1–3. A 30-year lifespan was defined for marine power systems in this study. This was within the lifespan range of marine vessels presented in the literature i.e. 25 years by [69] and [225], 30 years by [422] and 40 years by [86]. Due to the broad range of innovative technologies, operational profiles and vessel types, more than one configuration design could be technically applied to retrofit and new-build systems. The configurations assessed in Case Studies 2 and 3 were proposed by research consortium involved in the project, which represented the state-of-the-art designs. Data were gathered and standardised from various sources, as explained in each case study. Based on the data, LCA models for individual components were created using commercial software i.e. GaBi (Version 6). The characterisation factors of individual chemicals in correspondence to relevant impact categories, the associated environmental mechanisms and characterisation models were readily incorporated into the software.

All data inputted into the LCA models would be assigned to relevant impact categories for characterisation. In this study, CML2001 might be a preferable choice of characterisation methodology in the marine context as it differentiated marine, freshwater and terrestrial ecotoxicity potential and estimated human toxicity potential. However, ILCD differentiated between marine and freshwater eutrophication and was more relevant in the European context. Estimates made by using Eco-Indicator99 were diverged from those of CML2001 and ILCD, but worth-noting because of their endpoint approach. The LCI and LCIA results (i.e. category indicator results) for individual components were analysed. To estimate the total impact attributable to each power system, the LCIA results for individual components were summed up, i.e. a **bottom-up** approach. The LCIA results were not normalised mainly because (i) by comparing LCIA results to some reference information, normalisation could change the conclusions drawn from the LCIA phase, as pointed out by ISO 14044; (ii) there was no consensus on how to define reference information for any specific industry [124]; (iii) environmental scales and processes would be ignored if regulatory (or economic) boundaries were used as the reference information [315]; (iv) existing reference information could be miscalculated if shipping emissions were previously underestimated, as reported in **Chapter 1**; and (v) it was intended to apply the case study on the conventional system i.e. Case Study 1 as the reference system for the comparative study. Weighting was not performed to minimise the involvement of value choice.

As it was not transparent how impact assessment methodologies were incorporated in the software, the most suitable approach to address uncertainty issue in this study would be scenario analysis, which had been recognised as a method for uncertainty and sensitivity analysis. The influence of input data on the overall LCIA results were determined by varying selected parameters one by one whilst keeping other parameters unchanged. The LCIA results gained from additional scenarios were analysed prior to drawing conclusions. The results of the case studies were compared to verify if innovative power systems were more environmental friendly. In all cases, a review was carried out by Offshore Renewable Energy Catapult.

5.2 Case Study 1: Conventional Power System

The following sub-objectives were set for this case study:

- define goal and scope of the case study;
- estimate resources consumed, emissions released and consequently the environmental impact caused by the conventional power system under study throughout its life cycle;
- identify the main causes of significant resources, emissions and impact; and
- explore the influence, if any, of selected parameters over the estimated impact via scenario analysis.

The selection and the profile of the reference ship are described in **Chapter 5.2.1**, followed by a brief coverage in **Chapter 5.2.2** on data gathered for the study. The four LCA phases are presented in the consecutive sections, i.e. goal and scope definition in **Chapter 5.2.3**, LCI results with a focus on resource consumption and emissions in **Chapter 5.2.4**, LCIA results in **Chapter 5.2.5**, and interpretation via scenario analysis in **Chapter 5.2.6**.

5.2.1 *Selection and profile of the reference ship*

An intra-European RoRo cargo ship receiving regular calls in the same ports within ECAs with regular transients and frequent manoeuvring was selected by the research consortium involved in the project as the reference ship. The selection was made mainly because of

(i) data availability, such as details about system design and real-time operational profile;

(ii) the prospect of retrofitting existing RoRo cargo ships to meet stricter regulations set by IMO;

(iii) the important role of RoRo cargo ships in Europe, as indicated by the number of orders for new-build ships (as reported in **Chapter 1)**; and

(iv) the business route near coastal areas in which the population would be relatively more affected by the impact.

The ship, with an overall length of 182.77 metres, a gross tonnage of 21 kilotonnes and a deadweight tonnage of 12.4 kilotonnes, was ordered in 1997, launched in March 2004 and constantly operated by 12 crews to travel between Harwich, UK and Europort, Netherlands which required an auxiliary power of 650 kW in port and 850 kW at sea. Both voyages involved 113.9 and 112.1 nautical miles where the ship travelled 98.5 and 97.5 nautical miles at sea for 5.46–6.57 hours at a speed between 15 and 17 knots respectively. In a year, she spent 128.59 and 161.42 hours respectively to enter Harwick and Europort, 128.29 and 161.42 hours on mooring, 2579.95 and 1702.32 hours for waiting as well as 99.96 and 149.36 hours to leave the ports. In total, 365 return trips were estimated each year resulting in 10950 trips in 30 years of operation.

5.2.2 *Data sources*

Primary data gathered for the study included (a) the real-time operational profile recorded by the ship operator between 1 January and 31 March 2011; and (b) simulation results detailing the optimised usage profiles, fuel consumption and power generation (whichever relevant) of individual components on a daily trip basis generated using General Energy Software (GES) and the Particle Swarm Optimisation (PSO) method developed in Matlab by research partners. Based on these data, emissions were estimated using factors proposed by [420] which differentiated between fuel types, technology components and operational profiles. Background data for individual components were provided by the ship owner and the consortium, when available. These included (i) brief descriptions, for example, manufacturer, manufacturing plant, year of build, model, function, efficiency and life span; (ii) component diagrams and system design; (iii) physical properties such as materials, total mass and mass breakdown; (iv) manufacture details, for instance, processes, (electricity and/or fuel) energy consumed and transport mode used; and (v) maintenance profiles, i.e. how often a component was maintained.

Manufacturing a product from raw materials might involve casting and moulding, forming, separating, conditioning, assembling and finishing. Details, such as what processes and materials were involved and exactly how much was required for each, were generally classified by manufacturers as sensitive information. Information presented in product manuals and manufacturers' annual reviews, if any, was incomplete. Such information was limited or not covered at all in existing peer-reviewed journal publications, which would have been the most reliable source. The issue was dealt with by using average data, i.e. data gathered and standardised from alternative sources including expert judgement from the industrial consortium, technical reports, textbooks and proceedings in addition to manuals and reviews, as summarised in Table 4.7 in **Chapter 4**. Alternative data source i.e. Ecoinvent Database v2.2 was sought if data were missing or not available.

In relation to the end of life phase, data standardised from literature as reported in **Chapter 4, Table 4.10** were applied for metallic scrap. In relation to treating and recovering used lubricating oil, data were gathered from [423-426]. Relevant Ecoinvent datasets were adopted for disposing metallic and non-metallic scrap to incineration plants and landfill. The input and output data used for developing the LCA models are shown in Appendix.

5.2.3 *Goal and scope definition*

The intended application and the reason of this study were closely related to each other: the former was to estimate the environmental impact of a conventional marine power system onboard a RoRo cargo ship whilst the latter was to gain insights into the system under study. The intended audience included not only the funding bodies but also maritime stakeholders and the public. It was hoped that findings and conclusions presented in this case study could offer a reference for future LCA studies on any innovative marine power systems, be it retrofit or new-build design.

Marine power technologies, regardless of conventional or innovative, varied in terms of function and lifespan: some could provide propulsion or auxiliary power whilst others would supply both; some could operate for 30 years whilst others would require a replacement due to a shorter lifespan. Instead of individual technologies, the power system was chosen as the product system under study as the reference ship could only fully function if the technologies were integrated as a whole system (to avoid allocation via system expansion). The function of the power system was to supply energy required for propulsion and operation of a cargo ship. Due to the diversity in lifespan of individual technologies, neither the number of journey nor travelling distance was defined as the functional unit. Instead, the functional unit was the operation of the power system of a RoRo cargo ship over 30 years on regular routes.

The conventional power system consisted of 4 main diesel engines and 2 shaft generators connecting 2 gearboxes respectively driving 2 propellers, in addition to 2 bow thrusters run by built-in motors for manoeuvring purpose whilst 2 auxiliary generators functioned with 2 thermal oil boilers and 2 economisers to meet hotel loads for services and auxiliary use. These components were defined as the system boundary of the case study, as illustrated in Figure 5.2, where their background data are summarised in Table 5.1. Relevant manufacturing processes and mass breakdown as reported in **Chapter 4** were applied for these components.

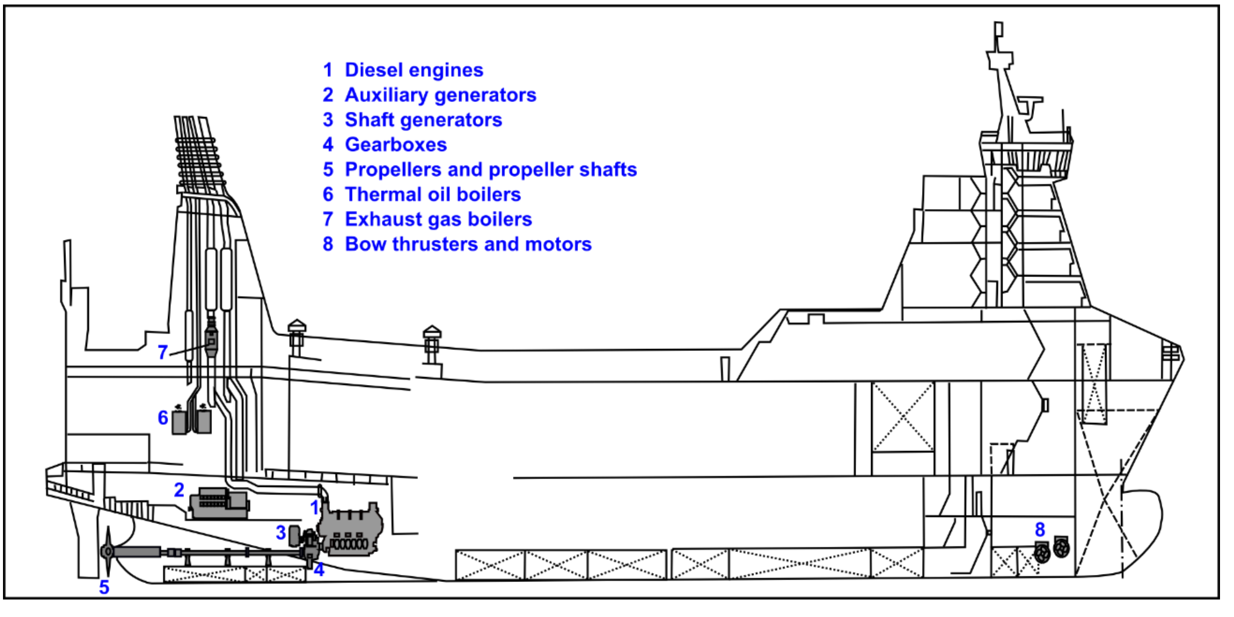


Figure 5.2: System boundary of the case study on the conventional power system.

Table 5.1: Background data of individual components used in LCA models for the base case scenario.

Component, make, type and number	Function	Design or operational detail	Lifespan	Unit mass
Main diesel engines, Sulzer 8ZA40S, 4 units	Supply power for ship propulsion	5760 kW, 4-stroke, medium speed, non-reversible, 400 mm bore, 560 mm stroke, 510 rpm engine speed	30 years	78000 kg
Auxiliary generators, MAN B&W 7L28/32H, 2 units	Generate auxiliary power for hotel loads	1563 kW, 4-stroke, in-line, 280 mm bore, 320 mm stroke, 13.3:1 compression ratio, 750 rpm engine speed	30 years	39400 kg
Shaft generators, AvK DSG 88M1-4, 2 units	Function as asynchronous alternators to assist ship propulsion	2125 kVA, not in use	30 years	2125 kg
Gearboxes, Renk AD NDSHL3000, 2 units	Enable optimum speed of engines and propellers	5760 kW at 510 rpm, an output speed of 130 rpm at a reduction ratio of 3.923:1	30 years	1415 kg
Propellers and shafts, Lips 4CPS160, 2 units	Propel the ship during transiting	4-blade, controllable pitch for ice application with outward turning, overall diameter of 5 m, with 105.4 m shaft	30 years	Propeller 24000 kg; shaft 35400 kg
Bow thrusters and motors, Lips, 2 units	Navigate the ship during manoeuvring	1000 kWh each, transverse, controllable pitch, standard design with propeller diameter of 1.75 m	30 years	5600 kg
Boilers, Wiesloch 25V0-13, 2 (plus 2) units	Meet power demand for heating and hot water	1453 kW each, thermal oil boilers burning MDO with an inlet/outlet temperature of 160/200 ^{o}C	20 years	3170 kg (estimated)
Economisers, Heatmaster THE3-60, 2 (plus 2) units	Recover exhaust waste heat	When engines run at 75-100% maximum continuous rating, exhaust gas inlet and outlet were 206-223 ^{o}C and 340-350 ^{o}C	15 years	2200 kg (estimated)

Prior to the enforcement of SO_x control in North Sea in November 2007, one of the diesel engines and an auxiliary generator were in operation which burned MDO (i) before entering and after leaving a port for approximately 0.5–1 hour; and (ii) during manoeuvring and docking. When the ship was transiting at sea, the main diesel engine which previously burned MDO in port would switch fuel, and run together with another diesel engine at a constant speed─both engines burned HFO (with 1% sulphur). Meanwhile, the auxiliary generator which burned MDO would be shut down whilst the other auxiliary generator would be run by burning HFO. Exhaust from the diesel engines was supplied to economisers to produce steam for auxiliary use such as pre-conditioning HFO and MDO that would be burned by the engines and auxiliary generators. When the ship was approaching a port, one of the diesel engines and the auxiliary generator would be shut down; another diesel engine would switch fuel and the other auxiliary generator would be run─both burned MDO. During manoeuvring and mooring, bow thrusters were in use or in standby mode. After the enforcement, only MDO was consumed. Throughout the life cycle, boilers burned MDO only. Regardless of manoeuvring, mooring or transiting, auxiliary electrical power and steam service demands were met by running an auxiliary generator and a boiler. NOx emission was controlled via water injection instead of SCR. The other two diesel engines and both shaft generators were not in use mainly because of the relatively low power demand of the reference ship. Whilst most components had a 30-year lifespan, a replacement of boilers and economisers was required after 15–20 years in service. In the absence of data, assumptions were made necessarily, as summarised in Table 5.2.

Table 5.2: Assumptions made in the study.

Component	Assumption
Product system	The same business routes and the operational profiles were valid for 30 years.
Diesel engines	Two diesel engines were not in operation for the whole life cycle. The assumption was made in line with the operational profile provided by the ship operator, where only 2 diesel engines were in operation for current business routes. Lubricating oil was changed for every 1500 operating hours, requiring 189.3 litres per engine.
Auxiliary generators	Manufacture of auxiliary generators was similar to that of diesel engines. For each generator, 94.6 litres of lubricating oil per 1500 operating hours was required.
Shaft generators	Shaft generators were in good condition for reuse after 30 years.
Gearboxes	The model was no longer produced and available information was limited due to organisational changes of the manufacturer. It was assumed that the casing, gears and shaft ends were respectively 20%, 70% and 10% of the total mass in line with [293] which reported that gear casings were made of cast iron or welded steel and the shaft ends were covered by an aluminium, split and non-contact seal.

Boilers	It was assumed that Wiesloch 25V0-13 boiler with a capacity of 1453 kW was similar to existing Aalborg marine boilers of the same type, i.e. Aalborg Mission TFO as Wiesloch was acquired by Aalborg (known as Alfa Laval Aalborg to date) in 1999 and marketed under the MISSION™ brand. The weight of a TFO-015 was 3170 kg with a capacity of 1700 kW [427]. The assumption was in agreement with GESAB-HTI thermal oil heaters [428] with a capacity of 1396 kW and a weight of 3800 kg.
Economisers	Materials and processes involved in manufacturing economisers were similar to those of boilers.
End of life management	The not-in-use components would be reused. With respects to the end of life of diesel engines and auxiliary generators, it was assumed that they were dissembled where components in a satisfactory condition were refurbished for remanufactured engines and generators, and the remaining materials were recycled or disposed to incineration plants or landfill following a reuse-recycling-incineration-landfill ratio of 3:3:2:2. Scrap from other components would be recycled, disposed to incineration plants or landfill, 33.3% each. Input and output data presented in the Ecoinvent dataset named 'blast furnace gas, burned in power plant' and [411] were adjusted and used for copper recovery in this study. By assuming that input/output data used for zinc recycling was 40% of those for primary production, data used in this study were adjusted from [411, 412] and Ecoinvent dataset named 'smelting, primary zinc production'. An existing Ecoinvent dataset named 'tin, at regional storage' presented data involved in the processes of mining and beneficiating tin ore as well as smelting and refining tin. As recycling tin alloy scrap involves smelting and refining only, it was assumed that LCI for tin recycling process was 10% of the data presented in this dataset. Input and output data used for lead recovery were adjusted from the data presented by [411, 412, 415] and the Ecoinvent dataset named 'blast furnace gas, burned in power plant'. Data from literature and Ecoinvent dataset named 'ferronickel, 25% Ni, at plant' were adjusted for nickel recovery process.

A gate-to-grave life cycle was considered for each component, from the acquisition of energy and raw materials to manufacture, operation, maintenance (if relevant) and the end of life (i.e. dismantling, recycling and disposal). Engineering design and approval, as included in Figure 4.12 due to its important role for innovative development and ship building, was perceived to have minimal environmental burdens and therefore was not assessed. Installation and testing at shipyard was excluded because no information was available and the environmental impact was perceived as trivial too when compared to that of the operation phase. For the same reasons, auxiliaries such as switchboards, cables, piping and fuel oil systems were also excluded. For individual technologies and components, numerous manufacturers, models and manufacturing plants had been available worldwide. Due to time and resource constraints, the locations of manufacturing plants and recycling sites were not taken into account. Transportation was not considered with the exception of non-metallic scrap management where existing Ecoinvent datasets were directly applied. Material loss during manufacture was also beyond the scope. As average data for conventional technologies were used as background data, neither technology change in future nor spatial and temporal differentiation was addressed. Although relevant, impact categories such as thermal pollution and noise disturbance to marine biodiversity were not assessed as they had not been incorporated into the software. Altogether, these exclusions formed the limitations of the study.

Value choice was involved not only in selecting the ship type (which was based on data availability, technical consideration and expert judgement from the consortium) but also in determining the characterisation models applied in the study. LCIA was carried out using the midpoint-oriented methodologies i.e. CML2001 and ILCD, and the endpoint-oriented Eco-Indicator99 methodology. The choice was made in line with [281] which pointed out that both midpoint and endpoint approaches should be consistently presented in series or parallel. Using LCA models, LCIA was performed in which the LCI results were characterised into a range of impact categories. These impact categories were grouped in line with LCIA methodologies, ranked in terms of their magnitude from the highest to the lowest, and for brevity and consistency, and are labelled as I–XXVI as in the following in all relevant figures illustrated in this chapter:

- I CML2001: *Marine Aquatic Ecotoxicity Potential*, kg 1,4- dichlorobutane ($C_4H_8Cl_2$) equivalent
- II CML2001: *Global Warming Potential*, kg CO_2 equivalent
- III CML2001: *Global Warming Potential, excluding Biogenic Carbon*, kg CO_2 equivalent
- IV CML2001: *Freshwater Aquatic Ecotoxicity Potential*, kg $C_4H_8Cl_2$ equivalent
- V CML2001: *Human Toxicity Potential*, kg $C_4H_8Cl_2$ equivalent
- VI CML2001: *Acidification Potential*, kg SO_2 equivalent

VII CML2001: *Eutrophication Potential*, kg phosphate equivalent

VIII CML2001: *Abiotic Depletion of Fossil*, MJ

IX CML2001: *Photochemical Ozone Creation Potential*, kg ethene equivalent

X CML2001: *Terrestric Ecotoxicity Potential*, kg $C_4H_8Cl_2$ equivalent

XI ILCD: *Ecotoxicity for Aquatic Freshwater, USEtox (recommended)*, Comparative Toxic Unit for ecosystems (CTUe)

XII ILCD: *IPCC Global Warming, including Biogenic Carbon*, kg CO_2 equivalent, where IPCC was the acronym for Intergovernmental Panel on Climate Change

XIII ILCD: *IPCC Global Warming, excluding Biogenic Carbon*, kg CO_2 equivalent

XIV ILCD: *Terrestrial Eutrophication, Accumulated Exceedance*, mole of nitrogen equivalent

XV ILCD: *Acidification, Accumulated Exceedance*, mole of hydrogen ion equivalent

XVI ILCD: *Photochemical Ozone Formation, LOTOS-EUROS Model, ReCiPe*, kg non-methane volatile organic compound (NMVOC)

XVII ILCD: *Total Freshwater Consumption, Including Rainwater, Swiss Ecoscarcity*, kg

XVIII ILCD: *PM/Respiratory Inorganics, RiskPoll*, kg $PM_{2,5}$ equivalent

XIX ILCD: *Marine Eutrophication*, *EUTREND model, ReCiPe*, kg nitrogen equivalent

XX ILCD: *Resource Depletion, Fossil and Mineral, Reserve based*, CML2002, kg antimony equivalent

XXI Eco-Indicator99: *Ecosystem Quality–Acidification/Nitrification*, PDF*m^2*a (where PDF was the shortened form of Potentially Disappeared Fraction)

XXII Eco-Indicator99: *Ecosystem Quality–Ecotoxicity*, PDF*m^2*a

XXIII Eco-Indicator99: *Resources–Minerals*, MJ surplus energy

XXIV Eco-Indicator99: *Resources–Fossil Fuels*, MJ surplus energy

XXV Eco-Indicator99: *Ecosystem Quality–Land-Use*, PDF*m^2*a

XXVI Eco-Indicator99: *Human Health–Respiratory (Inorganic)*, DALY

Impact categories were analysed based on their magnitude. In addition to indicating the environmental impact of the product system under study, these indicator results could be used for comparison and/or validation in future research. In performing life cycle interpretation, significant issues, such as components and processes which resulted in noticeable environmental burdens, were identified. The results were checked for completeness and consistency with the defined goal and scope. Sensitivity analysis was performed via scenario analysis to investigate the influence of some parameters, including mass, material proportion, alternative component, fuel type and quantity, and end of life management plan on the indicator results. For this purpose, additional scenarios were modelled as described in **Chapter 5.2.6**.

5.2.4 *LCI results: resource consumption and emissions*

Manufacture of the components employed in the power system consumed a range of materials, as illustrated in Figure 5.3. In descending order, cast iron, steel, copper and aluminium were the top four most consumed materials, accounting for 2.85×10^5, 1.77×10^5, 4.71×10^4 and 1.49×10^4 kg respectively. The processes used up 5.76×10^5 MJ of heat provided by natural gas boilers, 2.29×10^5 MJ and 2.52×10^3 MJ of energy released by furnaces which burned light and heavy fuel oils respectively, in addition to 1.40×10^5 MJ of energy from electricity. Such energy consumption was mainly due to diesel engines, propellers and shafts, and auxiliary generators, which were held culpable for 40.7–56.7%, 15.5–21.6% and 10.3–13.1% respectively.

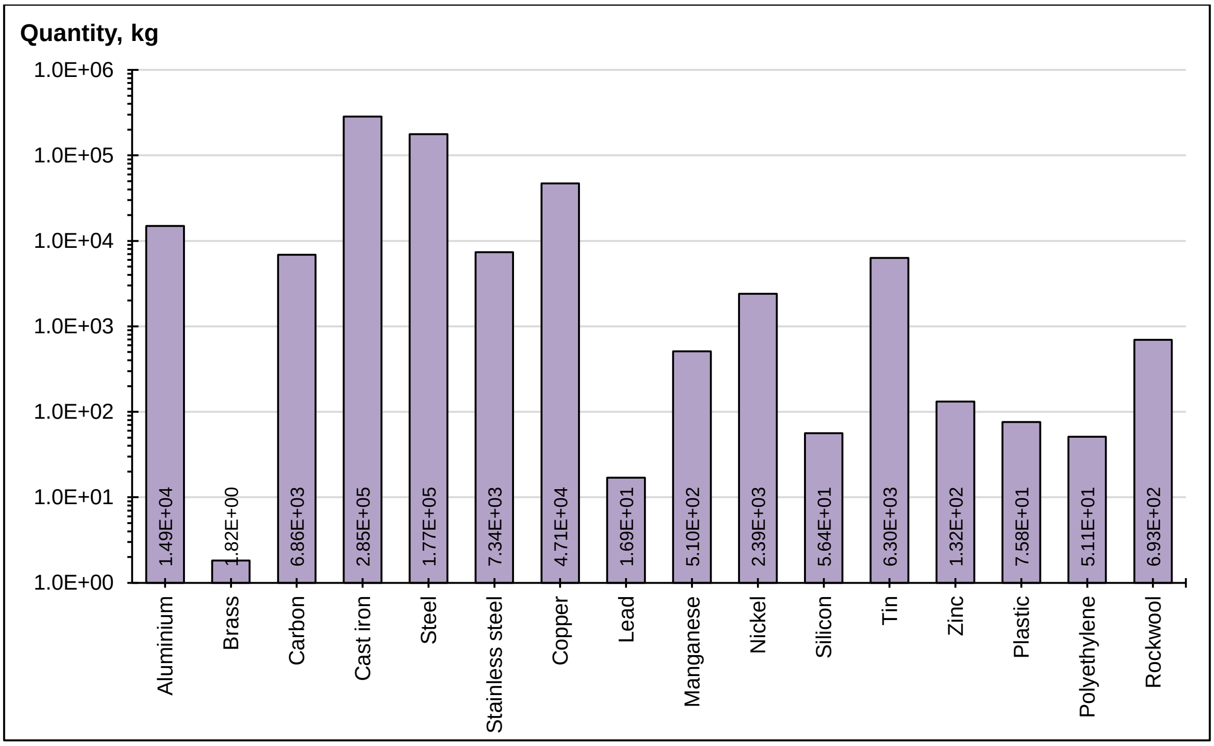
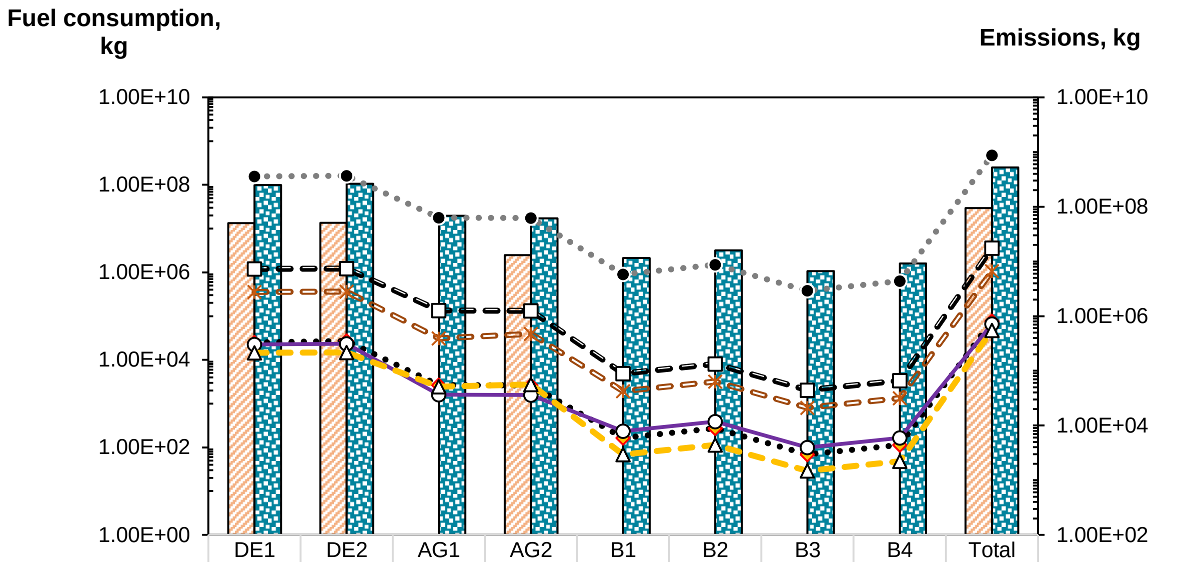


Figure 5.3: Materials consumed in manufacturing the components incorporated into the conventional power system, in kg.

Based on the real-time operational profile and simulation results, it was estimated that 2.93x10^7 kg of HFO and 2.50x10^8 kg of MDO would be burned by diesel engines, generators and boilers over 30 years in service, as illustrated in Figure 5.4. Consequently, 8.75x10^8 kg of CO_2, 1.75x10^7 kg of NO_x, 6.01x10^6 kg of SO_2, 8.13x10^5 kg of CO, 7.17x10^5 kg of HC and 5.49x10^5 kg of PM were released. Because of longer hours in operation, diesel engines were the main consumer of fuel, leading to their standing as the major source of emissions, each accounted for 38–47% of the total consumption and emissions. During regular maintenance, lubricating oil contained in diesel engines, auxiliary generators and boilers would be replaced, which amounted to 4.43x10^4 kg in total. Resources involved in treating and recovering used oil included 120–160 kg of light fuel oil, liquefied petroleum and diesel respectively, which required energy supplied by electricity and natural gas, i.e. 3.08x10^6 MJ and 2.74x10^5 MJ respectively.



	DE1	DE2	AG1	AG2	B1	B2	B3	B4	Total
HFO	1.3E+07	1.3E+07	0.0E+00	2.5E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.9E+07
MDO	9.9E+07	1.1E+08	2.0E+07	1.7E+07	2.1E+06	3.2E+06	1.1E+06	1.6E+06	2.5E+08
CO	3.3E+05	3.5E+05	5.5E+04	5.4E+04	5.9E+03	8.9E+03	3.0E+03	4.4E+03	8.1E+05
CO2	3.6E+08	3.7E+08	6.3E+07	6.2E+07	5.8E+06	8.7E+06	2.9E+06	4.4E+06	8.7E+08
HC	3.0E+05	3.1E+05	3.6E+04	3.6E+04	7.9E+03	1.2E+04	3.9E+03	5.9E+03	7.2E+05
NOx	7.3E+06	7.4E+06	1.3E+06	1.3E+06	8.9E+04	1.3E+05	4.4E+04	6.6E+04	1.8E+07
SO2	2.8E+06	2.8E+06	3.9E+05	4.7E+05	4.2E+04	6.4E+04	2.1E+04	3.2E+04	6.6E+06
PM	2.1E+05	2.2E+05	5.1E+04	5.6E+04	3.0E+03	4.4E+03	1.5E+03	2.2E+03	5.5E+05

Figure 5.4: Fuel consumption and emissions released, both in kg, during the operation of the marine power system for individual components including diesel engines (DE1–DE4), auxiliary generators (AG1 and AG2) and boilers (B1–B4) over 30 years.

When the system became obsolete, it would be dismantled. As illustrated in Figure 5.5, electricity and coal were resources most commonly consumed during dismantling, which accounted for 5 orders of magnitude each, if compared to natural gas and light fuel. For individual components, parts which were in good condition would be sold for reuse; metallic scrap would be recycled or disposed to incineration plants or landfill. 4.19×10^3 kg of coal anthracite, 5.5×10^2 kg of coke and 3.23×10^2 kg of crude oil were consumed in recycling and disposing metallic scrap, along with energy from various sources where blast furnace gas, natural gas and electricity were most highly demanded, ranging between 7.76×10^4 and 1.41×10^5 MJ.

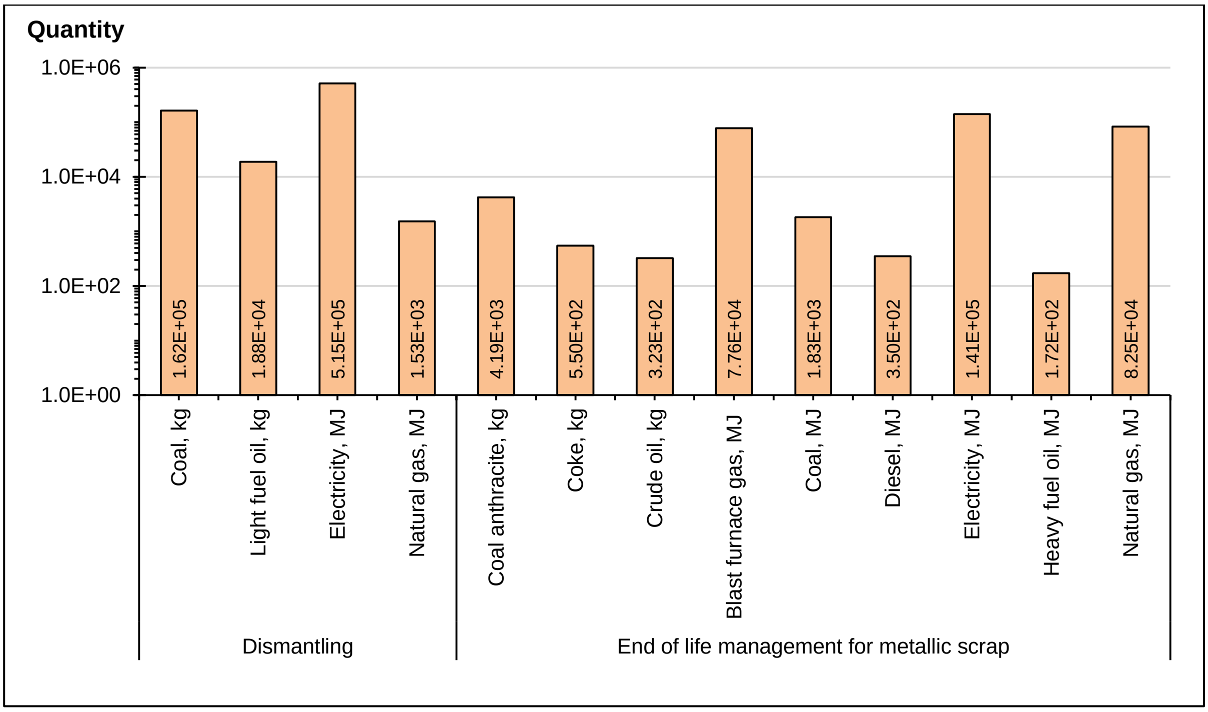


Figure 5.5: Resource and energy consumption during dismantling and the end of life of the conventional system.

Using LCA models created in GaBi, emissions released throughout the life cycle into the air and freshwater were characterised as inorganic, organic, long-term, heavy metals and particles. The analysis showed that 9.01×10^8 kg of inorganic emissions to air, 2.35×10^5 kg of inorganic emissions to freshwater, 7.29×10^5 kg of organic emissions to air i.e. volatile organic compounds (VOC), 5.16×10^5 kg of particles to air and 1.56×10^5 kg of long-term emissions to freshwater were emitted. Heavy metals released to air and freshwater were 9.94×10^3 kg and 6.21×10^2 kg respectively. As illustrated in Figure 5.6, diesel engines were the prime source of emissions in which they contributed (i) 83.2–91.0 % of inorganic to air, organic and particles to air and freshwater; and (ii) 46.9–49.4 % of heavy metals to air and freshwater, inorganic and long-term emissions to freshwater. Whilst emissions released by auxiliary generators were more consistent i.e. 8.4–14.3 % for each emission type, propellers and shafts were accountable for approximately 30% of heavy metals to air and freshwater, inorganic and long-term emissions to freshwater.

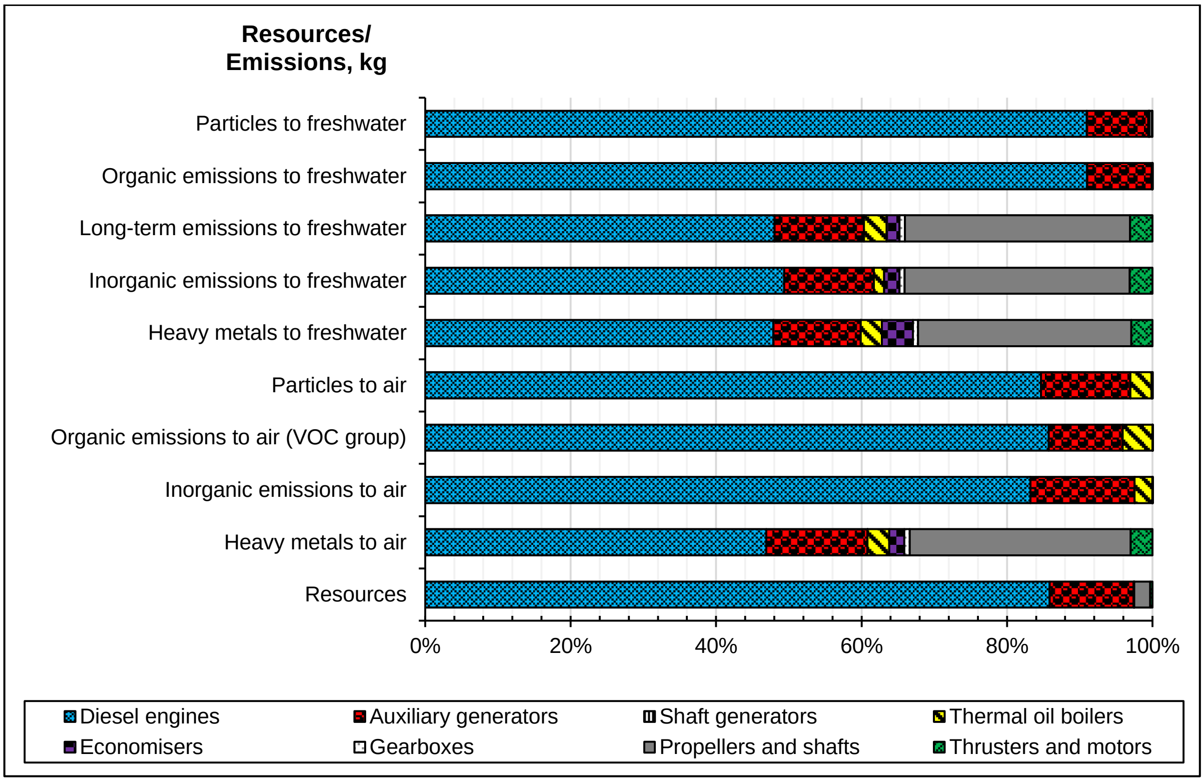


Figure 5.6: Emissions released from the conventional power system from acquisition of raw materials and energy to end of life management as per individual technologies, which were estimated via LCA models developed in GaBi for base case scenario.

5.2.5 *LCIA results*

LCIA results for impact categories assessed using CML2001, ILCD and Eco-Indicator99 for base case scenario and the contribution of individual technologies towards the total results are illustrated in Figures 5.7 and 5.8 respectively.

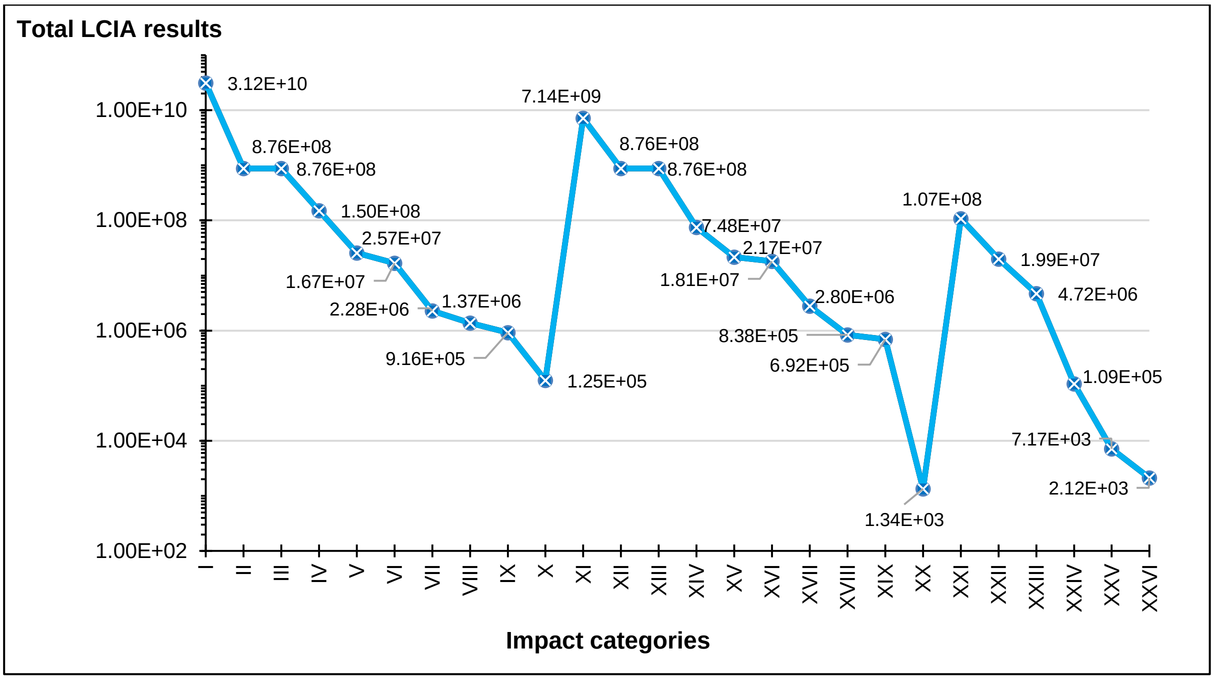


Figure 5.7: Total environmental burdens attributable to the conventional power system, characterised as per impact categories.

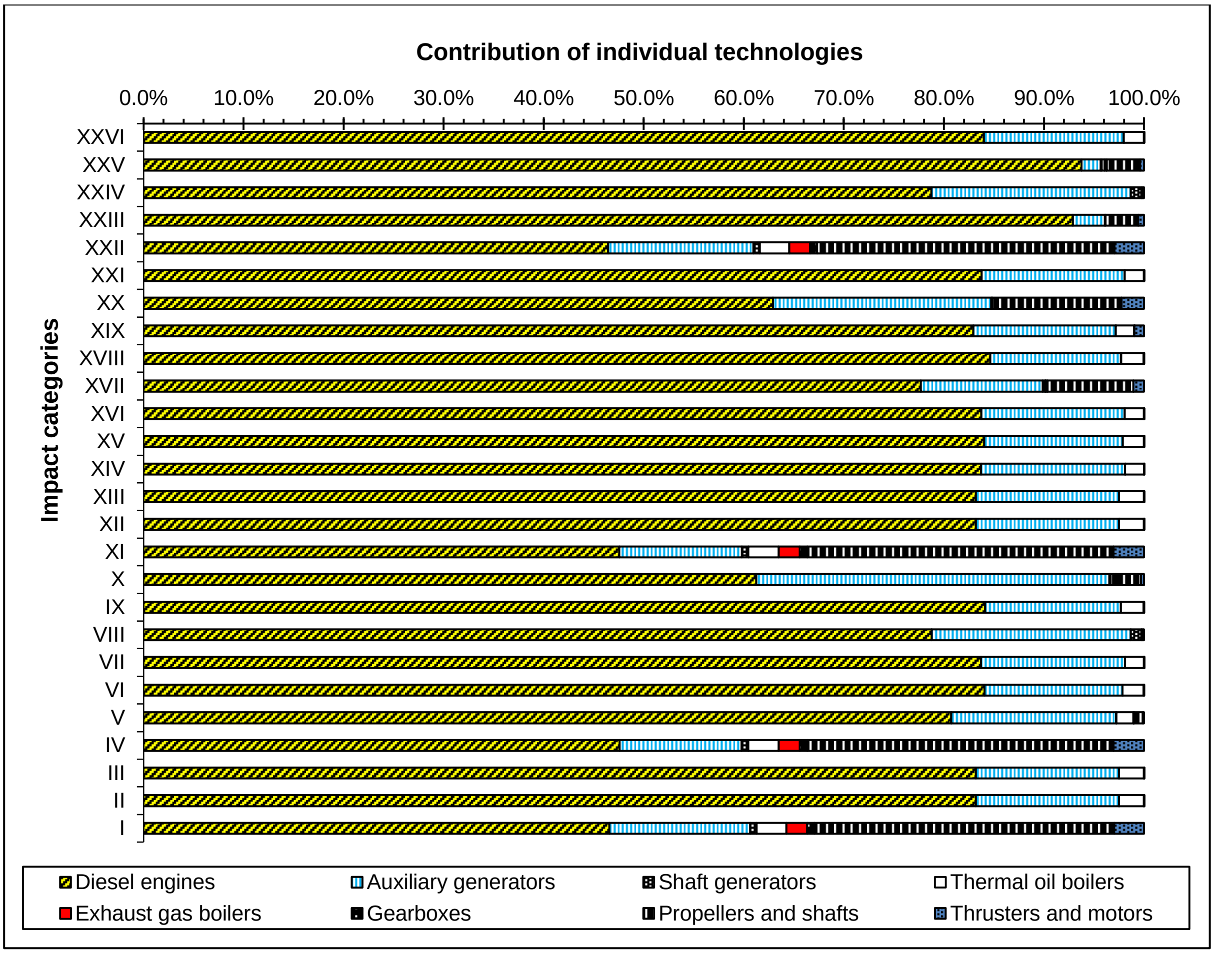


Figure 5.8: Contribution of individual components towards individual impact categories.

For CML2001, *Marine Aquatic Ecotoxicity Potential* and *Global Warming Potential* showed at least 8 orders of magnitude i.e. 3.12×10^{10} kg $C_4H_8Cl_2$ equivalent and 8.76×10^{8} kg CO_2 equivalent respectively (labelled as I and II). Other impact categories such as *Freshwater Aquatic Ecotoxicity Potential*, *Human Toxicity Potential*, *Acidification Potential*, *Eutrophication Potential*, *Abiotic Depletion of Fossil* (labelled as III–VIII respectively) ranged between 6 and 8 orders of magnitude. Significant processes for impact categories assessed based on CML2001 are summarised in Table 5.3. The analysis showed that:

(i) diesel engines resulted in 46.6% of *Marine Aquatic Ecotoxicity Potential* and 83.2% of *Global Warming Potential*, mainly due to disposing metallic scrap to incineration plants at the end of life and operating the engines over 30 years respectively;

(ii) in addition, diesel engines were the largest contributor of all impact categories assessed by CML2001 which resulted in more than 77.7% for 7 impact categories and 46–62% for the remaining, where operation and disposal of metallic scrap were found significant;

(iii) the contribution of auxiliary generators towards all impact categories was consistently within the range of 12.2–21.8%, with the exception of *Terrestric Ecotoxicity Potential* (35.3%, in which the use of cast iron during manufacture was the main cause);

(iv) propellers and shafts resulted in approximately 30% of *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, mainly because of disposing metallic scrap of propellers and shafts to incineration plants; and

(v) other impact categories caused by propellers and shafts during resource acquisition and consumption, storage and dismantling were negligible compared to the impact caused by diesel engines and auxiliary generators.

Table 5.3: The main cause(s) of individual impact categories attributable to diesel engines, auxiliary generators, propellers and shafts respectively, as assessed by CML2001. The causes were classified as A: Operation; B: Disposal of metallic scrap to incineration plants; C: Disposal of metallic scrap to landfill; and D: Others (specified).

Impact categories	Diesel engines	Auxiliary generators	Propellers and shafts
I	B	B	B
II and III	A	A	D (copper recycling) *
IV	B	B	B
V	A	A	B, C, D (nickel consumption) *
VI	A	A	D (nickel consumption) *
VII	A	A	D (dismantling)
VIII	D (crude oil acquisition)	D (crude oil acquisition)	–
IX	A	A	D (nickel consumption) *
X	D (chromium consumption)	D (cast iron consumption)	C

* less than 3% of the total LCIA results for the product system

When ILCD was applied, *Ecotoxicity for Aquatic Freshwater* showed the highest magnitude, i.e. 7.14×10^9 CTUe, followed by *IPCC Global Warming* i.e. 8.76×10^8 kg CO_2 equivalent. The indicator results of *Terrestrial Eutrophication, Acidification* and *Photochemical Ozone Formation* were of 7 orders of magnitude. Other impact categories such as *Total Freshwater Consumption, PM/Respiratory Inorganics* and *Marine Eutrophication* were of lower magnitude by 1–2 orders. The impact was mainly caused by diesel engines, auxiliary generators, propellers and shafts. Significant processes that contributed to individual impact categories are summarised in Table 5.4. It was worth noting that

(i) ILCD did not assess marine aquatic ecotoxicity potential.

(ii) ILCD and CML2001 had adopted different terminologies and modelling approaches for *Ecotoxicity for Aquatic Freshwater* (labelled as XI and IV respectively), and therefore both estimates were not of the same order of magnitude in which ILCD showed a higher magnitude than CML2001 by one order.

(iii) different trends were shown by ILCD and CML2001 in *Ecotoxicity for Aquatic Freshwater* and *IPCC Global Warming* (labelled as XI–XIII and II–IV respectively). Unlike CML2001, *Ecotoxicity for Aquatic Freshwater* was recognised by ILCD as a heavier burden than *IPCC Global Warming*; nevertheless, the contribution of individual components towards these impact categories assessed by both ILCD and CML2001 were similar among one another, as shown in Figure 5.8.

(iv) dissimilar mathematic relations and environmental mechanisms were also adopted by ILCD and CML2001 for *Acidification* and *Photochemical Ozone Formation Potential* (labelled as XV, XVI, VI and IX respectively), leading to different measures but of the same order of magnitude.

(v) again, the influence of diesel engines was far-reaching which contributed to 47.6% and 84.0% of all impact categories assessed by ILCD, because of metallic scrap disposal to incineration plants and the operation phase.

(vi) auxiliary generators contributed 12.2–14.4% to all impact categories with the exception of *Resource Depletion, Fossil and Mineral* (labelled as XX), which accounted for 21.8%. Operation was the main cause for most impact categories caused by auxiliary generators.

(vii) propellers and shafts only contributed to three impact categories, namely *Ecotoxicity for Aquatic Freshwater*, *Total Freshwater Consumption* and *Resource Depletion, Fossil and Mineral* (labelled as XI, XVII and XX), i.e. 30.6%, 8.6% and 12.9%. The main causes were metallic scrap disposal to incineration plants, water consumption and copper acquisition respectively.

Table 5.4: The main cause(s) of individual impact categories attributable to diesel engines, auxiliary generators, propellers and shafts respectively, as assessed by ILCD. The causes were classified as A: Operation; B: Disposal of metallic scrap to incineration plants; C: Disposal of metallic scrap to landfill; and D: Others (specified).

Impact categories	Diesel engines	Auxiliary generators	Propellers and shafts
XI	B	B	B
XII - XIII	A	A	D (steel and copper recycling, blast furnace gas, natural gas, light and heavy fuels and charcoal) *
XIV	A	A	D (dismantling) *
XV	A	A	D (nickel consumption) *
XVI	A	A	D (nickel consumption) *
XVII	D (tap water)	D (oil refinery)	D (tap water)
XVIII	A	A	D (nickel consumption and steel recycling) *
XIX	A	A	D (nickel consumption) *
XX	D (tin acquisition)	D (copper acquisition)	D (copper acquisition)

* less than 3% of the total LCIA results for the product system

Looking at the impact categories assessed by Eco-Inidcator99, 1.07x10^8 PDF*m^2*a of *Ecosystem Quality─Acidification/Nitrification* and 1.99x10^7 PDF*m^2*a of *Ecosystem Quality─Ecotoxicity* (labelled as XXI–XXII) were reported. This was followed by impact categories relevant to resource consumption, i.e. *Resources─Minerals* and *Resources─Fossil Fuels*, which accounted for 4.72x10^6 and 1.09x10^5 MJ surplus energy. Similar to the impact categories assessed by CML2001 and ILCD, significant processes that resulted in the impact categories assessed by Eco-Indicator99 were identified, as summarised in Table 5.5. The analysis showed that

(i) Eco-Inidcator99 did not differentiate terrestrial, freshwater and marine aquatic ecotoxicity potential but merely assessed such potential in an all-in-one impact category, namely *Ecosystem Quality─Ecotoxicity* (labelled as XXII).

(ii) diesel engines appeared, again, as the primary contributor which accounted for 46.4–93.8% of impact categories assessed by Eco-Indicator99. However, different significant processes were identified. The impact categories were in a relationship with operation, disposal of metallic scrap to incineration plants, acquisition of tin and crude oil, and storage respectively.

(iii) contribution of auxiliary generators towards impact categories assessed by Eco-Indicator99 ranged between 14.0% and 19.9%, with the exception of *Resources─Minerals* and *Ecosystem Quality─Land-Use* (labelled as XXIII and XXV respectively), which was also caused by operation, disposal of metallic scrap to incineration plants and the acquisition of copper and crude oil.

(iv) propellers and shafts resulted in 29.7% of *Ecosystem Quality─Ecotoxicity* (labelled as XXII), mainly because of disposing metallic scrap to incineration plants. A negligible or not at all contribution was made by propellers and shafts towards other impact categories assessed by Eco-Inidcator99.

Table 5.5: The main cause(s) of individual impact categories attributable to diesel engines, auxiliary generators, propellers and shafts respectively, as assessed by Eco-Inidcator99. The causes were classified as A: Operation; B: Disposal of metallic scrap to incineration plants; C: Disposal of metallic scrap to landfill; and D: Others (specified).

Impact categories	Diesel engines	Auxiliary generators	Propellers and shafts
XXI	A	A	D (nickel consumption) *
XXII	B	B	B
XXIII	D (tin acquisition)	D (copper acquisition)	D (copper, nickel and tin consumption)
XXIV	D (crude oil acquisition)	D (crude oil acquisition)	-
XXV	D (storage)	D (storage) *	D (storage and landfill facility)
XXVI	A	A	-

* less than 3% of the total LCIA results for the product system

When all LCIA results were taken into consideration, the findings of significant components and processes were consistent, as illustrated in Figure 5.8 and summarised in Tables 5.3–5.5:

i For all impact categories, at least 90.62% of the environmental burdens were attributable to diesel engines, auxiliary generators, propellers and shafts, indicating that the contribution of shaft generators, gearboxes, boilers, economisers, bow thrusters and motors were relatively negligible;

ii Diesel engines were the largest contributor of all impact categories which resulted in more than 77.7% for 20 impact categories, where operation and disposal of metallic scrap were found significant;

iii The contribution of auxiliary generators towards all impact categories were consistently within the range of 12.2–21.8 % (either because of the operation or the disposal of metallic scrap to incineration plants), except for CML2001: *Terrestric Ecotoxicity Potential* (labelled as X, 35.3%, where the use of cast iron in manufacture was the main cause), Eco-Inidcator99: *Resources–Minerals* and Eco-Inidcator99: *Ecosystem Quality–Land-Use* (labelled as XXIII and XXV respectively,1.9–3.2 %, mainly due to the use of copper during manufacture and space used up for storage respectively);

iv Propellers and shafts resulted in approximately 30% of ecotoxicity potential i.e. CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Inidcator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, XI and XXII), with the exception of CML2001: *Terrestric Ecotoxicity Potential* (labelled as X). Disposing metallic scrap of propellers and shafts to incineration plants was the major contributor of the former impact categories;

v The indicator results of other impact categories caused by propellers and shafts due to resource acquisition and consumption, storage, dismantling, recycling and landfill, were negligible compared to those of diesel engines and auxiliary generators; and

vi Throughout the life cycle of a conventional marine power system, critical processes included the operation of diesel engines and auxiliary generators, and the end of life of diesel engines, auxiliary generators, propellers and shafts, in particular disposal of metallic scrap to incineration plants.

As LCA practitioners were subject to personal preference, value choice was involved in choosing LCIA methodologies, as previously reported in **Chapter 5.2.3**. Also, the LCI and LCIA results presented here were subject to assumptions and limitations (see **Chapter 5.2.3**). Varying any assumptions and overcoming any limitations were likely to increase the magnitude of LCI results (unless a shorter lifespan was defined or less scrap was handled) and exert an influence on the LCIA results. Considering the complex nature of marine power systems and the massive scope of the studies, the influence of these assumptions and limitations could be pronounced, moderate or minimal. However, no conclusive correlation could be suggested without in-depth investigation.

As noted in **Chapter 4.2.4**, no literature had defined risk threshold of each impact category to any AoPs i.e. human beings, resources and ecosystems. The effect of all impact categories on human beings, resources and ecosystems would be of varying significance degrees. It was unclear to what extent a particular impact category could be considered as harmless, moderate or fatal. Also, it was possible that the effect of any impact categories with smaller orders of magnitude to a particular area of protection would be more serious than other impact categories of any higher orders of magnitude. For instance, *Human Toxicity Potential* would affect human beings more if compared to natural resources and ecosystems whilst all types of ecotoxicity potential would affect ecosystems more. No conclusive remark could be made before the advance of existing knowledge and establishment of relevant risk threshold for individual impact categories. Nevertheless, the LCIA results estimated in this study enhanced current understanding on conventional marine power systems in terms of the estimated magnitude of their environmental impact and identification of significant components as well as processes.

5.2.6 *Life cycle interpretation*

As indicated in previous section, significant processes which resulted in most impact categories were operation and metallic scrap disposal. As LCA could only offer an estimate of potential environmental impact, as clearly indicated by ISO 14040, absolute accuracy was not possible in any LCA study. Any changes in the identified significant processes as well as other parameters might influence the estimated impact minimally, moderately or greatly, considering the range of technologies and the number of components integrated into the power system throughout the life cycle. Parameters such as mass, material proportion, alternative component, fuel type and quantity, and end of life management were worth investigating. The sensitivity of individual impact categories to these parameters was investigated via scenario analysis, in which each parameter was varied in additional scenarios one by one whilst others were kept unchanged. Parameters and additional scenarios under study included

1. mass of diesel engines (as the key component) i.e. 78000 kg in base case scenario, which was
   - (i) reduced by 10%;
   - (ii) reduced by 20%;
   - (iii) reduced by 30%;
   - (iv) increased by 10%;
   - (v) increased by 20%; and
   - (vi) increased by 30%;
2. material proportion of diesel engines, which was altered by substituting
   - (i) 10% of steel for 10% of cast iron (which was the most commonly consumed material);
   - (ii) 20% of steel for 20% of cast iron;
   - (iii) 10% of aluminium for 10% of cast iron;
   - (iv) 3% of chromium and 1% of tin for 2% chromium and tin, each;
3. fuel type, in which all-MDO was substituted for fuel mix applied in base case scenario;

4 fuel consumption if

   (i) 10% less fuel was burned by diesel engines;
   (ii) 20% less fuel was burned by diesel engines;
   (iii) 10% more fuel was burned by diesel engines;
   (iv) 20% more fuel was burned by diesel engines;
   (v) 10% less fuel was burned by auxiliary generators;
   (vi) 20% less fuel was burned by auxiliary generators;
   (vii) 10% more fuel was burned by auxiliary generators;
   (viii) 20% more fuel was burned by auxiliary generators;

5 alternative component, where CuNiAl propellers were replaced by stainless steel propellers;

6 end of life management plans for significant components i.e. diesel engines, where metallic scrap was

   (i) 50% recycled, 30% disposed to incineration plants and 20% sent to landfill;
   (ii) 50% recycled, 20% disposed to incineration plants and 30% sent to landfill;
   (iii) 100% recycled;
   (iv) 100% disposed to incineration plants;
   (v) 100% disposed to landfill; and

7 end of life management plans for all components, which were similar to 6 (i)–(v).

The LCIA results for each additional scenario were compared to those of base case scenario.

<u>Mass and material proportion of diesel engines (the largest contributor of all impact categories)</u>

As illustrated in Figure 5.9, impact categories relevant to ecotoxicity (including CML2001: *Marine Aquatic*, *Freshwater Aquatic* and *Terrestric Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality*─*Ecotoxicity*, labelled as I, IV, X, XI and XXII), resource consumption/depletion (including CML2001: *Abiotic Depletion of Fossil*, ILCD: *Resource Depletion, Fossil and Mineral*, Eco-Indicator99: *Resources*─*Minerals* and *Resources*─*Fossil Fuels*, labelled as VIII, XX and XXIII–XXIV) and land use (i.e. Eco-Indicator99: *Ecosystem Quality*─*Land-Use*, labelled as XXV) were sensitive to the variation in the mass of diesel engines. It was also found that every ±10% subsequent change in mass could accordingly alter these impact categories by ±2.3–4.8%. Changes in the LCIA results of other impact categories were not significant. Impact categories, which were relevant to global warming, acidification, eutrophication, photochemical ozone creation and human health were nearly not affected at all whilst human toxicity and freshwater consumption were affected minimally. Therefore, for diesel engines with the same power capacity, a lighter model would be more environmentally beneficial as its ecotoxicity potential was less burdensome in addition to less resource consumption and space occupation.

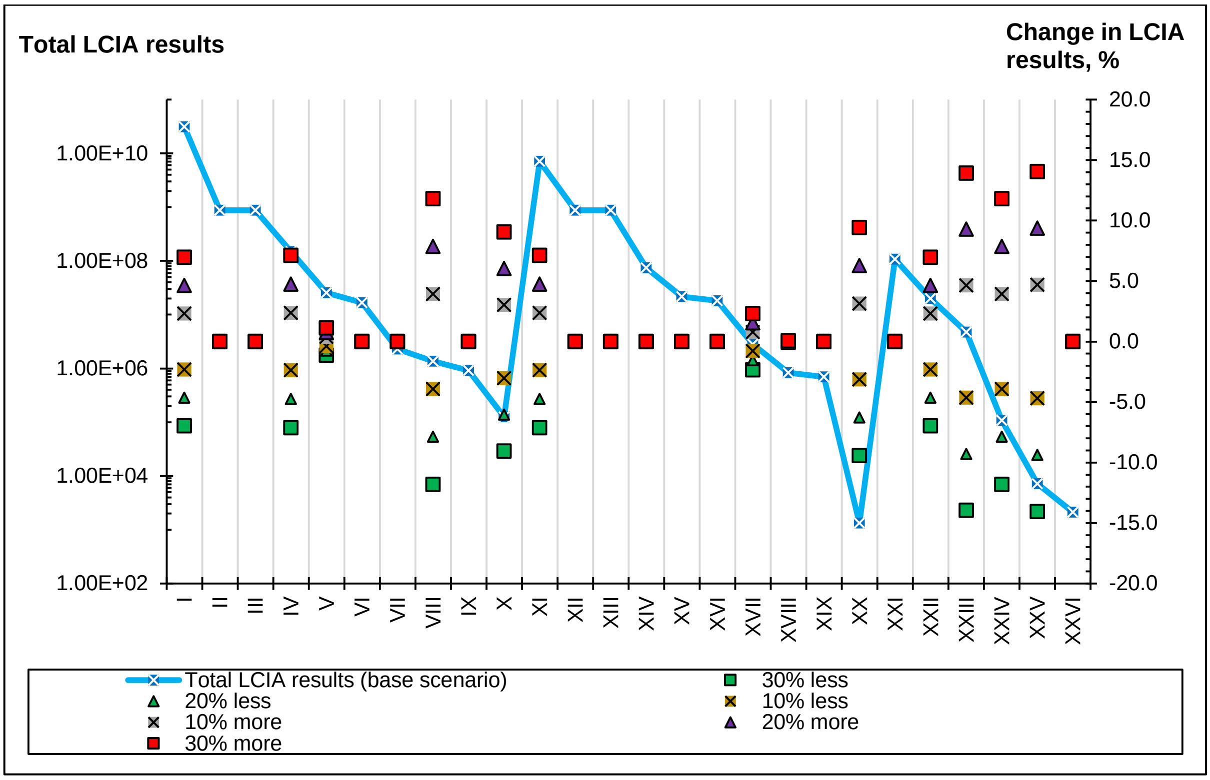


Figure 5.9: Difference in LCIA results due to the variation in the mass of diesel engines when compared to the base case.

In investigating the impact of materials on the overall environmental burdens of the product system, cast iron was reduced in different scenarios to allow for an extra quantity of 10% of steel, 20% of steel, or 10% of aluminium respectively (equivalent to 4 orders of magnitude). Compared to base case scenario, LCIA results for these scenarios declined by 0.6–1.2% in terrestric ecotoxicity potential and altered less than 0.3% for the remaining impact categories. In relation to chromium and tin consumption (which were the major cause of terrestric ecotoxicity and mineral consumption/depletion, i.e. CML2001: *Terrestric Ecotoxicity Potential*, ILCD: *Resource Depletion, Fossil and Mineral* and Eco-Indicator99: *Resources–Minerals*, labelled as X, XX and XXIII, and modelled as 2% each in base case scenario), the LCIA results did not change much for CML2001: *Terrestric Ecotoxicity Potential* but declined by 15.7% for ILCD: *Resource Depletion, Fossil and Mineral* and 23.2% for Eco-Indicator99: *Resources–Minerals*, following the 1% change in the quantity of tin and chromium being consumed (equivalent to 2 orders of magnitude). No noticeable change was observed for other impact categories. Thus, consuming extra chromium by 2 orders of magnitude would have a more distinct effect in impact categories relevant to resources than consuming 4 orders of magnitude of common materials such as cast iron, steel and aluminium.

Alternative component–stainless steel propellers

Alternatively, propellers made of 100% stainless steel could be employed, which consisted of 18–20% chromium, 8–10.5% nickel, 1% silicon, 0.03% sulphur, 0.045% phosphorous and the remaining was iron [429]. The estimated mass was 12450 kg. In base case scenario, diesel engines contributed more environmental burdens than propellers, as illustrated in Figure 5.10. The situation was reversed for some impact categories when stainless steel propellers were substituted for CuNiAl propellers.

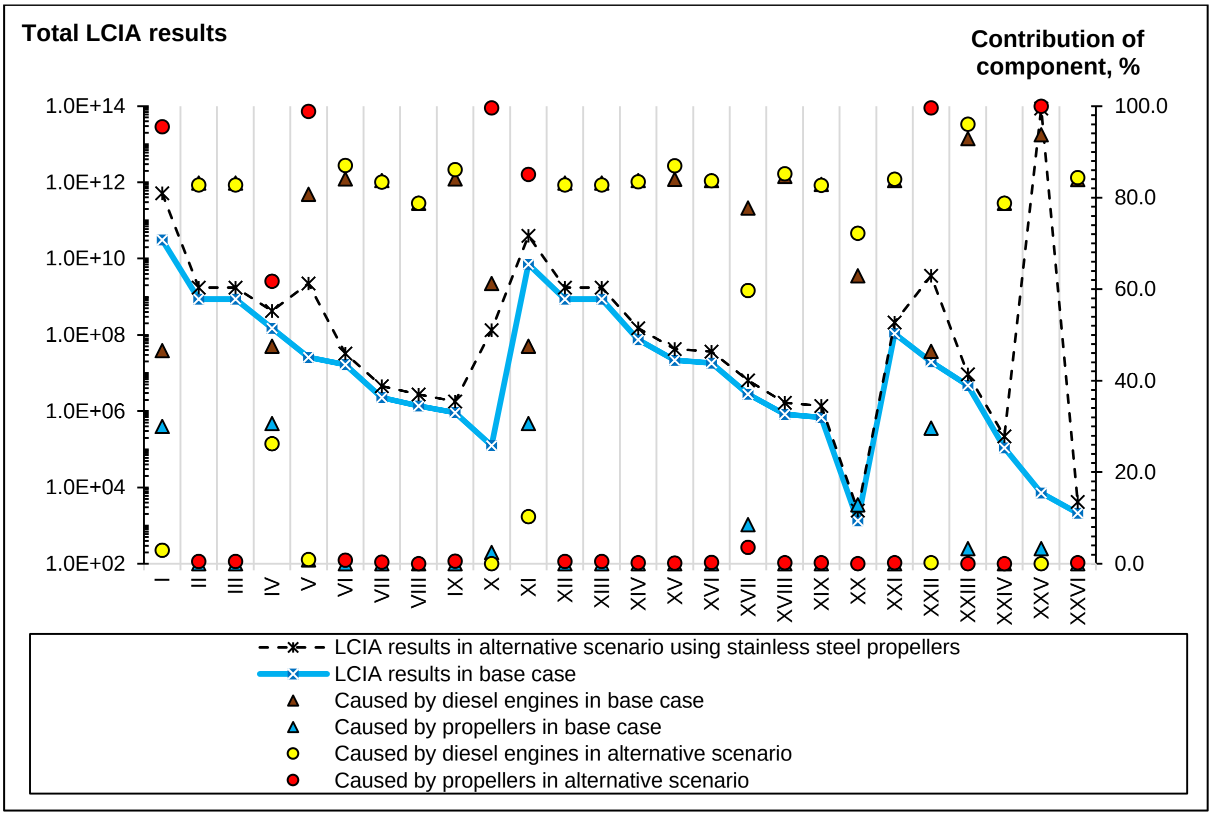


Figure 5.10: Difference in LCIA results compared to the base case scenario when stainless steel propellers were substituted for CuNiAl propellers.

It was found that CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity*, and *Human Toxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater,* Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* and *Ecosystem Quality–Land-Use* (labelled as I, IV, V, X, X I, XXII, and XXV) would show an increase ranging between 8 and 13 orders of magnitude. Such immense increases were mainly dominated by the end of life phase of stainless steel propellers, in particular disposing metallic scrap to landfill. Changes in other impact categories were very minimum. Still, CuNiAl propellers were a better choice than stainless steel propellers from an environmental perspective. Compared to base case scenario, a reduction of up to 31% could be achieved if metallic scrap of stainless steel propellers was 100% recycled (although not happening in current practice). The more metallic scrap was recycled, the more environmental friendly the product system would be. The impact of other end of life options i.e. 100% incineration, 50% recycling, 30% incineration and 20% landfill and 50% recycling, 20% incineration and 30% landfill, was more moderate than the base case scenario. Nevertheless, sending metallic scrap of stainless steel propellers to landfill was not ideal as its burdens on the environment, particularly ecotoxicity potential, could be significant.

Fuel type

In the scenario of substituting all-MDO for fuel mix (as modelled in base case scenario), 8.64×10^8 kg of CO_2, 1.73×10^7 kg of NO_x, 4.83×10^6 kg of SO_2, 8.09×10^5 kg of CO, 7.09×10^5 kg of HC and 5.15×10^5 kg of PM would be released from burning 2.78×10^8 kg of MDO over 30 years in service. The additional quantity of MDO i.e. approximately 11% was consumed to the benefits of HFO elimination and emission reduction, in particular an up to 20% decline in SO_2. Because of the elimination of HFO, some impact categories including CML2001: *Acidification Potential*, CML2001: *Photochemical Ozone Creation Potential*, ILCD: *Acidification,* ILCD: *Total Freshwater Consumption* and ILCD: *PM/Respiratory Inorganics* (labelled as VI, IX, XV, XVII and XVIII) as illustrated in Figure 5.11, would be scaled down by 5–12%. Other impact categories showed an insignificant sign of abating, i.e. mostly less than 2%. The findings justified the recommendation of MARPOL to adopt clean fuels as one of the strategies for emission reduction.

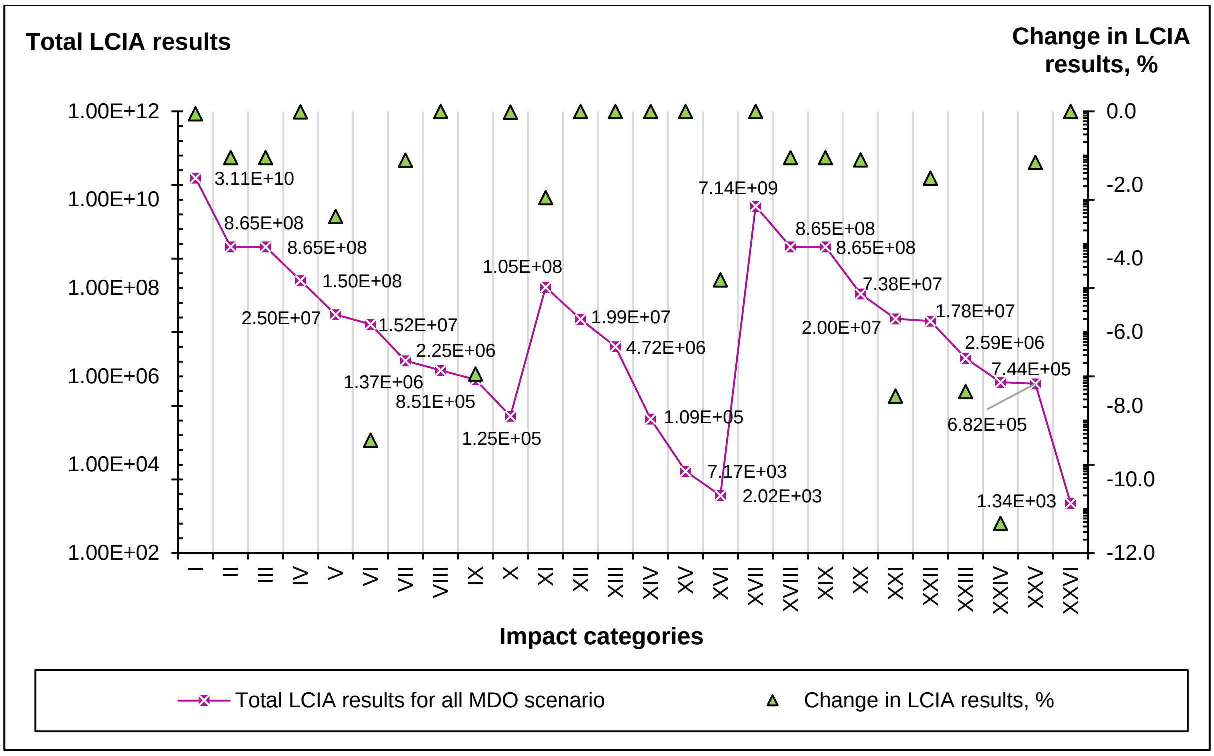
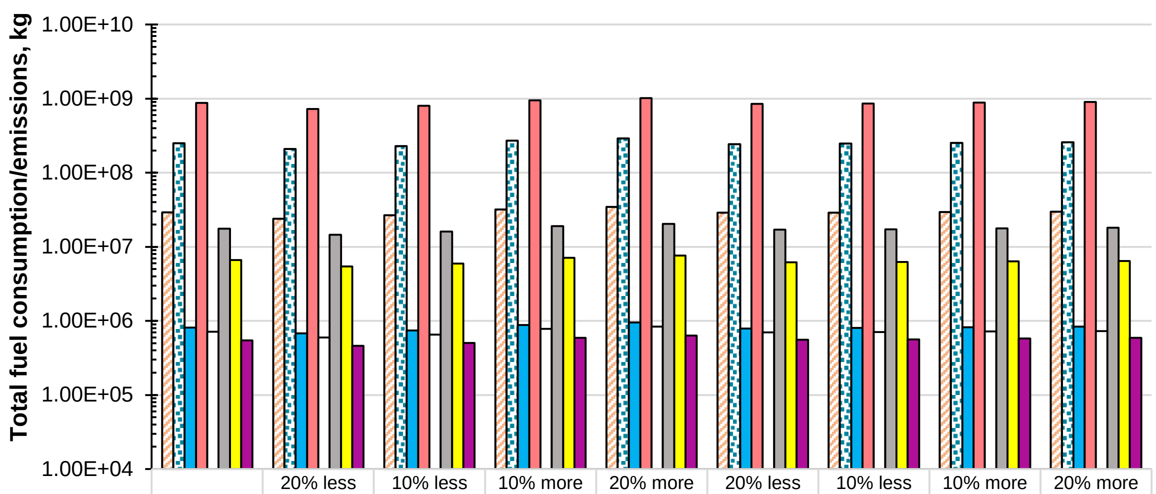


Figure 5.11: Difference in LCIA results compared to the base case scenario when all-MDO was substituted for fuel mix.

Fuel quantity

In real-time operation, diesel engines and auxiliary generators might be run without strictly following the optimal profile (as modelled in the base case scenario) because of weather conditions, unexpected demand variation and unstructured business routines. These additional scenarios would be insightful and valuable to marine stakeholders. In these scenarios, it was assumed that an x% of change in fuel quantity consumed by individual components would result in the same percentage of variation in their emissions. Due to changes in the fuel quantity consumed by diesel engines and auxiliary generators, the quantity of emissions released by the system differed accordingly, as illustrated in Figure 5.12. The more fuel consumed, the more emissions were released.



	Total in base case	20% less fuel burned by diesel engines	10% less fuel burned by diesel engines	10% more fuel burned by diesel engines	20% more fuel burned by diesel engines	20% less fuel burned by generators	10% less fuel burned by generators	10% more fuel burned by generators	20% more fuel burned by generators
HFO	2.93E+07	2.39E+07	2.66E+07	3.20E+07	3.47E+07	2.88E+07	2.90E+07	2.95E+07	2.98E+07
MDO	2.50E+08	2.09E+08	2.30E+08	2.71E+08	2.92E+08	2.43E+08	2.47E+08	2.54E+08	2.58E+08
CO	8.13E+05	6.77E+05	7.45E+05	8.81E+05	9.49E+05	7.91E+05	8.02E+05	8.24E+05	8.35E+05
CO2	8.75E+08	7.29E+08	8.02E+08	9.48E+08	1.02E+09	8.50E+08	8.62E+08	8.87E+08	9.00E+08
HC	7.17E+05	5.94E+05	6.56E+05	7.79E+05	8.41E+05	7.03E+05	7.10E+05	7.25E+05	7.32E+05
NOx	1.75E+07	1.46E+07	1.61E+07	1.90E+07	2.05E+07	1.70E+07	1.73E+07	1.78E+07	1.81E+07
SO2	6.60E+06	5.42E+06	5.97E+06	7.09E+06	7.65E+06	6.20E+06	6.25E+06	6.37E+06	6.42E+06
PM	5.49E+05	4.63E+05	5.06E+05	5.92E+05	6.35E+05	5.56E+05	5.64E+05	5.81E+05	5.89E+05

HFO MDO CO CO2 HC NOx SO2 PM

Figure 5.12: Total fuel consumption and emissions of the power system in Case Study 1 after taking into account changes in fuel consumption quantity by diesel engines and auxiliary generators separately.

In addition, changes in the quantity of fuel consumption would influence the LCIA results of CML2001: *Global Warming (including* and *excluding Biogenic Carbon*), *Human Toxicity*, *Acidification*, *Eutrophication*, *Abiotic Depletion of Fossil* and *Photochemical Ozone Creation Potential* (labelled as II–III, V–VIII and IX), ILCD: *IPCC Global Warming (including* and *excluding Biogenic Carbon)*, *Terrestrial Eutrophication, Acidification, Photochemical Ozone Formation, Total Freshwater Consumption, PM/Respiratory Inorganics*, *Marine Eutrophication* and *Resource Depletion, Fossil and Mineral* (labelled as XII–XX), and Eco-Indicator99: *Ecosystem Quality—Acidification/Nitrification*, *Resources—Fossil Fuels* and *Human Health—Respiratory (Inorganic)* (labelled as XXI, XXIV and XXVI), as illustrated in Figure 5.13. For every 10% of difference in fuel quantity consumed by diesel engines and auxiliary generators, the results for these impact categories in additional scenarios would vary by 3.9–8.5% and 0.3–1.4% respectively, in which the former was about 6 times the latter.

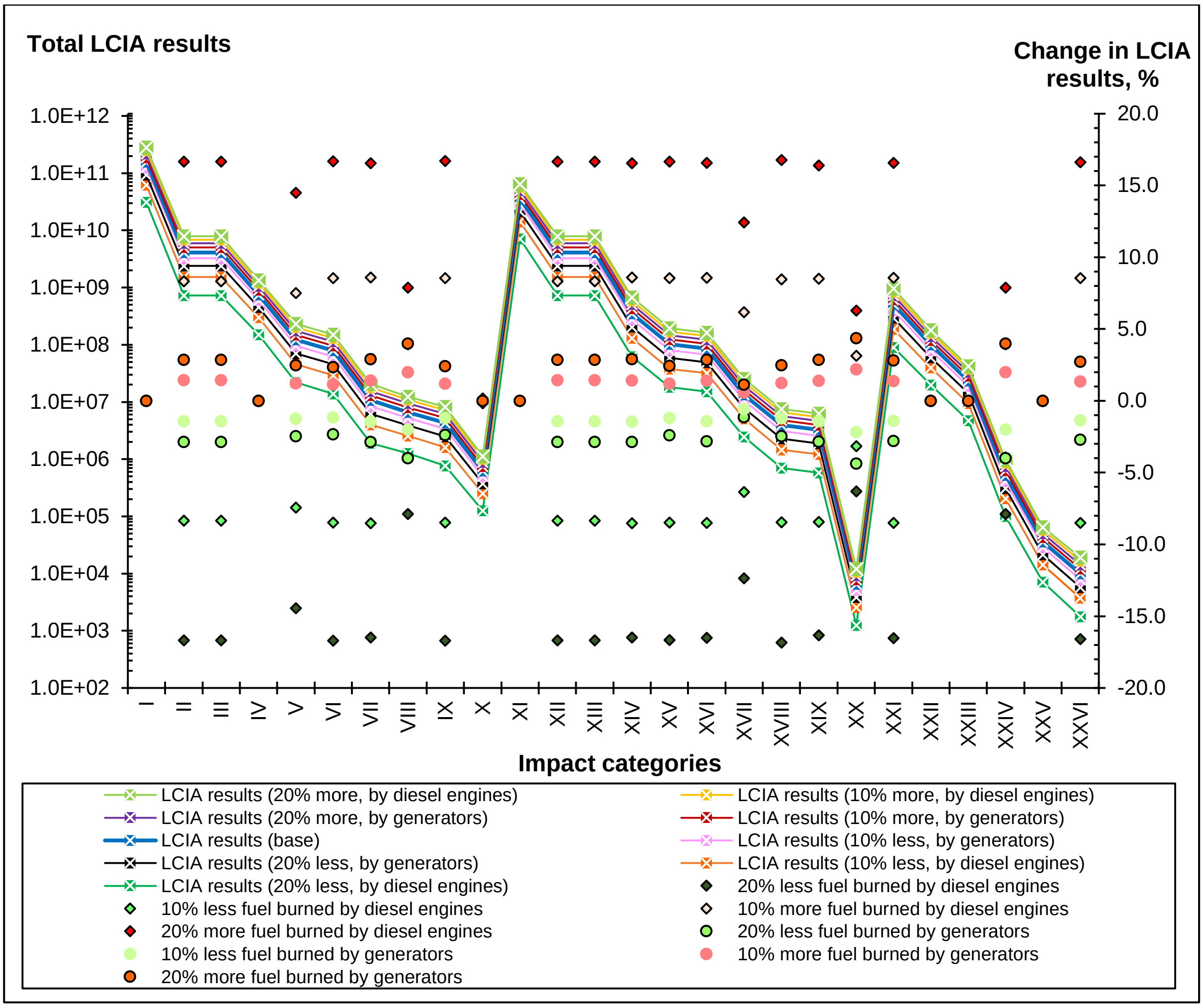


Figure 5.13: Changes in LCIA results due to variation in fuel consumption quantity.

In base case scenario, diesel engines burned 91.6% and 82.1% of the total amount of HFO and MDO respectively whilst auxiliary generators consumed 8.4% of HFO and 14.7% of MDO. HFO and MDO burned by diesel engines were therefore approximately 11 and 6 times, respectively, of the quantities consumed by auxiliary generators. The LCIA results were affected by changes in MDO consumption to a greater extent if compared to HFO consumption. This was because total MDO consumption had exceeded total HFO consumption by 2.2×10^8 kg. As expected, the less fuel consumed, the more environmentally friendly the power system would be. Impact relevant to ecotoxicity potential, mineral consumption and land use, including CML2001: *Marine Aquatic*, *Freshwater Aquatic* and *Terrestric Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater,* Eco-Indicator99: *Ecosystem Quality–Ecotoxicity, Resources–Minerals* and *Ecosystem Quality–Land-Use* (labelled as I, IV, X, XI, XXII, XXIII and XXV) was not sensitive to changes in fuel consumption.

End of life management plans for diesel engines

In reality, it was uncertain to what extent metallic scrap would be recycled or disposed to incineration plants or landfill. They were theoretically modelled in base scenario for better understanding and further explored in additional scenarios as a part of sensitivity analysis. Changes in LCIA results due to various end of life management plans of diesel engines are illustrated in Figure 5.14.

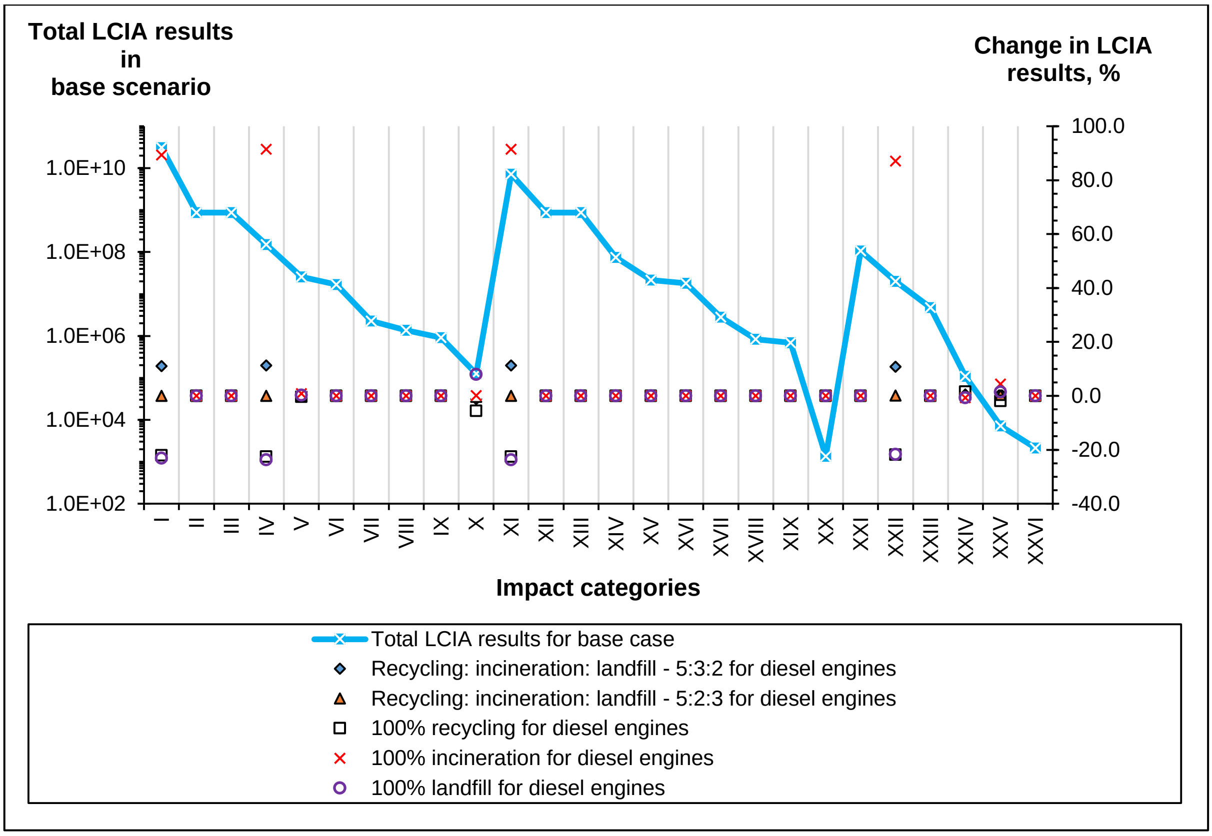


Figure 5.14: Difference in LCIA results compared to the base case scenario due to various end of life scenarios of diesel engines.

For various end of life scenarios of diesel engines, the total LCIA results of four impact categories, including CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, XI and XXII respectively) would be affected significantly whilst CML2001: *Terrestric Ecotoxicity Potential* and Eco-Indicator99: *Ecosystem Quality–Land-Use* (labelled as X and XXV respectively) were affected very slightly. When 50% of the metallic scrap from diesel engines was recycled, 30% was disposed to incineration plants and 20% was sent to landfill, an approximate increase of 11% was observed in CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99:

Ecosystem Quality–Ecotoxicity. When the rates of incineration and landfill were reversed, no dramatic change was observed in these impact categories (as well as others). When metallic scrap of diesel engines was 100% recycled, the LCIA results of these four impact categories declined by 21.8–22.6%. Changes caused by the 100% landfill scenario were similar to those of the 100% recycling scenario. On the contrary, these impact categories showed an opposite trend when the metallic scrap was 100% disposed to incineration plants. The changes in LCIA results included an increase of 89.3% in CML2001: *Marine Aquatic Ecotoxicity Potential*, 91.5% in CML2001: *Freshwater Aquatic Ecotoxicity Potential* and ILCD: *Ecotoxicity for Aquatic Freshwater* respectively, and 87.1% in Eco-Indicator99: *Ecosystem Quality–Ecotoxicity*. The analysis indicated that both recycling and landfill were more environmentally friendly than incineration. The latter would be a bad end of life option for diesel engines.

End of life management plans for all components

When the end of life management plans for all components were taken into account, LCIA results showed similar trends in CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, XI and XXII respectively). The trends were in agreement to those reported in the additional scenarios of the end of life management plans for diesel engines but to a greater extent, as illustrated in Figure 5.15.

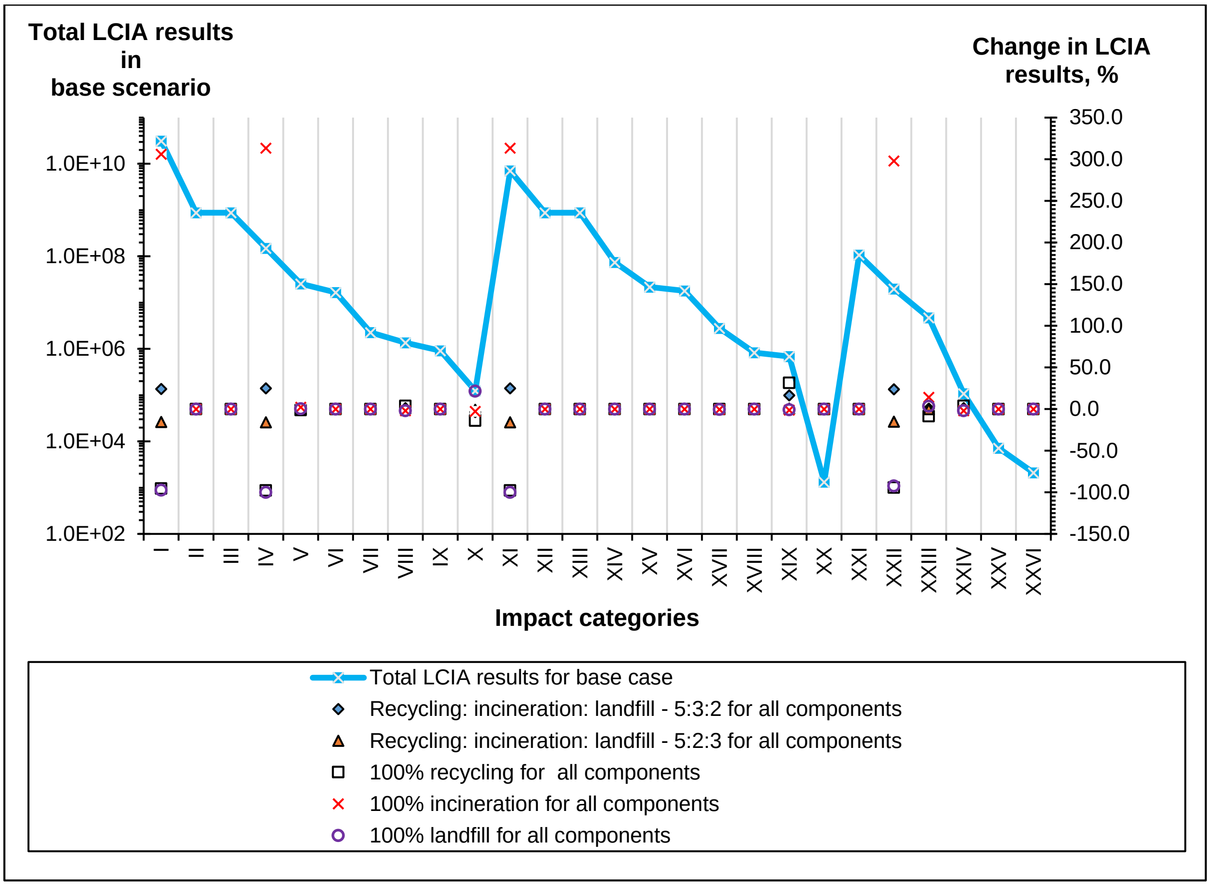


Figure 5.15: Difference in LCIA results compared to the base case scenario due to various end of life scenarios of all components.

The scenario of 50% recycling, 30% incineration and 20% landfill would increase these impact categories by 16.7–25.1% whilst reducing CML2001: *Terrestric Ecotoxicity Potential* (labelled as X) by approximately 3%. A decline ranging 14.7–15.8% was shown in these impact categories when 50% of metallic scrap was recycled, 20% was disposed to incineration plants and 30% was sent to landfill. Although 100% recycling could cut down these impact categories by up to 97.5%, it would also increase ILCD: *Marine Eutrophication* by 31.6%. Meanwhile, 100% landfill could reduce these four impact categories to the same extent as the scenario of 100% recycling without any significant increase in ILCD: *Marine Eutrophication*; however an increase in CML2001:*Terrestric Ecotoxicity Potential* by 21.6% came along with this 100% landfill scenario. The fallout of incineration was very large which would increase these impact categories up to 313.5% if scrap was fully disposed to incineration plants. The LCIA results showed that the magnitude of environmental burdens was sensitive to end of life scenarios for some impact categories, which could be reduced at the expense of magnifying other impact categories. As reduction in all impact categories would not be possible in reality, it was reasonable to find no improvement and even more an increase in a few impact categories along with a decline in other impact categories.

Altogether, the scenario analysis showed that the environmental impact of a conventional power system was less sensitive to material proportion (of diesel engines for the difference in tin, chromium, cast iron, steel or aluminium ranging 2–4 orders of magnitude), slightly sensitive to mass (of diesel engines); modestly influenced, in ascending order, by fuel type, fuel quantity and component choice; and greatly affected by end of life management. Changes made to a choice might result in no improvement, a decline or an increase in different impact categories. In other words, a decline in some impact categories by any choice/strategy would come along with no improvement and even more an increase in other impact categories. As such, life cycle of a marine power system should be managed appropriately to avoid aggravating its environmental burdens.

5.3 Case Study 2: Marine Retrofit Power System

To ensure consistency with Case Study 1, the following sub-objectives were set for this case study:

- define goal and scope of the case study on the retrofit power system;
- estimate resources, emissions and the environmental impact attributable to the marine retrofit power system;
- identify resource consumption and the causes of the impact; and
- understand the environmental implications of implementing the retrofit system design and operating the power system over its full life cycle via scenario analysis.

Retrofit design and integration of additional components into an existing system were necessary in retrofitting a power system. How emerging technologies were selected and sources of data are explained in **Chapters 5.3.1** and **5.3.2**, followed by goal and scope definition in **Chapter 5.3.3**, LCI results in **Chapter 5.3.4**, LCIA results in **Chapter 5.3.5** and life cycle interpretation in **Chapter 5.3.6**.

5.3.1 *Selection of emerging power technologies*

The retrofit design was proposed for RoRo cargo ships which employed a conventional power system with the same configuration as the one onboard the reference ship, as investigated in Case Study 1. In principle, the retrofit design should be (i) innovative; (ii) within the interest of the industry involved; (iii) making use of existing components on-board the reference ship; (iv) able to store and use surplus energy when required; and (v) able to improve operational performance during manoeuvring and transiting. Recent recommendations on emerging technologies that were also considered included a hybrid design incorporating renewable sources e.g. solar as power augmentation for ships [225], energy storage, slow steaming [430] and cold ironing which was perceived to reduce total emission by up to 20% [9]. In line with the established criteria, the retrofit design was the technical outcome of collaboration and discussion among consortium members and the ship owner involved in the project over 4 years. The retrofit system was anticipated to consume less fuel and release less harmful emissions.

5.3.2 Data sources

LCA was applied for Case Study 2, covering the existing system for 10 years and the retrofit design for 20 years in service. The 20-year lifespan was set for the retrofit system in line with the total lifespan assumed for a marine vessel in Case Study 1, i.e. 30 years. Data were processed and estimates were made in the same way as in Case Study 1, including

- gathering and standardising background data for energy, raw materials and manufacturing processes of components from various sources e.g. manufacturers, Ecoinvent database and literature;
- using the outcome of Simplex and PSO models under optimum power system operation which detailed usage profiles, fuel consumption and power generation of individual components (whichever relevant) on a daily basis;
- estimating emissions based on factors proposed by [420];
- applying data gathered from literature for recovering metallic scrap and used lubricating oil; and
- adopting Ecoinvent datasets for recycling non-metallic scrap and disposing both metallic and non-metallic scrap to incineration plants and landfill.

5.3.3 *Goal and scope definition*

The reason for conducting this case study was to explore the environmental implications of redesigning the marine power system on-board a RoRo cargo ship. Marine stakeholders including ship owners, industry practitioners, researchers, academics and the public were the targeted audience. The results were made accessible to the public through research dissemination, which could be used as a reference in future work for comparison or validation. The product system under study was the power system on-board the reference ship chosen in Case Study 1 which was retrofitted after 10 years in service. Thus, the product system of Case Study 2 covered both existing and retrofit configurations, for 10 and 20 years in operation respectively. The designed retrofit system, as illustrated in Figure 5.16, integrated cold ironing, PV and lithium-ion battery systems, implemented slow steaming with PTO/PTI (using shaft generators which were not in service on-board the reference ship), and took advantage of variable frequency drives (VFDs), and thrusters governed by frequency converters to eliminate stand-by mode and ensure high starting current.

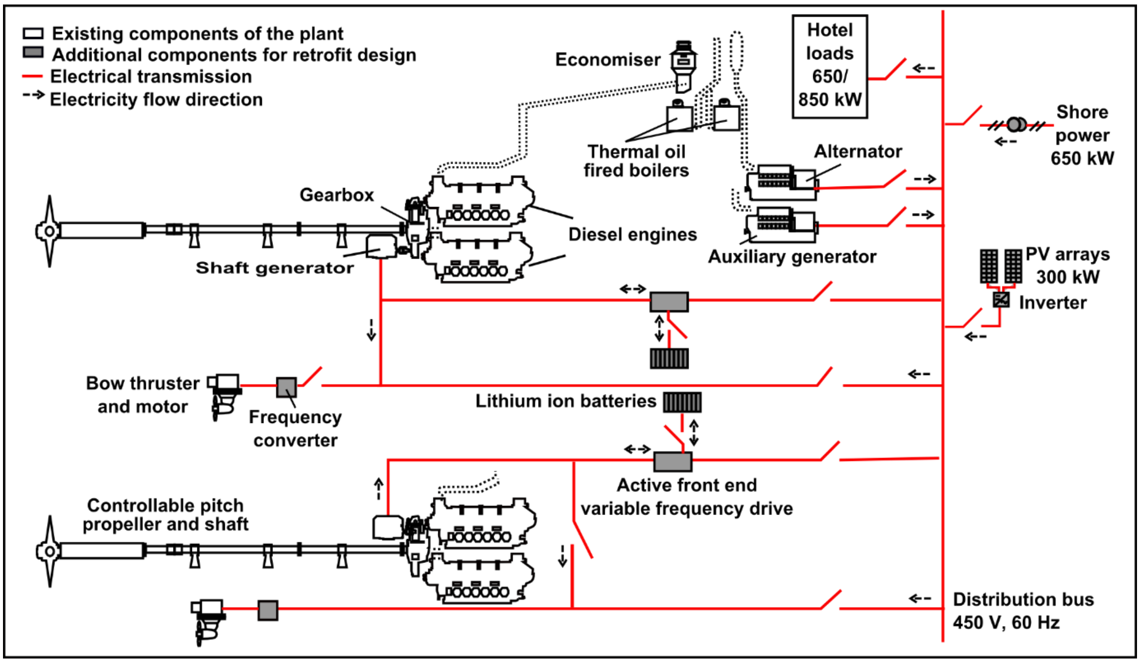


Figure 5.16: The theoretical retrofit system design.

The function of the product system was to supply main and auxiliary power. Therefore, the functional unit was the operation of the power system over 30 years i.e. existing and retrofit systems for 10 and 20 years respectively on-board a RoRo cargo ship on regular routes. Details of individual components that incorporated into the existing and retrofit systems (including make, type, characteristics, speed, power, mass and lifespan) are summarised in Table 5.6. Both systems and all the components formed the system boundary of the case study. Onshore infrastructure and transformers were required for cold-ironing implementation; however only transformers on-board the ship were included within the system boundary.

Table 5.6: Details of individual components integrated into the power system under study over 30 years in operation.

Component, number [a]	Detail
Diesel engines [b], 4 units	Sulzer 8ZA40S, 4-stroke, in-line, medium speed, 510 rpm, non-reversible, 5760 kW, 78000 kg, 30 years each
Auxiliary generators [b], 2 units	MAN B&W 7L28/32H, 4-stroke, in-line, 750 rpm, 1563 kW, 39400 kg, 30 years each
Shaft generators [b], 2 units	AvK DSG 88M1-4, 2125 kVA, 2125 kg, 30 years each
Gearboxes [b], 2 units	Renk AD NDSHL3000, output speed of 130 rpm at a reduction ratio of 3.923:1, 510 rpm, 5760 kW, 1415 kg, 30 years each
Propellers and shafts [b], 2 units	Lips 4CPS160, 4-blade, controllable pitch for ice application with outward turning, diameter of 5 m with 105.4 m shaft, 24000 kg and 35400 kg respectively, 30 years each
Bow thrusters and built-in motors [b], 2 units	Lips CT175H, transverse, controllable pitch, standard design with propeller diameter of 1.75 m, 1465-1755 rpm (input), 316-379 rpm (output), 50-60 Hz, 1000 kWh, 5900 kg, 30 years each
Thermal oil boilers [b], 2 (plus 2) units	Wiesloch 25V0-13, thermal oil as working fluid, burn MDO with an inlet/outlet temperature of 160/200 ^oC, 1453 kW, 3170 kg (estimated), 20 years each
Economisers [b], 2 (plus 2) units	Heatmaster THE 3-60, exhaust gas inlet and outlet temperatures are 206-223 ^oC and 340-350 ^oC when engines run at 75-100% maximum continuous rating, 2200 kg (estimated), 15 years each
Frequency converters, 2 (plus 2) units	ABB ACS800-07, standard cabinet-built drive, 500 V, 1000 kW, 1410 kg, 10 years each
Active front end (AFE) VFDs, 2 (plus 2) units	Ingeteam™ LV4F-32-131WA-348+Z, water cooled cabinet, 480 V, 1774 kVA, 3600 kg, 10 years each
PV, single-array, 1 system	1212 units of Kyocera KD245GX-LPB module, 1994 m^2, 25452 kg, 30 years and a Schneider Electric GT 250-480 inverter, 300-480 V, 250 kW AC, 2018 kg, 10 years
Lithium-ion battery, 2 systems	Seanergy® LiFePO4 VL 41M Fe 265 Wh/liter, rechargeable, 2 MWh, 21900 kg with cabinets (or 16800 kg without cabinets), 20 years each
Cold ironing, 1 (plus 1) unit	Onboard transformer only - an ABB RESIBLOC® cast-resin dry transformer, 1000 kVA, 3150 kg, 20 years

[a] The additional number of components used for replacement was included in brackets. Details for all components, with the exception of the PV system, were presented as individual components.

[b] Components of the existing power system, which were the same as those presented in Case Study 1.

The operational profile of the reference ship from 1 January to 31 March 2011 which was provided by the ship operator and used in Case Study 1 was also adopted for this case study. Accordingly, the power system operated in the same manner as the conventional system in Case Study 1 in the first 10 years of its lifespan. To recap, the operational profile included (i) running two diesel engines continuously at a constant speed for propulsion purpose, supplying exhaust from the engines to economisers, running an auxiliary generator and a boiler for auxiliary power demand when the ship was transiting at sea; and (ii) shutting down all diesel engines, running an auxiliary generator and a boiler for auxiliary power, and operating bow thrusters (or in standby mode) when the ship was manoeuvring, mooring or waiting in port. The retrofit power system was proposed to be installed after the existing ship power system was operated for 10 years.

Similar to Case Study 1, energy management for the retrofit system was modelled using Simplex method developed in GES and optimised using PSO method based on voyage conditions. The optimised operational profile showed that when the ship with retrofit power system travelled at sea, main power would be delivered by running 2–4 diesel engines and augmented with energy from a PV and lithium-ion battery systems. Auxiliary load would be (i) partially supplied by shaft generators in PTO mode when connected to diesel engines; or (ii) fully supplied by auxiliary generators when shaft generators worked in PTI mode to drive propellers. Thus, at least one of the auxiliary generators would be run when the retrofit ship was transiting at sea. During slow steaming, only one propeller would be powered by PTO/PTI. Whilst manoeuvring, mooring and waiting in port, both diesel engines and auxiliary generators would not be running. Thrusters would be governed by frequency converters to operate at variable speeds during manoeuvring and mooring. In port, cold ironing electricity supply would be used to charge the battery systems and supply auxiliary power together with one of the boilers for hotel services.

Although Case Study 2 was carried out independently, the scope of Case Study 2 was defined in a similar manner to those of Case Study 1 to ensure consistency and allow for comparison. The common features included:

- assessing the environmental impact of the power system based on an integrated system approach;

- avoiding allocation via system expansion in which components for any replacement were included within the system boundary;
- covering the acquisition of energy and raw materials, manufacture, operation and maintenance, dismantling and the end of life management as the life cycle phases under study;
- assuming that (i) the environmental impact during engineering design and installation was insignificant, as did auxiliary equipment such as fuel oil systems, piping, cables and switchboards; (ii) neither materials nor devices were lost or defective during manufacture and operation; (iii) chemicals required for manufacture and end of life treatment were reused; and (iv) at the end of life, parts and metallic scrap from engines and generators were reused (30%), recycled (30%) or disposed to incineration plants and landfill sites (20% each); for other components, 33.3% of the parts and metallic scrap were recycled, disposed to incineration plants or landfilled respectively;
- applying average data gathered from existing database and literature for most life cycle phases, and adopting specific data i.e. simulation results based on the real-time operational profile for the operation phase, in relation to data requirements;
- involving value choice in choosing the ship type and LCIA methodologies i.e. CML2001, ILCD and Eco-Indicator99 for the assessment;
- covering 26 impact categories as defined in Case Study 1 (see **Chapter 5.2.3**) in which the indicator results were compared based on their magnitude without normalisation nor weighting;
- having the same limitations which did not consider engineering design and approval, installation and testing at shipyard, material loss during manufacture, locations of manufacturing plants and recycling sites, transportation (except the ones included in existing Ecoinvent database for non-metallic scrap management), auxiliaries (such as switchboards, cables, piping and fuel oil systems), technology change in future, spatial and temporal differentiation, and impact categories that had not been incorporated into the software; and
- applying scenario analysis to investigate sensitivity and uncertainty of the results for life cycle interpretation.

5.3.4 *LCI results: resource consumption and emissions*

Among a wide variety of materials required for manufacturing components that were incorporated into the power system under study, aluminium, copper, steel and cast iron, in ascending order ranging between 2.88x10^4 kg and 2.85x10^5 kg, were most commonly consumed, as illustrated in Figure 5.17.

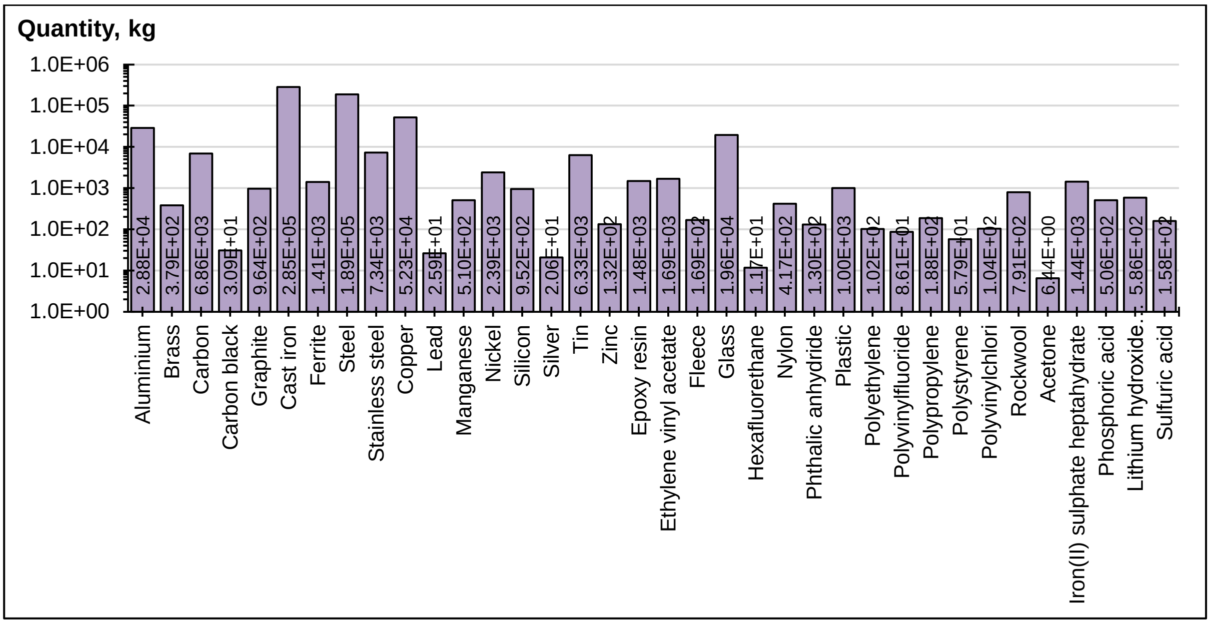
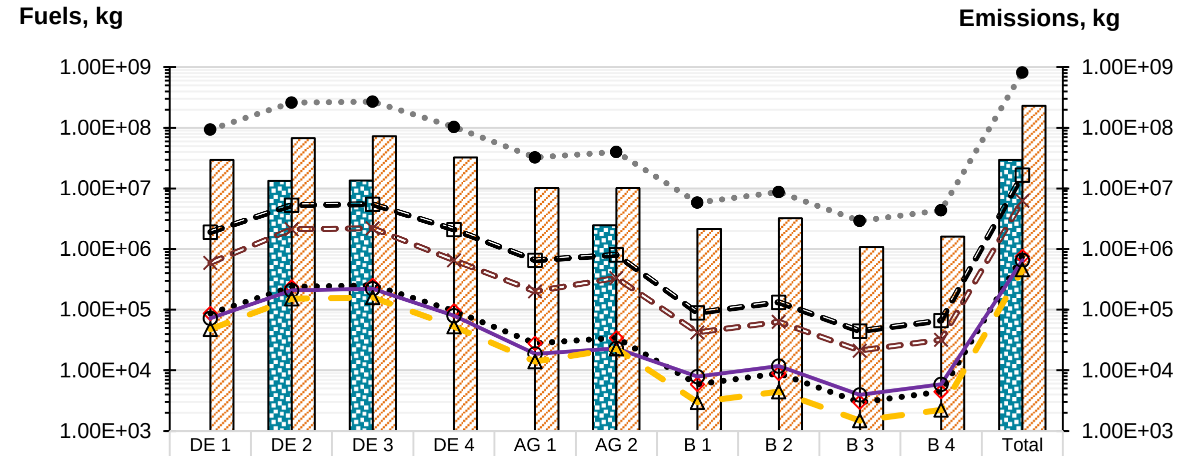


Figure 5.17: Materials used in manufacturing components incorporated into the power system under study, in kg.

The LCI results showed that diesel engines, propellers and shafts, and VFDs played a significant role in consuming these four materials. Diesel engines were accountable for 29.3% of aluminium, 35.2% of steel and 76.2% of cast iron consumption; propellers and shafts used 73.4% of copper and 38.8% of steel; and VFDs were responsible for 25.3% of aluminium consumption. In total, manufacture of all components incorporated into the power system involved 2.68x10^3 MJ and 2.43x10^5 MJ of energy due to industrial furnaces burning heavy and light fuel oils respectively, together with 3.30x10^5 MJ of energy from electricity and 6.19x10^5 MJ of heat from gas boilers. Among all, diesel engines, propellers and shafts, diesel generators, frequency converters and the PV system contributed significantly towards total energy consumption. Diesel engines required 53.4%, 46.5% and 48.0% of energy supplied from burning heavy and light fuel oils in furnaces and natural gas in boilers respectively, followed by propellers and shafts i.e. 20.3%, 17.7% and 18.3% respectively, in addition to 13.5%, 11.7% and 12.1% respectively used in manufacturing diesel generators. Frequency converters and PV systems were the two biggest consumers of electricity, i.e. 37.6% and 19.2% respectively. Besides, glass and iron sulphate (II) heptahydrate appeared as the largest constituent of non-metallic materials and chemicals being consumed, i.e. 1.96×10^4 kg and 1.44×10^3 kg, which were almost entirely consumed for the manufacture of PV and battery systems respectively.

Based on the optimised profile for the vessel, the operation of the marine power system consumed 2.93×10^7 kg of HFO and 2.30×10^8 kg of MDO, which were burned by diesel engines, auxiliary generators and boilers, and consequently, released 8.20×10^8 kg of CO_2, 1.66×10^7 kg of NO_x, 6.26×10^6 kg of SO_2, 7.58×10^5 kg of CO, 6.51×10^5 kg of HC and 4.58×10^5 kg of PM, as illustrated in Figure 5.18. The analysis showed that diesel engines were accountable for 91.6% of total HFO consumption, 87.7% of total MDO consumption and more than 87% of total emissions released. It was mainly because of the running of 2 to 4 diesel engines for ship propulsion when the ship was transiting at sea.



	DE 1	DE 2	DE 3	DE 4	AG 1	AG 2	B 1	B 2	B 3	B 4	Total
HFO	0.0E+00	1.3E+07	1.3E+07	0.0E+00	0.0E+00	2.5E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.9E+07
MDO	2.9E+07	6.8E+07	7.2E+07	3.2E+07	1.0E+07	1.0E+07	2.1E+06	3.2E+06	1.1E+06	1.6E+06	2.3E+08
CO	8.7E+04	2.4E+05	2.5E+05	9.5E+04	2.8E+04	3.5E+04	5.9E+03	8.9E+03	3.0E+03	4.4E+03	7.6E+05
CO2	9.3E+07	2.6E+08	2.7E+08	1.0E+08	3.2E+07	4.0E+07	5.8E+06	8.7E+06	2.9E+06	4.4E+06	8.2E+08
HC	7.2E+04	2.1E+05	2.2E+05	8.0E+04	1.9E+04	2.3E+04	7.9E+03	1.2E+04	3.9E+03	5.9E+03	6.5E+05
NOx	1.9E+06	5.3E+06	5.5E+06	2.1E+06	6.5E+05	8.1E+05	8.9E+04	1.3E+05	4.4E+04	6.6E+04	1.7E+07
SO2	5.9E+05	2.1E+06	2.2E+06	6.5E+05	2.0E+05	3.3E+05	4.2E+04	6.4E+04	2.1E+04	3.2E+04	6.3E+06
PM	4.8E+04	1.5E+05	1.6E+05	5.3E+04	1.4E+04	2.3E+04	3.0E+03	4.4E+03	1.5E+03	2.2E+03	4.6E+05

Figure 5.18: Fuel consumption and emissions released, both in kg, during the operation of the power system over 30 years, as per components including diesel engines (DE1–DE4), auxiliary generators (AG1 and AG2) and boilers (B1–B4).

Additional resources were consumed during ship maintenance. Based on information provided by industrial partners, replacing lubricating oil on a regular basis was necessary for optimal performance of the power system, which amounted to 5.06×10^4 kg. To treat and recover used lubricating oil, 120–170 kg of diesel, light fuel oil and liquefied petroleum were required, in addition to energy supplied from electricity and natural gas, i.e. 3.17×10^6 MJ and 2.82×10^5 MJ respectively. Similarly, resources and energy were consumed in dismantling the power system and handling metallic scrap at the end of life, as illustrated in Figure 5.19. The LCI results showed that coal was the most widely consumed resource i.e. 2.68×10^5 kg whilst electricity was the most popular source of energy i.e. 1.03×10^6 MJ during dismantling and the end of life. Resources consumed during the end of life of non-metallic scrap were included using Ecoinvent datasets, which were found negligible and therefore not further investigated.

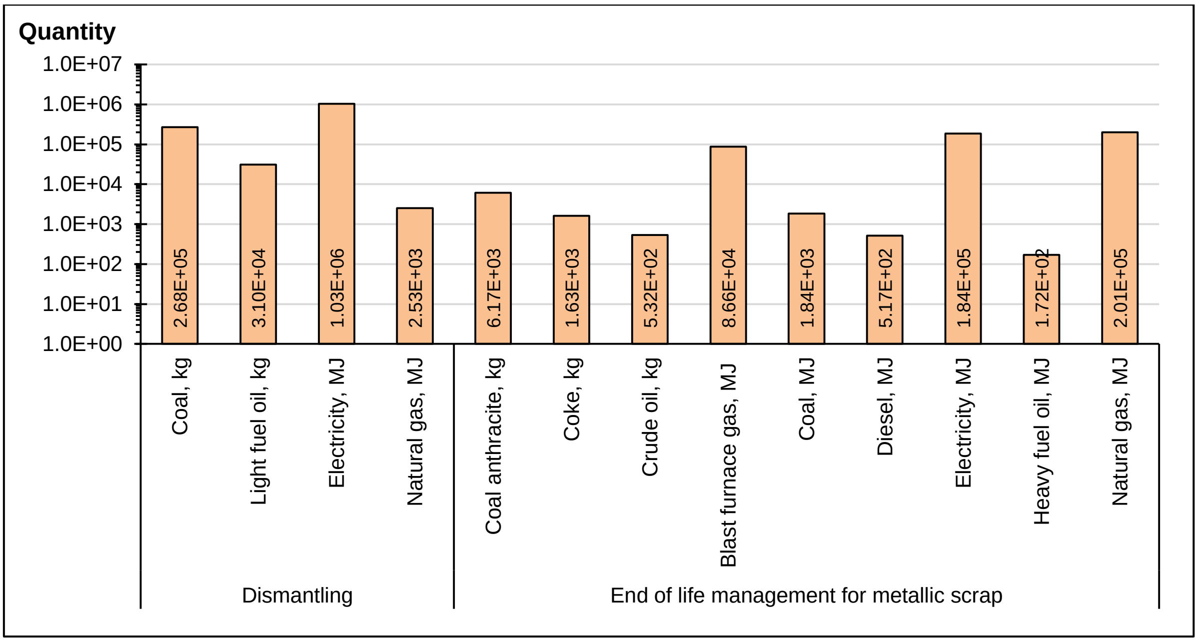


Figure 5.19: Resource and energy consumption during dismantling and the end of life.

Throughout the full life cycle, emissions were released into various ecosystems such as air, freshwater, sea water, agricultural soil and industrial soil, as indicated by the outcome of LCA models developed using GaBi. The results showed that 6.90×10^2 kg of heavy metals and 2.66×10^5 kg of inorganic emissions were emitted to freshwater whilst 1.11×10^4 kg of heavy metals, 4.84×10^5 kg of particles, 6.69×10^5 kg of organic emissions and 8.44×10^8 kg of inorganic emissions were released to air. By taking the whole system and all life cycle phases into account, diesel engines were the main source of emissions (as well as material consumption). Their contribution to particles, organic and inorganic emissions to air was profound, as shown in Figure 5.20.

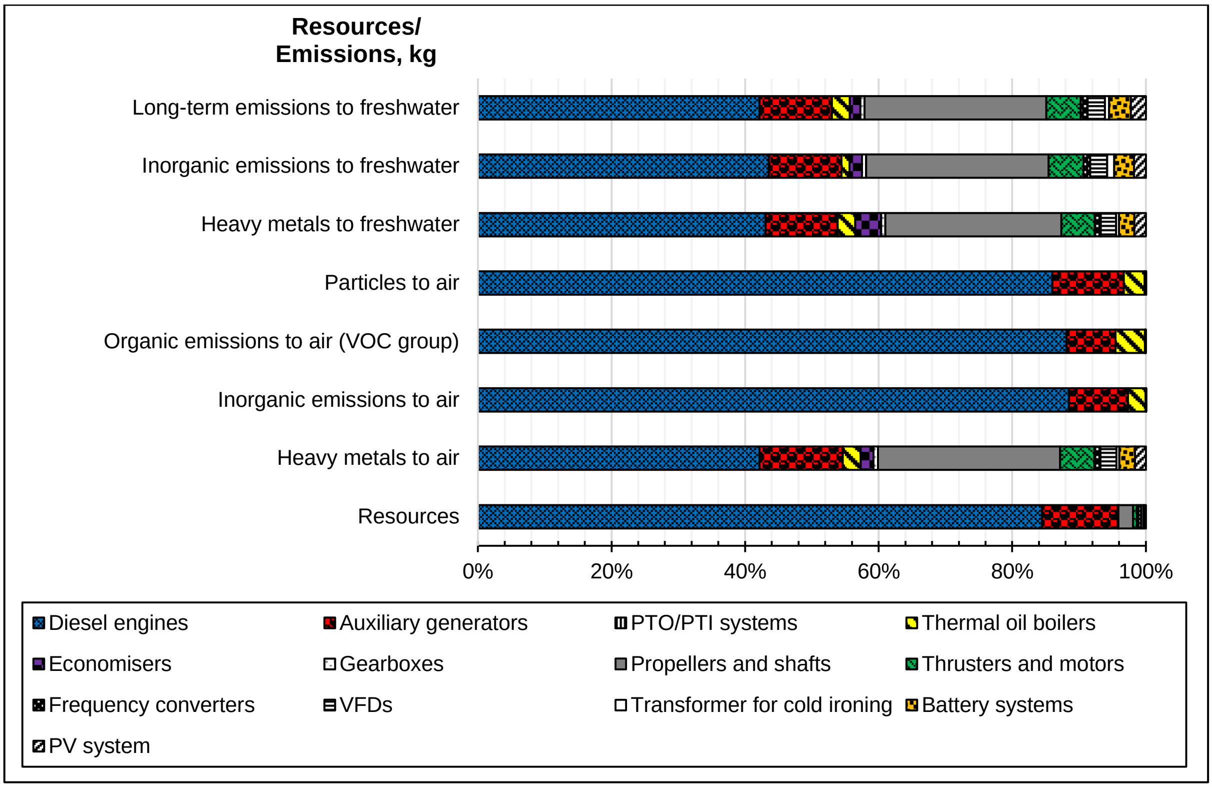


Figure 5.20: Emissions of the power system from acquisition of raw materials and energy to end of life management as per individual technologies, which were estimated via LCA models developed in GaBi for base case scenario.

For each emission category, the release of PM, HC and CO_2 into the atmosphere during the operation phase appeared as the major sources. CO, NO_x and SO_2 were sources of inorganic emissions; however, they were less noticeable as their orders of magnitude were 2–3 times less than that of CO_2. In addition, diesel engines also resulted in 42.2–43.5% of heavy metal emissions to air (i.e. iron) and long-term, inorganic as well as heavy metal emissions to freshwater (i.e. aluminium, copper and iron respectively), as the consequences of disposing metallic scrap to incineration plants and landfill. Emissions attributable to propellers and shafts were mainly from metallic scrap disposal, with similar wastes accounting for approximately 27% of the quantity of these four emission categories, individually. In this context, emissions attributable to auxiliary generators were more consistent across all categories, ranging from 7.4% to 12.5%, with evident waste from both operation and metallic scrap disposal. Emissions to sea water, agricultural and industrial soils ranged 1–3 orders of magnitude, as indicated by the outcome of the models in GaBi. Such magnitude was perceived as relatively negligible when compared with emissions to freshwater and air, which were greater than 5 orders of magnitude with the exception of heavy metals. The trend of less emissions to agricultural and industrial soils and more emissions to freshwater and air was justifiable, considering the length of time involved during manufacture and operation i.e. a few months versus 30 years. During operation, emissions from the power system were primarily released to the air.

5.3.5 *LCIA results*

Covering raw materials and energy acquisition, manufacture, operation, maintenance, dismantling and end of life management, the life cycle implications of the power system for the environment and human beings were characterised into individual impact categories. Using CML2001, ILCD and Eco-Indicator99, the LCIA results for most impact categories were greater than 5 orders of magnitude, as shown in Figure 5.21. The contribution of individual technologies towards each impact category is illustrated in Figure 5.22 (in which individual impact categories are labelled as I–XXVI).

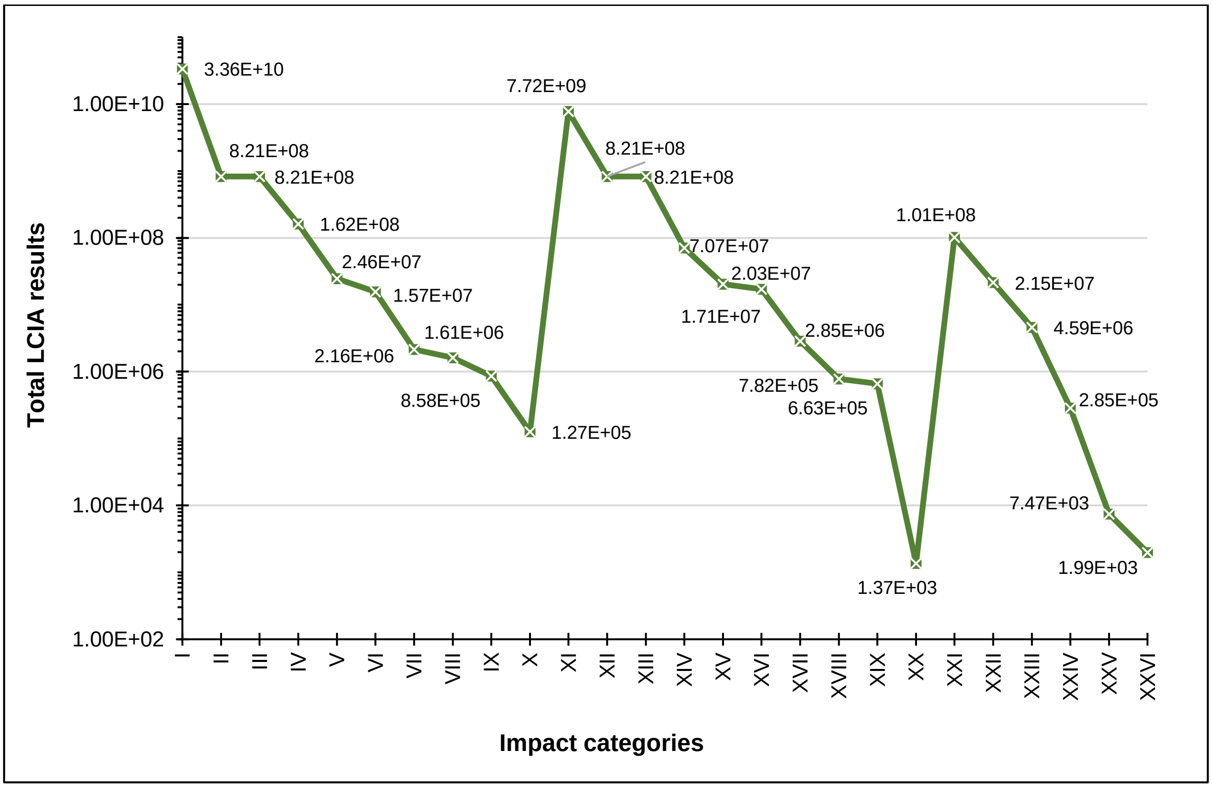


Figure 5.21: Total environmental burdens attributable to the power system.

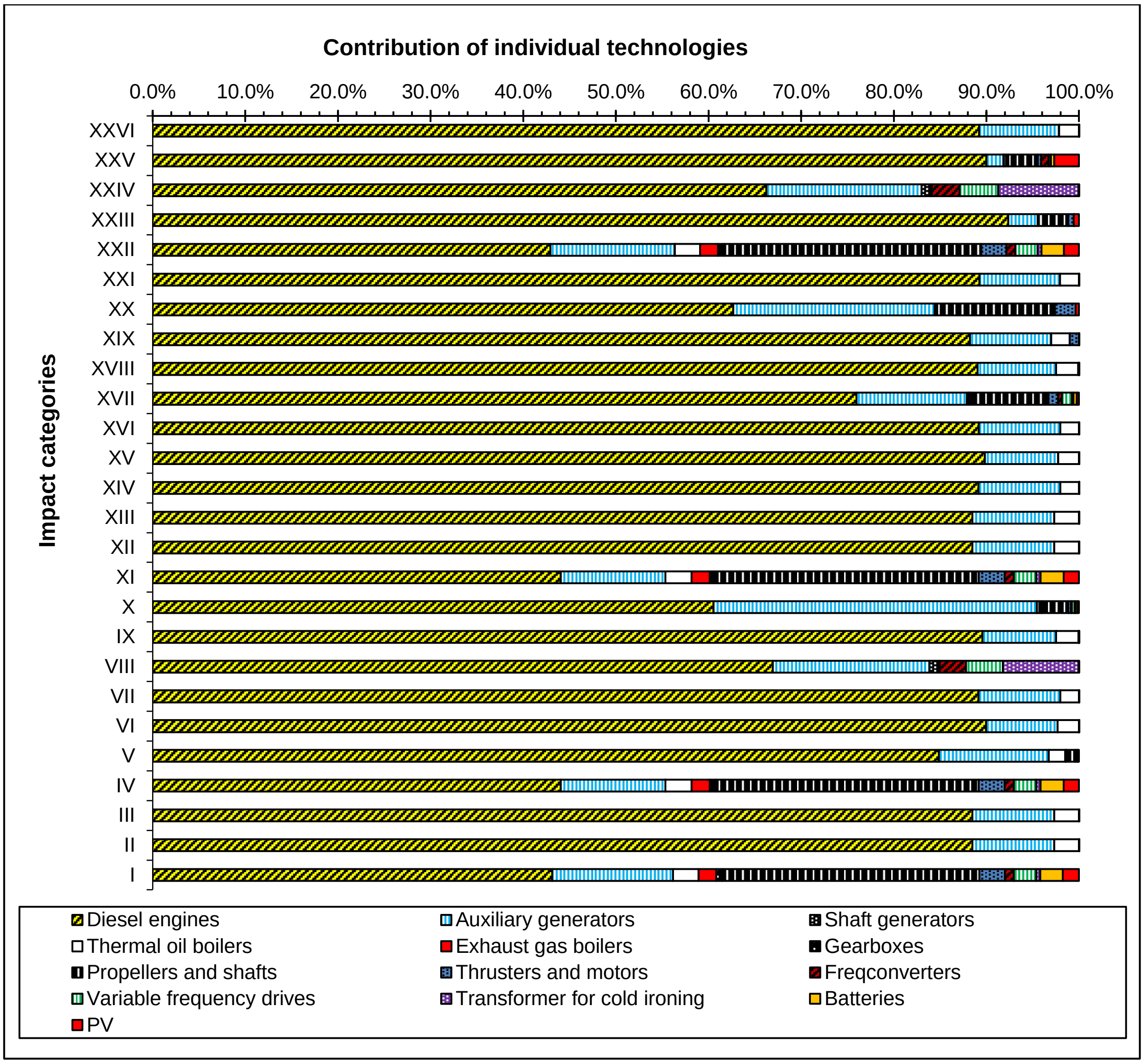


Figure 5.22: Contribution of individual components towards individual impact categories.

Based on a midpoint approach, 3.36×10^{10} kg $C_4H_8Cl_2$ equivalent of CML2001: *Marine Aquatic Ecotoxicity Potential*, 1.62×10^{8} kg $C_4H_8Cl_2$ equivalent of CML2001: *Freshwater Aquatic Ecotoxicity Potential*, and 7.72×10^{9} CTUe of ILCD: *Ecotoxicity for Aquatic Freshwater* (labelled as I, IV and XI respectively) were reported. The LCIA results estimated by Eco-Indicator99 for *Ecosystem Quality–Ecotoxicity* (labelled as XX) based on an endpoint approach was of lower magnitude, i.e. 2.15×10^{7} PDF*m^2*a. Unlike CML2001 and ILCD which showed the highest indicator results on ecotoxicity potential, Eco-Indicator99 identified *Ecosystem Quality–Acidification/Nitrification* (labelled as XXI) as the impact category that showed the highest indicator results i.e. 1.0×10^{8} PDF*m^2*a, The results estimated using these three characterisation models differed by at least one order of magnitude. The use of distinct environmental mechanisms and indicators in developing these methodologies was perceived as a plausible explanation for the difference. In relation to global warming potential assessed by both CML2001 and ILCD (labelled as II–III and XII–XIII), the estimates were in agreement as the result of applying the same method developed by IPCC.

The environmental burdens of the power system could be further analysed to identify significant causes of individual impact categories. At least 83.70% of all impact categories were attributable to significant components. By analysing the contribution of individual technologies towards the overall environmental burdens of the power system, as illustrated in Figure 5.22, the environmental burdens caused by diesel engines, auxiliary generators, propellers and shafts, as well as other components, were disproportionate to their mass, i.e. 48.4%, 18.4%, 12.2% and 21% of the total mass of the power system. For all categories, diesel engines played a pronounced role in instigating 42.9–92.4% of the environmental burdens. The contribution of auxiliary generators was observable for most impact categories ranging 7.7–13.4% with the exception of CML2001: *Terrestric Ecotoxicity Potential* (labelled as X, 34.9%), CML2001: *Abiotic Depletion of Fossil* (labelled as VIII, 16.8%), ILCD: *Resource Depletion, Fossil and Mineral* (labelled as XX, 21.8%), Eco-Indicator99: *Resources─Fossil Fuels* (labelled as XXIV, 16.8%), Eco-Indicator99: *Resources─Minerals*, (labelled as XXIII, 3.2%) and Eco-Indicator99: *Ecosystem Quality─Land-Use* (labelled as XXV, 1.8%). This was followed by propellers and shafts which brought approximately 28% of CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality* (labelled as I, IV, XI and XXI respectively). The following key contributors were identified for individual impact categories:

i. Consuming resources
   - cast iron for CML2001: *Human Toxicity Potential* (labelled as V);
   - chromium for stainless steel production for CML2001: *Terrestric Ecotoxicity Potential* (labelled as X);
   - tin and copper for Eco-Indicator99: *Resources─Minerals* (labelled as XXIII) and ILCD: *Resource Depletion, Fossil and Mineral* (labelled as XX);
   - crude oil for CML2001: *Abiotic Depletion of Fossil* (labelled as VIII);

- resources for Eco-Indicator99: *Resources—Fossil Fuels* (labelled as XXIV); and
- water for ILCD: *Total Freshwater Consumption* (labelled as XVII).

ii. Storing resources

- Eco-Indicator99: *Ecosystem Quality—Land-Use* (labelled as XXV).

iii. Operating diesel engines and auxiliary generators

- CML2001: *Global Warming* (*including* and *excluding Biogenic Carbon*), *Human Toxicity*, *Acidification*, *Eutrophication* and *Photochemical Ozone Creation Potential* (labelled as II–III, V–VII and IX respectively);
- ILCD: *IPCC Global Warming* (*including* and *excluding Biogenic Carbon*), *Terrestrial Eutrophication*, *Acidification*, *Photochemical Ozone Formation*, *PM/Respiratory Inorganics* and *Marine Eutrophication* (labelled as XII–XVI, XVIII–XIX respectively);
- Eco-Indicator99: *Ecosystem Quality—Acidification/Nitrification* and *Human Health—Respiratory (Inorganic)* (labelled as XXI and XXVI respectively).

iv. Disposing metallic scrap of diesel engines, auxiliary generators, propellers and shafts to incineration plants

- CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential* (labelled as I and IV respectively);
- ILCD: *Ecotoxicity for Aquatic Freshwater* (labelled as XI); and
- Eco-Indicator99: *Ecosystem Quality—Ecotoxicity* (labelled as XXI).

From a life cycle perspective, the analysis showed that despite a large quantity of resources including energy and materials involved during the acquisition and manufacturing phases, most environmental burdens of the power system occurred during operation and the end of life. A correlation between key contributors and the magnitude of the indicator results for impact categories was observed: when CML2001, ILCD and Eco-Indicator99 were applied, resource consumption and storage led to impact categories which were of lower magnitude, operating diesel engines and auxiliary generators resulted in impact categories which were moderate, and disposing metallic scrap was the main cause for the impact categories that showed higher magnitude. As discussed in Case Study 1, the LCI and LCIA results presented here were subject to change provided more data were available to either avoid the need of making any particular assumption or address any specific limitation in the current case. Similar to Case Study 1, the influence of assumptions and limitations presented in the study on the overall LCI and LCIA results might be negligible, moderate or pronounced; and without in-depth investigation, no conclusion could be drawn. The influence of individual assumptions and limitations, should be examined one by one in future study.

5.3.6 *Life cycle interpretation*

To fully understand the environmental implications of the power system under study, a few additional scenarios were explored in line with issues that had been of special interest to marine stakeholders from a life cycle perspective. The results of Case Study 1 showed that the environmental impact of a conventional system was moderately affected by fuel type, fuel quantity and component choice whilst greatly affected by the end of life management. The environmental implications of retrofitting the existing power system consuming different fuel types as well as quantities and handling metallic scrap with different end of life management plans were explored in the following scenarios as a part of life cycle interpretation in Case Study 2:

1. no implementation of retrofit design i.e. the system continued to operate in a 'business as usual' scenario;
2. fuel type, in which diesel engines and auxiliary generators only burned MDO where no HFO was consumed;
3. fuel consumption quantity if
   - (i) 10% less fuel was burned by diesel engines;
   - (ii) 20% less fuel was burned by diesel engines;
   - (iii) 10% more fuel was burned by diesel engines;
   - (iv) 20% more fuel was burned by diesel engines;
   - (v) 10% less fuel was burned by auxiliary generators;
   - (vi) 20% less fuel was burned by auxiliary generators;
   - (vii) 10% more fuel was burned by auxiliary generators;
   - (viii) 20% more fuel was burned by auxiliary generators;
4. end of life management plans for all components, where metallic scrap was
   - (i) 50% recycled, 30% disposed to incineration plants and 20% sent to landfill;

(ii) 50% recycled, 20% disposed to incineration plants and 30% sent to landfill;

(iii) 100% recycled;

(iv) 100% disposed to incineration plants; and

(v) 100% disposed to landfill;

Component choice was not further analysed as CuNiAl propellers (which were integrated in the base case) were proved to be more environmental friendly than stainless steel propellers in Case Study 1. Others parameters were not further addressed due to resource constraints. Results gained from these scenarios were compared with the base case scenario i.e. LCI and LCIA results presented in **Chapters 5.3.4** and **5.3.5**.

<u>*Business as usual*</u>

The LCIA results as illustrated in Figure 5.22 showed that new components that were incorporated into the retrofit power system were accountable for less than 8.0% of individual impact categories, with the exception of CML2001: *Abiotic Depletion of Fossil* (15.0%, labelled as VIII) and Eco-Indicator99: *Resources─Fossil Fuels* (15.9%, labelled as XXIV). Without further analysis, it was uncertain whether these new components had no significant environmental impact at all or they had reduced the environmental burdens of the power system substantially. The uncertainty was addressed by examining the significance of the retrofit design (as implemented in the base case) based on a 'business as usual' scenario using an integrated system approach, which was consistent with the defined goal and scope of the study.

In the 'business as usual' scenario, the conventional system was operated for 30 years where no retrofit design was implemented. The 'business as usual' scenario indeed was the base case scenario of Case Study 1. The LCI showed that prior to the operation phase, $5.16x10^3$ kg of copper, $1.38x10^4$ kg of aluminium, $1.17x10^5$ kg of steel as well as most non-metallic materials and chemicals would not be consumed if the retrofit design was not implemented. Consequently, energy supplied by operating furnaces, boilers and electricity during manufacture could be reduced by $1.51x10^4$ MJ, $4.68x10^4$ MJ and $1.94x10^5$ MJ respectively. Having stated this, an additional $2.07x10^7$ kg of MDO would be consumed during operation if the power system continued its operation without implementing retrofit changes, which would release more emissions, i.e. $4.31x10^4$ kg of PM, $5.51x10^4$ kg of CO, $6.61x10^4$ kg of HC, $4.11x10^5$ kg of SO_2, $9.63x10^5$ kg of NO_x and $5.48x10^7$ kg of CO_2. As $6.36x10^3$ kg less lubricating oil was needed for maintaining components, energy required for treating and recovering used lubricating oil could be scaled down by $9.07x10^4$ MJ. From a full life cycle perspective, the LCI showed that the 'business as usual' scenario would result in less heavy metals to air, inorganic and long-term emissions to freshwater by $1.14x10^3$ kg, $3.11x10^4$ kg and $2.15x10^4$ kg respectively at the expense of releasing more inorganic, organic and particle emissions to air and heavy metals to freshwater by $5.62x10^7$ kg, $5.93x10^4$ kg, $3.11x10^4$ kg and $2.66x10^3$ kg respectively.

As illustrated in Figure 5.23, the LCIA results showed that some impact categories, in particular those relevant to ecotoxicity and resource depletion, were less burdensome in the 'business as usual' scenario. They included CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity*, and *Abiotic Depletion of Fossil*, ILCD: *Ecotoxicity for Aquatic Freshwater,* Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* and *Resources–Fossil Fuels* (labelled as I, IV, VIII, XI, XXII and XXIV). The indicator results for these impact categories, which were attributable to the base case of retrofitting existing power system, were much higher than those of the 'business as usual' scenario mainly because of additional metallic scrap being disposed to incineration plants at the end of life. It was worth noting that other impact categories covering global warming, human toxicity, acidification, eutrophication etc. could be reduced by 4–7 orders of magnitude if the retrofit changes to the system as proposed in the base case were implemented. Although a reduction in most impact categories came at the expense of an increase in other impact categories (i.e. those which were relevant to ecotoxicity and resource depletion), the environmental benefits of the retrofit system could not be denied.

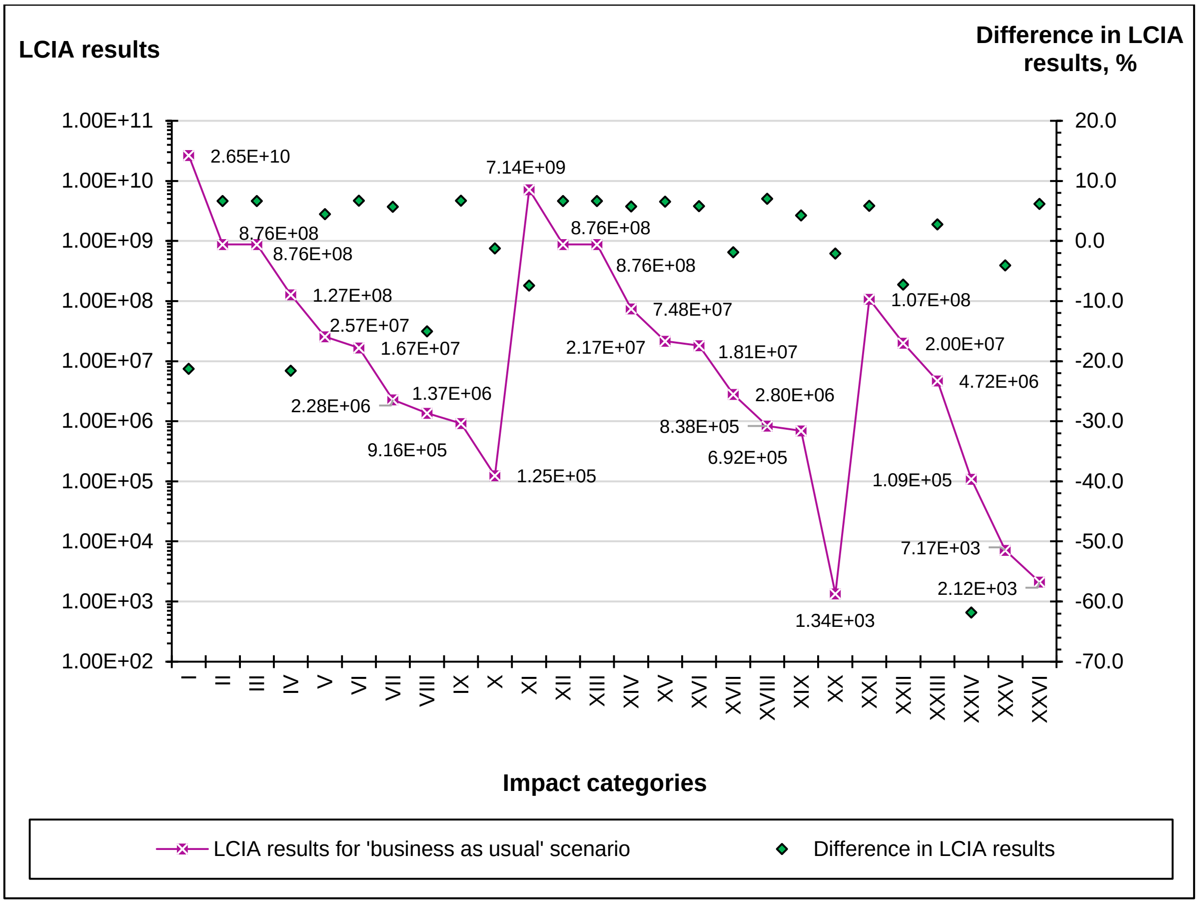


Figure 5.23: Difference in LCIA results when the 'business as usual scenario' was compared to the base case of retrofitting existing power system.

Fuel type

Prior to SOx control in North Sea, diesel engines and one of the auxiliary generators burned HFO when the ship was transiting at sea. Provided only MDO was consumed by the components throughout the whole lifespan and the retrofit system was implemented in the eleventh year of service, 2.58×10^8 kg of MDO would be burned by engines, generators and boilers. As a result, 8.09×10^8 kg of CO_2, 1.64×10^7 kg of NO_x, 5.16×10^6 kg of SO_2, 7.54×10^5 kg of CO, 6.43×10^5 kg of HC and 4.18×10^5 kg of PM would be released from burning 2.58×10^8 kg of MDO over 30 years in service. The consumption of 2.93×10^7 kg of HFO was avoided at the expense of an additional quantity of MDO i.e. 2.78×10^7 kg. Nevertheless, a reduction in all emission types was observed, i.e. 1.3% for CO_2, 1.4% for NO_x, 17.6% for SO_2, 0.5% for CO, 1.3% for HC and 8.7% for PM. As fewer emissions were released, the environmental impact attributable to the power system was alleviated across all impact categories by a minimum of 5.3%, with the exception of Eco-Indicator99: *Resources—Minerals* and Eco-Indicator99: *Ecosystem Quality—Land-Use* (labelled as XXIII and XXV respectively), as illustrated in Figure 5.24.

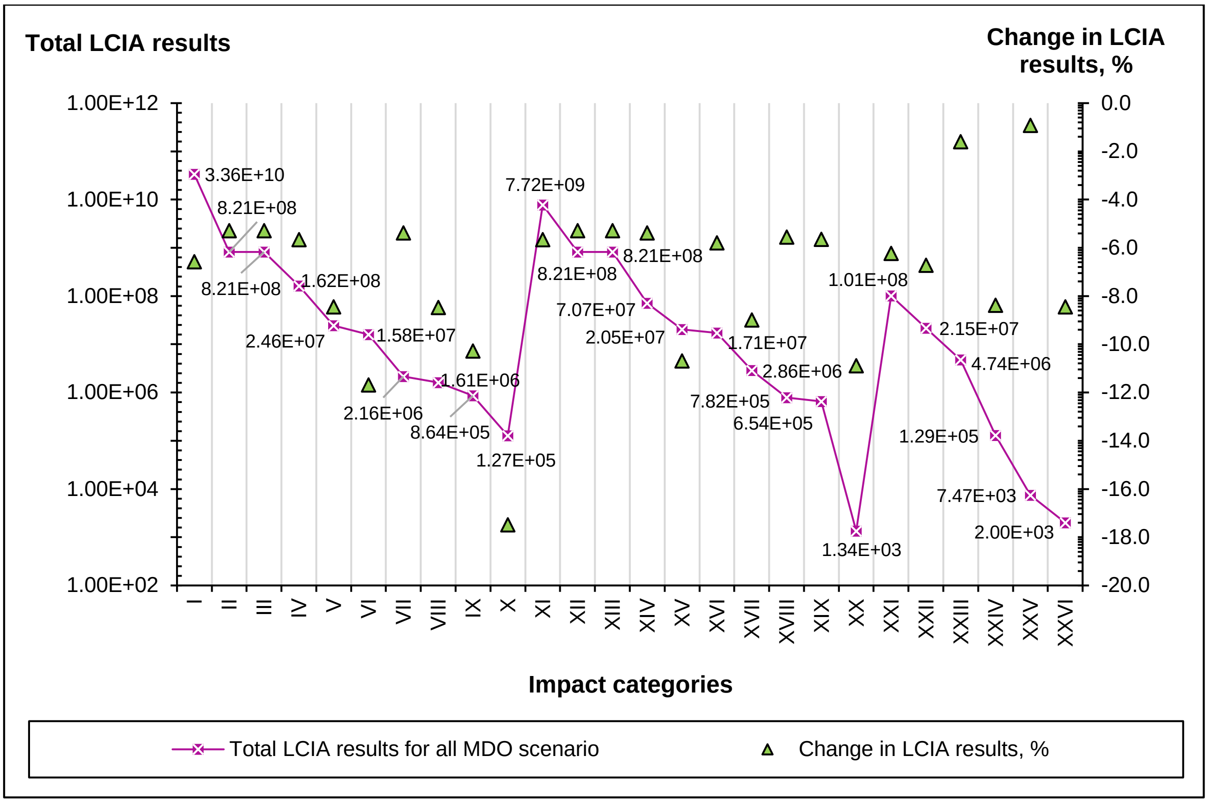
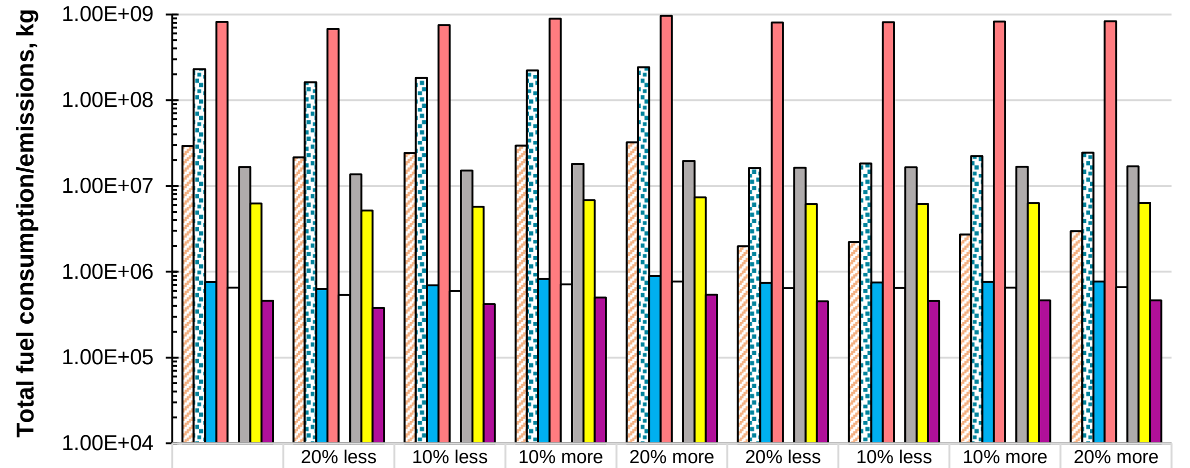


Figure 5.24: Difference in LCIA results compared to the base case scenario when all-MDO was substituted for fuel mix in Case Study 2.

Amongst all impact categories, CML2001: *Terrestric Ecotoxicity Potential* (labelled as X) showed the highest reduction rate i.e. 17.5%. This was followed by CML2001: *Acidification* and *Photochemical Ozone Creation Potential*, ILCD: *Acidification*, *Resource Depletion, Fossil and Mineral* (labelled as VI, IX, XV and XX respectively), which showed a reduction of 11% approximately. Compared to the all-MDO scenario in Case Study 1 which demonstrated an up to 11.2% of reduction in a few impact categories, the environmental benefits across nearly all impact categories offered by the all-MDO scenario in this case study were more attractive. The difference between both scenarios was indeed the systems under study, i.e. conventional system over 30 years in Case Study 1 and conventional system for 10 years and retrofit system for 20 years in this case study. Therefore, the additional reduction (when both systems burned MDO only) was the immediate outcome of implementing the retrofit system. The findings of this scenario supplemented those presented by the ‘business as usual’ scenario, in which the environmental benefits of implementing the retrofit system were verified.

Fuel consumption quantity

As previously reported, the operational profiles of diesel engines and auxiliary generators were subject to change due to various factors, which affected the quantity of fuel consumed by the components throughout their lifespans. In this scenario, the total fuel consumption and emissions estimated for the additional scenarios are illustrated in Figure 5.25. For each scenario under study, the estimated emissions were lower than those of similar scenarios in Case Study 1, as a result of less fuel consumed by the power system in this case study than that in Case Study 1.



	Base case	20% less fuel burned by diesel engines	10% less fuel burned by diesel engines	10% more fuel burned by diesel engines	20% more fuel burned by diesel engines	20% less fuel burned by generators	10% less fuel burned by generators	10% more fuel burned by generators	20% more fuel burned by generators
HFO	2.93E+07	2.15E+07	2.41E+07	2.95E+07	3.22E+07	1.97E+06	2.22E+06	2.71E+06	2.96E+06
MDO	2.30E+08	1.61E+08	1.81E+08	2.22E+08	2.42E+08	1.62E+07	1.83E+07	2.23E+07	2.43E+07
CO	7.58E+05	6.23E+05	6.91E+05	8.25E+05	8.93E+05	7.45E+05	7.52E+05	7.64E+05	7.70E+05
CO2	8.20E+08	6.75E+08	7.48E+08	8.93E+08	9.65E+08	8.06E+08	8.13E+08	8.27E+08	8.35E+08
HC	6.51E+05	5.35E+05	5.93E+05	7.09E+05	7.67E+05	6.43E+05	6.47E+05	6.56E+05	6.60E+05
NOx	1.66E+07	1.36E+07	1.51E+07	1.81E+07	1.95E+07	1.63E+07	1.64E+07	1.67E+07	1.69E+07
SO2	6.26E+06	5.15E+06	5.70E+06	6.82E+06	7.37E+06	6.15E+06	6.21E+06	6.31E+06	6.37E+06
PM	4.58E+05	3.76E+05	4.17E+05	4.99E+05	5.40E+05	4.50E+05	4.54E+05	4.61E+05	4.65E+05

Figure 5.25: Total fuel consumption and emissions of the power system in Case Study 2 after taking into account changes in fuel consumption quantity by diesel engines and auxiliary generators separately.

In the base case scenario of Case Study 2, diesel engines consumed 91.6% of HFO and 87.7% of MDO whilst auxiliary generators burned 8.4% of HFO and 8.8% of MDO respectively. As diesel engines were the main consumers of both HFO and MDO, the analysis showed that every variation of ±10% in fuel consumed by diesel engines would approximately result in a change of ±8.9% in the total amount of each emission type. Less than 1% of change in emissions would be triggered by every variation of ±10% in fuel burned by auxiliary generators. In terms of impact categories, some were under the influence of fuel consumption quantity whilst the others were slightly or not affected at all, as illustrated in Figure 5.26.

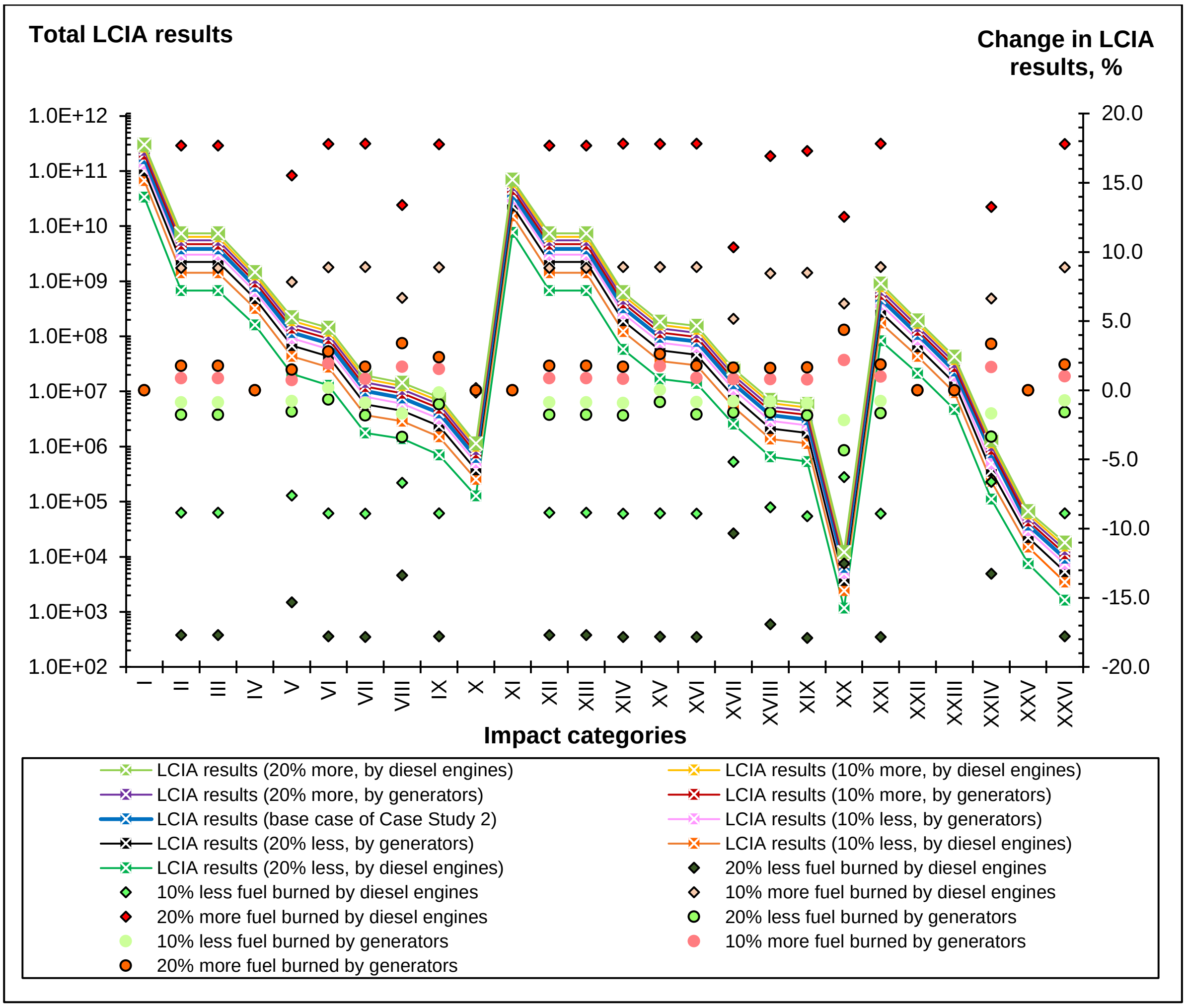


Figure 5.26: Changes in LCIA results due to variation in fuel quantity consumed by diesel engines and generators in Case Study 2.

Impact categories which were affected by changes in fuel consumption quantity included CML2001: *Global Warming (including* and *excluding Biogenic Carbon*), *Human Toxicity*, *Acidification*, *Eutrophication*, *Abiotic Depletion of Fossil* and *Photochemical Ozone Creation Potential* (labelled as II–III, V–VIII and IX), ILCD: *IPCC Global Warming (including* and *excluding Biogenic Carbon)*, *Terrestrial Eutrophication, Acidification, Photochemical Ozone Formation, Total Freshwater Consumption, PM/Respiratory Inorganics*, *Marine Eutrophication* and *Resource Depletion, Fossil and Mineral* (labelled as XII–XX), and Eco-Indicator99: *Ecosystem Quality–Acidification/Nitrification*, *Resources–Fossil Fuels* and *Human Health–Respiratory (Inorganic)* (labelled as XXI, XXIV and XXVI). This was in agreement with the findings gained from similar scenarios of Case Study 1.

However, fuel consumption quantity in Case Study 2 had exerted a slightly stronger influence over such impact categories if compared to Case Study 1, in which the LCIA results for these impact categories would vary by 6.7–9.1% and 0.2–1.7% for every ±10% of fuel consumed by diesel engines and auxiliary generators respectively.

End of life management plans for all components

Disposing metallic scrap to incineration plants was identified as the major cause of ecotoxicity potential (which was reported as one of the two impact categories with the highest indicator results) for both base case and 'business as usual' scenarios based on LCIA results shown by CML2001, ILCD and Eco-Indicator99. For the base case scenario, a reusing-recycling-incineration-landfill ratio of 3:3:2:2 was adopted for the metallic scrap of engines and generators whilst for other components, 33.3% of metallic scrap was recycled, disposed to incineration plants or landfilled respectively. Similar to Case Study 1, sensitivity analysis in this case study was extended to cover end of life management plans of all components to shed light on the possibility to alleviate ecotoxicity potential. The LCIA results are illustrated in Figure 5.27.

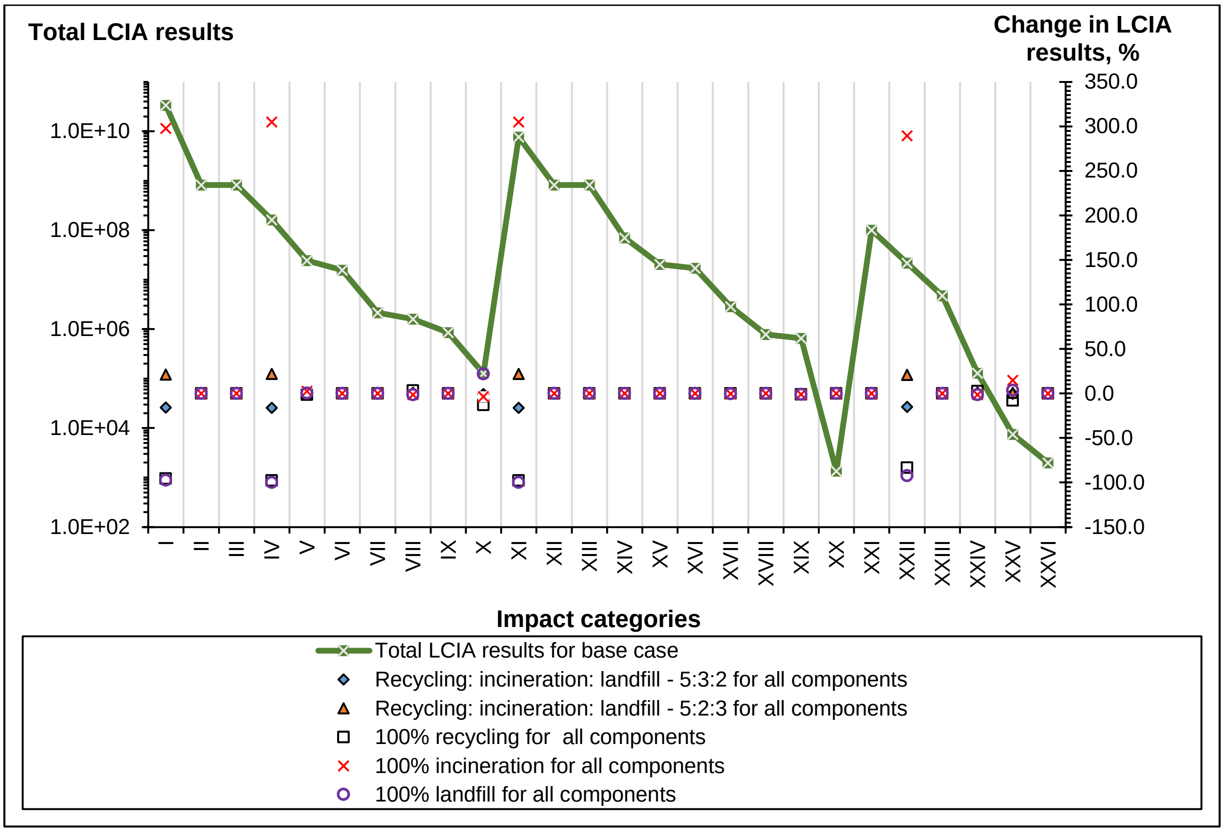


Figure 5.27: Difference in LCIA results due to various end of life management plans for all components.

CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality─Ecotoxicity* (labelled as I, IV, XI and XXII) were sensitive with scrap handling scenarios. The LCIA results for these impact categories were lower when more scrap was recycled or landfilled i.e. declining by 15.3–100.0% if the scrap was fully recycled or landfilled. Nevertheless, the fallout of incineration was very large i.e. increasing up to 305% if scrap was fully sent to incineration plants. In these scenarios, changes in LCIA results when compared to the base case scenario as shown by CML2001, ILCD and Eco-Indicator99 were in agreement. All other impact categories, with the exception of CML2001: *Terrestric Ecotoxicity Potential* and Eco-Indicator99: *Ecosystem Quality─Land-Use* (labelled as X and XXV), showed either no response at all or up to 3.3% of difference in their LCIA results. The LCIA results of CML2001: *Terrestric Ecotoxicity Potential* indicated a 13% reduction when metallic scrap was 100% recycled. Eco-Indicator99: *Ecosystem Quality─Land-Use* was slightly more responsive to the scenarios of 100% recycling and 100% incineration, where a reduction of 7.6% and an increase of 14.9% of the indicator results were showns. Such a variation should be taken into account in deciding the end of life management plan for the power system as it could imply difference in individual impact categories by 1–6 orders of magnitude. Overall, the findings of end of life management plans for the power systems assessed in Case Studies 1 and 2 were in agreement.

Sensitivity analysis, which was performed using scenario analysis, indicated that retrofitting existing power system with emerging marine power technologies could effectively reduce the magnitude of some impact categories, which would inevitably come along with an increase in resource depletion. After all, the new components brought about some environmental impact but such burdens, altogether, were modest and only accounted for less than 15.8% of the total. The impact category that showed the top two highest indicator results, i.e. ecotoxicity potential, could be diminished by recycling or landfilling more scrap instead of disposal to incineration plants.

5.4 Case Study 3: New-Build All-Electric Power System

Following the studies on conventional and retrofit systems, Case Study 3 aimed to assess the impact of a new-build all-electric power system designed for RoRo cargo ships using the same methodology, i.e. LCA based on a bottom-up integrated system approach. Similar to Case Studies 1 and 2, the following sub-objectives were set in compliance with the four LCA phases recommended by ISO 14040:

- define goal and scope of the case study;
- estimate resources consumed and emissions released throughout the life cycle;
- perform impact assessment;
- identify impact and the main contributors; and
- interpret results based on scenario analysis to explore the influence of selected parameters.

The selection of technologies incorporated into the new-build all-electric power system and data sources were reported in **Chapters 5.4.1** and **5.4.2** respectively. Whilst the goal and scope of the case study was defined in **Chapter 5.4.3**, LCI and LCIA results were discussed in **Chapters 5.4.4** and **5.4.5** respectively. Relevant scenario analysis was presented for life cycle interpretation in **Chapter 5.4.6**.

5.4.1 *Selection of technologies incorporated into the new-build system*

An innovative all-electric power system was assessed in this case study. In addition to diesel gensets and additional components such as propulsion motors and power electronics that were necessary for an all-electric power system, emerging technologies included in Case Study 2 i.e. PV and battery systems as well as cold ironing, were also incorporated in this case study. The system was chosen based on four interconnected criteria i.e. industry's interest, innovation, technology readiness and sustainability. The design was perceived to have the potential for commercial applications, innovative but already ready for implementation with reduced environmental burdens if compared to a conventional diesel-mechanical configuration. Similar to Case Study 2, the system was jointly designed by the consortium involved in the project through technical collaboration.

5.4.2 *Data sources*

In principle, background data of primary sources (i.e. on-site, first-hand input/output data recorded by ship owners and operators at real manufacturing plants and end of life management facilities) and high quality (in particular those reported in journal articles) were preferable. However, such data were expensive and not readily available. The requirements on data and their quality were therefore compromised by adopting data from other sources to make the first move to offer insights in this matter. Expert judgement from industry, although subjective, was valuable in this case as the recommendations were made based on day-to-day working experience. The operational profile used in this study was the outcome of an energy management model created in GES based on Simplex method using real-time operational data of a RoRo cargo ship which received frequent port calls within ECAs provided by the ship owner. The approaches applied in Case Studies 1 and 2 in estimating emissions, treating and recovering used lubricating oil, recycling and disposing metallic and non-metallic scrap were also adopted in Case Study 3.

5.4.3 *Goal and scope definition*

The reason of conducting this LCA study was to assess the environmental impact of a new-build all-electric system proposed for RoRo cargo ships. Its application was to support research development and provide information to marine stakeholders and LCA community (i.e. the targeted audience) on selected emerging marine system design i.e. the all-electric power system─the product system of this case study. The findings, which were intended to be disseminated to the targeted audience would provide a reference for a comparative study. The product system of Case Study 3 is illustrated in Figure 5.28. The system consisted of diesel gensets (acting as prime movers and auxiliary generators) augmented by PV and battery systems as well as onboard cold-ironing facility for hotel services in addition to ship propulsion and manoeuvring via motor driven propellers and thrusters, which were altogether enabled by power electronics such as transformers, VFDs, AC-AC converters, inverters and rectifiers. For each component, an appropriate model was proposed as summarised in Table 5.7.

The function of the product system was to supply power to all consumers onboard a RoRo cargo ship for 30 years. The operation of the new-build all-electric system implemented onboard a RoRo cargo ship travelling on regular routes within ECAs over a lifespan of 30 years was set as the functional unit. Acquiring raw materials and energy, manufacturing, operating, maintaining, and handling end of life scrap of all components incorporated into the system were defined as the system boundary. Replacing some technology components was necessary because of their shorter lifespans. To avoid allocation, system expansion was applied to include these additional units as a part of the system boundary.

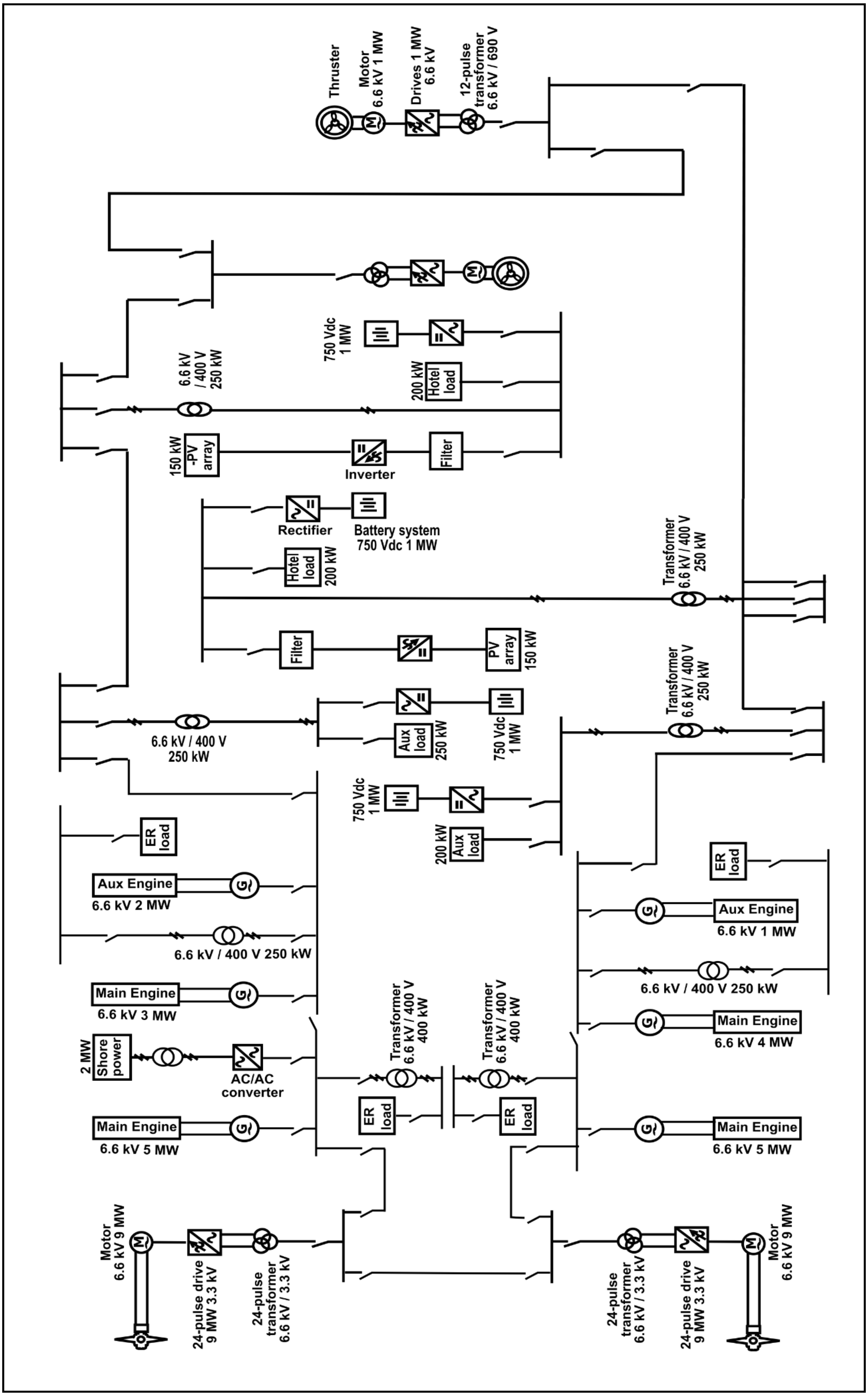


Figure 5.28: Single-line diagram of the power system under study.

Table 5.7: Components incorporated into the new-build power system.

Component	Details (number, make, speed, power rate, mass and lifespan) *
Diesel gensets	• Two units of Wärtsilä W9L32E, 5 MW, 47000 kg, 30 years • One unit of Wärtsilä W8L32E, 4 MW, 43500 kg, 30 years • One unit of Wärtsilä W6L32E, 3 MW, 33500 kg, 30 years • One unit of Wärtsilä W6L26, 2 MW, 17000 kg, 30 years • One unit of Wärtsilä W6L20, 1 MW, 9300 kg, 30 years
PV systems	• Two PV arrays of fixed tilted planes, each consisted of 598 modules manufactured by Kyocera (Type KD245GX-LPB, 245 W_p per module at standard test conditions), 13 modules arranged in series per string for 46 strings occupying 984 m^2 supplying 147 kW_p, 21 kg per module, 30 years • One inverter per array, made by Schneider Electric GT100-208, 300–480 V, 100 kW AC, 1.7 m x 1.2 m x 1.9 m, 1361 kg, 10 years
Lithium-ion battery systems	• Four phosphate graphite lithium-ion battery systems, manufactured by SAFT Speciality Battery Group (referred to as Seanergy® battery system Type LiFePO4 VL 41M Fe 265 Wh/liter), 8 battery racks contributing to 1 MWh per system, each rack (composed of 14 modules and each module consisted of 14 cells) was 6 m x 8 m x 12–23 m and 730 kg or 560 kg with or without cabinet, 20 years • One unit of Sitras® REC rectifier per battery system, 750 V, 0.8 m x 2.2 m x 1.4 m, 850 kg, 10 years
Cold ironing	• One unit of RESIBLOC® cast-resin transformer with a power of 1000 kVA produced by ABB, 3150 kg with a dimension of 2.08 m x 1.58 m x 2.20 m (inclusive casing), 20 years • One unit of SINAMICS G150-42-2EA3 AC/AC converter, 2150 kW, 3.6 m x 2.0 m x 0.6 m, 3070 kg, 20 years
Propellers and motors	• Two Wärtsilä controllable pitch propellers 4D1190 with a hub diameter of 1.19 m, 59400 kg, 30 years • Two units of brushless, synchronous propulsion motors made by Hyundai Type HHI/HAN3245-16, 8900 kW, 15–125 rpm, 3 phases, 16 poles, 110000 kg, 30 years
Thrusters and motors	• Two units of Wärtsilä CT/FT 175M controllable pitch transverse thrusters, standard design, 60 Hz, 1170 rpm, 995 kW, 5600 kg, 30 years • Two units of squirrel cage, induction thruster motors made by Hyundai Type HHI/HRN7567-6, 1250 kW, 1200 rpm, 3 phases, 6 poles, 630 V, 60 Hz, 75000 kg, 30 years
VFDs	• Two units of ABB MEGADIVE LCI drives A1212-211N465 connecting propulsion motors, air-cooled, 9100 kW, 10000 kVA, 7000 kg, 15 years • Two units of Altivar ATV1200-A1190-4242 medium voltage VFDs connecting thruster motors, 995 kW, 1190 kVA, 4.06 m x 1.40 m x 2.67 m, 5000 kg, 15 years
Transformers	• Two units of 24-pulse transformers connecting propulsion motors, each unit consisted of two 12-pulse, dry cast resin transformers made by TRAFOTEK, 6890 kVA, 6600 V, 60 Hz, 3.25 m x 2.56 m x 1.68 m, 10900 kg, 20 years

	• Two units of 12-pulse, dry transformers connecting thruster motors, made by TRAFOTEK, 1750 kVA, 6600 V, 60 Hz, 2.63 m x 1.99 m x 1.38 m, 3600 kg, 20 years • Distribution transformers–2 units of ABB RESIBLOC® transformers, 400 kVA under no load loss condition, 1.66 m x 1.17 m x 1.71 m, 1580 kg (or 1420 kg without casing); 6 units of ABB RESIBLOC® transformers, 250 kVA under no load loss condition, 1.51 m x 1.12 m x 1.66 m and 1220 kg (or 810 kg without casing), 15 years

* All details, with the exception of the number of components, were presented for a single unit; models were proposed by the industrial consortium.

The same method i.e. GES and real-time data from the same reference ship were used in modelling the operational profile of the all-electric system. Having said that, the operational profile of the system was different from the systems assessed in Case Studies 1 and 2. At sea, three or more gensets and at least one propeller would be run for power generation and ship propulsion. With sufficient radiation during day time, energy was generated by PV systems. The generated power from all sources was taken and distributed by a main switchboard via distribution bus bars to meet power demand of all consumers for propulsion, hotel loads, heating, ventilation, cooling etc. Surplus energy was stored up by battery systems which supplemented power supply during peak loads. Thrusters were in operation during manoeuvring and mooring whilst power demand was met mainly by running two gensets. The ship was connected to onshore power which supplied electricity for hotel services, cargo equipment, deck machinery and battery charging when waiting in port for unloading/loading cargos before the following journey. Electric motors and power electronics were in use in line with their connecting propellers, thrusters, gensets, onshore power supply, PV or battery systems. MDO was the only fuel type burned by gensets.

Similar to Case Studies 1 and 2, it was assumed that (i) the cargo ship would operate within ECAs with fixed business routes; (ii) without retrofit, the power system would operate to meet the power demand onboard the cargo ship ranging 1250–9033 kW over 30 years experiencing no malfunction; (iii) materials used in manufacturing power electronics such as inverters, rectifiers and converters and their processes were similar, as were 24-pulse, 12-pulse and distribution transformers; (iv) components of old diesel gensets could be reused if in good condition, and therefore the scrap was 30% reused, 30% recycled, 20% disposed to incineration plants and the rest was disposed to landfill (as modelled in the base case); and (v) metallic scrap of other technology components would be equally recycled, disposed to incineration plants or landfill.

For consistency, this case study also had limitations as in Case Studies 1 and 2. The limitations included the exclusion of engineering design and approval, material loss during manufacture, ancillaries such as the main switchboard, bus bars, circuit breakers, fuses, wires, fuel oil systems, pipings and an emergency power supply system from system boundary (although the product system could only function appropriately and safely in practice with the use of these devices), installation, transportation, spatially and temporally specific data, and changes in future technology. The exclusion was necessary due to limited resources, the already complicated scope (without taking account of ancillaries), and their relatively negligible impact if compared to the system under study which consisted of components that were currently included in the system boundary. Other features which were in common with Case Studies 1 and 2 included (i) value choice (with respects to the selection of ship type, technologies and characterisation models); (ii) comparison of impact categories i.e. 26 in total as defined in **Chapter 5.2.3** based on magnitude of the indicator results; (iii) avoidance of normalisation and weighting to allow for comparative study; (iv) identification of significant components and processes, check for completeness and consistency; and (v) use of scenario analysis for sensitivity analysis during life cycle interpretation.

5.4.4 *LCI results: resources and emissions*

As illustrated in Figure 5.29, a selection of materials ranging 1–5 orders of magnitude would be required in manufacturing components that were incorporated into the new-build power system. In descending order, steel, cast iron, copper and aluminium were estimated as the top four most commonly consumed materials i.e. $4.52x10^5$ kg, $1.48x10^5$ kg, $1.11x10^5$ kg and $9.03x10^4$ kg respectively.

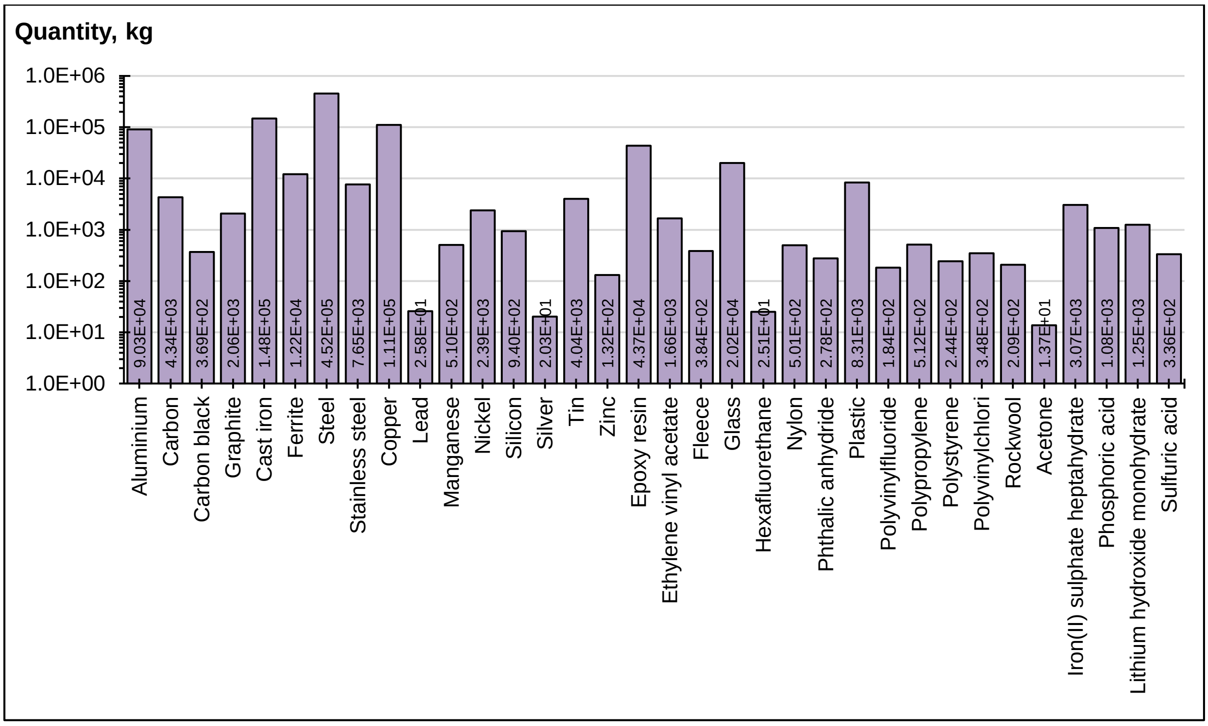
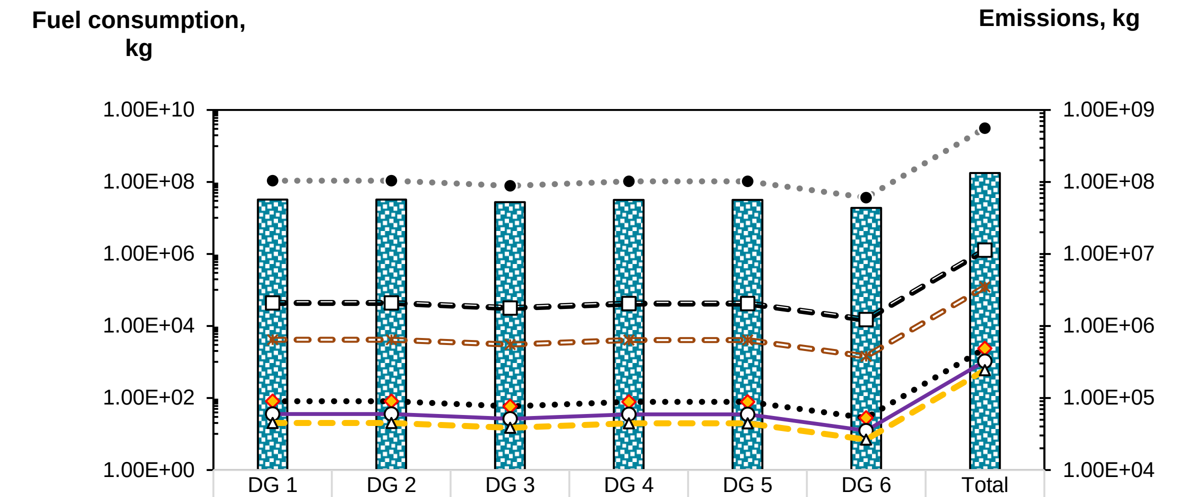


Figure 5.29: Materials used in manufacturing components incorporated into new-build system, in kg.

The main constituents of these materials would be used in manufacturing diesel gensets, propellers and shafts, propulsion motors and the connecting drives as well as transformers and thruster motors. Significant usage included (i) 16.2%, 27.3% and 40.0% of steel for propellers and shafts, thruster motors and propulsion motors respectively; (ii) 92.5% of cast iron for diesel gensets; (iii) 14.9%, 21.8% and 34.6% of copper for thruster motors, propulsion motors and propellers and shafts respectively; and (iv) 15.7% and 43.1% of aluminium for the drives and transformers that connected to propulsion motors. During the processes, 4.15×10^3 MJ, 3.15×10^5 MJ, 8.86×10^5 MJ and 2.24×10^5 MJ of energy would be provided, respectively, by furnaces which burned heavy and light fuel oils respectively, and boilers which burned natural gas and electricity directly. Among all, manufacturing propellers and shafts, thruster motors, diesel gensets and propulsion motors would use up approximately 13%, 16%, 22% and 24% of the energy provided by furnaces and boilers, respectively. Meanwhile, approximately 75% of electricity would be required for manufacturing thruster motors, diesel gensets, propulsion motors and PV systems, accounting for 12.3%, 16.1%, 18.0% and 27.9% respectively. In terms of the two largest non-metallic material types being utilised, 70.0% of epoxy resin and 93.4% of glass would be consumed in manufacturing transformers connecting propulsion drives and PV systems respectively.

Without fuel mix, the operation of diesel gensets over 30 years would burn 1.76×10^8 kg of MDO, which in turn released 4.87×10^5 kg of CO, 5.60×10^8 kg of CO_2, 2.43×10^5 kg of PM, 3.25×10^5 kg of HC, 1.13×10^7 kg of NO_X and 3.49×10^6 kg of SO_2, as illustrated in Figure 5.30.



	DG 1	DG 2	DG 3	DG 4	DG 5	DG 6	Total
MDO	3.3E+07	3.3E+07	2.8E+07	3.2E+07	3.2E+07	1.9E+07	1.8E+08
CO	9.0E+04	9.0E+04	7.7E+04	8.9E+04	8.9E+04	5.3E+04	4.9E+05
CO2	1.0E+08	1.0E+08	8.8E+07	1.0E+08	1.0E+08	6.1E+07	5.6E+08
HC	6.0E+04	6.0E+04	5.1E+04	5.9E+04	5.9E+04	3.5E+04	3.2E+05
NOx	2.1E+06	2.1E+06	1.8E+06	2.1E+06	2.1E+06	1.2E+06	1.1E+07
SO2	6.5E+05	6.5E+05	5.5E+05	6.3E+05	6.3E+05	3.8E+05	3.5E+06
PM	4.5E+04	4.5E+04	3.8E+04	4.4E+04	4.4E+04	2.6E+04	2.4E+05

Figure 5.30: Fuel consumption and emissions released, both in kg, during the operation of the new-build power system, as per diesel gensets (DG1–DG6) over 30 years.

With consultation from industrial consortium members involved in this study, it was estimated that 9.46×10^4 kg of lubricating oil would be required in maintaining diesel gensets, propellers, thrusters and motors regularly over the lifespan for optimum performance. To treat and recover used lubricating oil, 1.91×10^2 kg of light fuel oil, 2.29×10^2 kg of liquefied petroleum, 2.54×10^2 kg of diesel, 4.38×10^5 MJ of heat supplied by burning natural gas and 4.92×10^6 MJ of energy supplied by electricity would be needed. As illustrated in Figure 5.31, 6.58×10^5 MJ of electricity and 5.51×10^5 MJ of heat supplied by burning natural gas were reported as the largest energy sources to be consumed in dismantling the power system and handling the scrap.

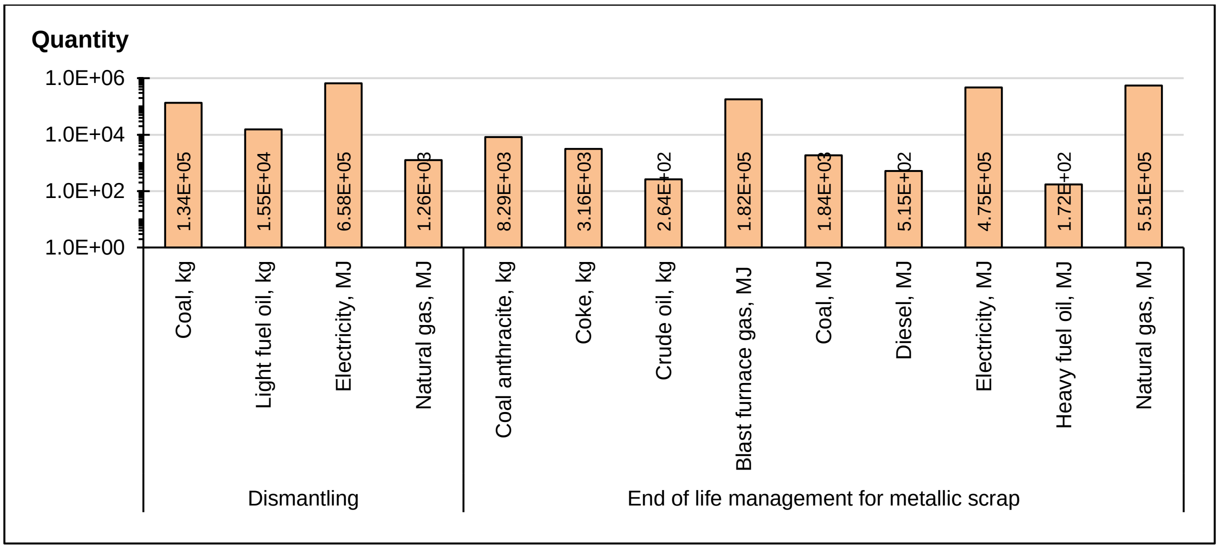


Figure 5.31: Resource consumption during dismantling and the end of life.

From a life cycle perspective, emissions would be mainly released to air and freshwater: (i) 1.89×10^4 kg of heavy metals, 2.51×10^5 kg of particles, 3.30×10^5 kg of organic emissions and 5.76×10^8 kg of inorganic emissions to air; and (ii) 2.52×10^2 kg of organic emissions, 1.14×10^3 kg of heavy metals, 3.31×10^3 kg of particles, 3.25×10^5 kg of Ecoinvent long-term emissions and 5.26×10^5 kg of inorganic emissions to freshwater. Contribution of individual technologies towards each emission type is illustrated in Figure 5.32 based on LCI results estimated using GaBi models. For emissions released to air, diesel gensets were the primary contributors, accounting for approximately 99% of particles, organic and inorganic emissions respectively. Heavy metals released to air due to propulsion and thruster motors were noticeable (i.e. 29.1% and 19.8% respectively), together with diesel gensets as well as propellers and shafts (each resulted in approximately 16%). In relation to organic and particle emissions to freshwater, transformers connecting propulsion motors were accountable for 70.6–72.6%. A more balanced distribution was observed for inorganic, heavy metals and ecoinvent long-term emissions to freshwater, in which the major contributors were propulsion motors (24.7–28.8%), thruster motors (16.9–19.6%), propellers and shafts (13.8–15.9%) and diesel gensets (13.4–15.6%). Whilst transformers connecting propulsion drives instigated 6.7–15.5% of such emissions, other technologies were accounted for 1.0–4.6% each.

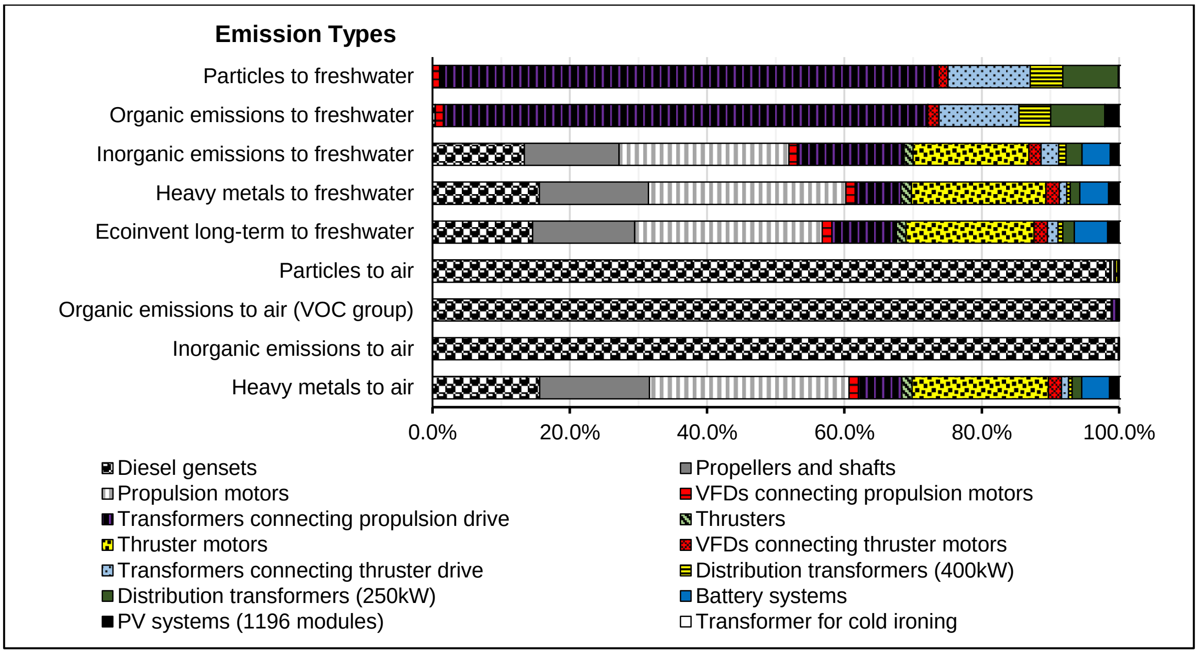


Figure 5.32: Emissions of the all-electric power system from acquisition of raw materials and energy to end of life management as per individual technologies, which were estimated via LCA models developed in GaBi for base case scenario.

5.4.5 *LCIA results*

By applying CML2001, ILCD and Eco-Indicator99, the LCIA results for these impact categories are illustrated in Figure 5.33.

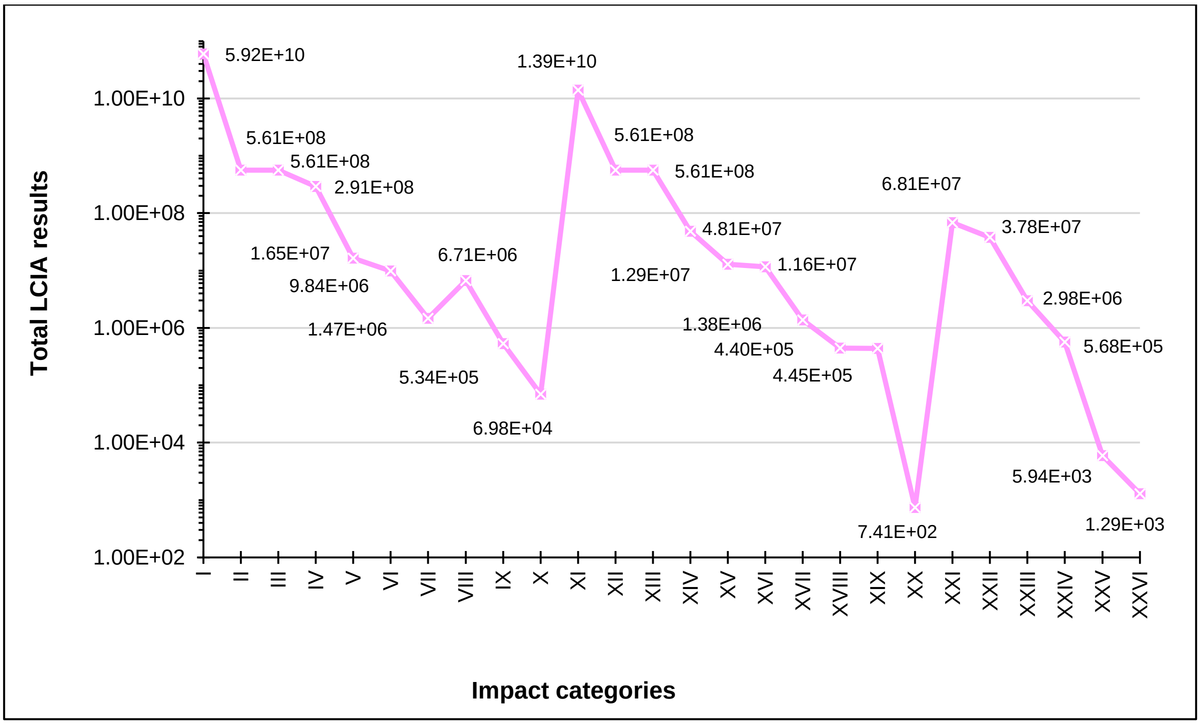


Figure 5.33: Total environmental burdens attributable to the new-build power system, characterised for individual impact categories.

Similar to Case Studies 1 and 2, the impact categories that showed the highest indicator results as assessed by these methodologies were not of the same kind i.e. CML2001: *Marine Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality─Acidification/Nitrification* (labelled as I, XI and XXI respectively). The estimated indicator results for these impact categories were 5.92x10^{10} kg $C_4H_8Cl_2$ equivalent, 1.39x10^{10} CTUe and 6.81x10^7 PDF*m^2*a respectively. Again, such disparity was mainly because of the adoption of diverse underlying environmental mechanisms and mathematical relationships. The orders of magnitude for CML2001: *Marine Aquatic Ecotoxicity Potential* and ILCD: *Ecotoxicity for Aquatic Freshwater* were in agreement, indicating 3 orders of magnitude more burdensome than that assessed by Eco-Indicator99. The majority of the impact categories were in the range of 5–8 orders of magnitude whilst CML2001: *Terrestric Ecotoxicity Potential* was of 2 orders of magnitude. In Case Studies 1 and 2, CML2001: *Abiotic Depletion of Fossil* (labelled as VIII) was less burdensome than CML2001: *Eutrophication Potential* (labelled as VII), although both were of the same order of magnitude. However, Case Study 3 showed a contrary trend. The analysis showed that the magnitude of CML2001: *Abiotic Depletion of Fossil* was higher due to the consumption of natural gas and crude oil in producing epoxy resin liquid, which was required for manufacturing transformers. The contribution of individual technologies towards all estimated impact categories is illustrated in Figure 5.34. At least 73.99% of all impact categories (except CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources─Fossil Fuels*, labelled as VIII and XXIV respectively) were attributable to diesel gensets, propellers and shafts, propulsion and thruster motors.

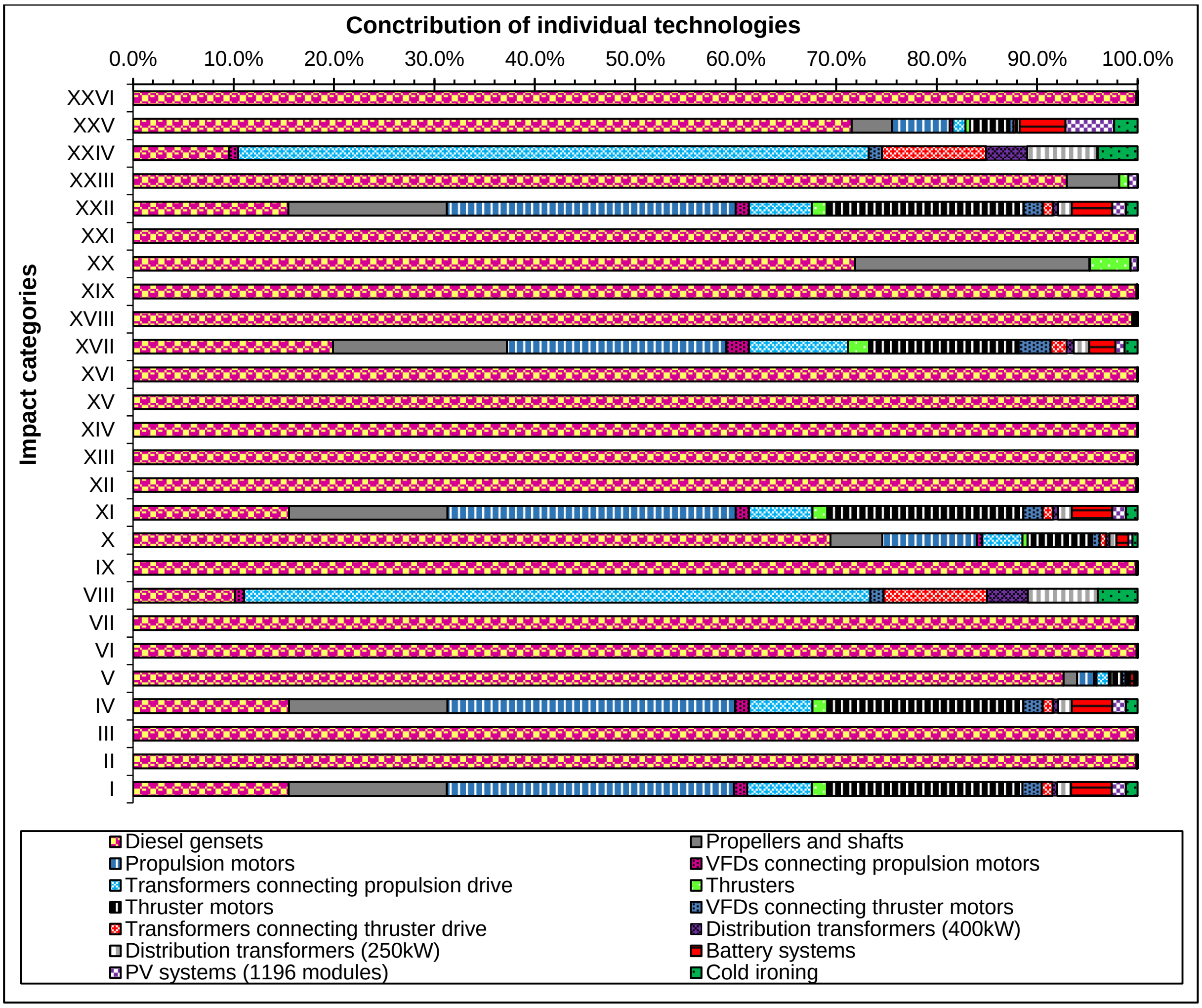


Figure 5.34: Contribution of individual components towards individual impact categories attributable to the new-build all-electric system.

Correlations between impact categories and technologies were observed. In total, 14 impact categories were relevant to global warming, acidification, eutrophication, photochemical ozone creation and PM/respiratory inorganic health issue (labelled as II–III, VI–VII, IX, XII–XVI, XVIII–XIX, XXI and XXVI respectively). Diesel gensets were nearly fully accountable for these impact categories i.e. more than 99.0%, predominantly caused by their operation. The other 12 impact categories covered ecotoxicity, human toxicity, resource depletion and consumption (labelled as I, IV–V, VIII, X–XI, XVII, XX and XXII–XXV respectively). Disposing metallic scrap of diesel gensets to incineration plants was significant, leading to CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity*, and *Human Toxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, V, XI and XXII respectively).

Due to tin and chromium consumption during manufacture and fossil consumption during operation, diesel gensets also contributed remarkably towards CML2001:

Terrestric Ecotoxicity Potential, ILCD: *Resource Depletion, Fossil and Mineral* and Eco-Indicator99: *Ecosystem Quality–Land-Use* (labelled as X, XX and XXV, ranging 69.4–71.9%) and approximately 93% of Eco–Indicator99: *Resources–Minerals* (labelled as XXIII). A noteworthy effect on these impact categories was resulted by propellers and shafts, their connecting motors and transformers and/or thruster motors.

Approximately 62% of the LCIA results for CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources–Fossil Fuels* (labelled as VIII and XXIV respectively) were caused by transformers connected to propulsion drives, mostly due to the production of epoxy resin liquid used in manufacturing the transformers. In relation to CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and *Total Freshwater Consumption*, and Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, XI, XVII and XXII), contributions from propellers and shafts, propulsion motors and thruster motors ranged 15.8–17.3%, 21.8–28.8% and 14.9–19.6% respectively, in which disposing metallic scrap of these components to incineration plants was the main cause. Other technologies including VFDs, distribution transformers, battery systems, PV systems and cold ironing contributed to the environmental burdens to such an extent that they were relatively negligible when compared to diesel gensets, propellers and shafts, propulsion and thruster motors, in spite of resources being consumed and the components being operated over the same period of lifespan.

5.4.6 *Life cycle interpretation*

Throughout the life cycle of the all-electric system, operating diesel gensets and disposing metallic scrap of diesel gensets, propellers and shafts, propulsion and thruster motors to incineration plants were identified as the key processes with serious consequences. Both were significant to such an extent that the former largely resulted in 14 impact categories (i.e. II–III, VI–VII, IX, XII–XVI, XVIII–XIX, XXI and XXVI respectively) whilst the latter was conspicuously accountable for impact categories which were relevant to ecotoxicity i.e. the impact category that showed the top two highest indicator results as assessed by CML2001, ILCD and Eco-Indicator99. To further investigate these two factors, the following additional scenarios were modelled and the LCIA results were compared to those of base case scenario:

1 fuel consumption if fuel consumed by diesel gensets, compared to the quantity in base case scenario, was

- (i) 10% less;
- (ii) 20% less;
- (iii) 30% less;
- (iv) 10% more;
- (v) 20% more;
- (vi) 30% more;

2 end of life management plans for significant components of Case Study 3 (i.e. diesel gensets, propellers and shafts, propulsion and thruster motors), if metallic scrap was

- (i) 50% recycled, 30% disposed to incineration plants and 20% sent to landfill;
- (ii) 50% recycled, 20% disposed to incineration plants and 30% sent to landfill;
- (iii) 100% recycled;
- (iv) 100% disposed to incineration; and
- (v) 100% disposed to landfill; and

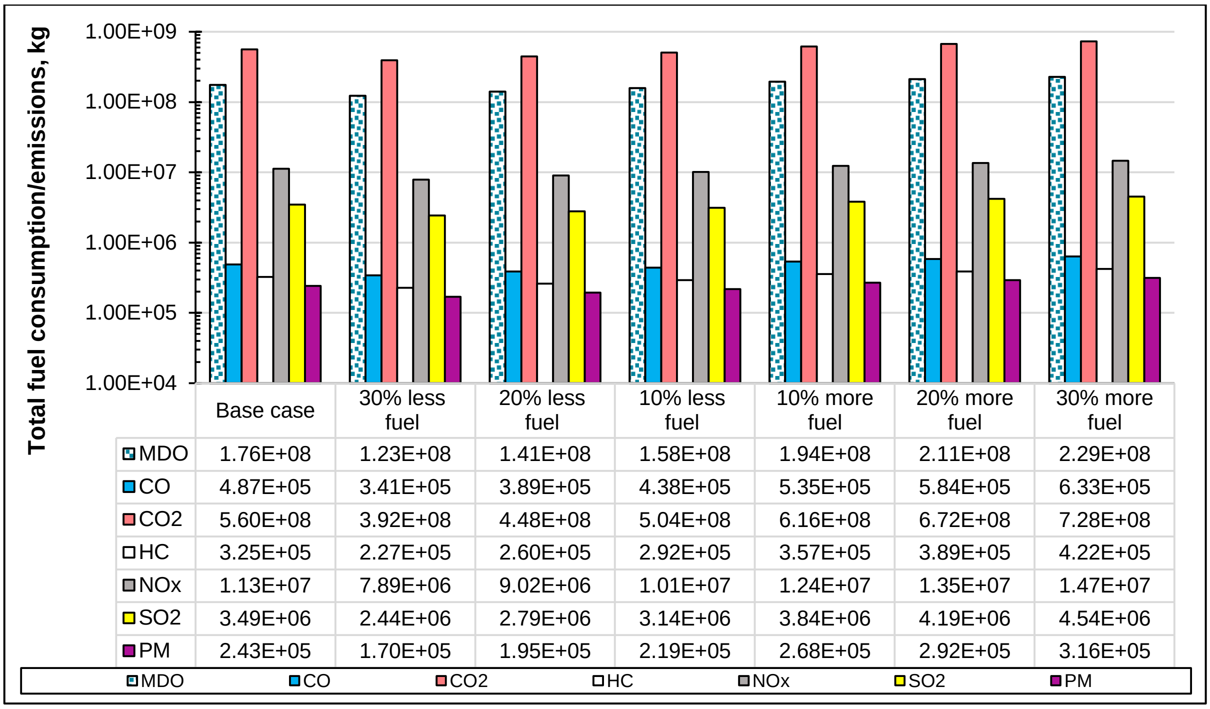
3 end of life management plans for all components, similar to 2 (i)–(v).

The influence of other parameters including mass, material proportion, alternative component and fuel type were not explored due to different reasons: mass and material proportion were perceived to have less influence on the overall LCIA results, as demonstrated in Case Study 1; no alternative component was suggested for individual technologies; and the system was designed to operate by burning MDO fuel only without fuel mix.

Fuel consumption

Similar to the diesel engines and generators assessed in Case Studies 1 and 2, the operation of the diesel gensets that were incorporated into the new-build system was subject to change in practice and might not strictly follow the optimal profile. Emissions released by the power system when fuel burned by diesel gensets varied by 10%, 20% and 30% are illustrated in Figure 5.35.

Because diesel gensets were the only components that burned fuel, the magnitude of emissions was estimated to be directly varied with the change in fuel consumption.



	Base case	30% less fuel	20% less fuel	10% less fuel	10% more fuel	20% more fuel	30% more fuel
MDO	1.76E+08	1.23E+08	1.41E+08	1.58E+08	1.94E+08	2.11E+08	2.29E+08
CO	4.87E+05	3.41E+05	3.89E+05	4.38E+05	5.35E+05	5.84E+05	6.33E+05
CO2	5.60E+08	3.92E+08	4.48E+08	5.04E+08	6.16E+08	6.72E+08	7.28E+08
HC	3.25E+05	2.27E+05	2.60E+05	2.92E+05	3.57E+05	3.89E+05	4.22E+05
NOx	1.13E+07	7.89E+06	9.02E+06	1.01E+07	1.24E+07	1.35E+07	1.47E+07
SO2	3.49E+06	2.44E+06	2.79E+06	3.14E+06	3.84E+06	4.19E+06	4.54E+06
PM	2.43E+05	1.70E+05	1.95E+05	2.19E+05	2.68E+05	2.92E+05	3.16E+05

Figure 5.35: Emissions of the power system, in kg, when different quantities of fuel were burned by diesel gensets.

Following variation in fuel consumption, changes in LCIA results when compared to base case scenario are illustrated in Figure 5.36.

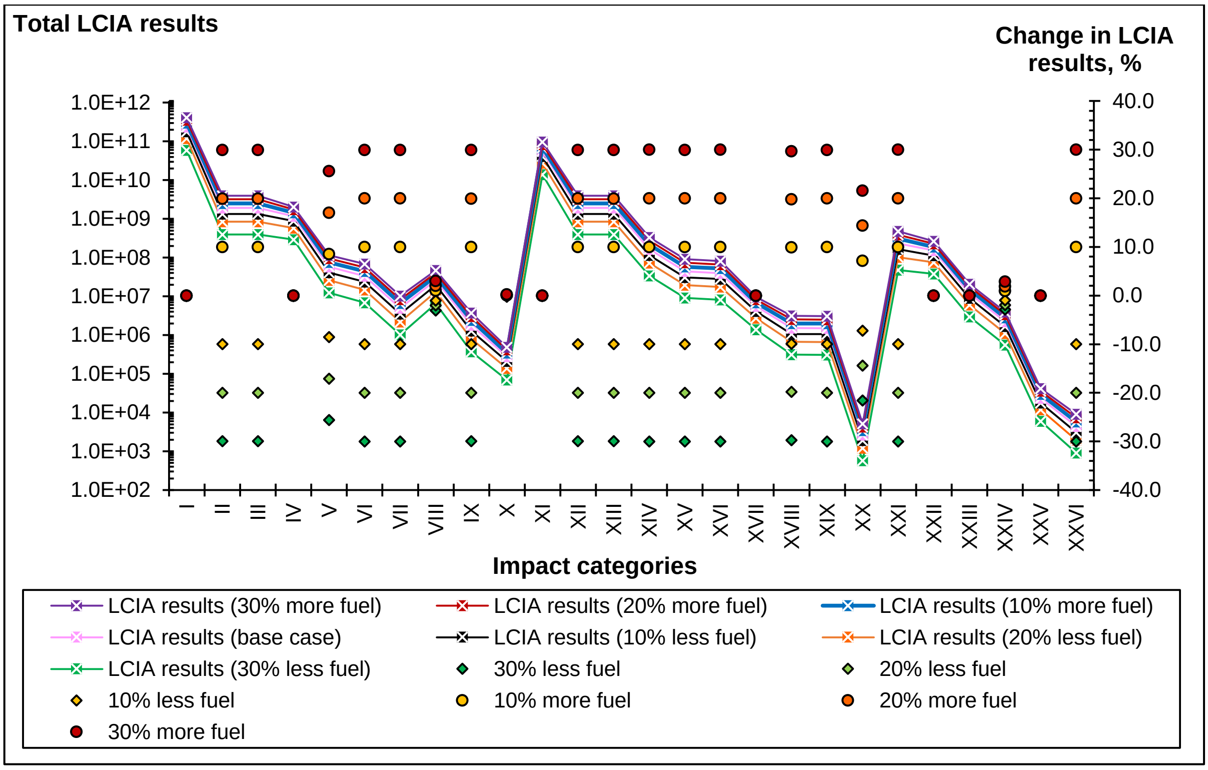


Figure 5.36: Changes in LCIA results for all impact categories compared to the base case scenario when fuel consumed by diesel gensets was reduced by 10%, 20% and 30% or increased by 10%, 20% and 30% respectively.

Correlations between fuel consumption and impact categories were observed. An x% of increase (or decrease) in fuel consumption would lead to approximately x% of such change in the environmental impact categories that were largely caused by diesel gensets. They included CML2001: *Global Warming (including and excluding Biogenic Carbon)*, *Acidification*, *Eutrophication* and *Photochemical Ozone Creation Potential*, ILCD: *IPCC Global Warming (including and excluding Biogenic Carbon)*, *Terrestrial Eutrophication*, *Acidification*, *Photochemical Ozone Formation*, *PM/Respiratory Inorganics* and *Marine Eutrophication* and Eco-Indicator99: *Ecosystem Quality–Acidification/Nitrification* (labelled as II–III, VI–VII, IX, XII–XVI, XVIII–XIX and XXI). A linear relationship was formed. The more fuel was consumed, the larger magnitude of these impact categories would be. It was worth noting that battery systems, PV systems and cold ironing were incorporated to lighten power loads; without them, more fuel would be consumed. By investigating the scenarios of burning 10%, 20% and 30% more fuel, the benefits of these emerging technologies were justified indirectly too.

Variation in LCIA results for impact categories related to fossil fuels was dependent on the total contribution of diesel gensets towards such impact categories. The variation ranged 0.95–3.04% for CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources–Fossil Fuels* (labelled as VIII and XXIV; 10.14% and 9.54% respectively caused by diesel gensets in base case scenario) and 7.2–21.6 % for ILCD: *Resource Depletion, Fossil and Mineral* (labelled as XX; 71.9% attributable to diesel gensents in base case scenario). Thus, the more diesel gensets contributed to these impact categories, the more profound the change in LCIA results would be due to variation in fuel consumption quantity.

A unique causal relationship was found between CML2001: *Human Toxicity Potential* (labelled as V) and fuel consumption. Although the impact was still a function of fuel consumption, the ratio of difference in the LCIA result to change in fuel consumption was not one to one due to the influence of other technologies. For impact categories relevant to ecotoxicity, mineral and freshwater consumption i.e. CML2001: *Marine, Freshwater Aquatic* and *Terrestric Ecotoxicity*, ILCD: *Ecotoxicity for Aquatic Freshwater, Total Freshwater Consumption,* Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* and *Resources–Minerals* (labelled as I, IV, X, XI, XVII and XXII–XXIII), the influence of changes in fuel consumption was very minimal or had no influence at all. This was in agreement with previous analysis which showed that operating diesel gensets had insignificant influence on these impact categories.

The analysis indicated that the impact attributional to the power system varied with fuel consumed by diesel gensets significantly, less noticeably or very minimally, depending on the overall contribution of diesel gensets towards individual impact categories.

End of life management plans for significant components

In relation to the end of life phase of components incorporated into the system, the extent to which they were reused, recycled and disposed to incineration plants or landfill in reality was uncertain. In base case scenario, a reuse-recycling-incineration-landfill ratio of 3:3:2:2 was adopted for diesel gensets whilst for other components, 33.3% of metallic scrap was recycled, disposed to incineration plants or landfill respectively. Considering that theoretical analysis could provide insights into this complex matter, additional scenarios were modelled with a focus on significant components i.e. diesel gensets, propellers and shafts, propulsion and thruster motors. Changes in LCIA results for the additional scenarios are illustrated in Figure 5.37.

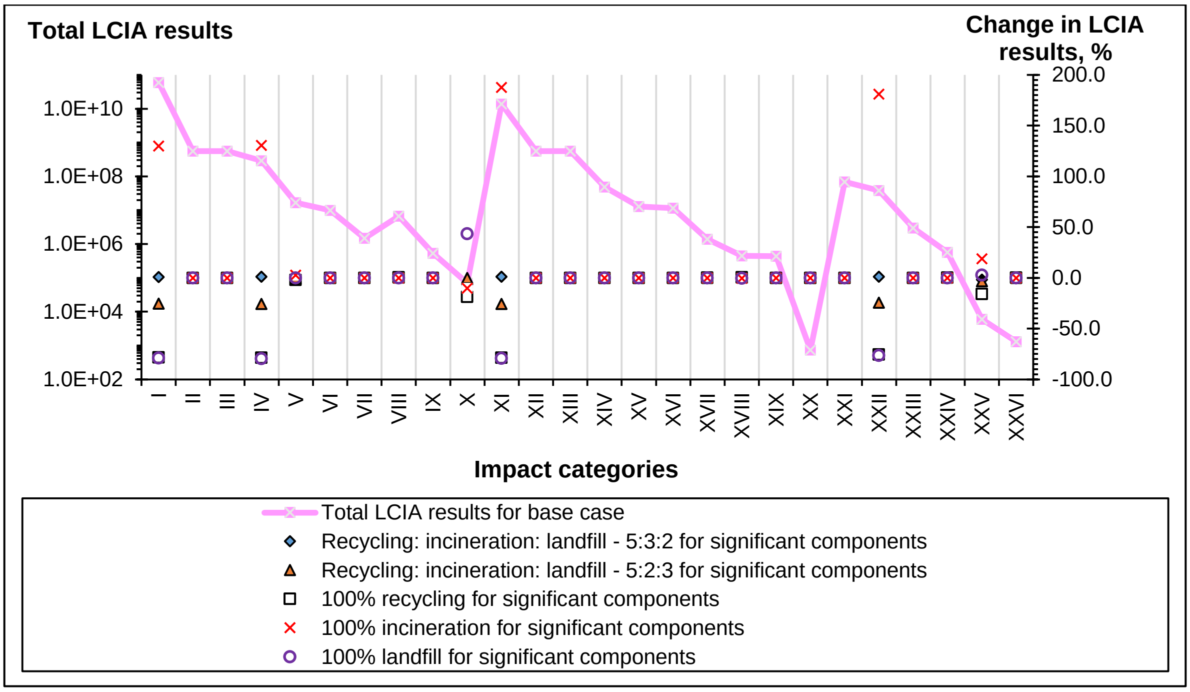


Figure 5.37: Difference in LCIA results due to changes in the end of life management plans of significant components i.e. diesel gensets, propellers and shafts, propulsion and thruster motors.

It was found that the end of life management scenarios would affect ecotoxicity more whilst exerting a less significant influence over other impact categories. Similar trends were observed for CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, XI and XXII) but not exactly for CML2001: *Terrestric Ecotoxicity Potential* (labelled as X). The former impact categories could be reduced by up to 79% if the scrap was fully recycled or disposed to landfill, but increased by 130–188% for the case of 100% disposal to incineration plants to the contrary. An approximate 25% reduction was observed when 50%, 20% and 30% of the scrap were recycled, disposed to incineration plants and landfilled respectively. With the same recycling rate but reversed ratios for incineration and landfill, the difference was imperceptible (as the rate for incineration was close to that in base case). The trends shown by CML2001: *Terrestric Ecotoxicity Potential* (labelled as X) were dissimilar because in most scenarios, chromium and cast iron consumption during manufacture had exerted a greater influence over the impact compared to metallic scrap disposal at the end of life. The situation altered when the scrap was 100% disposed to landfill where a sharp increase in the potential was triggered.

<u>End of life management plans for all components</u>

When all components were taken into account, LCIA results for the additional scenarios showed a similar trend to previous scenarios which considered significant components only, but to a greater extent. Changes in LCIA results due to variation in the end of life management plans of all components are illustrated in Figure 5.38.

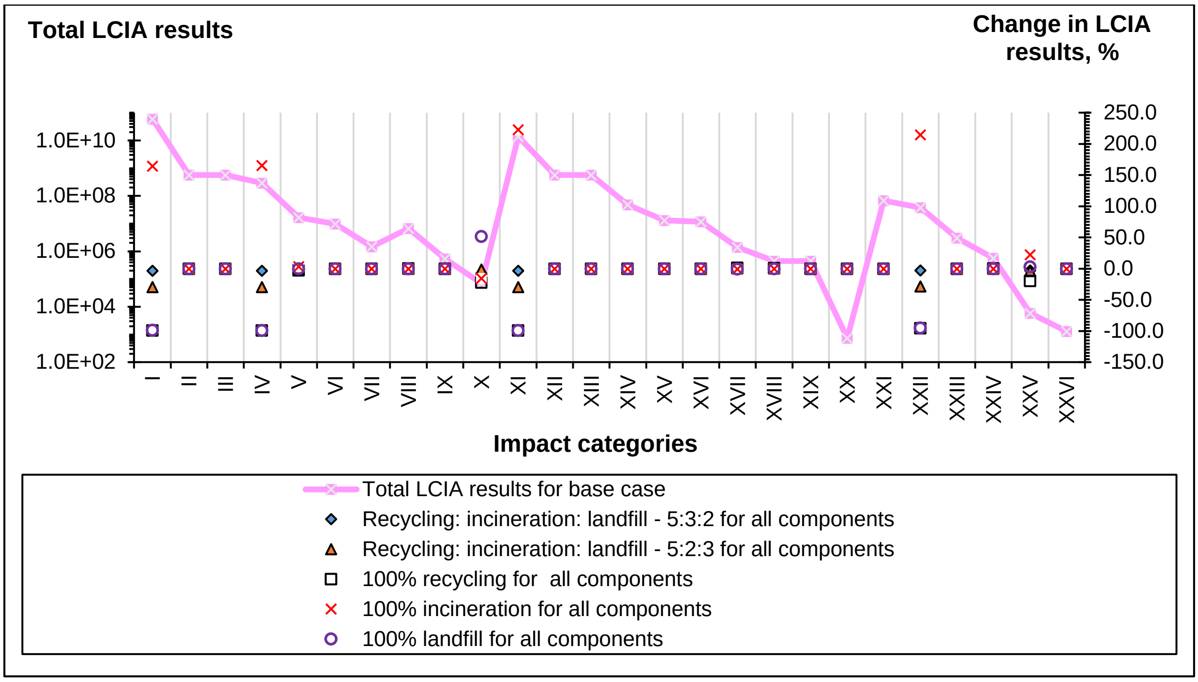


Figure 5.38: Difference in LCIA results due to changes in the end of life management plans of all components.

Compared to base case scenario, CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, XI and XXII) were reduced by 95.4–99.2% if the scrap was fully recycled or disposed to landfill. The indicator results for these impact categories could be only reduced by approximately 30% and 3% when the scrap was 20% and 30% disposed to incineration plants respectively. The indicator results were further intensified with the quantity of scrap disposed to incineration plants, in which a 100% disposal to incineration plants would worsen the impact categories by 164.6–222.7%. An 8% of change in CML2001: *Terrestric Ecotoxicity Potential* (labelled as X) was observed when all components were considered, compared to the scenario which considered end of life management plans of diesel gensets, propellers and shafts, propulsion and thruster motors only.

The findings proved that disposing scrap to incineration plants had the strongest influence on CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, XI and XXII) whilst recycling and disposing scrap to landfill had a moderate effect. Reduction in some environmental burdens following a course of action (e.g. CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99:

Ecosystem Quality–Ecotoxicity) would come along with an increase in other burdens (e.g. CML2001: *Terrestric Ecotoxicity Potential*); and therefore, the end of life phase needed to be appropriately managed to avoid substantial burdens to the environment.

5.5 Comparative LCA Study of Conventional, Retrofit and New-Build Power Systems

Despite growing interest in advanced power systems for possible improved sustainability, the environmental benefits of integrating innovative technologies into retrofit and new-build power systems had not yet been compared in a single study. Without comparison, it was uncertain which power system would be more environmentally friendly, and therefore a knowledge gap existed. This comparative study aimed to identify the environmentally friendly power system design by comparing the advanced power systems to a reference system (i.e. the conventional system) from an environmental perspective in a comparative LCA study. The sub-objectives of the study included

- define goal and scope of the comparative study;
- compare LCI results and LCIA results; and
- interpret the results to gain insights into the matter.

5.5.1 *Methods*

The comparative study was carried out following Case Studies 1, 2 and 3 as presented in previous sections. Research methodologies i.e. the bottom-up integrated system approach, primary and secondary data sources, vessel type, operation profiles, LCA software, characterisation methodologies, and impact categories involved in estimating the environmental impact of individual power systems in previous chapters were applied consistently. After defining goal and scope of the study, LCI and LCIA results were compared and analysed. The comparison among power systems under study was made based on relative contribution of significant components towards individual impact categories, as applied by [431], to verify environmental benefits of the power systems and identify the system which was more environmentally friendly.

5.5.2 *Goal and scope definition*

The reasons of carrying out this comparative LCA study were to verify the environmental performance of selected marine power systems when compared to a reference system (i.e. the conventional system presented in Case Study 1 as illustrated in Figure 5.2 and detailed in Table 5.1) and identify the power system which was more environmentally friendly. The targeted audience included, but not limited to, maritime stakeholders, in particular ship owners, operators, policy makers, and LCA practitioners. The application was to justify the employment of innovative power systems as a sustainable approach to mitigate the environmental burdens of marine transport and furthermore assist maritime stakeholders in their decision making. Based on the findings, the study intended to present comparative assertions to the public. The retrofit and new-build systems previously presented in Case Studies 2 and 3 were the product systems of this comparative study (see Figures 5.17 and 5.29, Tables 5.6 and 5.7). All power systems under study served the same function i.e. to supply energy required for propulsion and operation of the RoRo cargo ship. A common functional unit was defined i.e. operation of the power system for the same RoRo cargo ship travelling on regular routes over 30 years. A common reference flow across all power systems was defined i.e. one power system required by the ship for a 30-year service. Uniformity in cargo ship type, function, business route, lifespan, system boundary, life cycle phases, allocation, assumptions and limitations was ensured. The impact categories were analysed and grouped in line with methodologies, and ranked based on their magnitude. The LCIA results for both systems were compared to the reference system. Neither normalisation nor weighting was performed. During life cycle interpretation, significant issues, such as components and processes which resulted in noticeable environmental burdens, were identified. Mass was adopted as the cut-off criterion for all power systems in which the analysis focussed on components that contributed at least 5% of the total mass (hereafter ‘significant components’). Therefore, the significant components in this comparative study, as listed in the following, were not exactly the same as those in Case Studies 1–3:

- the reference system: diesel engines, auxiliary generators, propellers and shafts, which made up 92.66% of the total mass;
- the retrofit system: diesel engines, auxiliary generators, propellers and shafts and batteries, which summed up to 85.88% of the total mass; and

- the new-build system: diesel gensets, propulsion motors, thruster motors, propellers and shafts, which constituted 74.93% of the total mass.

The results were checked for completeness and consistency with the defined goal and scope. Critical review was conducted internally by partners involved in the project.

5.5.3 *LCI results*

As illustrated in Figure 5.39, materials and energy required during manufacture increased from the reference system to the retrofit and new-build all-electric systems as a result of more components being integrated into the latter systems.

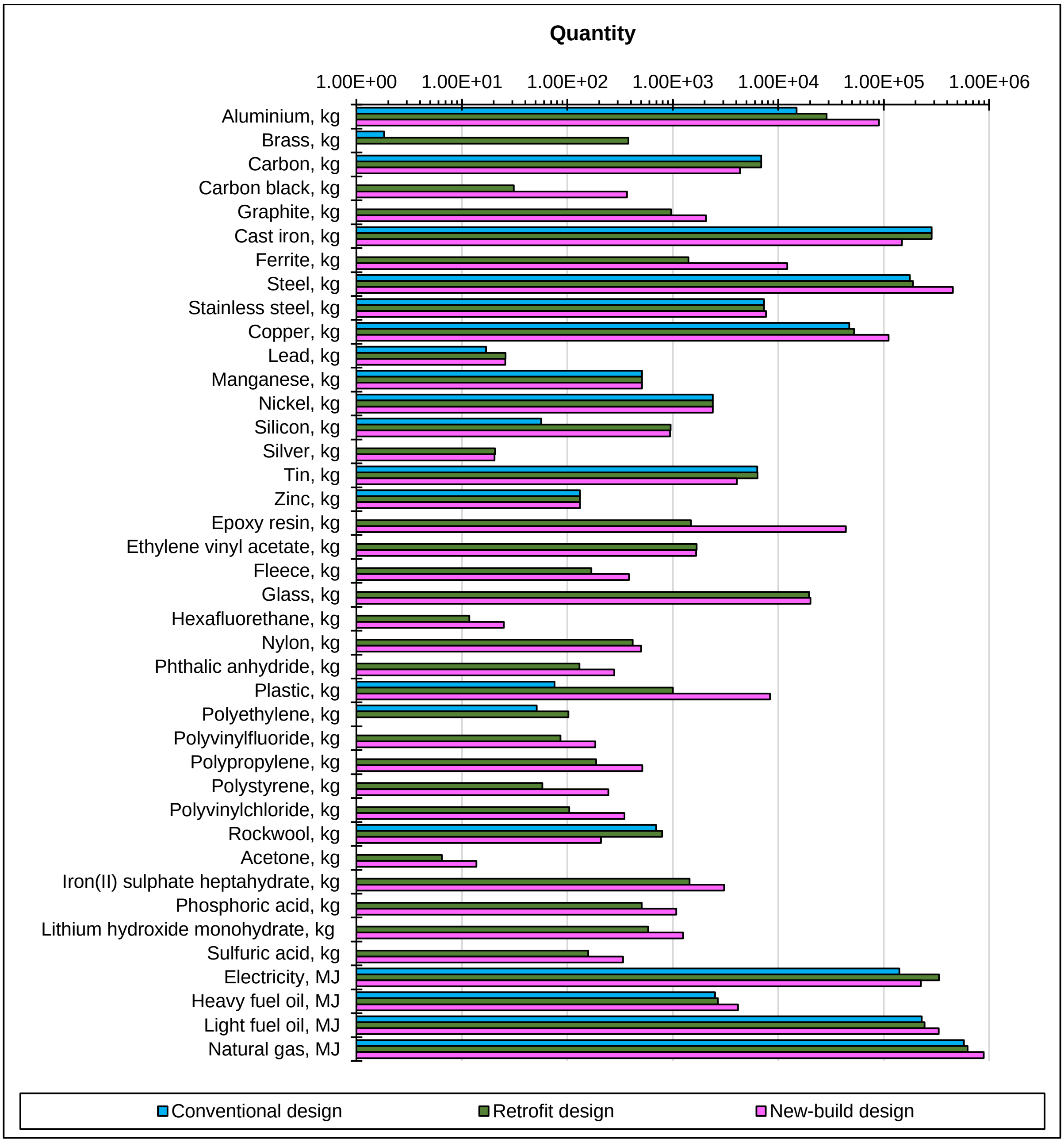


Figure 5.39: Comparison of power systems: materials consumed during manufacture.

Metallic and non-metallic materials that were consumed by the retrofit and new-build systems but not the reference system included carbon black, graphite, ferrite, silver, epoxy resin, ethylene vinyl acetate, fleece, glass, hexafluorethane, nylon, phthalic anhydride, polyvinylfluoride, polypropylene, polystyrene, polyvinylchloride, acetone, iron (II) sulphate heptahydrate, phosphoric acid, lithium hydroxide monohydrate and sulfuric acid. For other materials illustrated in Figure 5.39, an increase was shown (i) by the retrofit system by up to 2 orders of magnitude; and (ii) in most materials consumed by the new-build system with the exception of brass, carbon, cast iron, tin, polyethylene and rockwool, when compared to the reference system. During manufacture, the retrofit system consumed 138.3% more electricity and 6.3–8.1% more heavy fuel oil, light fuel oil and natural gas compared to the reference system.

A different trend was shown by the new-build system i.e. 59.8% more electricity than the reference system (which was less than the quantity consumed by the retrofit system) and 45.0–64.9% more heavy fuel oil, light fuel oil and natural gas than the reference system (which exceeded the quantities consumed by the retrofit system). Overall, more materials and energy were involved in manufacturing components that were incorporated into the retrofit and new-build systems when compared to the reference system, as a result of more components being integrated into the former systems.

Fuel consumption and emissions involved in the operation phase and their comparisons to those of the reference system are illustrated in Figure 5.40. A scale of 1 was shown by HFO as a result of no difference between retrofit and reference systems (in line with the conditions defined for energy management modelling). Meanwhile, MDO consumed by the retrofit system was 0.92 times that of the reference system due to optimised operation as well as the integration of emerging technologies to augment power supply.

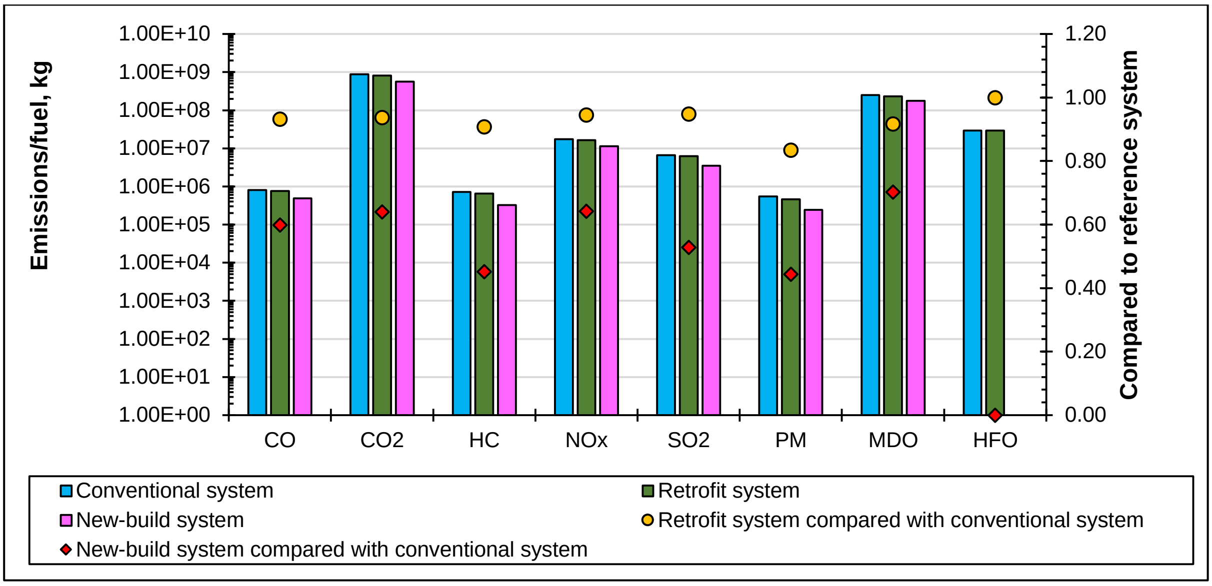


Figure 5.40: Total emissions and fuel consumption of both retrofit and new-build systems compared to the reference system during the operation phase (in which a scale of 1 indicated no difference between the system being compared and the reference system).

The analysis showed that 8.28% less fuel was consumed by the retrofit system compared to the reference system which led to emission reduction of 5.2–16.6%. As such, CO_2, NOx, SO_2, CO, HC and PM released by the retrofit system were 0.83–0.95 times those of the reference system, when the quantities were compared directly. With regard to the new-build system, the least quantity of fuel and emissions was involved i.e. 29.7% less MDO and 100% elimination of HFO compared to the reference system, leading to 29.7–55.6% of emission reduction. As a result, CO_2, NOx, SO_2, CO, HC and PM released by the new-build system were 0.45–0.70 times those of the reference system. As a whole system, the new-build system consumed less fuels and released less emissions compared to the retrofit system during operation.

Having said that, a different trend was observed during dismantling and the end of life, as illustrated in Figure 5.41. The analysis showed that the retrofit system consumed more resources than the reference system. The increase varied from a small magnitude as shown by HFO (i.e. less than 1%) to a significant level as shown by coke (i.e. up to 196.8%). Whilst coke and natural gas burned at the end of life phase of the retrofit system were 2.97 and 2.44 times the quantities required by the reference system, other resources consumed during dismantling and the end of life were 1–2 times those required by the reference system. In connection to new-build system, a reduced consumption of coal, light fuel oil and natural gas during dismantling (i.e. approximately 18%) came along with a slightly higher electricity demand (i.e. 27.8%) when compared to the reference system. During the end of life of the new-build system, a higher demand of most resources was observed i.e. 1.47–6.69 times those consumed by the reference system. Natural gas consumption was found as the mostly consumed resource i.e. 568.6% increase compared to the reference system, which came along with a marginal change in coal and HFO consumption i.e. 0.82 times those of the reference system.

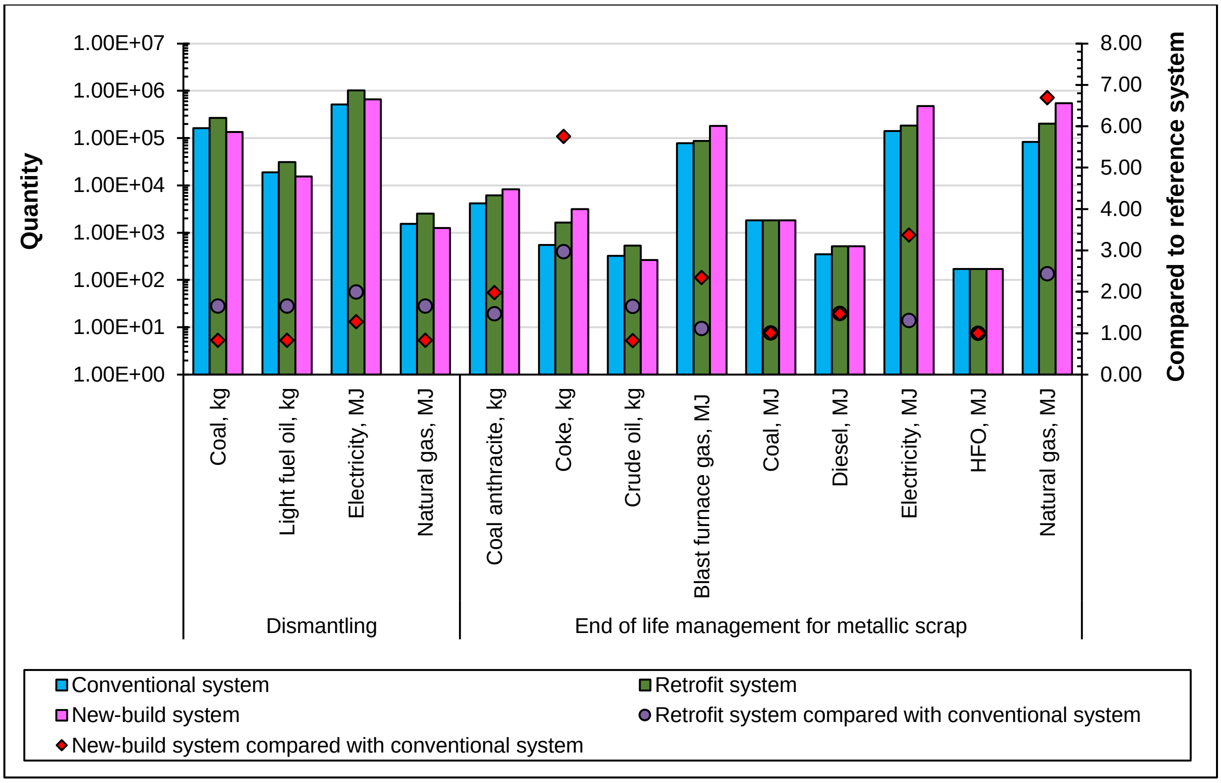


Figure 5.41: Materials and fuel consumption of both retrofit and new-build systems when compared to the reference system during dismantling and the end of life (in which a scale of 1 indicated no difference between the system being compared and the reference system).

The quantity of resources consumed and emissions released by the power systems was mainly influenced by (i) mass of the components incorporated into the power systems during manufacture, dismantling and the end of life; and (ii) power demand and operation profiles of components which were run to meet such demand (hereafter ‘fuel consumers’) during operation. The total mass of all components incorporated into the reference, retrofit and new-build systems was 549960 kg, 644420 kg and 915619 kg respectively. Correlations between resource consumption, emissions, fuel consumers, significant components and life cycle phases were observed: whilst significant components used up most of the resources during manufacture, dismantling and the end of life, fuel consumers were the primary cause of resource consumption and emissions during operation.

5.5.4 *LCIA results*

In relation to LCIA results, as illustrated in Figure 5.42, all impact categories were found either of the same order or varied by 1 order of magnitude. However, the difference as per impact categories when compared to the reference system, showed a broad range from significant reduction of 50.7% to a very pronounced increase of 422.2%, as illustrated in Figure 5.43. Among all impact categories, the two most pronounced increases were shown by the new-build system i.e. CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources–Fossil Fuels* (labelled as VIII and XXIV), which accounted for 391.3% and 422.2% respectively. The same impact categories caused by the retrofit system were, to a lesser extent, only 17.7% and 161.9% more burdensome than those attributable to the reference system.

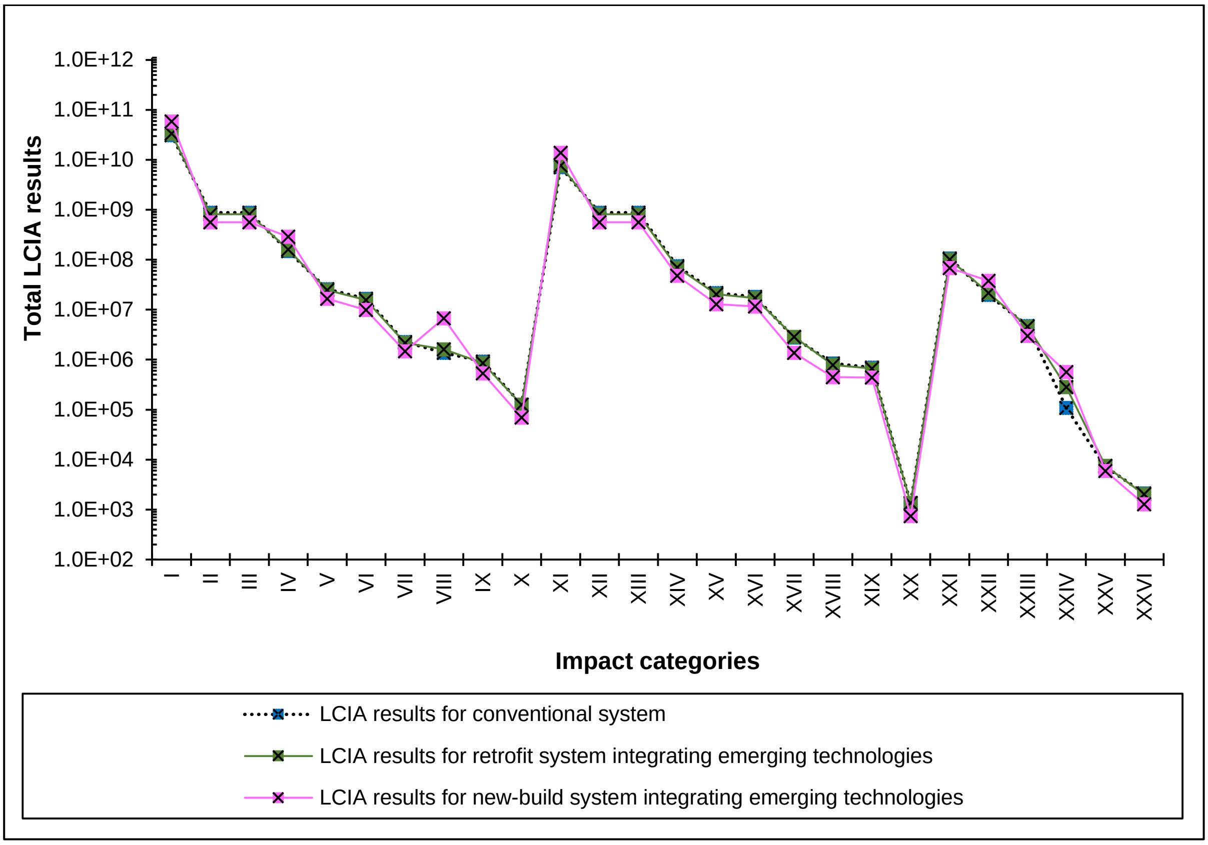


Figure 5.42: LCIA results of reference, retrofit and new-build systems.

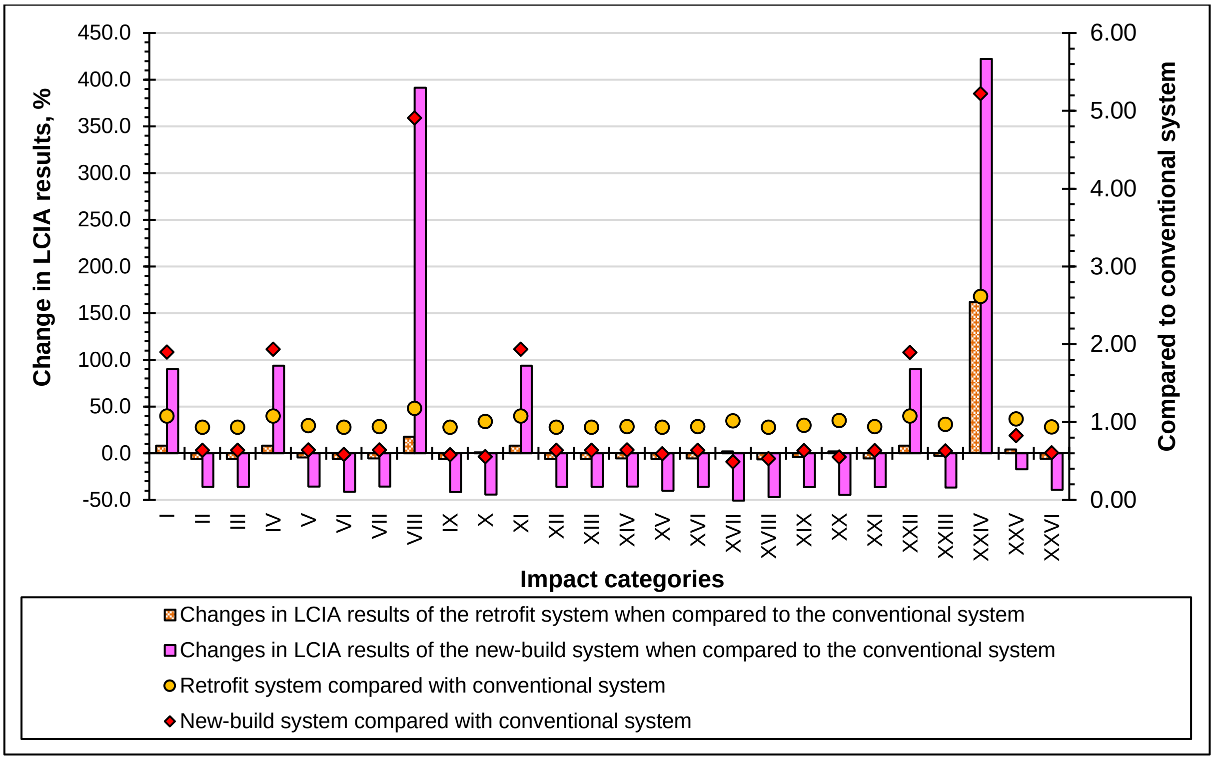


Figure 5.43: Changes in LCIA results of the retrofit and new-build systems and the scale of the impact categories when compared to the conventional system.

In relation to other impact categories, the retrofit system showed a decline ranging 2.7–6.6% in most impact categories at the expense of an increase of approximately 8% in CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality—Ecotoxicity* (labelled as I, IV, XI and XXII respectively), 1–2% in CML2001: *Terrestric Ecotoxicity Potential* and ILCD: *Resource Depletion, Fossil and Mineral* (labelled as X and XX respectively), and 18% in CML2001: *Abiotic Depletion of Fossil* (labelled as VIII). As such, the environmental impact attributable to the retrofit system was 0.93–1.18 times that caused by the reference system, with the exception of Eco-Indicator99: *Resources—Fossil Fuels* (labelled as XXIV).

When the new-build system was compared to the reference system, most of the impact categories showed a reduction, to a greater extent, ranging between 35.7% and 50.7%, with the exception of 7 impact categories. A slight decline, i.e. 17.1%, was observed in Eco-Indicator99: *Ecosystem Quality—Land-Use* (labelled as XXV), whilst CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources—Fossil Fuels* (labelled as VIII and XXIV) showed the top two most pronounced increases among all impact categories. The other four impact categories included CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic*

Freshwater and Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, XI and XXII respectively), which were 90.0–93.9% more burdensome than the indicator results of the reference system for these impact categories. Therefore, the environmental impact attributable to the new-build system was 0.49–1.94 times that caused by the reference system, with the exception of CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources–Fossil Fuels* (labelled as VIII and XXIV).

The analysis showed that CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources–Fossil Fuels* (labelled as VIII and XXIV) were the two impact categories significantly affected by the implementation of the retrofit and new-build systems, although CML: *Marine Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality–Acidification/Nitrification* were the impact categories that showed the highest indicator results. Despite more materials and energy were consumed during manufacture and the end of life phase, an overall improvement in environmental performance was achieved, as indicated by the reduction in the majority of the impact categories, to the detriment of a few impact categories. Between retrofit and new-build systems, the later showed the potential for the greatest abatement in most impact categories at the expense of a greater scale of burdens in one or two impact categories. As such, the new-build all-electric power system was more environmentally friendly than the retrofit system. The environmental benefits brought by emerging technologies incorporated into an existing or a new-build power system as a whole were verified, but the life cycle of the system must be appropriately managed with due care to avoid shifting the burdens from one impact category to another whilst alleviating the environmental burdens at the same time.

5.5.5 *Life cycle interpretation*

In identifying significant issues, the contribution of significant components towards individual impact categories was analysed. It was found that LCIA results for most impact categories were largely caused by significant components, as illustrated in Figure 5.44.

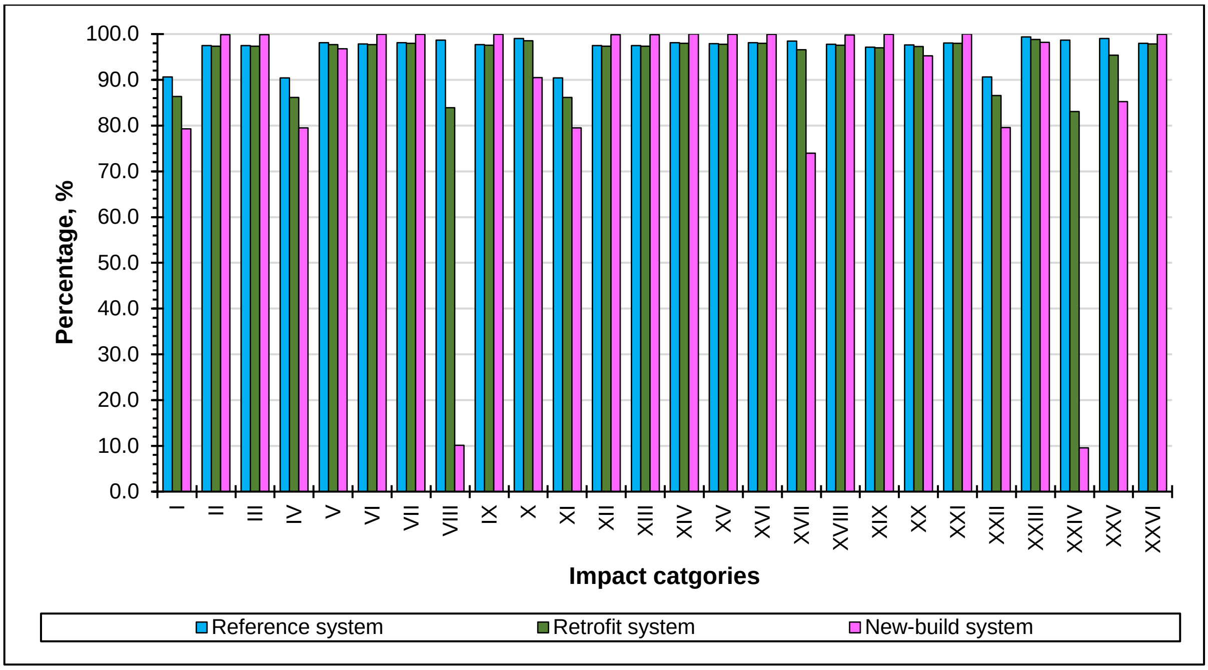


Figure 5.44: Contribution of significant components, in %, towards LCIA results of individual impact categories for each power system.

In the reference system, significant components (i.e. diesel engines, auxiliary generators, propellers and shafts which represented 92.66% of the total mass) were the primary cause of all impact categories, which resulted in approximately 91% of CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality–Ecotoxicity* (labelled as I, IV, XI and XXII) and more than 97% for the other impact categories.

The total mass of the retrofit system was 1.17 times that of the reference system. When emerging technologies were incorporated into the retrofit system, contributions from significant components (i.e. diesel engines, auxiliary generators, propellers and shafts and batteries which made up 85.88% of the total mass) remained profound as they were attributable to approximately 84% of CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources–Fossil Fuels* (labelled as VIII and XXIV) and 86.33–98.88% for the remaining impact categories. In comparison with the reference system, contributions from these components dropped by

- approximately 15% in two particular impact categories i.e. CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources–Fossil Fuels* (labelled as VIII and XXIV);
- approximately 4% in CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater,* Eco-

Indicator99: *Ecosystem Quality─Ecotoxicity* and *Ecosystem Quality─Land-Use* (labelled as I, IV, XI, XXII and XXV); and

- less than 2% for the rest of the impact categories.

The new-build system had a total mass of 1.66 times that of the reference system. Although most of the impact categories attributable to the new-build system were of a lesser extent, as reported in **Chapter 5.5.4**, the influence of significant components (i.e. diesel gensets, propulsion and thruster motors, propellers and shafts which made up 74.93% of the total mass) were more prominent for most impact categories, which indicated an approximately 2% of increase in their contribution when compared to the reference system. The exception was observed in

- CML2001: *Marine* and *Freshwater Aquatic Ecotoxicity Potential*, ILCD: *Ecotoxicity for Aquatic Freshwater* and Eco-Indicator99: *Ecosystem Quality─Ecotoxicity* (labelled as I, IV, XI and XXII), in which transformers connecting propulsion drives were accounted for 6.27–6.42% whilst other components resulted in approximately 14% of these impact categories;
- Eco-Indicator99: *Ecosystem Quality─Land-Use* (labelled as XXV), in which PV and batteries systems resulted in approximately 5% each;
- ILCD: *Total Freshwater Consumption* (labelled as XVII), in which transformers connecting propulsion drives contributed approximately 10% whilst VFDs connecting propulsion and thruster motors, batteries and thruster motors resulted in 2–3% of each impact;
- CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources─Fossil Fuels* (labelled as VIII and XIV), in which transformers connecting propulsion and thruster drives, and those for distribution purpose at a power rate of 400kW and 250kW were the main sources i.e. approximately 63%, 10%, 4% and 7% respectively.

As such, it showed that the influence of significant components

- in both reference and retrofit systems (with a variation of 17.2% in the total mass) was in close proximity for most impact categories. Components which constituted less than 5% of the total mass would have a negligible effect towards most impact categories and a mild consequence on the impact relevant to (i) ecotoxicity potential in both reference and retrofit systems; and (ii) depletion of fossil for the retrofit system.

- in the new-build system was more dynamic when compared to the reference system (with a variation of 66.5% in the total mass), in which significant components had triggered a 2% increase in their contribution towards most impact categories when compared to the reference system. Individual components, such as transformers, PV and battery systems which individually made up less than 5% of the total mass, had exerted a noticeable pressure on impact categories relevant to depletion of fossil, ecotoxicity potential, freshwater consumption and land use.

An additional remark was worth-noting. The environmental impact of a power system was less sensitive to the mass of diesel engines alone (as previously reported in **Chapter 5.2.6**); however, the influence of mass on the overall environmental impact became remarkable when the mass of significant components was all taken into account (as indicated here).

A closer look was taken at individual components as well as the environmental impact to compare critical processes of these power systems. The analysis indicated that the reference, retrofit and new-build systems were in agreement as similar correlations were shown among critical processes, significance of individual components, and nature of the impact categories assessed by CML2001, ILCD and Eco-Indicator99:

- disposing metallic scrap of (i) diesel engines, auxiliary generators, propellers and shafts for the reference and retrofit systems; and (ii) diesel gensets, propulsion motors, thruster motors, propellers and shafts for the new-build system, was the principal contributors of impact categories that were relevant to ecotoxicity potential, which showed one of the top two highest indicator results;
- operating (i) diesel engines and auxiliary generators for both reference and retrofit systems; and (ii) diesel gensets for the new-build system resulted in impact categories which were more moderate, i.e. impact categories that were relevant to global warming, acidification, eutrophication, photochemical ozone creation and PM/respiratory inorganic health issues; and

- consuming resources during the manufacture of (i) diesel engines for both reference and retrofit systems; and (ii) diesel gensets for the new-build system, and other less prominent components, i.e. auxiliary generators, propellers and shafts for the reference and retrofit systems, propellers and shafts, their connecting motors and transformers and/or thruster motors for the new-build system, led to impact categories which were of lower magnitude i.e. those relevant to resource depletion.

Overall, despite a large quantity of resources i.e. energy and materials were consumed during the acquisition and manufacturing phases, most environmental burdens of the power system occurred during operation and the end of life phase of the significant components. Other technologies such as boilers, economisers, thrusters, VFDs, distribution transformers, battery systems, PV systems and cold ironing contributed to the environmental burdens to such an extent that they were relatively negligible when compared to these significant components. The use of average data in LCA studies with a massive system boundary was appropriate as the estimated indicator results for all impact categories assessed by CML2001, ILCD and Eco-Indicator99 and their correlations with key parameters were consistent among all case studies.

5.6 Summary

LCA case studies on conventional, retrofit and new-build power systems were presented and supplemented by an LCA comparative study. All cases focused on the same ship type, business route, lifespan and life cycle phases, in which the same methodology approach, functional unit, data sources, assumptions, software, characterisation models and impact categories were applied to ensure consistency and allow for the comparative study. Resources i.e. materials and energy consumed throughout the life cycle were estimated. For each case study, LCIA results were analysed to determine the impact of marine power systems, followed by further investigation on selected parameters via scenario analysis. The key results of the case studies were summarised in Table 5.8. It was found that both retrofit and new-build systems (i) consumed less fuel and produced fewer emissions during the operation but required larger quantities of materials and energy during the other life cycle phases; and (ii) showed a decline in most impact categories to the detriment of a few impact categories. As such, the study verified the benefits of retrofit and new-build systems from an environmental perspective. It was important to point out that the risk threshold of individual impact categories towards human beings, resources and ecosystems was still missing, and therefore, it was not clear to what extent the magnitude of an impact category could be considered as harmless, moderate or fatal. The findings could be revisited and refined in future work when more (newer and of higher quality) data were available to minimise the need of making any particular assumption or address any specific limitation in current cases. How well the research goals have been met, how the LCA study has reflected back to the regulations, how to use the results in decision making, contributions of the study and recommendations for future work are presented in **Chapter 6**.

Table 5.8: Key LCI and LCIA results of the power systems assessed in the case studies.

	Conventional system	Retrofit system	New-build system
Most consumed materials, in descending order, consumed during manufacture	Cast iron, steel, copper and aluminium i.e. $2.85x10^5$, $1.77x10^5$, $4.71x10^4$ and $1.49x10^4$ kg	Cast iron, steel, copper and aluminium i.e. $2.85x10^5$, $1.89x10^5$, $5.23x10^4$ and $2.88x10^4$ kg	Steel, cast iron, copper and aluminium i.e. $4.52x10^5$, $1.48x10^5$, $1.11x10^5$ and $9.03x10^4$ kg respectively
Total fuel consumption during operation	$2.93x10^7$ kg of HFO and $2.50x10^8$ kg of MDO	$2.93x10^7$ kg of HFO and $2.30x10^8$ kg of MDO	$1.76x10^8$ kg of MDO
Total emissions during operation	$8.75x10^8$ kg of CO_2, $1.75x10^7$ kg of NOx, $6.01x10^6$ kg of SO_2, $8.13x10^5$ kg of CO, $7.17x10^5$ kg of HC and $5.49x10^5$ kg of PM	$8.20x10^8$ kg of CO_2, $1.66x10^7$ kg of NO_X, $6.26x10^6$ kg of SO_2, $7.58x10^5$ kg of CO, $6.51x10^5$ kg of HC and $4.58x10^5$ kg of PM	$5.60x10^8$ kg of CO_2, $1.13x10^7$ kg of NO_X, $3.49x10^6$ kg of SO_2, $4.87x10^5$ kg of CO, $3.25x10^5$ kg of HC, and $2.43x10^5$ kg of PM
Total lubricating oil during maintenance	$4.43x10^4$ kg	$5.06x10^4$ kg	$9.46x10^4$ kg
The top two most commonly consumed resources during dismantling	Electricity and coal i.e. $5.15x10^5$ MJ and $1.62x10^5$ kg respectively	Electricity and coal i.e. $1.03x10^6$ MJ and $2.68x10^5$ kg respectively	Electricity and coal i.e. $6.58x10^5$ MJ and $1.34x10^5$ kg respectively
The top two most commonly consumed resources during	Electricity and natural gas i.e. $1.41x10^5$ MJ and $8.25x10^4$ MJ respectively	Natural gas and electricity i.e. $2.01x10^5$ MJ and $1.84x10^5$ MJ respectively	Natural gas and electricity i.e. $5.51x10^5$ MJ and $4.75x10^5$ MJ respectively

the end of life phase			
Impact assessed by CML2001 that showed the highest magnitude	*Marine Aquatic Ecotoxicity Potential*, i.e. 3.12×10^{10} kg $C_4H_8Cl_2$ equivalent	*Marine Aquatic Ecotoxicity Potential*, 3.36×10^{10} kg $C_4H_8Cl_2$ equivalent	*Marine Aquatic Ecotoxicity Potential*, 5.92×10^{10} kg $C_4H_8Cl_2$ equivalent
Impact assessed by ILCD that showed the highest magnitude	*Ecotoxicity for Aquatic Freshwater*, 7.14×10^{9} CTUe	*Ecotoxicity for Aquatic Freshwater*, 7.72×10^{9} CTUe	*Ecotoxicity for Aquatic Freshwater*, 1.39×10^{10} CTUe
Impact assessed by Eco-Indicator99 that showed the highest magnitude	*Ecosystem Quality─Acidification/ Nitrification*, 1.07×10^{8} PDF*m^{2}*a	*Ecosystem Quality─Acidification/ Nitrification*, 1.01×10^{8} PDF*m^{2}*a	*Ecosystem Quality─Acidification/ Nitrification*, 6.81×10^{7} PDF*m^{2}*a
Significant components (which contributed more than 5% of the total mass of the power system)	Diesel engines, auxiliary generators, propellers and shafts; 92.66% of the total mass	Diesel engines, auxiliary generators, propellers and shafts; 85.88% of the total mass	Diesel gensets, propellers and shafts, propulsion motors and thruster; 74.93% of the total mass
Correlations between significant components and impact	At least 90.62% of all impact categories were attributable to significant components	At least 83.70% of all impact categories were attributable to significant components	At least 73.99% of all impact categories except CML2001: *Abiotic Depletion of Fossil* and Eco-Indicator99: *Resources─Fossil Fuels* were attributable to significant components
Critical processes	Operation of diesel engines and auxiliary generators, and the end of life phase of diesel engines, auxiliary generators, propellers and shafts	Operation of diesel engines and auxiliary generators, and the end of life phase of diesel engines, auxiliary generators, propellers and shafts	Operation of diesel gensets, and the end of life phase of diesel gensets, propellers and shafts, propulsion and thruster motors

Chapter 6. Conclusions and Recommendations for Future Work

"*Science is simply common sense at its best, that is, rigidly accurate in observation, and merciless to fallacy in logic*."

Thomas Huxley
An Introduction to the Study of Zoology: the Crayfish, 1880

The focus of **Chapter 6** is illustrated in Figure 6.1, covering reflections (in **Chapter 6.1**), contribution of the work (in **Chapter 6.2)** and recommendations for future work (in **Chapter 6.3**).

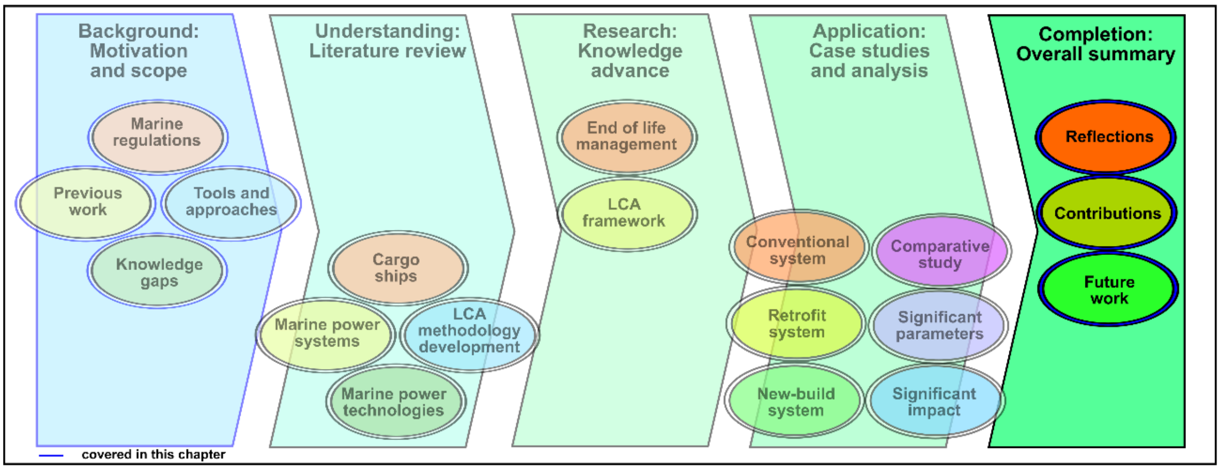


Figure 6.1: The focus of **Chapter 6**.

6.1 Reflections

The thesis presented an exploratory study. It aimed to contribute to the conceptual understanding of LCA study on marine power systems. This was achieved by overviewing cargo ships, power systems and technologies, reviewing LCA methodology development, developing LCA framework in the context of marine power systems and performing LCA case studies as well as a comparative study. In the case studies, the environmental impact of selected power systems was estimated, significant component and critical processes were identified and the sensitivity of the results were investigated. In the comparative study, the environmental benefits of innovative power systems were verified via comparison with the conventional system. As such, all the set research goals as listed in **Chapter 1.4** have been fully met.

The retrofit and new-build systems assessed in the study were designed in accordance with Annex VI which enforced a lower SOx threshold (i.e. Regulation 14) and required alternative solutions (i.e. Regulation 4) for the prevention of air pollution from ships. Both systems burned MDO (i.e. low-sulphur fuel) and implemented advanced technologies as alternative solutions to emission reduction. The study showed that MDO and advanced technologies were effective for reducing not only emissions but also the environmental impact attributable to marine power systems. As such, the LCA study provided evidence for maritime stakeholders to adopt such measures and adhere to the regulations.

In this matter, the findings of the study could assist decision-making among maritime stakeholders in particular policy makers and ship owners. The stakeholders must consider alternatives to meet their commercial and legislative goals. From an organisational perspective, the results of this study could be used to identify significant environmental aspects (e.g. critical processes and energy consumers) and furthermore set priorities for management action. Also, bearing the results of this study in mind, the ship owners could decide which power system design to adopt and whether to retrofit existing power systems or order advanced systems onboard new-build ships, for instance. As such, the results in this study could allow for improved decision making.

6.2 Contribution of the Work

Prior to this study, knowledge gaps existed. It was unclear what environmental impact would be caused by a marine power system, what parameters would affect such impact and whether incorporating innovative technologies into marine power systems would add any environmental benefits. The study presented in this thesis has contributed to existing knowledge as it bridged the gaps systematically from exploring background information, understanding literature and researching into the subject to applying the developed concept. The study made the following significant contributions:

- The overview on cargo ships, power systems and technologies in **Chapter 2** painted an overall picture of the subject, which would be beneficial to general readers who had no prior knowledge.
- The review of recent LCA methodology development in **Chapter 3** made the ever first attempt to integrate and compare the findings of LCA reviews and research articles, which uncovered research trends and identified

areas for future development. As such the study enhanced research and development quality and stimulated a better understanding;

- The research into the end of life management of ships, power technologies and metallic scrap in **Chapter 4** advanced existing knowledge as it presented a holistic view that was applicable to the LCA studies on marine power systems.
- The LCA framework which was developed in the context of marine power systems in **Chapter 4** offered a starting point in particular for those lacking prerequisite knowledge regarding LCA of marine power systems. The framework had practical implications for future research work because all relevant elements and requirements were described phase by phase, which were supplemented by background information and expected results.
- The case studies in **Chapter 5** addressed the research questions directly as they (i) estimated resource consumption and environmental burdens attributable to the chosen power systems via LCA applications; (ii) identified significant components and critical processes; (iii) provided insights into selected parameters using scenario analysis; and (iv) presented a reference to enable comparison with other power system designs (that were not assessed in this study) and further validation in future work. Consistency shown by the estimated indicator results for all impact categories and their correlations with key parameters in all case studies verified the appropriateness of using average data in estimating the environmental impact of a massive product system in an LCA study.
- the comparative study in **Chapter 5** complemented the case studies as it identified the system that was more environmentally friendly, and verified the environmental benefits of retrofit and new-build systems compared to a conventional system.

6.3 Recommendations for Future Work

To improve LCA applications in the marine context, further research should address the limitations presented in this study and explore other factors that would affect the environmental burdens of a marine power system onboard a cargo ship. A number of research needs have been identified, as follows:

(i) develop characterisation methodology for space use, odour, non-ionizing radiation and thermal pollution and incorporate impact of noise, thermal pollution and working environment into commercial software in terms of LCI and LCIA methodology development

(ii) extend the framework to include more alternative technical options and methodological choices

(iii) carry out LCA case studies on other power system designs and cargo ship types

(iv) broaden the scope by performing economic and risk assessments as the benefits of implementing an advanced system would always come with financial burdens and risks

In practice, the life cycle (in particular the operation and the end of life) of marine power systems should be planned, managed and monitored appropriately not only for energy efficiency but also for reduced implications on the natural environment.

References

1. Chapman, L., *Transport and climate change: a review.* Journal of Transport Geography, 2007. **15**(5): p. 354-367.
2. *Review of maritime transport*. 2014, United Nations Conference on Trade and Development (UNCTAD): New York and Geneva.
3. Faber, J., et al., *Technical support for European action to reducing greenhouse gas emissions from international maritime transport*. 2009: Delft.
4. *Review of maritime transport*, D. Barki and J. Rogers, Editors. 2015, United Nations Conference on Trade and Development (UNCTAD): New York and Geneva. p. 1-122.
5. Eyring, V., et al., *Transport impacts on atmosphere and climate: Shipping.* Atmospheric Environment, 2010. **44**(37): p. 4735-4771.
6. Stern, D.I., *Global sulfur emissions from 1850 to 2000.* Chemosphere, 2005. **58**(2): p. 163-175.
7. Wang, C. and J. Corbett, *The costs and benefits of reducing SO2 emissions from ships in the US West Coastal waters.* Transportation Research Part D 2007. **12**(8): p. 577-588.
8. McCollum, D.L., G. Gould, and D.L. Greene, *Greenhouse gas emissions from aviation and marine transportation: mitigation potential and policies*. 2010, Institute of Transportation Studies (ITS) UC Davis.
9. Miola, A., et al., *Regulating air emissions from ships.* The State of the Art on Methodologies, Technologies and Policy Options. Joint Research Centre Reference Report, Luxembourg, EUR24602EN, ISBN, 2010: p. 978-92.
10. *Third IMO GHG study*. 2014 [cited 2016 4 February]; Available from: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Greenhouse-Gas-Studies-2014.aspx.
11. Winiwarter, W., et al., *Quality considerations of European PM emission inventories.* Atmospheric Environment, 2009. **43**(25): p. 3819-3828.
12. Colvile, R., et al., *Chapter 6 The transport sector as a source of air pollution.* Atmospheric Environment, 2001. **35**: p. 1537-1565.
13. Tse, L.K.C., et al., *Solid oxide fuel cell/gas turbine trigeneration system for marine applications.* J Power Sources, 2011. **196**(6): p. 3149-3162.
14. *Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, as modified by the Protocol of 1978 relating thereto (Revised MARPOL Annex VI)*, in *Annex 13*

Resolution MEPC.176(58). 2008, International Maritime Organisation (IMO): UK. p. 1-45.

15. *International Convention for the Prevention of Pollution from Ships (MARPOL)*. 2011 [cited 2012 5 March]; Available from: http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx.
16. Golomb, D., *Transport systems for ocean disposal of CO2 and their environmental effects.* Energy Convers Manag, 1997. **38, Supplement**: p. S279-S286.
17. Kildow, J., *Testing the waters: an analytical framework for testing the political feasibility of scenario-based proposals for disposing of CO2 in the oceans.* Energy Convers Manag, 1997. **38, Supplement**: p. S295-S300.
18. Derwent, R.G., et al., *The contribution from shipping emissions to air quality and acid deposition in Europe.* Ambio, 2005. **34**(1): p. 54-59.
19. Wang, C., J.J. Corbett, and J. Firestone, *Modeling energy use and emissions from North American shipping: application of the ship traffic, energy, and environment model.* Environ Sci Technol, 2007. **41**(9): p. 3226-3232.
20. Matthias, V., et al., *The contribution of ship emissions to air pollution in the North Sea regions.* Environmental Pollution, 2010. **158**(6): p. 2241-2250.
21. Winnes, H. and E. Fridell, *Emissions of NOx and particles from manoeuvring ships.* Transport Res D - Tr E, 2010. **15**(4): p. 204-211.
22. Walsh, C. and A. Bows, *Size matters: exploring the importance of vessel characteristics to inform estimates of shipping emissions.* Appl Energy, 2012. **98**: p. 128-137.
23. Ma, H., et al., *Well-to-wake energy and greenhouse gas analysis of SOx abatement options for the marine industry.* Transport Res D - Tr E, 2012. **17**(4): p. 301-308.
24. Yang, Z.L., et al., *Selection of techniques for reducing shipping NOx and SOx emissions.* Transport Res D - Tr E, 2012. **17**(6): p. 478-486.
25. Ushakov, S., et al., *Emission characteristics of GTL fuel as an alternative to conventional marine gas oil.* Transport Res D - Tr E, 2013. **18**: p. 31-38.
26. Heitmann, N. and S. Peterson, *The potential contribution of the shipping sector to an efficient reduction of global carbon dioxide emissions.* Environ Sci Policy, 2014. **42**: p. 56-66.

27. Lindstad, H., I. Sandaas, and S. Steen, *Assessment of profit, cost, and emissions for slender bulk vessel designs.* Transport Res D - Tr E, 2014. **29**: p. 32-39.
28. Jiang, L., J. Kronbak, and L.P. Christensen, *The costs and benefits of sulphur reduction measures: sulphur scrubbers versus marine gas oil.* Transport Res D - Tr E, 2014. **28**: p. 19-27.
29. Westerlund, J., M. Hallquist, and Å.M. Hallquist, *Characterisation of fleet emissions from ships through multi-individual determination of size-resolved particle emissions in a coastal area.* Atmos Environ, 2015. **112**: p. 159-166.
30. Moreno-Gutiérrez, J., et al., *Methodologies for estimating shipping emissions and energy consumption: a comparative analysis of current methods.* Energy, 2015. **86**: p. 603-616.
31. Uriondo, Z., et al., *Effects of charged air temperature and pressure on NOx emissions of marine medium speed engines.* Transport Res D - Tr E, 2011. **16**(4): p. 288-295.
32. Vanesa Durán Grados, C., et al., *Correcting injection pressure maladjustments to reduce NOX emissions by marine diesel engines.* Transport Res D - Tr E, 2009. **14**(1): p. 61-66.
33. Duran, V., Z. Uriondo, and J. Moreno-Gutiérrez, *The impact of marine engine operation and maintenance on emissions.* Transport Res D - Tr E, 2012. **17**(1): p. 54-60.
34. Di Natale, F. and C. Carotenuto, *Particulate matter in marine diesel engines exhausts: Emissions and control strategies.* Transport Res D - Tr E, 2015. **40**: p. 166-191.
35. Attah, E.E. and R. Bucknall, *An analysis of the energy efficiency of LNG ships powering options using the EEDI.* Ocean Eng, 2015. **110**: p. 62-74.
36. Papanikolaou, A., *Holistic ship design optimization.* Comput Aided Design, 2010. **42**(11): p. 1028-1044.
37. Nielsen, R.F., F. Haglind, and U. Larsen, *Design and modeling of an advanced marine machinery system including waste heat recovery and removal of sulphur oxides.* Energy Convers Manag, 2014. **85**: p. 687-693.
38. Cao, T., et al., *Performance investigation of engine waste heat powered absorption cycle cooling system for shipboard applications.* Appl Therm Eng, 2015. **90**: p. 820-830.

39. Haglind, F., *A review on the use of gas and steam turbine combined cycles as prime movers for large ships. Part I: background and design.* Energy Convers Manag, 2008. **49**(12): p. 3458-3467.
40. Haglind, F., *A review on the use of gas and steam turbine combined cycles as prime movers for large ships. Part II: previous work and implications.* Energy Convers Manag, 2008. **49**(12): p. 3468-3475.
41. Romero Gómez, J., et al., *Analysis and efficiency enhancement of a boil-off gas reliquefaction system with cascade cycle on board LNG carriers.* Energy Convers Manag, 2015. **94**: p. 261-274.
42. Welaya, Y., M.M. El Gohary, and N.R. Ammar, *A comparison between fuel cells and other alternatives for marine electric power generation.* Int J Nav Arch Ocean 2011. **3**(2): p. 141-149.
43. Izaguirre-Alza, P., et al., *EU-CargoXpress: wind propulsion concept.* Procedia - Social and Behavioral Sciences, 2012. **48**(0): p. 1314-1323.
44. Traut, M., et al., *Propulsive power contribution of a kite and a Flettner rotor on selected shipping routes.* Appl Energy, 2014. **113**: p. 362-372.
45. Majewska, K., et al., *Experimental method of strain/stress measurements on tall sailing ships using Fibre Bragg Grating sensors.* Appl Ocean Res, 2014. **47**: p. 270-283.
46. Li, Q., et al., *A study on the performance of cascade hard sails and sail-equipped vessels.* Ocean Eng, 2015. **98**: p. 23-31.
47. Coppola, T., et al., *A sustainable electrical interface to mitigate emissions due to power supply in ports.* Renew Sustain Energy Rev, 2016. **54**: p. 816-823.
48. Sciberras, E.A., B. Zahawi, and D.J. Atkinson, *Electrical characteristics of cold ironing energy supply for berthed ships.* Transport Res D - Tr E, 2015. **39**: p. 31-43.
49. Psaraftis, H.N. and C.A. Kontovas, *Speed models for energy-efficient maritime transportation: a taxonomy and survey.* Transport Res C - Emer, 2013. **26**: p. 331-351.
50. Fagerholt, K. and H.N. Psaraftis, *On two speed optimisation problems for ships that sail in and out of emission control areas.* Transport Res D - Tr E, 2015. **39**: p. 56-64.
51. Johnson, H. and L. Styhre, *Increased energy efficiency in short sea shipping through decreased time in port.* Transport Res A-Pol, 2015. **71**: p. 167-178.

52. Fagerholt, K., et al., *Maritime routing and speed optimization with emission control areas.* Transport Res C - Emer, 2015. **52**: p. 57-73.
53. Schøyen, H. and S. Bråthen, *Measuring and improving operational energy efficiency in short sea container shipping.* RTBM, 2015. **17**: p. 26-35.
54. Armstrong, V.N., *Vessel optimisation for low carbon shipping.* Ocean Eng, 2013. **73**: p. 195-207.
55. Cichowicz, J., G. Theotokatos, and D. Vassalos, *Dynamic energy modelling for ship life-cycle performance assessment.* Ocean Eng, 2015. **110, Part B**: p. 49-61.
56. Yang, M.-H., *Thermal and economic analyses of a compact waste heat recovering system for the marine diesel engine using transcritical Rankine cycle.* Energy Convers Manag, 2015. **106**: p. 1082-1096.
57. Bal Beşikçi, E., et al., *An artificial neural network based decision support system for energy efficient ship operations.* Comput Oper Res, 2016. **66**: p. 393-401.
58. Jafarzadeh, S. and I.B. Utne, *A framework to bridge the energy efficiency gap in shipping.* Energy, 2014. **69**: p. 603-612.
59. Psaraftis, H.N. and C.A. Kontovas, *Balancing the economic and environmental performance of maritime transportation.* Transport Res D - Tr E, 2010. **15**(8): p. 458-462.
60. Kim, H.-J., et al., *An epsilon-optimal algorithm considering greenhouse gas emissions for the management of a ship's bunker fuel.* Transport Res D - Tr E, 2012. **17**(2): p. 97-103.
61. Shu, G., et al., *A review of waste heat recovery on two-stroke IC engine aboard ships.* Renew Sustain Energy Rev, 2013. **19**: p. 385-401.
62. Livanos, G.A., G. Theotokatos, and D.-N. Pagonis, *Techno-economic investigation of alternative propulsion plants for ferries and RoRo ships.* Energy Convers Manag, 2014. **79**: p. 640-651.
63. Baldi, F., U. Larsen, and C. Gabrielii, *Comparison of different procedures for the optimisation of a combined diesel engine and organic Rankine cycle system based on ship operational profile.* Ocean Eng, 2015. **110, Part B**: p. 85-93.
64. Brynolf, S., et al., *Compliance possibilities for the future ECA regulations through the use of abatement technologies or change of fuels.* Transport Res D - Tr E, 2014. **28**: p. 6-18.

65. Stevens, L., et al., *Is new emission legislation stimulating the implementation of sustainable and energy-efficient maritime technologies?* RTBM, 2015.

66. Ballini, F. and R. Bozzo, *Air pollution from ships in ports: The socio-economic benefit of cold-ironing technology.* RTBM, 2015. **17**: p. 92–98.

67. Lun, Y.H.V., et al., *Environmental governance mechanisms in shipping firms and their environmental performance.* Transport Res E - Log, 2015. **78**: p. 82-92.

68. Patricksson, Ø.S., K. Fagerholt, and J.G. Rakke, *The fleet renewal problem with regional emission limitations: case study from Roll-on/Roll-off shipping.* Transport Res C - Emer, 2015. **56**: p. 346-358.

69. Schøyen, H. and H. Sow, *A decision making tool concerning retrofit of shaft generator frequency converter.* Ocean Eng, 2015. **109**: p. 103-112.

70. Ölçer, A. and F. Ballini, *The development of a decision making framework for evaluating the trade-off solutions of cleaner seaborne transportation.* Transport Res D - Tr E, 2015. **37**: p. 150-170.

71. Dimopoulos, G.G., et al., *A general-purpose process modelling framework for marine energy systems.* Energy Convers Manag, 2014. **86**: p. 325-339.

72. Henriksson, T., et al., *Electric propulsion – state-of-the-art and trends in electric power generation, distribution, and propulsion, and their associated control systems*, in *8th ICMES/SNAME New York MetropolitanSection Symposium*, A.A. Kare and J.-F. Hansen, Editors. 2000, The Society of naval Architects and Marine Engineers: New York.

73. Kanerva, S. and J.-F. Hansen. *State of the art in electric propulsion – viewpoint on redundancy*. in *Electric Ship Technologies Symposium, 2009. ESTS 2009. IEEE*. 2009. IEEE.

74. McCoy, T.J. *Trends in ship electric propulsion*. in *Power Engineering Society Summer Meeting, 2002 IEEE*. 2002. IEEE.

75. Buja, G., et al. *Dependable design assessment of integrated power systems for all electric ships*. in *Electrical Systems for Aircraft, Railway and Ship Propulsion (ESARS), 2010*. 2010. IEEE.

76. Prousalidis, J.M., G.J. Tsekouras, and F. Kanellos. *New challenges emerged from the development of more efficient electric energy generation units*. in *Electric Ship Technologies Symposium (ESTS), 2011 IEEE*. 2011. IEEE.

77. Kanellos, F.D., J.M. Prousalidis, and G.J. Tsekouras, *Control system for fuel consumption minimisation – gas emission limitation of full electric propulsion ship power systems.* P I Mech Eng M - J Eng, 2014. **228**(1): p. 17-28.
78. Skjong, E., et al., *The marine vessel's electrical power system: from its birth to present day.* Proc IEEE, 2015. **103**(12): p. 2410-2424.
79. Dale, S., R. Hebner, and G. Sulligoi, *Electric ship technologies.* Proc IEEE, 2015. **103**(12): p. 2225-2228.
80. *Environmental management – Life cycle impact assessment – examples of application of ISO 14042*. 2003, British Standard.
81. Cullinane, K. and R. Bergqvist, *Emission control areas and their impact on maritime transport.* Transport Res D - Tr E, 2014. **28**: p. 1-5.
82. Fet, A.M. and E. Sørgård, *Life cycle evaluation of ship transportation – development of methodology and testing.* Aalesund College (HiA) in Cooperation with Det Norske Veritas (DNV)(HiA 10/B101/R-98/008/00), 1998: p. 32.
83. Johnsen, T. and A.M. Fet, *Screening life cycle assessment of M/V Color Festival*. 1999, Report.
84. Fet, A.M., O. Michelsen, and T. Johnsen, *Environmental performance of transportation - a comparative study*. 2000, Norwegian University of Science and Technology, Helge Gravås: Norway. p. 103.
85. Fet, A.M., *Environmental reporting in marine transport based on LCA.* Proc IMarEST J Marine Design Oper, 2002: p. 1476-1556.
86. Schmidt, J.H. and J. Watson, *Eco Island Ferry: Comparative LCA of island ferry with carbon fibre composite based and steel based structures*. 2014, 2.-0 LCA consultants.
87. Bengtsson, S., K. Andersson, and E. Fridell, *Life cycle assessment of marine fuels: a comparative study of four fossil fuels for marine propulsion*. 2011: Sweden.
88. Bengtsson, S., E. Fridell, and K. Andersson, *Environmental assessment of two pathways towards the use of biofuels in shipping.* Energy Pol, 2012. **44**: p. 451-463.
89. Alkaner, S. and P. Zhou, *A comparative study on life cycle analysis of molten carbon fuel cells and diesel engines for marine application.* J Power Sources, 2006. **158**(1): p. 188-199.

90. Strazza, C., et al., *Comparative LCA of methanol-fuelled SOFCs as auxiliary power systems on-board ships.* Appl Energy, 2010. **87**(5): p. 1670-1678.

91. Strand, K.H. and K.J. Aarskog, *Life cycle assessment of fuel cells onboard ships*, in *Department of Marine Technology*. 2010, Norwegian University of Science and Technology: Trondheim. p. 1-131.

92. Zuin, S., E. Belac, and B. Marzi, *Life cycle assessment of ship-generated waste management of Luka Koper.* Waste Manage, 2009. **29**: p. 3036–3046.

93. Jiven, K., et al., *LCA-ship, Design tool for energy efficient ships – a life cycle analysis program for ships*. 2004.

94. Kameyama, M., et al. *Development of LCA software for ships and LCI analysis based on actual shipbuilding and operation*. in *Proc. 6 th Int. Conf. on Ecobalance*. 2005.

95. Kameyama, M., K. Hiraoka, and H. Tauchi, *Study on life cycle impact assessment for ships.* NMRI (Japan), 2007.

96. Tincelin, T., et al., *A life cycle approach to shipbuilding and ship operation*, in *Ship design and operation for environmental sustainability*. 2007, The Royal Institution of Naval Architects: London.

97. Princaud, M., A. Cornier, and D. Froelich, *Developing a tool for environmental impact assessment and eco-design for ships.* P I Mech Eng M - J Eng, 2010. **224**(M3): p. 207-224.

98. Basurko, O.C. and E. Mesbahi, *Methodology for the sustainability assessment of marine technologies.* J Clean Prod, 2014. **68**(0): p. 155-164.

99. Chatzinikolaou, S.D. and N.P. Ventikos, *Holistic framework for studying ship air emissions in a life cycle perspective.* Ocean Eng, 2015. **110, Part B**: p. 113-122.

100. Lister, J., R.T. Poulsen, and S. Ponte, *Orchestrating transnational environmental governance in maritime shipping.* Global Environ Chang, 2015. **34**: p. 185-195.

101. *Life cycle assessment: Inventory guidelines and principles*. 1993: Ohio, US.

102. *Environmental management – life cycle assessment – principles and framework*. 1997, British Standard.

103. *Environmental management – life cycle impact assessment – goal and scope definition and inventory analysis*. 1998, British Standard.

104. *Environmental management – life cycle impact assessment – life cycle impact assessment*. 2000, British Standard.

105. *Environmental management – life cycle impact assessment – life cycle interpretation*. 2000, British Standard.
106. *Environmental management – life cycle impact assessment – principles and framework*. 2006, British Standard.
107. *Environmental management – life cycle impact assessment – requirements and guidelines*. 2006, International Organisation for Standardisation (ISO).
108. Bare, J.C., *Life cycle impact assessment research developments and needs.* Clean Technol Environ Policy, 2010. **12**(4): p. 341-351.
109. Pryshlakivsky, J. and C. Searcy, *Fifteen years of ISO 14040: a review.* J Clean Prod, 2013. **57**: p. 115-123.
110. Finkbeiner, M., et al., *The new international standards for life cycle assessment: ISO 14040 and ISO 14044.* Int J Life Cycle Assess, 2006. **11**(2): p. 80-85.
111. Bare, J.C. and T.P. Gloria, *Critical analysis of the mathematical relationships and comprehensiveness of life cycle impact assessment approaches.* Environ Sci Technol, 2006. **40**(4): p. 1104-1113.
112. *ILCD handbook: general guide for life cycle assessment – detailed guidance*. 2010: Luxembourg.
113. *Towards a life cycle sustainability assessment: making informed choices on products*. 2011.
114. *Global guidance principles for life cycle assessment databases - a basis for greener processes and products*. 2011.
115. Finnveden, G., et al., *Recent developments in life cycle assessment.* J Environ Manage, 2009. **91**(1): p. 1-21.
116. Pennington, D.W., et al., *Life cycle assessment Part 2: current impact assessment practice.* Environ Int, 2004. **30**(5): p. 721-739.
117. Udo de Haes, H.A., et al., *Best available practice regarding impact categories and category indicators in life cycle impact assessment/background document for the second indicators in life cycle impact assessment of SETAC Europe (WIA-20).* Int J Life Cycle Assess 1999. **4**: p. 66-74.
118. Chan, Y.T., R.B.H. Tan, and H.H. Khoo, *Characterisation framework development for the SIMPASS (Singapore impact assessment) methodology.* Int J Life Cycle Assess, 2012. **17**(1): p. 89-95.

119. Curran, M.A., *Co-product and input allocation approaches for creating life cycle inventory data: a literature review.* Int J Life Cycle Assess, 2007. **12**: p. 65-78.
120. *A scientific framework for LCA – Deliverable (D15) of work package 2 (WP2) CALCAS project*. 2009, Institute of Environmental Science, Leiden University.
121. Rebitzer, G., et al., *Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications.* Environ Int, 2004. **30**(5): p. 701-720.
122. Suh, S., et al., *System boundary selection in life-cycle inventories using hybrid approaches.* Environ Sci Technol, 2004. **38**(3): p. 657-664.
123. Reap, J., et al., *A survey of unresolved problems in life cycle assessment - Part 1: goal and scope and inventory analysis.* Int J Life Cycle Assess, 2008. **13**(4): p. 290-300.
124. Reap, J., et al., *A survey of unresolved problems in life cycle assessment - Part 2 impact assessment and interpretation.* Int J Life Cycle Assess, 2008. **13**: p. 374–388.
125. Earles, J.M. and A. Halog, *Consequential life cycle assessment: a review.* Int J Life Cycle Assess, 2011. **16**(5): p. 445-453.
126. Garrigues, E., et al., *Soil quality in life cycle assessment: towards development of an indicator.* Ecol Indic, 2012. **18**(0): p. 434-442.
127. Johnsen, F.M. and S. Løkke, *Review of criteria for evaluating LCA weighting methods.* Int J Life Cycle Assess, 2013. **18**(4): p. 840-849.
128. Kounina, A., et al., *Review of methods addressing freshwater use in life cycle inventory and impact assessment.* Int J Life Cycle Assess 2013. **18**(3): p. 707-721.
129. Hellweg, S. and L.M. i Canals, *Emerging approaches, challenges and opportunities in life cycle assessment.* Science, 2014. **344**(6188): p. 1109-1113.
130. Klinglmair, M., S. Sala, and M. Brandão, *Assessing resource depletion in LCA: a review of methods and methodological issues.* Int J Life Cycle Assess, 2014. **19**(3): p. 580-592.
131. Bolin, C.A. and S.T. Smith, *Life cycle assessment of pentachlorophenol-treated wooden utility poles with comparisons to steel and concrete utility poles.* Renew Sustain Energy Rev, 2011. **15**(5): p. 2475-2486.

132. Cho, Y.S., et al., *LCA application in the optimum design of high rise steel structures.* Renew Sustain Energy Rev, 2012. **16**(5): p. 3146-3153.
133. Lee, K., S. Tae, and S. Shin, *Development of a life cycle assessment program for building (SUSB-LCA) in South Korea.* Renew Sustain Energy Rev, 2009. **13**(8): p. 1994-2002.
134. Sharma, A., et al., *Life cycle assessment of buildings: a review.* Renew Sustain Energy Rev, 2011. **15**(1): p. 871-875.
135. Buyle, M., J. Braet, and A. Audenaert, *Life cycle assessment in the construction sector: a review.* Renew Sustain Energy Rev, 2013. **26**(0): p. 379-388.
136. Zhang, X., L. Shen, and L. Zhang, *Life cycle assessment of the air emissions during building construction process: a case study in Hong Kong.* Renew Sustain Energy Rev, 2013. **17**(0): p. 160-169.
137. Cabeza, L.F., et al., *Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: a review.* Renew Sustain Energy Rev, 2014. **29**(0): p. 394-416.
138. Islam, H., M. Jollands, and S. Setunge, *Life cycle assessment and life cycle cost implication of residential buildings - A review.* Renew Sustain Energy Rev, 2015. **42**(0): p. 129-140.
139. Chauhan, M.K., et al., *Life cycle assessment of sugar industry: a review.* Renew Sustain Energy Rev, 2011. **15**(7): p. 3445-3453.
140. González-García, S., et al., *Life cycle assessment of flax shives derived second generation ethanol fueled automobiles in Spain.* Renew Sustain Energy Rev, 2009. **13**(8): p. 1922-1933.
141. Faria, R., et al., *Impact of the electricity mix and use profile in the life-cycle assessment of electric vehicles.* Renew Sustain Energy Rev, 2013. **24**(0): p. 271-287.
142. Luo, L., E. van der Voet, and G. Huppes, *Life cycle assessment and life cycle costing of bioethanol from sugarcane in Brazil.* Renew Sustain Energy Rev, 2009. **13**(6–7): p. 1613-1619.
143. Hou, J., et al., *Life cycle assessment of biodiesel from soybean, jatropha and microalgae in China conditions.* Renew Sustain Energy Rev, 2011. **15**(9): p. 5081-5091.

144. Rehl, T., J. Lansche, and J. Müller, *Life cycle assessment of energy generation from biogas – attributional vs. consequential approach.* Renew Sustain Energy Rev, 2012. **16**(6): p. 3766-3775.
145. Wiloso, E.I., R. Heijungs, and G.R. de Snoo, *LCA of second generation bioethanol: A review and some issues to be resolved for good LCA practice.* Renew Sustain Energy Rev, 2012. **16**(7): p. 5295-5308.
146. Lopes Silva, D.A., et al., *Life cycle assessment of the sugarcane bagasse electricity generation in Brazil.* Renew Sustain Energy Rev, 2014. **32**(0): p. 532-547.
147. Rocha, M.H., et al., *Life cycle assessment (LCA) for biofuels in Brazilian conditions: a meta-analysis.* Renew Sustain Energy Rev, 2014. **37**(0): p. 435-459.
148. Morales, M., et al., *Life cycle assessment of lignocellulosic bioethanol: environmental impacts and energy balance.* Renew Sustain Energy Rev, 2015. **42**(0): p. 1349-1361.
149. Tabata, T., et al., *Life cycle assessment for co-firing semi-carbonized fuel manufactured using woody biomass with coal: A case study in the central area of Wakayama, Japan.* Renew Sustain Energy Rev, 2011. **15**(6): p. 2772-2778.
150. Sherwani, A.F., J.A. Usmani, and Varun, *Life cycle assessment of solar PV based electricity generation systems: a review.* Renew Sustain Energy Rev, 2010. **14**(1): p. 540-544.
151. Sumper, A., et al., *Life-cycle assessment of a photovoltaic system in Catalonia (Spain).* Renew Sustain Energy Rev, 2011. **15**(8): p. 3888-3896.
152. Peng, J., L. Lu, and H. Yang, *Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems.* Renew Sustain Energy Rev, 2013. **19**(0): p. 255-274.
153. Parisi, M.L., S. Maranghi, and R. Basosi, *The evolution of the dye sensitized solar cells from Grätzel prototype to up-scaled solar applications: A life cycle assessment approach.* Renew Sustain Energy Rev, 2014. **39**(0): p. 124-138.
154. Ardente, F., et al., *Energy performances and life cycle assessment of an Italian wind farm.* Renew Sustain Energy Rev, 2008. **12**(1): p. 200-217.
155. Tremeac, B. and F. Meunier, *Life cycle analysis of 4.5 MW and 250 W wind turbines.* Renew Sustain Energy Rev, 2009. **13**(8): p. 2104-2110.

156. Arvesen, A. and E.G. Hertwich, *Assessing the life cycle environmental impacts of wind power: A review of present knowledge and research needs.* Renew Sustain Energy Rev, 2012. **16**(8): p. 5994-6006.
157. Rashedi, A., I. Sridhar, and K.J. Tseng, *Life cycle assessment of 50 MW wind firms and strategies for impact reduction.* Renew Sustain Energy Rev, 2013. **21**(0): p. 89-101.
158. Bayer, P., et al., *Review on life cycle environmental effects of geothermal power generation.* Renew Sustain Energy Rev, 2013. **26**(0): p. 446-463.
159. Varun, I.K. Bhat, and R. Prakash, *LCA of renewable energy for electricity generation systems – a review.* Renew Sustain Energy Rev, 2009. **13**(5): p. 1067-1073.
160. Turconi, R., A. Boldrin, and T. Astrup, *Life cycle assessment (LCA) of electricity generation technologies: overview, comparability and limitations.* Renew Sustain Energy Rev, 2013. **28**(0): p. 555-565.
161. Asdrubali, F., et al., *Life cycle assessment of electricity production from renewable energies: review and results harmonization.* Renew Sustain Energy Rev, 2015. **42**(0): p. 1113-1122.
162. Li, X., et al., *An environmental impact assessment framework and index system for the pre-use phase of buildings based on distance-to-target approach.* Build Environ, 2015. **85**: p. 173-181.
163. Ribeiro, I., P. Peças, and E. Henriques, *A life cycle framework to support materials selection for Ecodesign: a case study on biodegradable polymers.* Mater Design, 2013. **51**: p. 300-308.
164. Brondi, C. and E. Carpanzano, *A modular framework for the LCA-based simulation of production systems.* CIRP J Manuf Sci Technol, 2011. **4**(3): p. 305-312.
165. Núñez, M., et al., *Estimating water consumption of potential natural vegetation on global dry lands: building an LCA framework for green water flows.* Environ Sci Technolo, 2013. **47**(21): p. 12258-12265.
166. Hischier, R., *Framework for LCI modelling of releases of manufactured nanomaterials along their life cycle.* Int J Life Cycle Assess, 2014. **19**(4): p. 838-849.
167. Nakatani, J., *Life cycle inventory analysis of recycling: mathematical and graphical frameworks.* Sustainability 2014. **6**(9): p. 6158-6169.

168. Quinteiro, P., et al., *A framework for modelling the transport and deposition of eroded particles towards water systems in a life cycle inventory.* Int J Life Cycle Assess, 2014. **19**(6): p. 1200-1213.
169. Frischknecht, R., et al., *The ecoinvent database: overview and methodological framework.* Int J Life Cycle Assess, 2005. **10**(1): p. 3-9.
170. Suh, S., et al., *Generalised make and use framework for allocation in life cycle assessment.* J Ind Ecol, 2010. **14**(2): p. 335-353.
171. Chen, I.C., et al., *A graphical representation for consequential life cycle assessment of future technologies. Part 1: methodological framework.* Int J Life Cycle Assess, 2012. **17**(2): p. 119-125.
172. Rugani, B., D. Panasiuk, and E. Benetto, *An input-output based framework to evaluate human labour in life cycle assessment.* Int J Life Cycle Assess, 2012. **17**(6): p. 795-812.
173. Suh, S. and B.C. Lippiatt, *Framework for hybrid life cycle inventory databases: a case study on the building for environmental and economic sustainability (BEES) database.* Int J Life Cycle Assess, 2012. **17**(5): p. 604-612.
174. Collinge, W.O., et al., *Dynamic life cycle assessment: framework and application to an institutional building.* Int J Life Cycle Assess, 2013. **18**(3): p. 538-552.
175. Yuan, C., et al., *Temporal discounting in life cycle assessment: a critical review and theoretical framework.* Environ Impact Assess Rev, 2015. **51**: p. 23-31.
176. Stewart, M. and B.P. Weidema, *A Consistent Framework for Assessing the Impacts from Resource Use-A focus on resource functionality (8 pp).* Int J Life Cycle Assess, 2005. **10**(4): p. 240-247.
177. Koellner, T. and R.W. Scholz, *Assessment of land use impacts on the natural environment – Part 1: an analytical framework for pure land occupation and land use change.* Int J Life Cycle Assess, 2007. **12**(1): p. 16-23.
178. Althaus, H.J., P. De Haan, and R.W. Scholz, *Traffic noise in LCA – Part 2: Analysis of existing methods and proposition of a new framework for consistent, context-sensitive LCI modeling of road transport noise emission.* Int J Life Cycle Assess, 2009. **14**(7): p. 676-686.
179. Bayart, J.-B., et al., *A framework for assessing off-stream freshwater use in LCA.* Int J Life Cycle Assess, 2010. **15**(5): p. 439-453.

180. Cucurachi, S., R. Heijungs, and K. Ohlau, *Towards a general framework for including noise impacts in LCA.* Int J Life Cycle Assess, 2012. **17**(4): p. 471-487.
181. Collinge, W., et al., *Indoor environmental quality in a dynamic life cycle assessment framework for whole buildings: focus on human health chemical impacts.* Build Environ, 2013. **62**: p. 182-190.
182. Cucurachi, S., et al., *A framework for deciding on the inclusion of emerging impacts in life cycle impact assessment.* J Clean Prod, 2014. **78**: p. 152-163.
183. Walser, T., et al., *Life-cycle assessment framework for indoor emissions of synthetic nanoparticles.* J Nanopart Res, 2015. **17**(6): p. 1-18.
184. Hertwich, E.G. and J.K. Hammitt, *A decision-analytic framework for impact assessment part I: LCA and decision analysis.* Int J Life Cycle Assess, 2001. **6**(1): p. 5-12.
185. Seppälä, J., L. Basson, and G.A. Norris, *Decision analysis frameworks for life-cycle impact assessment.* J Ind Ecol, 2001. **5**(4): p. 45-68.
186. Jung, J., N. von der Assen, and A. Bardow, *An uncertainty assessment framework for lca-based environmental process design*, in *Comput Aided Chem Eng* 2013. p. 937-942.
187. Dreyer, L.C., M.Z. Hauschild, and J. Schierbeck, *A framework for social life cycle impact assessment.* Int J Life Cycle Assess, 2006. **11**(2): p. 88-97.
188. Kim, I. and T. Hur, *Integration of working environment into life cycle assessment framework.* Int J Life Cycle Assess, 2009. **14**(4): p. 290-301.
189. Reitinger, C., et al., *A conceptual framework for impact assessment within SLCA.* Int J Life Cycle Assess, 2011. **16**(4): p. 380-388.
190. Ramirez, P.K.S., et al., *Subcategory assessment method for social life cycle assessment. Part 1: methodological framework.* Int J Life Cycle Assess, 2014. **19**(8): p. 1515-1523.
191. Onn, C.C. and S. Yusoff, *The formulation of life cycle impact assessment framework for Malaysia using Eco-indicator.* Int J Life Cycle Assess, 2010. **15**(9): p. 985-993.
192. Haas, G., F. Wetterich, and U. Geier, *Life cycle assessment framework in agriculture on the farm level.* Int J Life Cycle Assess, 2000. **5**(6): p. 345-348.
193. Popp, J.S., et al., *Collecting complex comprehensive farm level data through a collaborative approach: a framework developed for a life cycle assessment of fluid milk production in the US.* Int Dairy J, 2013. **31**(1): p. S15-S20.

194. De Camillis, C., A. Raggi, and L. Petti, *Life cycle assessment in the framework of sustainable tourism: a preliminary examination of its effectiveness and challenges.* Progr Ind Ecol, 2010. **7**(3): p. 205-218.
195. Fet, A.M., E.M. Schau, and C. Haskins, *A framework for environmental analyses of fish food production systems based on systems engineering principles.* INCOSE, 2010. **13**(2): p. 109-118.
196. Heller, M.C., G.A. Keoleian, and W.C. Willett, *Toward a life cycle-based, diet-level framework for food environmental impact and nutritional quality assessment: A critical review.* Environ Sci Technolo, 2013. **47**(22): p. 12632-12647.
197. Holma, A., et al., *Current limits of life cycle assessment framework in evaluating environmental sustainability - Case of two evolving biofuel technologies.* J Clean Prod, 2013. **54**: p. 215-228.
198. Bauer, C., et al., *The environmental performance of current and future passenger vehicles: life cycle assessment based on a novel scenario analysis framework.* Appl Energy, 2014.
199. Egede, P., et al., *Life cycle assessment of electric vehicles – a framework to consider influencing factors.* Procedia CIRP, 2015. **29**: p. 233-238.
200. Shin, S.-J., et al., *Process-oriented life cycle assessment framework for environmentally conscious manufacturing.* J Intell Manuf, 2015: p. 1-19.
201. Rabl, A. and M. Holland, *Environmental assessment framework for policy applications: life cycle assessment, external costs and multi-criteria analysis.* J Environ Plann Manag, 2008. **51**(1): p. 81-105.
202. Heijungs, R., G. Huppes, and J.B. Guinée, *Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis.* Polym Degrad Stabil, 2010. **95**(3): p. 422-428.
203. Goldstein, B., et al., *Quantification of urban metabolism through coupling with the life cycle assessment framework: concept development and case study.* Environ Res Lett, 2013. **8**(3).
204. Loiseau, E., et al., *Adapting the LCA framework to environmental assessment in land planning.* Int J Life Cycle Assess, 2013. **18**(8): p. 1533-1548.
205. Avadí, Á., I. Vázquez-Rowe, and P. Fréon, *Eco-efficiency assessment of the Peruvian anchoveta steel and wooden fleets using the LCA+DEA framework.* J Clean Prod, 2014. **70**: p. 118-131.

206. Liu, Z., T. Qiu, and B. Chen, *A LCA based biofuel supply chain analysis framework.* Chin J Chem Eng, 2014. **22**(6): p. 669-681.
207. Chang, D., et al., *A study on availability and safety of new propulsion systems for LNG carriers.* Reliab Eng Syst Saf, 2008. **93**(12): p. 1877–1885.
208. *Annex 11 Guidelines for calculation of reference lines for use with the energy efficiency desing index (EEDI)* in *Resolution MEPC.215(63)*, IMO, Editor. 2012.
209. *Reference manual on maritime transport statistics*. 2012, Eurostat.
210. *Review of maritime transport 2012*. 2012.
211. in *Significant ships of 2008 - A publication of The Royal Institution of Naval Architects*. 2008, Mark J Staunton-Lambert.
212. in *Significant ships of 2009 - A publication of The Royal Institution of Naval Architects*. 2009, Mark J Staunton-Lambert.
213. in *Significant ships of 2010 - A publication of The Royal Institution of Naval Architects*. 2010, Mark J Staunton-Lambert.
214. in *Significant ships of 2011 - A publication of The Royal Institution of Naval Architects*. 2011, Mark J Staunton-Lambert.
215. in *Significant ships of 2012 - A publication of The Royal Institution of Naval Architects*. 2012, Mark J Staunton-Lambert.
216. Buhaug, Ø., et al., *Second IMO GHG study 2009*. 2009: London, UK p. 220.
217. Koehler, H.W. and A. Werner Oehlers. *95 Years of diesel-electric propulsion form a makeshift solution to a modern propulsion system*. in *Norwegian Society of Chartered Engineers, 2 nd International Diesel electric propulsion conference, Helsinki, Finland*. 1998.
218. Veneri, O., et al. *Overview of electric propulsion and generation architectures for naval applications*. in *Electrical Systems for Aircraft, Railway and Ship Propulsion (ESARS), 2012*. 2012. IEEE.
219. Balashov, S., *Design of marine generators for alternative diesel-electric power systems.* 2011.
220. Narciso Pereira, N., *A diagnostic of diesel-electric propulsion for ships.* Ship Science & Technology, 2007. **1**(2): p. 27-42.
221. Zahedi, B., L.E. Norum, and K.B. Ludvigsen, *Optimized efficiency of all-electric ships by dc hybrid power systems.* J Power Sources, 2014. **255**: p. 341-354.
222. Schmitt, K., *Modeling and simulation of an all electric ship in random seas*. 2010, Massachusetts Institute of Technology.

223. Apsley, J.M., et al., *Propulsion drive models for full electric marine propulsion systems.* Industry Applications, IEEE Transactions on, 2009. **45**(2): p. 676-684.

224. Kosowski, K., *Ship turbine power plants: Fundamentals of thermodynamical cycles*. 2005: Foundation for the Promotion of Maritime Industry. 280.

225. Carlton, J., J. Aldwinkle, and J. Anderson, *Future ship powering options: exploring alternative methods of ship propulsion*, in *London: Royal Academy of Engineering*. 2013.

226. Veritas, D.N., *Technology outlook 2020.* DNV Research & Innovation, Høvik, 2010.

227. *Technology characterisation: reciprocating engines*. 2008, Energy and Environmental Analysis: US.

228. Woodyard, D., *Chapter one - theory and general principles*, in *Pounder's Marine Diesel Engines and Gas Turbines (Ninth Edition)*. 2009, Butterworth-Heinemann: Oxford. p. 1-40.

229. Lucke, C.E., *Internal combustion engines in marine service.* J Franklin Inst, 1921. **192**(1): p. 11-45.

230. Sharaf, O.Z. and M.F. Orhan, *An overview of fuel cell technology: fundamentals and applications.* Renew Sustain Energy Rev, 2014. **32**: p. 810-853.

231. Stambouli, A.B. and E. Traversa, *Solid oxide fuel cells (SOFCs): a review of an environmentally clean and efficient source of energy.* Renew Sustain Energy Rev, 2002. **6**(5): p. 433-455.

232. El-Gohary, M.M., *Overview of past, present and future marine power plants.* J Mar Sci Appl, 2013. **12**(2): p. 219-227.

233. Rosellini, S., G. Schmitt, and P. Fleischmann, *Molten carbonate fuel cell: a novel approach to powering large telecommunications facilities*. 2003: unknown.

234. Baker, J., *New technology and possible advances in energy storage.* Energy Pol, 2008. **36**(12): p. 4368-4373.

235. Dedes, E.K., D.A. Hudson, and S.R. Turnock, *Assessing the potential of hybrid energy technology to reduce exhaust emissions from global shipping.* Energy Pol, 2012. **40**: p. 204-218.

236. Doerffel, D. and S.A. Sharkh, *Large lithium-ion batteries – a review.* IN: Electric Vehicle Exhibition (EMA 2006), Aschaffenburg (Germany), 2006. **14**(2006): p. 15.
237. Zhou, Z., et al., *A review of energy storage technologies for marine current energy systems.* Renew Sustain Energy Rev, 2013. **18**: p. 390-400.
238. Dell, R.M., *Materials development for advanced traction batteries.* Mater Design, 1986. **7**(3): p. 124-131.
239. Dell, R.M., *Batteries: fifty years of materials development.* Solid State Ionics, 2000. **134**(1): p. 139-158.
240. Dell, R.M. and D.A.J. Rand, *Energy storage – a key technology for global energy sustainability.* J Power Sources, 2001. **100**(1): p. 2-17.
241. Schmid, H. *Less emissions through waste heat recovery*. in *Green Ship Technology Conference, London*. 2004.
242. Theotokatos, G. and G.A. Livanos, *Modern concepts of ferries propulsion plant for reducing fuel consumption cost and CO2 emissions*, in *Low Carbon Shipping Conference*. 2013: London, UK. p. 12.
243. Anish. *The green source of power on ship – shaft generator*. 2010 [cited 2015 15 January]; Available from: http://www.marineinsight.com/marine/environment/the-green-source-of-power-shaft-generator/.
244. McGeorge, H.D., *Shaft-driven generators*, in *Marine Electrical Equipment and Practice (Second Edition)*. 1993, Butterworth-Heinemann: Oxford. p. 130-136.
245. Salmi, T., et al., *Matlab/simulink based modeling of photovoltaic cell.* Int J Energy Res, 2012. **2**(2): p. 213-218.
246. Kobougias, I., E. Tatakis, and J. Prousalidis, *PV systems installed in marine vessels: technologies and specifications.* Adv Power Electron, 2013. **2013**.
247. *The Maltese Falcon*. 2010 [cited 2015 1 March]; Available from: http://www.symaltesefalcon.com/design-concepts.php.
248. Rojon, I. and C. Dieperink, *Blowin'in the wind? Drivers and barriers for the uptake of wind propulsion in international shipping.* Energy Pol, 2014. **67**: p. 394-402.
249. Raunek, K. *Top 7 green ship concepts using wind energy*. 2013 [cited 2014 2 June]; Available from: http://www.marineinsight.com/marine/marine-news/headline/top-7-green-ship-concepts-using-wind-energy/.

250. De Jonge, E., C. Hugi, and D. Cooper, *Service contract on ship emissions: assignment, abatement and market-based instruments*, in *Task 2a — Shore-Side Electricity, Final Report, Entec UK Limited*. 2005.
251. Hall, W.J., *Assessment of CO2 and priority pollutant reduction by installation of shoreside power.* Resour Conserv Recy, 2010. **54**(7): p. 462-467.
252. Arduino, G., et al., *How to turn an innovative concept into a success? An application to seaport-related innovation.* Research in Transportation Economics, 2013. **42**(1): p. 97-107.
253. Gibbs, D., et al., *The role of sea ports in end-to-end maritime transport chain emissions.* Energy Pol, 2014. **64**: p. 337-348.
254. Cornelissen, R.L. and G.G. Hirs, *The value of the exergetic life cycle assessment besides the LCA.* Energy Convers Manag, 2002. **43**(9–12): p. 1417-1424.
255. Li, D. and R. Wang, *Hybrid emergy-LCA (HEML) based metabolic evaluation of urban residential areas: the case of Beijing, China.* Ecol Complexity, 2009. **6**(4): p. 484-493.
256. Ramesh, T., R. Prakash, and K.K. Shukla, *Life cycle energy analysis of buildings: an overview.* Energy Build, 2010. **42**(10): p. 1592-1600.
257. Stamford, L. and A. Azapagic, *Life cycle sustainability assessment of UK electricity scenarios to 2070.* Energy Sustain Dev, 2014. **23**(0): p. 194-211.
258. *2011 Directory of sustainable life cycle assessment tools*. 2011, Portland: International Society of Sustainability Professionals.
259. Afrinaldi, F. and H.-C. Zhang, *A fuzzy logic based aggregation method for life cycle impact assessment.* J Clean Prod, 2014. **67**: p. 159-172.
260. Ahlroth, S., et al., *Weighting and valuation in selected environmental systems analysis tools–suggestions for further developments.* J Clean Prod, 2011. **19**(2): p. 145-156.
261. Althaus, H.-J., et al., *Implementation of life cycle impact assessment methods*, R. Hischier and B. Weidema, Editors. 2009.
262. Azapagic, A. and R. Clift, *Allocation of environmental burdens in co-product systems: product-related burdens (part 1).* Int J Life Cycle Assess 1999. **4**(6): p. 357-368.
263. Baitz, M., et al., *LCA's theory and practice: like ebony and ivory living in perfect harmony?* Int J Life Cycle Assess, 2012.

264. Bare, J., *TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0.* Clean Technol Environ Policy, 2011. **13**(5): p. 687-696.
265. Bare, J.C., et al., *TRACI: the tool for the reduction and assessment of chemical and other environmental impacts.* J Ind Ecol, 2008. **6**(3-4): p. 49-78.
266. Beloin-Saint-Pierre, D., R. Heijungs, and I. Blanc, *The ESPA (enhanced structural path analysis) method - a solution to an implementation challenge for dynamic life cycle assessment studies.* Int J Life Cycle Assess, 2014. **19**: p. 861-871.
267. Bengtsson, J. and N. Howard, *A life cycle impact assessment method for use in Australia - classification, characterisation and research needs*. 2010, Edge Environment Pty Ltd: Australia.
268. Boulay, A.-M., et al., *Categorising water for LCA inventory.* Int J Life Cycle Assess, 2011. **16**(7): p. 639-651.
269. Brander, M., et al., *Consequential and atrributional approaches to LCA: a guide to policy makers with specific reference to greenhouse gas LCA of biofuels*. 2009. p. 1-14.
270. Chevalier, J. and P. Rousseaux, *Classification in LCA: building of a coherent family of criteria.* Int J Life Cycle Assess, 1999. **4**(6): p. 352-356.
271. Crawford, R.H., *Validation of a hybrid life-cycle inventory analysis method.* J Environ Manage, 2008. **88**(3): p. 496-506.
272. Crettaz, P., et al., *Assessing human health response in life cycle assessment using ED10s and DALYs: Part 1 – cancer effects.* Risk Anal, 2002. **22**(5).
273. Cucurachi, S. and R. Heijungs, *Characterisation factors for life cycle impact assessment of sound emissions.* Sci Total Environ, 2014. **468**: p. 280-291.
274. Curran, M.A., *Life Cycle Assessment: principles and practice*. 2006. p. 1-80.
275. Dreyer, L.C., A.L. Niemann, and M.Z. Hauschild, *Comparison of three different LCIA methods: EDIP97, CML2001 and Eco-indicator 99 - Does it matter which one you choose?* Int J Life Cycle Assess, 2003. **8**(4): p. 191-200.
276. Ekvall, T. and G. Finnveden, *Allocation in ISO 14041 – a critical review.* J Clean Prod, 2001. **9**(3): p. 197-208.
277. Erlandsson, M. and L.-G. Lindfors, *On the possibilities to apply the result from an LCA disclosed to public.* Int J Life Cycle Assess, 2003. **8**(2): p. 65-73.

278. Franco, V., D. Garraín, and R. Vidal, *Methodological proposals for improved assessments of the impact of traffic noise upon human health.* Int J Life Cycle Assess, 2010. **15**(8): p. 869-882.

279. Frischknecht, R., et al., *The environmental relevance of capital goods in life cycle assessments of products and services.* Int J Life Cycle Assess, 2007. **12**: p. 7-17.

280. Garrigues, E., et al., *Development of a soil compaction indicator in life cycle assessment.* Int J Life Cycle Assess, 2013. **18**(7): p. 1316-1324.

281. Goedkoop, M., et al., *ReCiPe 2008 – a life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level*. 2009: The Nerthelands. p. 126.

282. Guinee, J. and R. Heijungs, *A proposal for the classification of toxic substances within the framework of life cycle assessment of products* Chemosphere, 1993. **26**(10): p. 1925-1944.

283. Guinee, J.B., et al., *Life cycle assessment: past, present, and future.* Environ Sci Technol, 2011. **45**(1): p. 90-96.

284. Guinee, J.B., et al., *Environmental life cycle assessment of products – backgrounds*, R. Heijungs, Editor. 1992, Centre of Environmental Science: Leiden.

285. Guinee, J.B., et al., *Environmental life cycle assessment of products – guide*, R. Heijungs, Editor. 1992, Centre of Environmental Science: Leiden.

286. Guo, M. and R.J. Murphy, *LCA data quality: Sensitivity and uncertainty analysis.* Sci Total Environ, 2012. **435**: p. 230-243.

287. Hauschild, M.Z., et al., *Identifying best existing practice for characterization modeling in life cycle impact assessment.* Int J Life Cycle Assess, 2012.

288. Hauschild, M.Z., et al., *Building a model based on scientific consensus for life cycle impact assessment of chemicals: the search for harmony and parsimony.* Environ Sci Technol, 2008. **42**(19): p. 7032-7037.

289. Hauschild, M.Z., et al., *Spatial differentiation in the characterisation of photochemical ozone formation – the EDIP2003 methodology.* Int J Life Cycle Assess, 2006. **11**: p. 72-80.

290. Heijungs, R. and S. Suh, *Reformulation of matrix-based LCI: from product balance to process balance.* J Clean Prod, 2006. **14**(1): p. 47-51.

291. Heijungs, R. and R.R. Tan, *Rigorous proof of fuzzy error propagation with matrix-based LCI.* Int J Life Cycle Assess, 2010. **15**(9): p. 1014-1019.

292. Heimersson, S., et al., *Including pathogen risk in life cycle assessment of wastewater management. 2. Quantitative comparison of pathogen risk to other impacts on human health.* Environ Sci Technol, 2014. **48** (16): p. 9446–9453.
293. Henderson, A.D., et al., *USEtox fate and ecotoxicity factors for comparative assessment of toxic emissions in life cycle analysis: sensitivity to key chemical properties.* Int J Life Cycle Assess, 2011. **16**(8): p. 701-709.
294. Hendrickson, C.T., et al., *Comparing two life cycle assessment approaches: a process model- vs. economic input-output-based assessment*, in *1997 IEEE International Symposium on electronics & the environment*. 1997, IEEE: San Francisco, California.
295. Hiejungs, R., et al., *Towards a life cycle impact assessment method which comprises category indicators at the midpoint and the endpoint level*. 2003: The Netherlands.
296. Huijbregts, M., *A critical view on scientific consensus building in life cycle impact assessment.* Int J Life Cycle Assess, 2014. **19**(3): p. 477-479.
297. Huijbregts, M.A.J., et al., *Human-toxicological effect and damage factors of carcinogenic and noncarcinogenic chemicals for life cycle impact assessment.* Integr Environ Assess Manag, 2005. **1**(3): p. 181-244.
298. Huijbregts, M.A.J., et al., *Priority assessment of toxic substances in life cycle assessment. Part I: calculation of toxicity potentials for 181 substances with the nested multi-media fate, exposure and effects model USES-LCA.* Chemosphere, 2000. **41**(4): p. 541-573.
299. Jeswani, H.K. and A. Azapagic, *Water footprint: methodologies and a case study for assessing the impacts of water use.* J Clean Prod, 2011. **19**(12): p. 1288-1299.
300. Jolliet, O., et al., *Global guidance on environmental life cycle impact assessment indicators: findings of the scoping phase.* Int J Life Cycle Assess, 2014. **19**(4): p. 962-967.
301. Koellner, T., et al., *Principles for life cycle inventories of land use on a global scale.* Int J Life Cycle Assess, 2013. **18**(6): p. 1203-1215.
302. Koellner, T. and R.W. Scholz, *Assessment of land use impacts on the natural environment – Part 2: generic characterization factors for local species diversity in central Europe.* Int J Life Cycle Assess, 2008. **13**(1): p. 32-48.

303. Laurent, A., et al., *Normalisation references for Europe and North America for application with USEtox (TM) characterization factors.* Int J Life Cycle Assess, 2011. **16**(8): p. 728-738.

304. Lee, J.J., P. Ocallaghan, and D. Allen, *Critical-review of life-cycle analysis and assessment techniques and their application to commercial activities.* Resour Conserv Recy, 1995. **13**(1): p. 37-56.

305. Lenzen, M., *Errors in conventional and input-output based life-cycle inventories* J Ind Ecol, 2000. **4**(4): p. 127-148.

306. Lenzen, M., *A guide for compiling inventories in hybrid life-cycle assessments: some Australian results.* J Clean Prod, 2002. **10**(6): p. 545-572.

307. Lenzen, M., *Dealing with double-counting in tiered hybrid life-cycle inventories: a few comments.* J Clean Prod, 2009. **17**(15): p. 1382-1384.

308. Levasseur, A., et al., *Considering time in LCA: dynamic LCA and its application to global warming impact assessments.* Environ Sci Technol, 2010. **44**(8): p. 3169-3174.

309. Li, T., et al., *A system boundary identification method for life cycle assessment.* Int J Life Cycle Assess, 2014. **19**(3): p. 646-660.

310. Lundie, S., A. Ciroth, and G. Huppes, *Inventory methods in LCA: towards consistency and improvement*. 2007.

311. Lundie, S., et al., *Australian characterisation factors and normalisation figures for human toxicity and ecotoxicity.* J Clean Prod, 2007. **15**(8–9): p. 819-832.

312. Mattila, T.J., S. Pakarinen, and L. Sokka, *Quantifying the total environmental impacts of an industrial symbiosis – a comparison of process-, hybrid and input-output life cycle assessment.* Environ Sci Technol, 2010. **44**: p. 4309-4314.

313. Nakamura, S., et al., *The waste input-output approach to materials flow analysis - concepts and application to base metals.* J Ind Ecol, 2007. **11**(4): p. 50-63.

314. Ossés de Eicker, M., et al., *The applicability of non-local LCI data for LCA.* Environ Impact Assess Rev, 2010. **30**(3): p. 192-199.

315. Owens, J.W., *Life cycle impact assessment: the Use in classification and characterization of subjective judgements.* Int J Life Cycle Assess, 1998. **3**(1): p. 43-46.

316. Owens, J.W., *Why life cycle impact assessment is now described as an indicator system.* Int J Life Cycle Assess, 1999. **4**(2): p. 81-86.

317. Owsianiak, M., et al., *IMPACT 2002+, ReCiPe 2008 and ILCD's recommended practice for characterization modelling in life cycle impact assessment: a case study-based comparison.* Int J Life Cycle Assess 2014. **19**(5): p. 1007-1021.
318. Pennington, D., et al., *Assessing human health response in life cycle assessment using ED10s and DALYs: Part 2 – noncancer effects.* Risk Anal, 2002. **22**(5): p. 947-963.
319. Pizzol, M., et al., *Eco-toxicological impact of "metals" on the aquatic and terrestrial ecosystem: a comparison between eight different methodologies for Life Cycle Impact Assessment (LCIA).* J Clean Prod, 2011. **19**(6-7): p. 687-698.
320. Pizzol, M., et al., *Impacts of "metals" on human health: a comparison between nine different methodologies for life cycle impact assessment (LCIA).* J Clean Prod, 2011. **19**(6-7): p. 646-656.
321. Raynolds, M., R. Fraser, and D. Checkel, *The relative mass-energy-economic (RMEE) method for system boundary selection.* Int J Life Cycle Assess, 2000. **5**(1): p. 37-46.
322. Ridoutt, B.G. and S. Pfister, *A new water footprint calculation method integrating consumptive and degradative water use into a single stand-alone weighted indicator.* Int J Life Cycle Assess, 2013. **18**(1): p. 204-207.
323. Rimos, S., A.F.A. Hoadley, and D.J. Brennan, *Consequence analysis of scarcity using impacts from resource substitution.* Procedia Engineering, 2012. **49**: p. 26-34.
324. Rosenbaum, R.K., et al., *USEtox-the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment.* Int J Life Cycle Assess, 2008. **13**(7): p. 532-546.
325. Rosenbaum, R.K., M. Margni, and O. Jolliet, *A flexible matrix algebra framework for the multimedia multipathway modeling of emission to impacts.* Environ Int, 2007. **33**(5): p. 624-634.
326. Scanlon, K.A., et al., *The work environment disability-adjusted life year for use with life cycle assessment: a methodological approach.* Environ Health, 2013. **12**(1): p. 21.

327. Scanlon, K.A., et al., *An approach to integrating occupational safety and health into life cycle assessment – development and application of work environment characterisation factors.* J Ind Ecol, 2014.

328. Sleeswijk, A.W., et al., *Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000.* Sci Total Environ, 2008. **390**(1): p. 227-240.

329. Stranddorf, H.K., L. Hoffmann, and A. Schmidt, *Impact categories, normalisation and weighting in LCA*, D.M.o.t.E.-E.P. Agency, Editor. 2005, Environmental News: Denmark.

330. Stromman, A.H., *Dealing with double-counting in tiered hybrid life-cycle inventories: a few comments – response.* J Clean Prod, 2009. **17**(17): p. 1607-1609.

331. Strømman, A.H., G.P. Peters, and E.G. Hertwich, *Approaches to correct for double counting in tiered hybrid life cycle inventories.* J Clean Prod, 2009. **17**(2): p. 248-254.

332. Suh, S. and G. Huppes, *Methods for life cycle inventory of a product.* J Clean Prod, 2005. **13**(7): p. 687-697.

333. Tan, R.R., *Using fuzzy numbers to propagate uncertainty in matrix-based LCI.* Int J Life Cycle Assess, 2008. **13**(7): p. 585-592.

334. Tillman, A.-M., et al., *Choice of system boundaries in life cycle assessment.* J Clean Prod, 1994. **2**(1): p. 21-29.

335. Van de Meent, D. and M.A. Huijbregts, *Calculating life‐cycle assessment effect factors from potentially affected fraction‐based ecotoxicological response functions.* Environ Toxicol Chem, 2005. **24**(6): p. 1573-1578.

336. Van Zelm, R., M.A.J. Huijbregts, and D. van de Meent, *USES - LCA 2.0 - a global nested multi-media fate, exposure, and effects model.* Int J Life Cycle Assess, 2009. **14**(3): p. 282-284.

337. Ventura, A., *Classification of chemicals into emission-based impact categories: a first approach for equiprobable and site-specific conceptual frames.* Int J Life Cycle Assess, 2011. **16**(2): p. 148-158.

338. Williams, E.D., C.L. Weber, and T.R. Hawkins, *Hybrid framework for managing uncertainty in life cycle inventories.* J Ind Ecol, 2009. **13**(6): p. 928-944.

339. Zamagni, A., et al., *Critical review of the current research needs and limitations relatecd to ISO-LCA practice*. 2008. p. 1-106.

340. Zamagni, A., et al., *Lights and shadows in consequential LCA.* Int J Life Cycle Assess, 2012. **17**(7): p. 904-918.
341. Zamagni, A., et al., *Finding life cycle assessment research direction with the aid of meta-analysis.* J Ind Ecol, 2012. **16**(s1): p. S39-S52.
342. *Environmental terminology and discovery service (ETDS)*. [cited 2014 17 December]; Available from: http://glossary.eea.europa.eu//.
343. Guinée, J.B., *Handbook on life cycle assessment operational guide to the ISO standards.* Int J Life Cycle Assess, 2002. **7**(5): p. 311-313.
344. *Environmental management systems – Requirements with guidance for use*. 2015, British Standard.
345. *Environmental management system – General guidelines on principles, systems and support techniques*. 2010, British Standard.
346. Owens, J.W., *Water resources in life-cycle impact assessment: considerations in choosing category indicators.* J Ind Ecol, 2001. **5**(2): p. 37-54.
347. Koehler, A., *Water use in LCA: managing the planet's freshwater resources.* Int J Life Cycle Assess, 2008. **13**(6): p. 451-455.
348. i Canals, L.M., et al., *Assessing freshwater use impacts in LCA: Part I – inventory modelling and characterisation factors for the main impact pathways.* Int J Life Cycle Assess, 2009. **14**(1): p. 28-42.
349. Pfister, S., A. Koehler, and S. Hellweg, *Assessing the environmental impacts of freshwater consumption in LCA.* Environ Sci Technol, 2009. **43**(11): p. 4098-4104.
350. Berger, M. and M. Finkbeiner, *Water footprinting: how to address water use in life cycle assessment?* Sustainability, 2010. **2**(4): p. 919-944.
351. Verones, F., et al., *Characterization factors for thermal pollution in freshwater aquatic environments.* Environ Sci Technol, 2010. **44**(24): p. 9364-9369.
352. Zelm, R.v., et al., *Implementing groundwater extraction in life cycle impact assessment: characterization factors based on plant species richness for the Netherlands.* Environ Sci Technol, 2010. **45**(2): p. 629-635.
353. Boulay, A.-M., et al., *Regional characterization of freshwater use in LCA: modeling direct impacts on human health.* Environ Sci Technol, 2011. **45**(20): p. 8948-8957.
354. Allan, J.A., *Virtual water: a strategic resource global solutions to regional deficits.* Groundwater, 1998. **36**(4): p. 545-546.

355. Hauschild, M.Z. and L. Alting, *Environmental assessment of products – volume 2: scientific background*. Vol. 2. 1998: Springer.

356. Müller-Wenk, R. and N.S. im Internationalen Kontext, *Depletion of abiotic resources weighted on base of "virtual" impacts of lower grade deposits used in future*. 1998: Institut für Wirtschaft und Ökologie, Universität St. Gallen (IWÖ-HSG).

357. Hoekstra, A.Y. and P.Q. Hung, *Virtual water trade*, in *A quantification of virtual water flows between nations in relation to international crop trade. Value of water research report series*. 2002. p. 166.

358. Smakhtin, V.Y., C. Revenga, and P. Döll, *Taking into account environmental water requirements in global-scale water resources assessments*. Vol. 2. 2004: IWMI.

359. Bösch, M.E., et al., *Applying cumulative exergy demand (CExD) indicators to the ecoinvent database.* Int J Life Cycle Assess, 2007. **12**(3): p. 181-190.

360. Frischknecht, R., R. Steiner, and N. Jungbluth, *Ökobilanzen: methode der ökologischen knappheit–ökofaktoren 2006* Zürich: öbu, 2008.

361. Althaus, H.-J., P. de Haan, and R.W. Scholz, *Traffic noise in LCA – Part 1: state-of-science and requirement profile for consistent context-sensitive integration of traffic noise in LCA* Int J Life Cycle Assess, 2009. **14**(6): p. 560-570.

362. Benetto, E., C. Dujet, and P. Rousseaux, *Fuzzy-sets approach to noise impact assessment* Int J Life Cycle Assess, 2006. **11**(4): p. 222-228.

363. Benetto, E., C. Dujet, and P. Rousseaux, *Integrating fuzzy multicriteria analysis and uncertainty evaluation in life cycle assessment.* Environ Model Softw, 2008. **23**(12): p. 1461-1467.

364. Garraín, D., et al., *The noise impact category in life cycle assessment.* Zaragoza, 2008.

365. Lafleche, V. and F. Sacchetto, *Noise assessment in LCA - a methodology attempt: a case study with various means of transportation on a set trip.* Int J Life Cycle Assess, 1997. **2**(2): p. 111-115.

366. Müller-Wenk, R., *A method to include in LCA road traffic noise and its health effects.* Int J Life Cycle Assess, 2004. **9**(2): p. 76-85.

367. Antonsson, A.-B. and H. Carlsson, *The basis for a method to integrate work environment in life cycle assessments.* J Clean Prod, 1995. **3**(4): p. 215-220.

368. Schmidt, A. and C. Bro, *The working environment in LCA: a new approach*. 2005: Danish Environmental Protection Agency.

369. Hofstetter, P. and G.A. Norris, *Why and how should we assess occupational health impacts in integrated product policy?* Environ Sci Technol, 2003. **37**(10): p. 2025-2035.

370. Hellweg, S., et al., *Integrating human indoor air pollutant exposure within life cycle impact assessment.* Environ Sci Technol, 2009. **43**(6): p. 1670-1679.

371. Demou, E., S. Hellweg, and K. Hungerbühler, *An occupational chemical priority list for future life cycle assessments.* J Clean Prod, 2011. **19**(12): p. 1339-1346.

372. Lo, S.-C., H.-w. Ma, and S.-L. Lo, *Quantifying and reducing uncertainty in life cycle assessment using the Bayesian Monte Carlo method.* Sci Total Environ, 2005. **340**(1–3): p. 23-33.

373. Huijbregts, M.A.J., *Part II: dealing with parameter uncertainty and uncertainty due to choices in life cycle assessment.* Int J Life Cycle Assess, 1998. **3**(6): p. 343-351.

374. Lloyd, S.M. and R. Ries, *Characterizing, propagating, and analyzing uncertainty in life‐cycle assessment: a survey of quantitative approaches.* J Ind Ecol, 2007. **11**(1): p. 161-179.

375. Baker, J.W. and M. Lepech. *Treatment of uncertainties in life cycle assessment*. in *Proc. Int'l Congress Structural Safety and Reliability*. 2009.

376. Heijungs, R. and M.A.J. Huijbregts. *A review of approaches to treat uncertainty in LCA*. in *iEMSs 2004 International Congress:" Complexity and Integrated Resources Management". International Environmental Modelling and Software Society, Osnabrueck, Germany*. 2004.

377. Huijbregts, M.A.J., et al., *Framework for modelling data uncertainty in life cycle inventories.* Int J Life Cycle Assess, 2001. **6**(3): p. 127-132.

378. Christopher Frey, H. and S.R. Patil, *Identification and review of sensitivity analysis methods.* Risk Anal, 2002. **22**(3): p. 553-578.

379. Pannell, D.J., *Sensitivity analysis of normative economic models: theoretical framework and practical strategies.* Agr Econ Res 1997 **16**: p. 139-152.

380. Ling-Chin, J., O. Heidrich, and A.P. Roskilly, *Life cycle assessment (LCA) – from analysing methodology development to introducing an LCA framework for marine photovoltaic (PV) systems.* Renew Sustain Energy Rev, 2016. **59**: p. 352-378.

381. *Green Paper on better ship dismantling*. 2007, Commission of the European Communities: Brussels.
382. *Safety and Health in Shipbreaking – Guidelines for Asian countries and Turkey*, in *MESHS/2003/1*. 2003, International Labour Organization Bangkok.
383. *The IMO Guidelines on ship recycling (Annotated)*, G.I.a.t.B.A.N. (BAN), Editor. 2005, International Maritime Organisation (IMO).
384. *Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal* T.U.N.E.P. (UNEP), Editor. 1989, The United Nations Environment Programme (UNEP). p. 116.
385. *Technical Guidelines for Environmentally Sound Management of the Full and Partial Dismantling of Ships*, in *Basel Convention series/SBC No. 2003/2*, S.o.t.B. Convention, Editor. 2003, The United Nations Environment Programme (UNEP).
386. *Regulation (EU) No 1257/2013 of the European Parliament and of the Council of 20 November 2013 on ship recycling and amending Regulation (EC) No 1013/2006 and Directive 2009/16/EC*. 2013, Official Journal of the European Union p. 20.
387. Naik, R.R. *Sulzer main engines and spare parts for sale*. [cited 20 February 2015]; Available from: http://www.marine-engines.in/search/label/Sulzer%20used%20and%20reconditioned#axzz3SHqdDSsL.
388. Smith, V.M. and G.A. Keoleian, *The Value of Remanufactured Engines: Life-Cycle Environmental and Economic Perspectives.* Journal of Industrial Ecology, 2004. **8**(1-2): p. 193-221.
389. Li, T., et al., *Environmental emissions and energy consumptions assessment of a diesel engine from the life cycle perspective.* J Clean Prod, 2013. **53**: p. 7-12.
390. *Safety data sheet - Saft*. 2014, Saft: France.
391. Gaines, L. and P. Nelson, *Lithium-ion batteries: examining material demand and recycling issues*. 2010, Minerals, Metals and Materials Society/AIME, 420 Commonwealth Dr., P. O. Box 430 Warrendale PA 15086 USA.
392. Sullivan, J.L. and L. Gaines, *A review of battery life-cycle analysis: state of knowledge and critical needs*. 2010, Argonne National Laboratory (ANL).
393. Gaines, L., *The future of automotive lithium-ion battery recycling: charting a sustainable course.* Sustainable Materials and Technologies, 2014. **1**: p. 2-7.

394. Jungbluth, N., et al., *Life cycle inventories of photovoltaics.* ESU-services Ltd., Uster, 2012.

395. Zhong, Z.W., B. Song, and P.E. Loh, *LCAs of a polycrystalline photovoltaic module and a wind turbine.* Renew Energ, 2011. **36**(8): p. 2227-2237.

396. Battisti, R. and A. Corrado, *Evaluation of technical improvements of photovoltaic systems through life cycle assessment methodology.* Energy, 2005. **30**(7): p. 952-967.

397. Tripanagnostopoulos, Y., et al., *Energy, cost and LCA results of PV and hybrid PV/T solar systems.* Progress in Photovoltaics: Research and applications, 2005. **13**(3): p. 235-250.

398. Schlenker, S., et al. *The second life of a 300 kW PV generator manufactured with recycled wafers from the oldest German PV power plant*. in *21st European Photovoltaic Solar Energy Conference*. 2006.

399. *Overview of ship recycling in the UK - Guidance*. 2007, Department for Environment, Food and Rural Affairs, UK: London.

400. Brogaard, L.K., et al., *Evaluation of life cycle inventory data for recycling systems.* Resour Conserv Recy, 2014. **87**: p. 30-45.

401. Reck, B.K. and T.E. Graedel, *Challenges in metal recycling.* Science, 2012. **337**(6095): p. 690-695.

402. Gaustad, G., E. Olivetti, and R. Kirchain, *Improving aluminum recycling: a survey of sorting and impurity removal technologies.* Resour Conserv Recy, 2012. **58**: p. 79-87.

403. Yellishetty, M., et al., *Environmental life-cycle comparisons of steel production and recycling: sustainability issues, problems and prospects.* Environ Sci Policy, 2011. **14**(6): p. 650-663.

404. Ness, H., *Recycling as an industry.* Environ Sci Technol, 1972. **6**(8): p. 700-704.

405. Damgaard, A., A.W. Larsen, and T.H. Christensen, *Recycling of metals: accounting of greenhouse gases and global warming contributions.* Waste Manage Res, 2009.

406. Moats, M., et al., *Recycling of nickel, cobalt and platinum-group metals*, in *Extractive metallurgy of nickel, cobalt and platinum group metals*. 2011, Elsevier.

407. Kaplan, R.S. and H. Ness, *Recycling of metals.* Conserv Recycling, 1987. **10**(1): p. 1-13.

408. Johnson, J., et al., *The energy benefit of stainless steel recycling.* Energy Pol, 2008. **36**(1): p. 181-192.

409. Green, J.A.S., *Aluminum recycling and processing for energy conservation and sustainability*. 2007: ASM International.

410. Paraskevas, D., et al., *Environmental modelling of aluminium recycling: a life cycle assessment tool for sustainable metal management.* J Clean Prod, 2014. **105**: p. 357–370.

411. Trozzi, C., et al., *EMEP/EEA air pollutant emission inventory guidebook 2013: technical guidance to prepare national emission inventories*. 2013: Luxembourg.

412. Norgate, T.E., *Metal recycling: an assessment using life cycle energy consumption as a sustainability indicator.* Minerals, Editor, 2004.

413. Muchova, L., P. Eder, and A. Villanueva, *End-of-waste criteria for copper and copper alloy scrap.* European Commission, Spain, 2011.

414. Gordon, R.B., et al., *The characterization of technological zinc cycles.* Resour Conserv Recy, 2003. **39**(2): p. 107-135.

415. Genaidy, A.M., et al., *Evidence-based integrated environmental solutions for secondary lead smelters: pollution prevention and waste minimization technologies and practices.* Sci Total Environ, 2009. **407**(10): p. 3239-3268.

416. Eckelman, M.J., *Facility-level energy and greenhouse gas life-cycle assessment of the global nickel industry.* Resour Conserv Recy, 2010. **54**(4): p. 256-266.

417. Reck, B.K., et al., *Anthropogenic nickel cycle: Insights into use, trade, and recycling.* Environ Sci Technol, 2008. **42**(9): p. 3394-3400.

418. van Vugt, H., et al., *Energy balance analysis: new models library, used for innovative ship design*. 2013. p. 127.

419. Mermiris, D., et al. *Dynamic energy modeling – a new approach to energy efficiency and cost effectiveness in shipping operations*. in *Proceedings of International Conference on Technologies, Operations, Logistics and Modelling for Low Carbon Shipping, Glasgow,* 2011.

420. Cooper, D., *Representative emission factors for use in quantification of emissions from ships associated with ship movements between port in the European Community.* IVL Swedish Environmental Research Institute Ltd (ENV. C. 1/ETU/2001/0090), 2002.

421. Craighill, A.L. and J.C. Powell, *Lifecycle assessment and economic evaluation of recycling: a case study.* Resour Conserv Recy, 1996. **17**(2): p. 75-96.
422. Brosnan, I.G., *The diminishing age gap between polar cruisers and their ships: a new reason to codify the IMO Guidelines for ships operating in polar waters and make them mandatory?* Mar Policy, 2011. **35**(2): p. 261-265.
423. Boughton, B. and A. Horvath, *Environmental assessment of used oil management methods.* Environ Sci Technol, 2004. **38**(2): p. 353-358.
424. Kalnes, T.N., D.R. Shonnard, and A. Schuppel, *LCA of a spent lube oil re-refining process.* Comput Aided Chem Eng 2006. **21**: p. 713-718.
425. Kanokkantapong, V., et al., *Used lubricating oil management options based on life cycle thinking.* Resour Conserv Recy, 2009. **53**(5): p. 294-299.
426. Pires, A. and G. Martinho, *Life cycle assessment of a waste lubricant oil management system.* Int J Life Cycle Assess, 2013. **18**(1): p. 102-112.
427. *Brand technical comparison*, in *Euroboilers group - Technical Seminar*. 2012, Garioni Naval.
428. Mersiowsky, I., *Eco-profiles and environmental declarations*. 2011. p. 1-51.
429. *Stainless steel specification and composition table chart*. 2000-2015 12 February 2015]; Available from: http://www.engineersedge.com/stainless_steel.htm.
430. Mansouri, S.A., H. Lee, and O. Aluko, *Multi-objective decision support to enhance environmental sustainability in maritime shipping: a review and future directions.* Transport Res E - Log, 2015. **78**: p. 3-18.
431. Martínez, E., et al., *Comparative evaluation of life cycle impact assessment software tools through a wind turbine case study.* Renew Energ, 2015. **74**: p. 237-246.

Appendix

Input and output data used in developing LCA models for individual components are presented in this section. For brevity, C, R and N are used to denote the components which were integrated into the conventional, retrofit and new-build systems respectively.

Manufacturing a diesel engine [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	2.11E+03	kg
Carbon [Organic intermediate products]	Mass	1.72E+03	kg
Cast iron part [Metal parts]	Mass	5.42E+04	kg
Chromium [Metals]	Mass	1.56E+03	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	3.57E+02	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	2.83E+04	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	7.46E+04	MJ
RER: tap water, at user [Appropriation]	Mass	9.75E+05	kg
Steel part [Metal parts]	Mass	1.66E+04	kg
Tin (99.92%) [Metals]	Mass	1.56E+03	kg
RER: electricity, at grid [Production mix]	Energy	1.43E+04	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	1.91E+03	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	1.07E+04	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	4.87E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	9.44E+02	m^3
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Waste heat [Other emissions to air]	Energy	1.43E+04	MJ

A diesel engine in operation (1) [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	1.34E+07	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	9.92E+07	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.60E+08	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.31E+05	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.13E+05	kg
Energy unspecific [Energy resources]	Energy	2.29E+09	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	3.04E+05	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	7.26E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.76E+06	kg

A diesel engine in operation (2) [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	1.35E+07	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	1.06E+08	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.68E+08	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.51E+05	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.17E+05	kg
Energy unspecific [Energy resources]	Energy	4.60E+08	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	3.11E+05	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	7.43E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.82E+06	kg

A diesel engine in operation (3) [c]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	0.00E+00	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	0.00E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	0.00E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	0.00E+00	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	0.00E+00	kg
Energy unspecific [Energy resources]	Energy	0.00E+00	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	0.00E+00	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	0.00E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	0.00E+00	kg

A diesel engine in operation (1) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	0.00E+00	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	2.93E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	9.32E+07	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.67E+04	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.77E+04	kg
Energy unspecific [Energy resources]	Energy	1.55E+08	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	7.23E+04	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.91E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.93E+05	kg

A diesel engine in operation (2) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	1.34E+07	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	6.75E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	2.59E+08	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.38E+05	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.51E+05	kg
Energy unspecific [Energy resources]	Energy	4.41E+08	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	2.08E+05	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	5.27E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.12E+06	kg

A diesel engine in operation (3) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	1.35E+07	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	7.23E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	2.71E+08	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.53E+05	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.59E+05	kg
Energy unspecific [Energy resources]	Energy	4.60E+08	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	2.20E+05	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	5.51E+06	kg

Sullphur dioxide [Inorganic emissions to air]	Mass	2.20E+06	kg

A diesel engine in operation (4) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	0.00E+00	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	3.23E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.03E+08	kg
Carbon monoxide [Inorganic emissions to air]	Mass	9.55E+04	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.25E+04	kg
Energy unspecific [Energy resources]	Energy	1.71E+08	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	7.96E+04	kg
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.10E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.52E+05	kg

Maintaining a diesel engine [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: lubricating oil [Organics]	Mass	1.50E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	1.50E+04	kg

Maintaining a diesel engine (1) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: lubricating oil [Organics]	Mass	6.08E+03	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	6.08E+03	kg

Maintaining a diesel engine (2) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: lubricating oil [Organics]	Mass	1.30E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	1.30E+04	kg

Maintaining a diesel engine (3) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: lubricating oil [Organics]	Mass	1.35E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	1.35E+04	kg

Maintaining a diesel engine (4) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
RER: lubricating oil [Organics]	Mass	3.38E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	3.38E+03	kg

Used lubricating oil treatment of a diesel engine [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	4.03E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	3.04E+01	kg

Liquefied petroleum gas [LPG, at production]	Mass	3.62E+01	kg
RER: electricity [Production mix]	Energy	7.76E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	6.04E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	1.50E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.14E+03	kg
Sludge [Hazardous waste]	Mass	4.86E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	1.34E+04	kg

Used lubricating oil treatment of a diesel engine (1) R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	1.64E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	1.23E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	1.47E+01	kg
RER: electricity [Production mix]	Energy	3.15E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	2.45E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	6.08E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	4.62E+02	kg
Sludge [Hazardous waste]	Mass	1.97E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	5.42E+03	kg

Used lubricating oil treatment of a diesel engine (2) R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	3.50E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	2.63E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	3.15E+01	kg
RER: electricity [Production mix]	Energy	6.74E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	5.24E+01	kg

Unspecified oil waste [Hazardous waste]	Mass	1.30E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	9.89E+02	kg
Sludge [Hazardous waste]	Mass	4.22E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	1.16E+04	kg

Used lubricating oil treatment of a diesel engine (3) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	3.63E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	2.74E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	3.27E+01	kg
RER: electricity [Production mix]	Energy	7.00E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	5.44E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	1.35E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.03E+03	kg
Sludge [Hazardous waste]	Mass	4.38E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	1.20E+04	kg

Used lubricating oil treatment of a diesel engine (4) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	9.09E+00	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	6.84E+00	kg
Liquefied petroleum gas [LPG, at production]	Mass	8.17E+00	kg
RER: electricity [Production mix]	Energy	1.75E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	1.36E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	3.38E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	2.57E+02	kg

Sludge [Hazardous waste]	Mass	1.10E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	3.01E+03	kg

Recovery of used lubricating oil of a diesel engine after treatment [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	6.99E+00	kg
Propane [Organic intermediate products]	Mass	9.84E+00	kg
RER: electricity [Production mix]	Energy	3.35E+03	MJ
RER: natural gas [Fuels]	Energy	6.94E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	3.88E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	1.34E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	1.76E-08	kg
Asphalt flux [Organic intermediate products]	Mass	4.54E+03	kg
Base oil from re-refining [Other fuels]	Mass	3.23E+03	kg
Cadmium [Heavy metals to air]	Mass	1.19E-06	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.87E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.43E+01	kg
Chromium [Heavy metals to air]	Mass	3.78E-08	kg
Electricity from waste to energy [System-dependent]	Energy	8.10E+04	MJ
Expanded clay [Minerals]	Mass	8.80E+00	kg
Flux and gas [Operating materials]	Mass	3.18E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	1.96E+02	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	3.51E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.74E-07	kg
Marine diesel oil [Other fuels]	Mass	3.47E+03	kg
Nickel [Heavy metals to air]	Mass	5.82E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	5.05E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	4.40E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	1.74E+02	kg

Sewage sludge (waste water processing) [Hazardous waste]	Mass	3.53E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.61E-01	kg
Waste heat [Other emissions to air]	Energy	3.55E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	1.96E+02	kg

Recovering used lubricating oil of a diesel engine after treatment (1) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	2.84E+00	kg
Propane [Organic intermediate products]	Mass	3.99E+00	kg
RER: electricity [Production mix]	Energy	1.36E+03	MJ
RER: natural gas [Fuels]	Energy	2.82E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	1.58E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	5.42E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	0.00E+00	kg
Asphalt flux [Organic intermediate products]	Mass	1.84E+03	kg
Base oil from re-refining [Other fuels]	Mass	1.31E+03	kg
Cadmium [Heavy metals to air]	Mass	4.84E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.17E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.81E+00	kg
Chromium [Heavy metals to air]	Mass	1.53E-08	kg
Electricity from waste to energy [System-dependent]	Energy	3.61E+05	MJ
Expanded clay [Minerals]	Mass	3.57E+00	kg
Flux and gas [Operating materials]	Mass	1.29E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	7.97E+01	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	1.43E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	7.05E-08	kg
Marine diesel oil [Other fuels]	Mass	1.41E+03	kg
Nickel [Heavy metals to air]	Mass	2.36E-06	kg

Nitrogen oxides [Inorganic emissions to air]	Mass	2.05E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	1.79E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	7.07E+01	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.43E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.50E-01	kg
Waste heat [Other emissions to air]	Energy	1.44E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	7.97E+01	kg

Recovering used lubricating oil of a diesel engine after treatment (2) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	6.06E+00	kg
Propane [Organic intermediate products]	Mass	8.54E+00	kg
RER: electricity [Production mix]	Energy	2.91E+03	MJ
RER: natural gas [Fuels]	Energy	6.02E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	3.37E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	1.16E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	1.53E-08	kg
Asphalt flux [Organic intermediate products]	Mass	3.94E+03	kg
Base oil from re-refining [Other fuels]	Mass	2.81E+03	kg
Cadmium [Heavy metals to air]	Mass	1.04E-06	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.49E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.24E+01	kg
Chromium [Heavy metals to air]	Mass	3.28E-08	kg
Electricity from waste to energy [System-dependent]	Energy	7.03E+04	MJ
Expanded clay [Minerals]	Mass	7.64E+00	kg
Flux and gas [Operating materials]	Mass	2.76E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	1.70E+02	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	3.05E-03	kg

Hydrogen sulphide [Inorganic emissions to air]	Mass	1.51E-07	kg
Marine diesel oil [Other fuels]	Mass	3.01E+03	kg
Nickel [Heavy metals to air]	Mass	5.05E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.38E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	3.82E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	1.51E+02	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	3.07E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	7.48E-01	kg
Waste heat [Other emissions to air]	Energy	3.08E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	1.70E+02	kg

Recovering used lubricating oil of a diesel engine after treatment (3) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	6.30E+00	kg
Propane [Organic intermediate products]	Mass	8.87E+00	kg
RER: electricity [Production mix]	Energy	3.02E+03	MJ
RER: natural gas [Fuels]	Energy	6.26E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	3.50E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	1.20E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	1.59E-08	kg
Asphalt flux [Organic intermediate products]	Mass	4.09E+03	kg
Base oil from re-refining [Other fuels]	Mass	2.91E+03	kg
Cadmium [Heavy metals to air]	Mass	1.08E-06	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.59E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.29E+01	kg
Chromium [Heavy metals to air]	Mass	3.41E-08	kg
Electricity from waste to energy [System-dependent]	Energy	7.30E+04	MJ
Expanded clay [Minerals]	Mass	7.93E+00	kg
Flux and gas [Operating materials]	Mass	2.87E+02	kg

Hazardous waste (unspecified) [Hazardous waste]	Mass	1.77E+02	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	3.17E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.56E-07	kg
Marine diesel oil [Other fuels]	Mass	3.13E+03	kg
Nickel [Heavy metals to air]	Mass	5.25E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.55E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	3.97E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	1.57E+02	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	3.18E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	7.76E-01	kg
Waste heat [Other emissions to air]	Energy	3.20E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	1.77E+02	kg

Recovering used lubricating oil of a diesel engine after treatment (4) R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	1.58E+00	kg
Propane [Organic intermediate products]	Mass	2.22E+00	kg
RER: electricity [Production mix]	Energy	7.55E+02	MJ
RER: natural gas [Fuels]	Energy	1.56E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	8.76E+00	kg
Treated lubricating oil [Waste for recovery]	Mass	3.01E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	3.97E-09	kg
Asphalt flux [Organic intermediate products]	Mass	1.02E+03	kg
Base oil from re-refining [Other fuels]	Mass	7.29E+02	kg
Cadmium [Heavy metals to air]	Mass	2.69E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.48E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.23E+00	kg
Chromium [Heavy metals to air]	Mass	8.52E-09	kg

Electricity from waste to energy [System-dependent]	Energy	1.83E+04	MJ
Expanded clay [Minerals]	Mass	1.98E+00	kg
Flux and gas [Operating materials]	Mass	7.17E+01	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	4.43E+01	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	7.92E-04	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	3.91E-08	kg
Marine diesel oil [Other fuels]	Mass	7.83E+02	kg
Nickel [Heavy metals to air]	Mass	1.31E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.14E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	9.92E-01	kg
Production residues (unspecified) [Waste for recovery]	Mass	3.93E+01	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	7.97E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.94E-01	kg
Waste heat [Other emissions to air]	Energy	8.00E+03	MJ
Waste water - untreated [Production residues in life cycle]	Mass	4.43E+01	kg

Engine dissembling and component recovering/refurbishing [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Crude oil [Crude oil, at consumer]	Mass	6.12E+03	kg
Electricity [Electric power]	Energy	2.56E+05	MJ
Main diesel engine [Metal parts]	Mass	7.80E+04	kg
Raw hardcoal [Resource]	Mass	5.29E+04	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	4.99E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium casting part [Metal parts]	Mass	6.32E+02	kg
Aluminium scrap [Waste for recovery]	Mass	6.32E+02	kg
Ammonium [Inorganic emissions to air]	Mass	9.18E-01	kg
BOD in waste water [Production residues in life cycle]	Mass	7.52E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	9.34E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.24E+02	kg
Cast iron [Metal parts]	Mass	1.63E+04	kg

Cast iron scrap [Waste for recovery]	Mass	1.63E+04	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	8.63E+01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	8.74E+02	kg
Hydrochloric acid [Waste for recovery]	Mass	2.29E+01	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	4.04E+01	kg
Metallic waste for incineration [Waste for disposal]	Mass	1.54E+04	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.54E+04	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.33E+02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	3.61E+02	kg
Steel cast part [Metal parts]	Mass	4.98E+03	kg
Steel scrap [Waste for recovery]	Mass	4.98E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	9.43E+02	kg

Recycling aluminium scrap of a diesel engine - ingot production [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.17E+01	kg
Aluminium scrap [Waste for recovery]	Mass	6.32E+02	kg
CH: anionic resin [Organics]	Mass	2.23E+00	kg
CH: cationic resin [Organics]	Mass	2.23E+00	kg
RER: natural gas [Fuels]	Energy	6.46E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	5.02E+00	kg
RER: electricity, at grid [Production mix]	Energy	6.02E+01	MJ
Water [Water]	Mass	5.37E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	5.58E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.44E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.58E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.58E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.67E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.79E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.03E+01	kg

Recovering cast iron scrap of a diesel engine [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Cast iron scrap [Waste for recovery]	Mass	1.63E+04	kg
Crude oil [Crude oil, at consumer]	Mass	8.00E+01	kg
Electricity [Electric power]	Energy	1.62E+03	MJ
Hard coal [Resource]	Mass	6.90E+02	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	6.51E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	1.19E-02	kg
BOD in waste water [Production residues in life cycle]	Mass	9.57E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.22E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.07E+01	kg
Cast iron [Metals]	Mass	1.63E+04	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	1.15E+00	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.15E+01	kg
Hydrochloric acid [Waste for recovery]	Mass	3.00E-01	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	5.28E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.40E+00	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	4.78E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.22E+01	kg

Recovering steel scrap of a diesel engine [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Crude oil [Crude oil, at consumer]	Mass	2.45E+01	kg
Electricity [Electric power]	Energy	4.97E+02	MJ
Hard coal [Resource]	Mass	2.12E+02	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	1.99E+00	MJ
Steel scrap [Waste for recovery]	Mass	4.98E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	3.64E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	2.93E-01	kg

Carbon dioxide [Inorganic emissions to air]	Mass	3.74E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.28E+00	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	3.52E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.52E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	9.21E-02	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.62E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.35E+00	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.47E+00	kg
RER: steel, unalloyed [Benefication]	Mass	4.98E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.75E+00	kg

Disposing metallic waste of a diesel engine to incineration plant [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	8.91E+03	MJ
CH: heat from waste [Incineration]	Energy	1.29E+04	MJ
CH: waste incineration plant [Incineration]	Number of pieces	3.84E-06	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.43E+04	kg
CH: slag compartment [Incineration]	Number of pieces	4.33E-05	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	1.54E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.25E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.07E+00	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.36E+00	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.01E+01	kg
Chloride [Inorganic emissions to freshwater]	Mass	6.41E+01	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	1.21E-01	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	5.27E-04	kg

Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.54E+04	kg
Copper (+II) [Heavy metals to freshwater]	Mass	5.33E-01	kg
Incineration of metallic waste [Waste for disposal]	Mass	1.54E+04	kg
Iron [Ecoinvent long-term to freshwater]	Mass	3.26E+03	kg
Iron [Heavy metals to freshwater]	Mass	5.24E-02	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	3.89E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.93E-02	kg
Solids [Ecoinvent long-term to freshwater]	Mass	4.07E+00	kg
Solids [Particles to freshwater]	Mass	1.75E-02	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	1.64E-04	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.02E+01	kg
Waste heat [Other emissions to air]	Energy	7.64E+03	MJ
Waste heat [Other emissions to freshwater]	Energy	1.26E+03	MJ

Disposing metallic waste of a diesel engine to landfill [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified [Binder]	Mass	3.95E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	9.86E+01	kg
CH: electricity from waste [Incineration]	Energy	5.28E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	5.81E+02	MJ
CH: heat from waste [Incineration]	Energy	8.54E+02	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	1.53E-02	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	3.60E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.55E-07	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	1.02E+03	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	9.86E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	5.73E+02	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	2.06E-07	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	8.54E-06	pcs.

CH: sewer grid [Wastewater treatment]	Length	8.54E-06	m
CH: slag compartment [Incineration]	Number of pieces	1.02E-06	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	2.18E-07	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.24E-03	kg
GLO: chemicals organic, at plant [Organics]	Mass	6.21E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.54E+04	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	7.41E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	7.05E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.52E+04	kg
Aluminium [Particles to air]	Mass	6.56E-01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.27E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	7.42E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	7.31E+01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	2.18E-06	kg
Copper (+II) [Heavy metals to air]	Mass	3.06E+00	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.94E-03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.80E-02	kg
Iron [Heavy metals to air]	Mass	1.09E+03	kg
Iron [Heavy metals to freshwater]	Mass	5.33E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	1.54E+04	kg
Methane [Organic emissions to air (VOC group)]	Mass	6.50E-03	kg
Tin (+IV) [Heavy metals to air]	Mass	5.98E+01	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	7.39E-02	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.80E-04	kg
Waste heat [Other emissions to air]	Energy	5.84E+02	MJ

Manufacturing an auxiliary generator [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	1.61E+02	kg
Cast iron part [Metal parts]	Mass	3.28E+04	kg
Copper [Metals]	Mass	3.62E+02	kg
RER: chromium steel, at plant [Benefication]	Mass	8.04E+01	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.80E+02	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.43E+04	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	3.77E+04	MJ
RER: tap water, at user [Appropriation]	Mass	4.93E+05	kg
Steel part [Metal parts]	Mass	5.99E+03	kg
RER: electricity, at grid [Production mix]	Energy	7.22E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	9.65E+02	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	5.40E+03	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	2.46E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	4.77E+02	m^3
Waste heat [Other emissions to air]	Energy	7.21E+03	MJ

Operating an auxiliary generator (1) [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	0.00E+00	kg
RER: diesel, low-sulphur [Fuels]	Mass	1.98E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.28E+07	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.46E+04	kg

Dust (PM2,5 - PM10) [Particles to air]	Mass	5.13E+04	kg
Energy unspecific [Energy resources]	Energy	2.63E+08	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	3.64E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.27E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.91E+05	kg

Operating an auxiliary generator (2) [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	2.46E+06	kg
RER: diesel, low-sulphur [Fuels]	Mass	1.71E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.23E+07	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.39E+04	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.61E+04	kg
Energy unspecific [Energy resources]	Energy	2.21E+08	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	3.59E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.26E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.73E+05	kg

Operating an auxiliary generator (1) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	0.00E+00	kg
RER: diesel, low-sulphur [Fuels]	Mass	1.02E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.23E+07	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.81E+04	kg

Dust (PM2,5 - PM10) [Particles to air]	Mass	1.40E+04	kg
Energy unspecific [Energy resources]	Energy	8.77E+07	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	1.87E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	6.51E+05	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.01E+05	kg

Operating an auxiliary generator (2) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Heavy fuel oil (1.0 wt.% S) [Refinery products]	Mass	0.00E+00	kg
RER: diesel, low-sulphur [Fuels]	Mass	1.01E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.00E+07	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.45E+04	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.27E+04	kg
Energy unspecific [Energy resources]	Energy	4.47E+08	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	2.30E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	8.08E+05	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.34E+05	kg

Maintaining an auxiliary generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
RER: lubricating oil [Organics]	Mass	7.50E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	7.50E+03	kg

Maintaining an auxiliary generator [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
RER: lubricating oil [Organics]	Mass	4.16E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	4.16E+03	kg

Maintaining an auxiliary generator [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
RER: lubricating oil [Organics]	Mass	6.50E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	6.50E+03	kg

Used lubricating oil treatment of an auxiliary generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	2.01E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	1.52E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	1.81E+01	kg
RER: electricity [Production mix]	Energy	3.88E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	3.02E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	7.50E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	2.43E+02	kg
Sludge [Hazardous waste]	Mass	6.68E+03	kg
Treated lubricating oil [Waste for recovery]	Mass	5.70E+02	kg

Used lubricating oil treatment of an auxiliary generator [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	1.12E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	8.42E+00	kg
Liquefied petroleum gas [LPG, at production]	Mass	1.01E+01	kg
RER: electricity [Production mix]	Energy	2.15E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	1.68E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	4.16E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.35E+02	kg
Sludge [Hazardous waste]	Mass	3.70E+03	kg
Treated lubricating oil [Waste for recovery]	Mass	3.16E+02	kg

Used lubricating oil treatment of an auxiliary generator [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	1.75E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	1.32E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	1.57E+01	kg
RER: electricity [Production mix]	Energy	3.36E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	2.62E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	6.50E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	2.11E+02	kg
Sludge [Hazardous waste]	Mass	5.79E+03	kg
Treated lubricating oil [Waste for recovery]	Mass	4.94E+02	kg

Recovering used lubricating oil of an auxiliary generator after treatment C			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	3.49E+00	kg
Propane [Organic intermediate products]	Mass	4.92E+00	kg
RER: electricity [Production mix]	Energy	1.67E+03	MJ
RER: natural gas [Fuels]	Energy	3.47E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	1.94E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	6.68E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	8.79E-09	kg
Asphalt flux [Organic intermediate products]	Mass	2.27E+03	kg
Base oil from re-refining [Other fuels]	Mass	1.62E+03	kg
Cadmium [Heavy metals to air]	Mass	5.97E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.44E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.15E+00	kg
Chromium [Heavy metals to air]	Mass	1.89E-08	kg
Electricity from waste to energy [System-dependent]	Energy	4.05E+04	MJ
Expanded clay [Minerals]	Mass	4.40E+00	kg
Flux and gas [Operating materials]	Mass	1.59E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	9.82E+01	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	1.76E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	8.68E-08	kg
Marine diesel oil [Other fuels]	Mass	1.74E+03	kg
Nickel [Heavy metals to air]	Mass	2.91E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.53E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	2.20E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	8.72E+01	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.77E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.31E-01	kg

Waste heat [Other emissions to air]	Energy	1.77E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	9.82E+01	kg

Recovering used lubricating oil of an auxiliary generator after treatment R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	1.94E+00	kg
Propane [Organic intermediate products]	Mass	2.73E+00	kg
RER: electricity [Production mix]	Energy	9.29E+02	MJ
RER: natural gas [Fuels]	Energy	1.93E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	1.08E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	3.70E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	4.88E-09	kg
Asphalt flux [Organic intermediate products]	Mass	1.26E+03	kg
Base oil from re-refining [Other fuels]	Mass	8.97E+02	kg
Cadmium [Heavy metals to air]	Mass	3.31E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	7.97E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.97E+00	kg
Chromium [Heavy metals to air]	Mass	1.05E-08	kg
Electricity from waste to energy [System-dependent]	Energy	2.25E+04	MJ
Expanded clay [Minerals]	Mass	2.44E+00	kg
Flux and gas [Operating materials]	Mass	8.82E+01	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	5.45E+01	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	9.75E-04	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	4.82E-08	kg
Marine diesel oil [Other fuels]	Mass	9.63E+02	kg
Nickel [Heavy metals to air]	Mass	1.61E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.40E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	1.22E+00	kg

Production residues (unspecified) [Waste for recovery]	Mass	4.84E+01	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	9.80E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.39E-01	kg
Waste heat [Other emissions to air]	Energy	9.84E+03	MJ
Waste water - untreated [Production residues in life cycle]	Mass	5.45E+01	kg

Recovering used lubricating oil of an auxiliary generator after treatment R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	3.03E+00	kg
Propane [Organic intermediate products]	Mass	4.26E+00	kg
RER: electricity [Production mix]	Energy	1.45E+03	MJ
RER: natural gas [Fuels]	Energy	3.01E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	1.68E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	5.79E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	7.62E-09	kg
Asphalt flux [Organic intermediate products]	Mass	1.97E+03	kg
Base oil from re-refining [Other fuels]	Mass	1.40E+03	kg
Cadmium [Heavy metals to air]	Mass	5.17E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.25E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.20E+00	kg
Chromium [Heavy metals to air]	Mass	1.64E-08	kg
Electricity from waste to energy [System-dependent]	Energy	3.51E+04	MJ
Expanded clay [Minerals]	Mass	3.81E+00	kg
Flux and gas [Operating materials]	Mass	1.38E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	8.51E+01	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	1.52E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	7.52E-08	kg
Marine diesel oil [Other fuels]	Mass	1.50E+03	kg

Nickel [Heavy metals to air]	Mass	2.52E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.19E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	1.91E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	7.55E+01	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.53E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.73E-01	kg
Waste heat [Other emissions to air]	Energy	1.54E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	8.51E+01	kg

Dissembling an auxiliary generator and recovering/refurbishing component [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Auxiliary generator [Metal parts]	Mass	3.94E+04	kg
Crude oil [Crude oil, at consumer]	Mass	3.09E+03	kg
Electricity [Electric power]	Energy	5.88E+02	MJ
Raw hardcoal [Resource]	Mass	2.67E+04	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	2.52E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium casting part [Metal parts]	Mass	4.82E+01	kg
Aluminium scrap [Waste for recovery]	Mass	4.82E+01	kg
Ammonium [Inorganic emissions to air]	Mass	4.64E-01	kg
BOD in waste water [Production residues in life cycle]	Mass	3.80E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.72E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.16E+02	kg
Cast iron [Metal parts]	Mass	9.84E+03	kg
Cast iron scrap [Waste for recovery]	Mass	9.84E+03	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	4.36E+01	kg
Copper [Metals]	Mass	1.09E+02	kg
Copper scrap [Waste for recovery]	Mass	1.09E+02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.41E+02	kg
Hydrochloric acid [Waste for recovery]	Mass	1.16E+01	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	2.04E+01	kg

Metallic waste for incineration [Waste for disposal]	Mass	7.88E+03	kg
Metallic waste for landfill [Waste for disposal]	Mass	7.88E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.68E+02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.82E+02	kg
Stainless steel [Metal parts]	Mass	2.41E+01	kg
Stainless steel scrap [Waste for recovery]	Mass	2.41E+01	kg
Steel cast part [Metal parts]	Mass	1.80E+03	kg
Steel scrap [Waste for recovery]	Mass	1.80E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.77E+02	kg

Recycling copper scrap of an auxiliary generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	1.09E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	5.37E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	3.65E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	4.26E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	4.30E-07	kg
Acetic acid [NMVOC Group to air]	Mass	6.50E-05	kg
Arsenic [Heavy metals to air]	Mass	1.52E-04	kg
Benzene [NMVOC Group to air]	Mass	4.97E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	2.84E-10	kg
Butane [NMVOC Group to air]	Mass	4.97E-04	kg
Cadmium [Heavy metals to air]	Mass	2.50E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.07E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.06E-03	kg
Copper [Heavy metals to air]	Mass	3.04E-03	kg
Dust (> PM10) [Particles to air]	Mass	2.82E-02	kg
Dust (PM2.5) [Particles to air]	Mass	1.02E-01	kg
Ethane [NMVOC Group to air]	Mass	7.36E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.78E-05	kg
Heat, waste [unspecified]	Energy	4.08E+02	MJ

Hexane (isomers) [NMVOC Group to air]	Mass	4.26E-04	kg
Lead [Heavy metals to air]	Mass	1.19E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.37E-04	kg
Nickel [Heavy metals to air]	Mass	1.41E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.76E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	5.37E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	6.18E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	4.01E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.56E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	4.30E-06	kg
Propane [NMVOC Group to air]	Mass	3.79E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	8.59E-06	kg
RER: copper, secondary [Benefication]	Mass	1.09E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.07E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	8.06E-07	kg

Recycling steel scrap of an auxiliary generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Crude oil [Crude oil, at consumer]	Mass	8.83E+00	kg
Electricity [Electric power]	Energy	3.88E+03	MJ
Raw hardcoal [Resource]	Mass	7.62E+01	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	7.19E-01	MJ
Steel scrap [Waste for recovery]	Mass	1.80E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	1.31E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	1.06E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.35E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.18E+00	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	1.27E-01	kg

Dust (PM2,5 - PM10) [Particles to air]	Mass	1.27E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	3.32E-02	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	5.83E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.86E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	5.28E-01	kg
RER: steel, unalloyed [Benefication]	Mass	1.80E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.35E+00	kg

Recycling cast iron scrap of an auxiliary generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Cast iron scrap [Waste for recovery]	Mass	9.84E+03	kg
Crude oil [Crude oil, at consumer]	Mass	4.84E+01	kg
Electricity [Electric power]	Energy	1.98E+04	MJ
Raw hardcoal [Resource]	Mass	4.17E+02	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	3.94E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	7.18E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	5.79E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	7.38E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.48E+00	kg
Cast iron [Metals]	Mass	9.84E+03	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	6.94E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.94E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	1.82E-01	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	3.19E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.66E+00	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.89E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	7.41E+00	kg

Recycling aluminium scrap of an auxiliary generator - ingot production [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	8.94E-01	kg
Aluminium scrap [Waste for recovery]	Mass	4.82E+01	kg
CH: anionic resin [Organics]	Mass	1.70E-01	kg
CH: cationic resin [Organics]	Mass	1.70E-01	kg
RER: natural gas [Fuels]	Energy	4.93E+02	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	3.83E-01	kg
RER: electricity, at grid [Production mix]	Energy	4.60E+00	MJ
Water [Water]	Mass	4.10E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	4.26E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.63E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.26E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.26E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.28E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.13E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	7.89E-01	kg

Disposing metallic waste of an auxiliary generator to incineration plants [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	4.57E+03	MJ
CH: heat from waste [Incineration]	Energy	6.61E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.97E-06	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.24E+04	kg
CH: slag compartment [Incineration]	Number of pieces	2.22E-05	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	7.88E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	6.40E+03	kg

Carbon monoxide [Inorganic emissions to air]	Mass	1.06E+00	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	6.95E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	5.18E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.28E+01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	7.88E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.73E-01	kg
Incineration of metallic waste [Waste for disposal]	Mass	7.88E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.67E+03	kg
Iron [Heavy metals to freshwater]	Mass	2.69E-02	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.99E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.04E-02	kg
Solids [Ecoinvent long-term to freshwater]	Mass	2.09E+00	kg
Solids [Particles to freshwater]	Mass	8.98E-03	kg
Waste heat [Other emissions to air]	Energy	3.91E+03	MJ
Waste heat [Other emissions to freshwater]	Energy	6.44E+02	MJ

Disposing metallic waste of an auxiliary generator to landfill [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	2.02E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	5.06E+01	kg
CH: disposal, paper [Incineration]	Mass	3.06E-01	kg
CH: disposal, plastics, mixture [Incineration]	Mass	3.06E-01	kg
CH: electricity from waste [Incineration]	Energy	2.71E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	2.98E+02	MJ
CH: heat from waste [Incineration]	Energy	4.38E+02	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	7.83E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	1.84E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.31E-07	pcs.

CH: process-specific burdens, waste incineration [Incineration]	Mass	5.22E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	5.06E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.94E+02	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.06E-07	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	4.38E-06	pcs.
CH: sewer grid [Wastewater treatment]	Length	4.38E-06	m
CH: slag compartment [Incineration]	Number of pieces	5.22E-07	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.12E-07	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	6.33E-04	kg
GLO: chemicals organic, at plant [Organics]	Mass	3.18E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	7.88E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	3.80E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	3.62E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	7.79E+03	kg
Aluminium [Particles to air]	Mass	3.36E-01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.17E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	3.80E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.75E+01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.12E-06	kg
Copper (+II) [Heavy metals to air]	Mass	1.57E+00	kg
Copper (+II) [Heavy metals to freshwater]	Mass	9.92E-04	kg
Hydrogen chloride [Inorganic emissions to air]	Mass	5.40E-01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.43E-02	kg
Iron [Heavy metals to air]	Mass	5.58E+02	kg
Iron [Heavy metals to freshwater]	Mass	2.73E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	7.88E+03	kg

Manufacturing a shaft generator [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	2.13E+01	kg
Cast iron part [Metal parts]	Mass	8.29E+02	kg
Copper [Metals]	Mass	1.81E+02	kg
Crude steel [Metals]	Mass	1.05E+03	kg
RER: chromium steel, at plant [Benefication]	Mass	1.06E+01	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	9.73E+00	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	7.71E+02	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	2.03E+03	MJ
RER: synthetic rubber, at plant [polymers]	Mass	3.19E+01	kg
RER: tap water, at user [Appropriation]	Mass	2.66E+04	kg
RER: electricity, at grid [Production mix]	Energy	3.89E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	5.21E+01	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	2.91E+02	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	1.33E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	2.57E+01	m^3
shaft generator [Metal parts]	Mass	2.13E+03	kg
Waste heat [Other emissions to air]	Energy	3.89E+02	MJ

Operating a shaft generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	0.00E+00	MJ
shaft generator [Metal parts]	Mass	2.13E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	0.00E+00	MJ
shaft generator [Metal parts]	Mass	2.13E+03	kg

Operating a shaft generator which functions as a PTO/PTI system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	1.19E+08	MJ
shaft generator [Metal parts]	Mass	2.13E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	7.31E+07	MJ
shaft generator [Metal parts]	Mass	2.13E+03	kg

Operating a shaft generator which functions as a PTO/PTI system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	7.61E+07	MJ
shaft generator [Metal parts]	Mass	2.13E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	1.32E+08	MJ
shaft generator [Metal parts]	Mass	2.13E+03	kg

Recovering a shaft generator and refurbishing its components [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Crude oil [Crude oil, at consumer]	Mass	1.67E+02	kg
Electricity [Electric power]	Energy	3.17E+01	MJ
Raw hardcoal [Resource]	Mass	1.44E+03	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	1.36E+01	MJ
shaft generator [Metal parts]	Mass	2.13E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium casting part [Metal parts]	Mass	6.38E+00	kg
Aluminium scrap [Waste for recovery]	Mass	6.38E+00	kg
Ammonium [Inorganic emissions to air]	Mass	2.50E-02	kg
BOD in waste water [Production residues in life cycle]	Mass	2.05E+00	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.55E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.24E+01	kg
Cast iron [Metal parts]	Mass	2.49E+02	kg
Cast iron scrap [Waste for recovery]	Mass	2.49E+02	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	2.35E+00	kg

Copper [Metals]	Mass	5.42E+01	kg
Copper scrap [Waste for recovery]	Mass	5.42E+01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.38E+01	kg
Hydrochloric acid [Waste for recovery]	Mass	6.25E-01	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.10E+00	kg
Landfill of plastic waste [Consumer waste]	Mass	2.23E+01	kg
Metallic waste for incineration [Waste for disposal]	Mass	4.19E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	4.19E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	9.08E+00	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	9.83E+00	kg
Plastic (unspecified) [Waste for recovery]	Mass	9.56E+00	kg
Stainless steel [Metal parts]	Mass	3.19E+00	kg
Stainless steel scrap [Waste for recovery]	Mass	3.19E+00	kg
Steel cast part [Metal parts]	Mass	3.16E+02	kg
Steel scrap [Waste for recovery]	Mass	3.16E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.57E+01	kg

Recycling aluminium scrap of a shaft generator - ingot production [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.18E-01	kg
Aluminium scrap [Waste for recovery]	Mass	6.38E+00	kg
CH: anionic resin [Organics]	Mass	2.25E-02	kg
CH: cationic resin [Organics]	Mass	2.25E-02	kg
RER: natural gas [Fuels]	Energy	6.52E+01	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	5.06E-02	kg
RER: electricity, at grid [Production mix]	Energy	6.08E-01	MJ
Water [Water]	Mass	5.42E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	5.63E+00	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.47E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.63E-03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.63E-03	kg

Nitrogen oxides [Inorganic emissions to air]	Mass	1.69E-02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.81E-02	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.04E-01	kg

Recycling copper scrap of a shaft generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	5.42E+01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	2.68E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.82E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	2.13E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	2.15E-07	kg
Acetic acid [NMVOC Group to air]	Mass	3.25E-05	kg
Arsenic [Heavy metals to air]	Mass	7.59E-05	kg
Benzene [NMVOC Group to air]	Mass	2.48E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.42E-10	kg
Butane [NMVOC Group to air]	Mass	2.48E-04	kg
Cadmium [Heavy metals to air]	Mass	1.25E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	5.36E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.02E-03	kg
Copper [Heavy metals to air]	Mass	1.52E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.41E-02	kg
Dust (PM2.5) [Particles to air]	Mass	5.10E-02	kg
Ethane [NMVOC Group to air]	Mass	3.67E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	8.88E-06	kg
Heat, waste [unspecified]	Energy	2.04E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	2.13E-04	kg
Lead [Heavy metals to air]	Mass	5.96E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.68E-04	kg
Nickel [Heavy metals to air]	Mass	7.04E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.88E-02	kg

Nitrous oxide [Inorganic emissions to air]	Mass	2.68E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	3.08E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	2.00E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	7.78E-15	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.15E-06	kg
Propane [NMVOC Group to air]	Mass	1.89E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	4.29E-06	kg
RER: copper, secondary [Benefication]	Mass	5.42E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.36E-03	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	4.02E-07	kg

Recycling cast iron scrap of a shaft generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	4.00E+00	kg
Argon [Inorganic intermediate products]	Mass	2.22E-01	kg
Cast iron scrap [Waste for recovery]	Mass	2.49E+02	kg
GLO: charcoal, at plant [Fuels]	Mass	9.91E+00	kg
Coke, metallurgic [Organic intermediate products]	Mass	3.45E+00	kg
Dolomite [Minerals]	Mass	4.86E+00	kg
Graphite [Inorganic intermediate products]	Mass	7.93E-01	kg
Lime finelime (ground) [Minerals]	Mass	1.64E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	8.79E+00	kg
Oxygen liquid [Inorganic intermediate products]	Mass	9.93E+00	kg
Pig iron (Fe carrier) [Metals]	Mass	3.73E+00	kg
Refractory [Minerals]	Mass	4.06E+00	kg
RER: natural gas [Fuels]	Energy	1.54E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	2.82E+01	kg
RER: electricity, at grid [Production mix]	Energy	4.24E+02	MJ
Water [Water]	Mass	4.61E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	2.61E+01	kg

Carbon monoxide [Inorganic emissions to air]	Mass	5.95E-01	kg
Cast iron [Metals]	Mass	1.98E+02	kg
Chromium [Heavy metals to air]	Mass	4.27E-04	kg
Dust (> PM10) [Particles to air]	Mass	5.00E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.97E+00	kg
Lead [Heavy metals to air]	Mass	2.90E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	5.96E-02	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	9.71E-05	kg
Refractory [Hazardous waste]	Mass	2.42E+00	kg
Sludge [Waste for disposal]	Mass	8.53E-01	kg
Steel works slag [Waste for recovery]	Mass	4.09E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.53E-02	kg

Recycling stainless steel scrap of a shaft generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.16E-01	kg
Argon [Inorganic intermediate products]	Mass	1.20E-02	kg
GLO: charcoal, at plant [Fuels]	Mass	5.35E-01	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.86E-01	kg
Dolomite [Minerals]	Mass	2.62E-01	kg
Graphite [Inorganic intermediate products]	Mass	4.28E-02	kg
Lime finelime (ground) [Minerals]	Mass	8.82E-01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	4.74E-01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	5.35E-01	kg
Pig iron (Fe carrier) [Metals]	Mass	2.01E-01	kg
Refractory [Minerals]	Mass	2.19E-01	kg
RER: natural gas [Fuels]	Energy	8.29E+00	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.52E+00	kg
Stainless steel scrap [Waste for recovery]	Mass	3.19E+00	kg
RER: electricity, at grid [Production mix]	Energy	2.29E+01	MJ
Water [Water]	Mass	2.49E-01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.41E+00	kg

Carbon monoxide [Inorganic emissions to air]	Mass	3.21E-02	kg
Chromium [Heavy metals to air]	Mass	2.30E-05	kg
Dust (> PM10) [Particles to air]	Mass	2.70E-03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.14E-01	kg
Lead [Heavy metals to air]	Mass	1.56E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.64E-05	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.24E-06	kg
Refractory [Hazardous waste]	Mass	1.30E-01	kg
Sludge [Waste for disposal]	Mass	4.60E-02	kg
Stainless steel (slab) [Metals]	Mass	3.14E+00	kg
Steel works slag [Waste for recovery]	Mass	2.21E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.36E-03	kg

Recycling steel scrap of a shaft generator [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	5.07E+00	kg
Argon [Inorganic intermediate products]	Mass	2.82E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	1.26E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	4.38E+00	kg
Dolomite [Minerals]	Mass	6.17E+00	kg
Graphite [Inorganic intermediate products]	Mass	1.01E+00	kg
Lime finelime (ground) [Minerals]	Mass	2.08E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.12E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	1.26E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	4.73E+00	kg
Refractory [Minerals]	Mass	5.16E+00	kg
RER: natural gas [Fuels]	Energy	1.95E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	3.57E+01	kg
Steel scrap [Waste for recovery]	Mass	3.16E+02	kg
RER: electricity, at grid [Production mix]	Energy	5.38E+02	MJ
Water [Water]	Mass	5.86E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.31E+01	kg

Carbon monoxide [Inorganic emissions to air]	Mass	7.55E-01	kg
Chromium [Heavy metals to air]	Mass	5.41E-04	kg
Dust (> PM10) [Particles to air]	Mass	6.34E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.03E+00	kg
Lead [Heavy metals to air]	Mass	3.68E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	7.56E-02	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.23E-04	kg
Refractory [Hazardous waste]	Mass	3.07E+00	kg
RER: steel, unalloyed [Benefication]	Mass	2.52E+02	kg
Sludge [Waste for disposal]	Mass	1.08E+00	kg
Steel works slag [Waste for recovery]	Mass	5.20E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.21E-02	kg

Disposing metallic waste of a shaft generator to incineration plants [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	2.43E+02	MJ
CH: heat from waste [Incineration]	Energy	3.51E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.05E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	6.61E+02	kg
CH: slag compartment [Incineration]	Number of pieces	1.18E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	4.19E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	3.40E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.65E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	3.69E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.75E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.75E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	4.19E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.45E-02	kg

Incineration of metallic waste [Waste for disposal]	Mass	4.19E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	8.87E+01	kg
Iron [Heavy metals to freshwater]	Mass	1.43E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.06E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.62E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.11E-01	kg
Solids [Particles to freshwater]	Mass	4.77E-04	kg
Waste heat [Other emissions to air]	Energy	2.08E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	3.42E+01	MJ

Disposing metallic waste of a shaft generator to landfill [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.08E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	2.69E+00	kg
CH: disposal, paper [Incineration]	Mass	1.62E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	1.62E-02	kg
CH: electricity from waste [Incineration]	Energy	1.44E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	1.58E+01	MJ
CH: heat from waste [Incineration]	Energy	2.33E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	4.16E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	9.80E+00	MJ
CH: waste incineration plant [Incineration]	Number of pieces	6.95E-09	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	2.78E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	2.69E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.56E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	5.61E-09	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	2.33E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	2.33E-07	m
CH: slag compartment [Incineration]	Number of pieces	2.78E-08	pcs.

CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	5.94E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	3.37E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	1.69E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	4.19E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	2.02E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.92E+00	MJ
Output			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	4.14E+02	kg
Aluminium [Particles to air]	Mass	1.79E-02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.20E-03	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.02E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.99E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	5.94E-08	kg
Copper (+II) [Heavy metals to air]	Mass	8.33E-02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	5.27E-05	kg
Hydrogen chloride [Inorganic emissions to air]	Mass	2.87E-02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	7.62E-04	kg
Iron [Heavy metals to air]	Mass	2.96E+01	kg
Iron [Heavy metals to freshwater]	Mass	1.45E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	4.19E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.77E-04	kg
Waste heat [Other emissions to air]	Energy	1.59E+01	MJ

Manufacturing a thermal oil boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: brass, at plant [Benefication]	Mass	2.69E-01	kg
CH: rock wool, packed, at plant [Manufacturing]	Mass	1.02E+02	kg
RER: electricity, at grid [Supply mix]	Energy	6.43E+03	MJ

RER: aluminium, primary [Benefication]	Mass	8.07E+01	kg
RER: brazing solder, cadmium free, at plant [Benefication]	Mass	3.23E+01	kg
RER: chromium steel, at plant [Benefication]	Mass	1.35E+02	kg
RER: copper, at regional storage [Benefication]	Mass	1.35E+02	kg
RER: corrugated board, mixed fibre [cardboard & corrugated board]	Mass	5.38E+01	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.45E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	5.44E+03	MJ
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	1.03E+04	MJ
RER: polyethylene, granulate, at plant [polymers]	Mass	7.54E+00	kg
RER: steel, low-alloyed [Benefication]	Mass	2.61E+03	kg
RER: tap water, at user [Appropriation]	Mass	3.99E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Thermal oil boiler [Heating]	Mass	3.17E+03	kg
Waste heat [Other emissions to air]	Energy	6.46E+03	MJ

Operating a thermal oil boiler (1) [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: diesel, low-sulphur [Fuels]	Mass	2.14E+06	kg
RER: lubricating oil [Organics]	Mass	1.78E+03	kg
Thermal oil boiler [Heating]	Mass	3.17E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	5.82E+06	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.92E+03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.96E+03	kg
Energy unspecific [Energy resources]	Energy	2.20E+07	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	7.89E+03	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	8.88E+04	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.24E+04	kg
Thermal oil boiler [Heating]	Mass	3.17E+03	kg

Operating a thermal oil boiler (2) [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: diesel, low-sulphur [Fuels]	Mass	3.21E+06	kg
RER: lubricating oil [Organics]	Mass	1.78E+03	kg
Thermal oil boiler [Heating]	Mass	3.17E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	8.72E+06	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.86E+03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.43E+03	kg
Energy unspecific [Energy resources]	Energy	3.10E+07	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	1.18E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.33E+05	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.35E+04	kg
Thermal oil boiler [Heating]	Mass	3.17E+03	kg

Operating a thermal oil boiler (3) [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: diesel, low-sulphur [Fuels]	Mass	1.07E+06	kg
RER: lubricating oil [Organics]	Mass	1.78E+03	kg
Thermal oil boiler [Heating]	Mass	3.17E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	2.91E+06	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.96E+03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.95E+03	kg
Energy unspecific [Energy resources]	Energy	1.10E+07	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	2.12E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.48E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.44E+04	kg
Thermal oil boiler [Heating]	Mass	3.17E+03	kg

Operating a thermal oil boiler (4) [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: diesel, low-sulphur [Fuels]	Mass	1.60E+06	kg
RER: lubricating oil [Organics]	Mass	1.78E+03	kg
Thermal oil boiler [Heating]	Mass	3.17E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	4.36E+06	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.43E+03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.22E+03	kg
Energy unspecific [Energy resources]	Energy	1.55E+07	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	5.91E+03	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	6.65E+04	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.18E+04	kg
Thermal oil boiler [Heating]	Mass	3.17E+03	kg

Dismantling a thermal oil boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	4.50E+01	MJ
Thermal oil boiler [Heating]	Mass	3.17E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	2.69E+01	kg
Brass scrap [Waste for recovery]	Mass	8.96E-02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	8.01E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.80E-01	kg
CH: disposal, packaging paper, 13.7% water [Incineration]	Mass	3.77E+01	kg
CH: disposal, packaging paper, 13.7% water [Landfill facility]	Mass	1.61E+01	kg
Copper scrap [Waste for recovery]	Mass	4.48E+01	kg
Dust (PM10) [Particles to air]	Mass	3.33E-02	kg
Metallic waste for incineration [Waste for disposal]	Mass	9.86E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	9.87E+02	kg

Methane [Organic emissions to air (VOC group)]	Mass	3.65E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.41E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	4.52E-04	kg
Polyethylene [Waste for recovery]	Mass	2.26E+00	kg
Polyethylene (unspecified) [Consumer waste]	Mass	5.27E+00	kg
Stainless steel scrap [Waste for recovery]	Mass	4.48E+01	kg
Steel scrap [Waste for recovery]	Mass	8.69E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	9.65E-02	kg
Unspecified oil waste [Hazardous waste]	Mass	1.78E+03	kg
Waste (unspecified) [Waste for disposal]	Mass	1.55E+02	kg

Oil waste treatment of a thermal oil boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	4.78E+00	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	3.60E+00	kg
Liquefied petroleum gas [LPG, at production]	Mass	4.30E+00	kg
RER: electricity [Production mix]	Energy	9.22E+04	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	7.17E+00	kg
Unspecified oil waste [Hazardous waste]	Mass	1.78E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.35E+02	kg
Sludge [Hazardous waste]	Mass	5.77E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	1.59E+03	kg

Recovery of used thermal oil after treatment [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	8.30E-01	kg
Propane [Organic intermediate products]	Mass	1.17E+00	kg
RER: electricity [Production mix]	Energy	3.98E+02	MJ
RER: natural gas [Fuels]	Energy	8.24E+03	MJ

Sodium hydroxide [Inorganic intermediate products]	Mass	4.61E+00	kg
Treated lubricating oil [Waste for recovery]	Mass	1.59E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	2.09E-09	kg
Asphalt flux [Organic intermediate products]	Mass	5.39E+02	kg
Base oil from re-refining [Other fuels]	Mass	3.84E+02	kg
Cadmium [Heavy metals to air]	Mass	1.42E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.41E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.70E+00	kg
Chromium [Heavy metals to air]	Mass	4.49E-09	kg
Electricity from waste to energy [System-dependent]	Energy	9.61E+03	MJ
Expanded clay [Minerals]	Mass	1.04E+00	kg
Flux and gas [Operating materials]	Mass	3.78E+01	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	2.33E+01	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	4.17E-04	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	2.06E-08	kg
Marine diesel oil [Other fuels]	Mass	4.12E+02	kg
Nickel [Heavy metals to air]	Mass	6.91E-07	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	6.00E-01	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	5.22E-01	kg
Production residues (unspecified) [Waste for recovery]	Mass	2.07E+01	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	4.20E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.02E-01	kg
Waste heat [Other emissions to air]	Energy	4.21E+03	MJ
Waste water - untreated [Production residues in life cycle]	Mass	2.33E+01	kg

Recycling aluminium scrap of a thermal oil boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	4.98E-01	kg
Aluminium scrap [Waste for recovery]	Mass	2.69E+01	kg

CH: anionic resin [Organics]	Mass	9.49E-02	kg
CH: cationic resin [Organics]	Mass	9.49E-02	kg
RER: natural gas [Fuels]	Energy	2.75E+02	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	2.14E-01	kg
RER: electricity, at grid [Production mix]	Energy	2.56E+00	MJ
Water [Water]	Mass	2.29E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	2.37E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.46E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.37E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.37E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	7.12E-02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.19E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	4.40E-01	kg

Recycling brass scrap of a thermal oil boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Brass scrap [Waste for recovery]	Mass	8.96E-02	kg
RER: blast furnace gas, burned in power plant [power plants]	Energy	4.44E-01	MJ
RER: gas power plant, 100MWe [power plants]	Number of pieces	3.01E-12	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC group to air]	Mass	3.52E-13	kg
Acetaldehyde (Ethanal) [NMVOC group to air]	Mass	3.55E-10	kg
Acetic acid [NMVOC group to air]	Mass	5.37E-08	kg
Arsenic [Heavy metals to air]	Mass	1.25E-07	kg
Benzene [NMVOC group to air]	Mass	4.11E-10	kg
Benzo{a}pyrene [PAH group to air]	Mass	2.35E-13	kg
Butane [NMVOC group to air]	Mass	4.11E-07	kg
Cadmium [Heavy metals to air]	Mass	2.06E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	8.87E-02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.65E-06	kg
Copper [Heavy metals to air]	Mass	2.51E-06	kg

Copper [Metals]	Mass	6.27E-02	kg
Dust (> PM10) [Particles to air]	Mass	2.33E-05	kg
Dust (PM2.5) [Particles to air]	Mass	8.43E-05	kg
Ethane [NMVOC group to air]	Mass	6.08E-07	kg
Formaldehyde (methanal) [NMVOC group to air]	Mass	1.47E-08	kg
Heat, waste [unspecified]	Energy	3.37E-01	MJ
Hexane (isomers) [NMVOC group to air]	Mass	3.52E-07	kg
Lead [Heavy metals to air]	Mass	9.86E-06	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.44E-07	kg
Nickel [Heavy metals to air]	Mass	1.17E-08	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.11E-05	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	4.44E-07	kg
Pentane (n-pentane) [NMVOC group to air]	Mass	5.10E-07	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	3.32E-07	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.29E-17	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	3.55E-09	kg
Propane [NMVOC group to air]	Mass	3.13E-07	kg
Propionic acid (propane acid) [NMVOC group to air]	Mass	7.10E-09	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.87E-06	kg
Toluene (methyl benzene) [NMVOC group to air]	Mass	6.65E-10	kg
Zinc [Metals]	Mass	2.69E-02	kg

Recycling copper scrap of a boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	4.48E+01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	2.22E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.51E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	1.76E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.77E-07	kg

Acetic acid [NMVOC Group to air]	Mass	2.68E-05	kg
Arsenic [Heavy metals to air]	Mass	6.27E-05	kg
Benzene [NMVOC Group to air]	Mass	2.05E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.17E-10	kg
Butane [NMVOC Group to air]	Mass	2.05E-04	kg
Cadmium [Heavy metals to air]	Mass	1.03E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.44E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.33E-03	kg
Copper [Heavy metals to air]	Mass	1.25E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.17E-02	kg
Dust (PM2.5) [Particles to air]	Mass	4.21E-02	kg
Ethane [NMVOC Group to air]	Mass	3.04E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	7.34E-06	kg
Heat, waste [unspecified]	Energy	1.69E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.76E-04	kg
Lead [Heavy metals to air]	Mass	4.93E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.22E-04	kg
Nickel [Heavy metals to air]	Mass	5.83E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.55E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	2.22E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	2.55E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.66E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	6.43E-15	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.77E-06	kg
Propane [NMVOC Group to air]	Mass	1.56E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	3.55E-06	kg
RER: copper, secondary [Benefication]	Mass	4.48E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.44E-03	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	3.33E-07	kg

Recycling stainless steel scrap of a boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.10E+00	kg
Argon [Inorganic intermediate products]	Mass	1.17E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	5.22E+00	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.82E+00	kg
Dolomite [Minerals]	Mass	2.56E+00	kg
Graphite [Inorganic intermediate products]	Mass	4.17E-01	kg
Lime finelime (ground) [Minerals]	Mass	8.61E+00	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	4.62E+00	kg
Oxygen liquid [Inorganic intermediate products]	Mass	5.22E+00	kg
Pig iron (Fe carrier) [Metals]	Mass	1.96E+00	kg
Refractory [Minerals]	Mass	2.14E+00	kg
RER: natural gas [Fuels]	Energy	8.09E+01	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.48E+01	kg
Stainless steel scrap [Waste for recovery]	Mass	3.11E+01	kg
RER: electricity, at grid [Production mix]	Energy	2.23E+02	MJ
Water [Water]	Mass	2.43E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.37E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.13E-01	kg
Chromium [Heavy metals to air]	Mass	2.24E-04	kg
Dust (> PM10) [Particles to air]	Mass	2.63E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.09E+00	kg
Lead [Heavy metals to air]	Mass	1.53E-04	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.57E-04	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.11E-05	kg
Refractory [Hazardous waste]	Mass	1.27E+00	kg
Sludge [Waste for disposal]	Mass	4.49E-01	kg
Stainless steel (slab) [Metals]	Mass	3.06E+01	kg
Steel works slag [Waste for recovery]	Mass	2.15E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.33E-02	kg

Recycling steel scrap of a thermal oil boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.40E+01	kg
Argon [Inorganic intermediate products]	Mass	1.38E+00	kg
GLO: charcoal, at plant [Fuels]	Mass	3.47E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.21E+01	kg
Dolomite [Minerals]	Mass	1.70E+01	kg
Graphite [Inorganic intermediate products]	Mass	2.77E+00	kg
Lime finelime (ground) [Minerals]	Mass	5.72E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	3.07E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	3.47E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	1.30E+01	kg
Refractory [Minerals]	Mass	1.42E+01	kg
RER: natural gas [Fuels]	Energy	5.37E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	9.84E+01	kg
Steel scrap [Waste for recovery]	Mass	8.69E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.48E+03	MJ
Water [Water]	Mass	1.61E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	9.12E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.08E+00	kg
Chromium [Heavy metals to air]	Mass	1.49E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.75E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.39E+01	kg
Lead [Heavy metals to air]	Mass	1.01E-03	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.08E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	3.39E-04	kg
Refractory [Hazardous waste]	Mass	8.46E+00	kg
RER: steel, unalloyed [Benefication]	Mass	6.93E+02	kg
Sludge [Waste for disposal]	Mass	2.98E+00	kg
Steel works slag [Waste for recovery]	Mass	1.43E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.85E-02	kg

Disposing metallic waste of a thermal oil boiler to incineration plants [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	5.71E+02	MJ
CH: heat from waste [Incineration]	Energy	8.27E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.46E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.56E+03	kg
CH: slag compartment [Incineration]	Number of pieces	2.78E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	9.86E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	8.02E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.70E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.33E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	6.48E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	4.11E+00	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	7.74E-03	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	3.38E-05	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	9.86E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	3.42E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	9.86E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.09E+02	kg
Iron [Heavy metals to freshwater]	Mass	3.36E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.49E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	3.81E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	2.61E-01	kg
Solids [Particles to freshwater]	Mass	1.12E-03	kg
Waste heat [Other emissions to air]	Energy	4.90E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	8.05E+01	MJ

Disposing metallic waste of a thermal oil boiler to landfill [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	2.53E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	6.33E+00	kg
CH: disposal, paper [Incineration]	Mass	3.83E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	3.83E-02	kg
CH: electricity from waste [Incineration]	Energy	3.39E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	3.73E+01	MJ
CH: heat from waste [Incineration]	Energy	5.48E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	9.80E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	2.31E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.64E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	6.54E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	6.33E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	3.68E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.32E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	5.48E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	5.48E-07	m
CH: slag compartment [Incineration]	Number of pieces	6.54E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.40E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	7.93E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	3.98E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	9.86E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	4.75E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	4.53E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	9.76E+02	kg

Aluminium (+III) [Inorganic emissions to freshwater]	Mass	4.21E-02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.46E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.76E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	4.69E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.96E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.40E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.24E-04	kg
Hydrogen chloride [Inorganic emissions to air]	Mass	6.76E-02	kg
Iron [Heavy metals to air]	Mass	6.98E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.79E-03	kg
Iron [Heavy metals to freshwater]	Mass	3.42E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	9.86E+02	kg

Manufacturing an exhaust gas boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: brass, at plant [Benefication]	Mass	1.87E-01	kg
CH: rock wool, packed, at plant [Manufacturing]	Mass	7.10E+01	kg
RER: electricity, at grid [Supply mix]	Energy	4.46E+03	MJ
RER: alkyd paint, 60% in solvent [Manufacturing]	Mass	9.34E+00	kg
RER: aluminium, primary [Benefication]	Mass	5.60E+01	kg
RER: brazing solder, cadmium free, at plant [Benefication]	Mass	2.24E+01	kg
RER: chromium steel, at plant [Benefication]	Mass	9.34E+01	kg
RER: copper, at regional storage [Benefication]	Mass	9.34E+01	kg
RER: corrugated board, mixed fibre [cardboard & corrugated board]	Mass	3.74E+01	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.01E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	3.77E+03	MJ
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	7.17E+03	MJ
RER: polyethylene, granulate, at plant [polymers]	Mass	5.23E+00	kg
RER: steel, low-alloyed [Benefication]	Mass	1.81E+03	kg
RER: tap water, at user [Appropriation]	Mass	2.77E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Exhaust gas boiler [Heating]	Mass	2.20E+03	kg
Waste heat [Other emissions to air]	Energy	4.48E+03	MJ

Operating an exhaust gas boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Exhaust gas boiler [Heating]	Mass	2.20E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	6.24E+07	MJ
Exhaust gas boiler [Heating]	Mass	2.20E+03	kg

Dismantling an exhaust gas boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	3.12E+01	MJ
Exhaust gas boiler [Heating]	Mass	2.20E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	1.87E+01	kg
Brass scrap [Waste for recovery]	Mass	6.22E-02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	5.56E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.94E-01	kg
CH: disposal, packaging paper, 13.7% water [Incineration]	Mass	2.61E+01	kg
CH: disposal, packaging paper, 13.7% water [Landfill facility]	Mass	1.12E+01	kg
Copper scrap [Waste for recovery]	Mass	3.11E+01	kg
Corrugated board [Materials from renewable raw materials]	Mass	3.74E+01	kg
Dust (PM10) [Particles to air]	Mass	2.31E-02	kg
Metallic waste for incineration [Waste for disposal]	Mass	6.84E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	6.84E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.53E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	9.81E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	3.14E-04	kg
Polyethylene [Waste for recovery]	Mass	1.57E+00	kg
Polyethylene (unspecified) [Consumer waste]	Mass	3.66E+00	kg
Stainless steel scrap [Waste for recovery]	Mass	3.11E+01	kg
Steel scrap [Waste for recovery]	Mass	6.03E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.69E-02	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.08E+02	kg

Recycling aluminium scrap of an exhaust gas boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	3.46E-01	kg
Aluminium scrap [Waste for recovery]	Mass	1.87E+01	kg
CH: anionic resin [Organics]	Mass	6.59E-02	kg
CH: cationic resin [Organics]	Mass	6.59E-02	kg
RER: natural gas [Fuels]	Energy	1.91E+02	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	1.48E-01	kg
RER: electricity, at grid [Production mix]	Energy	1.78E+00	MJ
Water [Water]	Mass	1.59E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	1.65E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.02E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.65E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.65E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.94E-02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.23E-02	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	3.05E-01	kg

Recycling brass scrap of an exhaust gas boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Brass scrap [Waste for recovery]	Mass	6.22E-02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	3.08E-01	MJ

RER: gas power plant, 100MWe [Power plants]	Number of pieces	2.09E-12	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	2.44E-13	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	2.46E-10	kg
Acetic acid [NMVOC Group to air]	Mass	3.73E-08	kg
Arsenic [Heavy metals to air]	Mass	8.71E-08	kg
Benzene [NMVOC Group to air]	Mass	2.85E-10	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.63E-13	kg
Butane [NMVOC Group to air]	Mass	2.85E-07	kg
Cadmium [Heavy metals to air]	Mass	1.43E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.16E-02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.62E-06	kg
Copper [Heavy metals to air]	Mass	1.74E-06	kg
Copper [Metals]	Mass	4.35E-02	kg
Dust (> PM10) [Particles to air]	Mass	1.62E-05	kg
Dust (PM2.5) [Particles to air]	Mass	5.85E-05	kg
Ethane [NMVOC Group to air]	Mass	4.22E-07	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.02E-08	kg
Heat, waste [unspecified]	Energy	2.34E-01	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	2.44E-07	kg
Lead [Heavy metals to air]	Mass	6.84E-06	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.08E-07	kg
Nickel [Heavy metals to air]	Mass	8.09E-09	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.16E-05	kg
Nitrous oxide [Inorganic emissions to air]	Mass	3.08E-07	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	3.54E-07	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	2.30E-07	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	8.93E-18	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.46E-09	kg
Propane [NMVOC Group to air]	Mass	2.17E-07	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	4.93E-09	kg

Sulphur dioxide [Inorganic emissions to air]	Mass	6.16E-06	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	4.62E-10	kg
Zinc [Metals]	Mass	1.87E-02	kg

Recycling copper scrap of an exhaust gas boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	3.11E+01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	1.54E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.05E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	1.22E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.23E-07	kg
Acetic acid [NMVOC Group to air]	Mass	1.86E-05	kg
Arsenic [Heavy metals to air]	Mass	4.35E-05	kg
Benzene [NMVOC Group to air]	Mass	1.43E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	8.14E-11	kg
Butane [NMVOC Group to air]	Mass	1.43E-04	kg
Cadmium [Heavy metals to air]	Mass	7.15E-05	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.08E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.31E-03	kg
Copper [Heavy metals to air]	Mass	8.71E-04	kg
Dust (> PM10) [Particles to air]	Mass	8.09E-03	kg
Dust (PM2.5) [Particles to air]	Mass	2.92E-02	kg
Ethane [NMVOC Group to air]	Mass	2.11E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	5.10E-06	kg
Heat, waste [unspecified]	Energy	1.17E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.22E-04	kg
Lead [Heavy metals to air]	Mass	3.42E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.54E-04	kg
Nickel [Heavy metals to air]	Mass	4.04E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.08E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.54E-04	kg

Pentane (n-pentane) [NMVOC Group to air]	Mass	1.77E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.15E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	4.46E-15	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.23E-06	kg
Propane [NMVOC Group to air]	Mass	1.09E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	2.46E-06	kg
RER: copper, secondary [Benefication]	Mass	3.11E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.08E-03	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	2.31E-07	kg

Recycling stainless steel scrap of an exhaust gas boiler C, R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.10E+00	kg
Argon [Inorganic intermediate products]	Mass	1.17E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	5.22E+00	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.82E+00	kg
Dolomite [Minerals]	Mass	2.56E+00	kg
Graphite [Inorganic intermediate products]	Mass	4.17E-01	kg
Lime finelime (ground) [Minerals]	Mass	8.61E+00	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	4.62E+00	kg
Oxygen liquid [Inorganic intermediate products]	Mass	5.22E+00	kg
Pig iron (Fe carrier) [Metals]	Mass	1.96E+00	kg
Refractory [Minerals]	Mass	2.14E+00	kg
RER: natural gas [Fuels]	Energy	8.09E+01	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.48E+01	kg
Stainless steel scrap [Waste for recovery]	Mass	3.11E+01	kg
RER: electricity, at grid [Production mix]	Energy	2.23E+02	MJ
Water [Water]	Mass	2.43E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.37E+01	kg

Carbon monoxide [Inorganic emissions to air]	Mass	3.13E-01	kg
Chromium [Heavy metals to air]	Mass	2.24E-04	kg
Dust (> PM10) [Particles to air]	Mass	2.63E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.09E+00	kg
Lead [Heavy metals to air]	Mass	1.53E-04	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.57E-04	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.11E-05	kg
Refractory [Hazardous waste]	Mass	1.27E+00	kg
Sludge [Waste for disposal]	Mass	4.49E-01	kg
Stainless steel (slab) [Metals]	Mass	3.06E+01	kg
Steel works slag [Waste for recovery]	Mass	2.15E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.33E-02	kg

Recycling steel scrap of an exhaust gas boiler [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	9.69E+00	kg
Argon [Inorganic intermediate products]	Mass	9.60E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	2.41E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	8.37E+00	kg
Dolomite [Minerals]	Mass	1.18E+01	kg
Graphite [Inorganic intermediate products]	Mass	1.92E+00	kg
Lime finelime (ground) [Minerals]	Mass	3.97E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	2.13E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	2.41E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	9.04E+00	kg
Refractory [Minerals]	Mass	9.86E+00	kg
RER: natural gas [Fuels]	Energy	3.73E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	6.83E+01	kg
Steel scrap [Waste for recovery]	Mass	6.03E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.03E+03	MJ
Water [Water]	Mass	1.12E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	6.33E+01	kg

Carbon monoxide [Inorganic emissions to air]	Mass	1.44E+00	kg
Chromium [Heavy metals to air]	Mass	1.04E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.21E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	9.62E+00	kg
Lead [Heavy metals to air]	Mass	7.04E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.45E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.35E-04	kg
Refractory [Hazardous waste]	Mass	5.87E+00	kg
RER: steel, unalloyed [Benefication]	Mass	4.81E+02	kg
Sludge [Waste for disposal]	Mass	2.07E+00	kg
Steel works slag [Waste for recovery]	Mass	9.93E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.14E-02	kg

Disposing metallic waste of an exhaust gas boiler to incineration plants C, R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	3.93E+02	MJ
CH: heat from waste [Incineration]	Energy	5.69E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.70E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.07E+03	kg
CH: slag compartment [Incineration]	Number of pieces	1.91E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	6.78E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	5.51E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	9.15E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	5.98E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.45E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	2.83E+00	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	5.32E-03	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	2.33E-05	kg

Copper (+II) [Ecoinvent long-term to freshwater]	Mass	6.78E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.35E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	6.78E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.31E-03	kg
Iron [Heavy metals to freshwater]	Mass	2.58E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.62E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.72E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.80E-01	kg
Solids [Particles to freshwater]	Mass	7.73E-04	kg
Waste heat [Other emissions to air]	Energy	3.37E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	5.54E+01	MJ

Disposing metallic waste of an exhaust gas boiler to landfill [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.74E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	4.35E+00	kg
CH: disposal, paper [Incineration]	Mass	2.63E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	2.63E-02	kg
CH: electricity from waste [Incineration]	Energy	2.33E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	2.56E+01	MJ
CH: heat from waste [Incineration]	Energy	3.77E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	6.74E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	1.59E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.13E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	4.50E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	4.35E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.53E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	9.09E-09	pcs.

CH: sewer grid [Wastewater treatment]	Length	3.77E-07	m
CH: slag compartment [Incineration]	Number of pieces	4.50E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	9.63E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	5.45E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	2.74E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	6.78E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	3.27E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	3.11E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	2.90E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	6.71E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.00E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	3.27E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.23E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.35E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	9.63E-08	kg
Copper (+II) [Heavy metals to freshwater]	Mass	8.54E-05	kg
Hydrogen chloride [Inorganic emissions to air]	Mass	4.65E-02	kg
Iron [Heavy metals to air]	Mass	4.80E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.23E-03	kg
Iron [Heavy metals to freshwater]	Mass	2.35E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	6.78E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.87E-04	kg
Waste heat [Other emissions to air]	Energy	2.58E+01	MJ

Manufacturing a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	3.78E+02	kg
Copper [Metals]	Mass	3.33E+03	kg
Crude steel [Metals]	Mass	1.60E+03	kg
Lead [Metals]	Mass	1.26E+00	kg
Lubricating oil [Operating materials]	Mass	8.80E+00	kg
Manganese [Metals]	Mass	4.62E+01	kg
Nickel [Metals]	Mass	1.89E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	2.56E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	2.03E+03	MJ
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	5.36E+03	MJ
RER: tap water, at user [Appropriation]	Mass	7.00E+04	kg
Silicon (99%) [Metals]	Mass	4.20E+00	kg
Tin (99.92%) [Metals]	Mass	4.20E+00	kg
RER: electricity, at grid [Production mix]	Energy	1.03E+03	MJ
Zinc [Metals]	Mass	4.20E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	1.37E+02	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	7.67E+02	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	3.49E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	6.78E+01	m^3
thruster [Assemblies]	Mass	5.60E+03	kg
Waste heat [Other emissions to air]	Energy	1.02E+03	MJ

Operating and maintaining a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	6.74E+06	MJ
Lubricating oil [Operating materials]	Mass	2.64E+02	kg
thruster [Assemblies]	Mass	5.60E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
thruster [Assemblies]	Mass	5.60E+03	kg
Unspecified oil waste [Hazardous waste]	Mass	2.64E+02	kg

Used lubricating oil treatment of a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	7.10E-01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	5.35E-01	kg
Liquefied petroleum gas [LPG, at production]	Mass	6.38E-01	kg
RER: electricity [Production mix]	Energy	1.37E+04	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	1.06E+00	kg
Unspecified oil waste [Hazardous waste]	Mass	2.64E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	2.01E+01	kg
Sludge [Hazardous waste]	Mass	8.56E+00	kg
Treated lubricating oil [Waste for recovery]	Mass	2.35E+02	kg

Recovering used lubricating oil of a bow thruster after treatment [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	1.23E-01	kg
Propane [Organic intermediate products]	Mass	1.73E-01	kg
RER: electricity [Production mix]	Energy	5.90E+01	MJ
RER: natural gas [Fuels]	Energy	1.22E+03	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	6.84E-01	kg
Treated lubricating oil [Waste for recovery]	Mass	2.35E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	3.10E-10	kg
Asphalt flux [Organic intermediate products]	Mass	7.99E+01	kg
Base oil from re-refining [Other fuels]	Mass	5.69E+01	kg
Cadmium [Heavy metals to air]	Mass	2.10E-08	kg
Carbon dioxide [Inorganic emissions to air]	Mass	5.06E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.52E-01	kg
Chromium [Heavy metals to air]	Mass	6.66E-10	kg

Electricity from waste to energy [System-dependent]	Energy	1.43E+03	MJ
Expanded clay [Minerals]	Mass	1.55E-01	kg
Flux and gas [Operating materials]	Mass	5.60E+00	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	3.46E+00	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	6.19E-05	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	3.06E-09	kg
Marine diesel oil [Other fuels]	Mass	6.12E+01	kg
Nickel [Heavy metals to air]	Mass	1.03E-07	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	8.89E-02	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	7.75E-02	kg
Production residues (unspecified) [Waste for recovery]	Mass	3.07E+00	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	6.22E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.52E-02	kg
Waste heat [Other emissions to air]	Energy	6.25E+02	MJ
Waste water - untreated [Production residues in life cycle]	Mass	3.46E+00	kg

Dismantling a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	8.35E+01	MJ
thruster [Assemblies]	Mass	5.60E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	1.26E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.49E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.19E-01	kg
Copper scrap [Waste for recovery]	Mass	1.11E+03	kg
Dust (PM10) [Particles to air]	Mass	6.18E-02	kg
Lead scrap [Waste for recovery]	Mass	4.20E-01	kg
manganese scrap [Waste for recovery]	Mass	1.54E+01	kg
Metallic waste for incineration [Waste for disposal]	Mass	1.86E+03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.86E+03	kg

Methane [Organic emissions to air (VOC group)]	Mass	6.77E-02	kg
nickel scrap [Waste for recovery]	Mass	6.29E+01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.62E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	8.39E-04	kg
silicon waste [Hazardous non organic waste for disposal]	Mass	1.40E+00	kg
Steel scrap [Waste for recovery]	Mass	5.33E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.79E-01	kg
Tin scrap [Waste for recovery]	Mass	1.40E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	5.60E+00	kg
Zinc scrap [Waste for recovery]	Mass	1.40E+01	kg

Recycling aluminium scrap of a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.33E+00	kg
Aluminium scrap [Waste for recovery]	Mass	1.26E+02	kg
CH: anionic resin [Organics]	Mass	4.44E-01	kg
CH: cationic resin [Organics]	Mass	4.44E-01	kg
RER: natural gas [Fuels]	Energy	1.29E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	1.00E+00	kg
RER: electricity, at grid [Production mix]	Energy	1.20E+01	MJ
Water [Water]	Mass	1.07E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	1.11E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.85E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.11E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.11E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.33E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.55E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	2.06E+00	kg

Recycling copper scrap of a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	1.11E+03	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	5.49E+03	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	3.73E-08	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	4.36E-09	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	4.40E-06	kg
Acetic acid [NMVOC Group to air]	Mass	6.65E-04	kg
Arsenic [Heavy metals to air]	Mass	1.55E-03	kg
Benzene [NMVOC Group to air]	Mass	5.09E-06	kg
Benzo{a}pyrene [PAH group to air]	Mass	2.91E-09	kg
Butane [NMVOC Group to air]	Mass	5.09E-03	kg
Cadmium [Heavy metals to air]	Mass	2.55E-03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.10E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.24E-02	kg
Copper [Heavy metals to air]	Mass	3.11E-02	kg
Dust (> PM10) [Particles to air]	Mass	2.89E-01	kg
Dust (PM2.5) [Particles to air]	Mass	1.04E+00	kg
Ethane [NMVOC Group to air]	Mass	7.53E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.82E-04	kg
Heat, waste [unspecified]	Energy	4.18E+03	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	4.36E-03	kg
Lead [Heavy metals to air]	Mass	1.22E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.49E-03	kg
Nickel [Heavy metals to air]	Mass	1.44E-04	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.85E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	5.49E-03	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	6.32E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	4.11E-03	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.59E-13	kg

Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	4.40E-05	kg
Propane [NMVOC Group to air]	Mass	3.87E-03	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	8.79E-05	kg
RER: copper, secondary [Benefication]	Mass	1.11E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.10E-01	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	8.24E-06	kg

Recycling lead scrap of a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Lead scrap [Waste for recovery]	Mass	4.20E-01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	2.94E+00	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	2.85E-12	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	5.55E-12	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	5.60E-09	kg
Acetic acid [NMVOC Group to air]	Mass	8.47E-07	kg
Arsenic [Heavy metals to air]	Mass	1.76E-05	kg
Benzene [NMVOC Group to air]	Mass	6.48E-09	kg
Benzo{a}pyrene [PAH group to air]	Mass	3.70E-12	kg
Butane [NMVOC Group to air]	Mass	6.48E-06	kg
Cadmium [Heavy metals to air]	Mass	5.87E-06	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.40E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.05E-04	kg
Dust (> PM10) [Particles to air]	Mass	4.45E-03	kg
Dust (PM2.5) [Particles to air]	Mass	3.31E-03	kg
Ethane [NMVOC Group to air]	Mass	9.59E-06	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	2.32E-07	kg
Heat, waste [unspecified]	Energy	5.32E+00	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	5.55E-06	kg
Lead [Heavy metals to air]	Mass	2.19E-03	kg
Lead secondary [Metals]	Mass	4.20E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.00E-06	kg

Nitrogen oxides [Inorganic emissions to air]	Mass	4.90E-04	kg
Nitrous oxide [Inorganic emissions to air]	Mass	7.00E-06	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	8.05E-06	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.34E-06	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	2.03E-16	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.60E-08	kg
Propane [NMVOC Group to air]	Mass	4.94E-06	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	1.12E-07	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.40E-04	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	1.05E-08	kg
Zinc [Heavy metals to air]	Mass	1.30E-05	kg

Recycling manganese scrap of a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: manganese concentrate, at beneficiation [Benefication]	Mass	1.61E+01	kg
GLO: non-ferrous metal smelter [Benefication]	Number of pieces	1.63E-13	pcs.
manganese scrap [Waste for recovery]	Mass	1.54E+01	kg
RER: ferromanganese, high-coal, 74.5% Mn, at regional storage [Benefication]	Mass	1.98E+01	kg
RER: electricity, at grid [Production mix]	Energy	1.46E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Heat, waste [unspecified]	Energy	1.46E+02	MJ
RER: manganese, at regional storage [Benefication]	Mass	2.34E+01	kg

Recycling nickel scrap of a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Blasting abrasive [Operating materials]	Mass	4.34E-03	kg
CH: disposal, nickel smelter slag, 0% water [Residual material landfill facility]	Mass	4.58E+01	kg
CH: limestone, milled, packed, at plant [others]	Mass	1.70E+00	kg

GLO: diesel, burned in building machine [Machines]	Energy	6.90E+00	MJ
GLO: non-ferrous metal mine, surface [Benefication]	Number of pieces	7.23E-09	pcs.
GLO: non-ferrous metal smelter [Benefication]	Number of pieces	2.34E-10	pcs.
nickel scrap [Waste for recovery]	Mass	6.29E+01	kg
Occupation, mineral extraction site [Hemerobie Ecoinvent]	Area time	5.96E-03	m^2*yr
RER: conveyor belt, at plant [Machines]	Length	2.89E-06	m
RER: hard coal, burned in industrial furnace [Heating systems]	Energy	1.45E+02	MJ
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.36E+01	MJ
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	1.08E+02	MJ
Transformation, from unspecified [Hemerobie Ecoinvent]	Area	1.99E-04	m^2
Transformation, to mineral extraction site [Hemerobie Ecoinvent]	Area	1.99E-04	m^2
RER: electricity, at grid [Production mix]	Energy	1.21E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	2.50E-06	kg
Antimony [Heavy metals to air]	Mass	7.31E-09	kg
Arsenic [Heavy metals to air]	Mass	5.19E-05	kg
Arsenic [Heavy metals to freshwater]	Mass	5.52E-07	kg
Beryllium [Inorganic emissions to air]	Mass	9.50E-08	kg
Biological oxygen demand (BOD) [Analytical measures to freshwater]	Mass	3.01E-04	kg
Boron [Inorganic emissions to air]	Mass	3.66E-07	kg
Cadmium [Heavy metals to air]	Mass	4.02E-09	kg
Cadmium [Heavy metals to freshwater]	Mass	7.72E-08	kg
Calcium (+II) [Inorganic emissions to freshwater]	Mass	1.98E-02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	7.47E-01	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	3.01E-04	kg
Chromium [Heavy metals to air]	Mass	3.66E-06	kg
Chromium [Heavy metals to freshwater]	Mass	7.29E-07	kg
Cobalt [Heavy metals to air]	Mass	1.09E-04	kg
Cobalt [Heavy metals to freshwater]	Mass	2.26E-08	kg
Copper [Heavy metals to freshwater]	Mass	1.54E-06	kg
Dioxins (unspecified) [Halogenated organic emissions to air]	Mass	3.62E-11	kg

DOC, Dissolved Organic Carbon [Ecoinvent long-term to freshwater]	Mass	1.18E-04	kg
Dust (> PM10) [Particles to air]	Mass	2.70E-03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.89E-02	kg
Dust (PM2.5) [Particles to air]	Mass	1.86E-02	kg
Fluorine [Inorganic emissions to air]	Mass	3.47E-05	kg
GLO: ferronickel, 25% Ni, at plant [Benefication]	Mass	3.62E+01	kg
Iron [Heavy metals to freshwater]	Mass	8.41E-06	kg
Lead [Heavy metals to air]	Mass	2.78E-04	kg
Lead [Heavy metals to freshwater]	Mass	4.80E-07	kg
Manganese [Heavy metals to air]	Mass	3.47E-05	kg
Manganese [Heavy metals to freshwater]	Mass	7.14E-07	kg
Mercury [Heavy metals to air]	Mass	1.83E-09	kg
Mercury [Heavy metals to freshwater]	Mass	8.22E-09	kg
Nickel [Heavy metals to air]	Mass	1.15E-04	kg
Nickel [Heavy metals to freshwater]	Mass	1.23E-06	kg
Nitrogen [Inorganic emissions to freshwater]	Mass	6.58E-04	kg
Selenium [Heavy metals to air]	Mass	1.83E-09	kg
Sulphate [Inorganic emissions to freshwater]	Mass	6.82E-02	kg
Tin [Heavy metals to air]	Mass	5.80E-05	kg
Tin [Heavy metals to freshwater]	Mass	7.13E-07	kg
Total organic carbon, TOC (Ecoinvent) [Ecoinvent long-term to freshwater]	Mass	1.18E-04	kg
Waste heat [Other emissions to air]	Energy	1.21E+02	MJ
Zinc [Heavy metals to air]	Mass	9.05E-04	kg
Zinc [Heavy metals to freshwater]	Mass	4.31E-06	kg

Recycling silicon scrap of a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, slag from MG silicon production, 0% water [Landfill facility]	Mass	5.18E-03	kg
DE: silica sand, at plant [Additives]	Mass	5.59E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	3.52E-02	kg
RER: graphite, at plant [Inorganics]	Mass	2.07E-02	kg
RER: hard coal coke, at plant [Fuels]	Energy	4.79E+00	MJ
RER: oxygen, liquid, at plant [Inorganics]	Mass	4.14E-03	kg
RER: petroleum coke, at refinery [Fuels]	Mass	1.04E-01	kg
RER: silicone plant [Inorganics]	Number of pieces	2.07E-12	pcs.

RER: wood chips, mixed, u=120%, at forest [Fuels]	Volume	6.74E-04	m^3
silicon waste [Hazardous non organic waste for disposal]	Mass	1.40E+00	kg
RER: electricity, at grid [Production mix]	Energy	8.21E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	3.21E-07	kg
Antimony [Heavy metals to air]	Mass	1.63E-09	kg
Arsenic [Heavy metals to air]	Mass	1.95E-09	kg
Boron [Inorganic emissions to air]	Mass	5.78E-08	kg
Cadmium [Heavy metals to air]	Mass	6.51E-11	kg
Calcium [Consumer waste]	Mass	1.61E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.08E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.14E-04	kg
Chlorine [Inorganic emissions to air]	Mass	1.63E-08	kg
Chromium [Heavy metals to air]	Mass	1.63E-09	kg
Cyanide (unspecified) [Inorganic emissions to air]	Mass	1.42E-06	kg
Dust (> PM10) [Particles to air]	Mass	1.61E-03	kg
Fluorine [Inorganic emissions to air]	Mass	8.03E-09	kg
Heat, waste [unspecified]	Energy	1.48E+01	MJ
Hydrogen fluoride [Inorganic emissions to air]	Mass	1.04E-04	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.04E-04	kg
Iron [Heavy metals to air]	Mass	8.03E-07	kg
Lead [Heavy metals to air]	Mass	7.12E-08	kg
Mercury [Heavy metals to air]	Mass	1.63E-09	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.02E-03	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	1.99E-05	kg
NO: MG-silicon, at plant [Benefication]	Mass	5.18E-01	kg
Silicon dust [Particles to air]	Mass	1.56E-03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.54E-03	kg
Tin [Heavy metals to air]	Mass	1.63E-09	kg

Recycling steel scrap of a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	8.57E+00	kg
Argon [Inorganic intermediate products]	Mass	4.76E-01	kg

GLO: charcoal, at plant [Fuels]	Mass	2.13E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	7.40E+00	kg
Dolomite [Minerals]	Mass	1.04E+01	kg
Graphite [Inorganic intermediate products]	Mass	1.70E+00	kg
Lime finelime (ground) [Minerals]	Mass	3.51E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.88E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	2.13E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	8.00E+00	kg
Refractory [Minerals]	Mass	8.72E+00	kg
RER: natural gas [Fuels]	Energy	3.30E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	6.04E+01	kg
Steel scrap [Waste for recovery]	Mass	5.33E+02	kg
RER: electricity, at grid [Production mix]	Energy	9.10E+02	MJ
Water [Water]	Mass	9.90E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	5.59E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.28E+00	kg
Chromium [Heavy metals to air]	Mass	9.15E-04	kg
Dust (> PM10) [Particles to air]	Mass	1.07E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	8.51E+00	kg
Lead [Heavy metals to air]	Mass	6.22E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.28E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.08E-04	kg
Refractory [Hazardous waste]	Mass	5.19E+00	kg
RER: steel, unalloyed [Benefication]	Mass	4.25E+02	kg
Sludge [Waste for disposal]	Mass	1.83E+00	kg
Steel works slag [Waste for recovery]	Mass	8.78E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.43E-02	kg

Recycling tin scrap of a bow thruster [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Blasting abrasive [Operating materials]	Mass	9.08E-02	kg
CH: disposal, dust, unalloyed EAF steel [Residual material landfill facility]	Mass	6.50E-02	kg

CH: gypsum, mineral, at mine [others]	Mass	5.69E-03	kg
CH: limestone, at mine [Additives]	Mass	1.64E-01	kg
GLO: diesel, burned in building machine [Machines]	Energy	1.95E+01	MJ
GLO: mine, iron [Benefication]	Number of pieces	4.71E-11	pcs.
GLO: non-ferrous metal mine, underground [Benefication]	Number of pieces	2.55E-14	pcs.
RER: anode, aluminium electrolysis [Benefication]	Mass	4.67E-04	kg
RER: heat, heavy fuel oil, at industrial furnace [Heating systems]	Energy	2.55E+00	MJ
Tin scrap [Waste for recovery]	Mass	1.40E+00	kg
RER: electricity, at grid [Production mix]	Energy	3.61E+01	MJ
UCTE: hard coal mix, at regional storage [Fuels]	Mass	1.34E-01	kg
Water [Water]	Mass	4.97E-01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	4.45E-01	kg
Dust (> PM10) [Particles to air]	Mass	8.56E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	7.70E-02	kg
Dust (PM2.5) [Particles to air]	Mass	8.56E-03	kg
Heat, waste [unspecified]	Energy	4.05E+01	MJ
RER: tin, at regional storage [Benefication]	Mass	1.20E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.33E-01	kg

Recycling zinc scrap of a bow thruster C, R, N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, inert waste, 5% water [Landfill facility]	Mass	8.78E-02	kg
CH: treatment, sewage, unpolluted [Wastewater treatment]	Volume	1.07E-01	m^3
GLO: diesel, burned in building machine [Machines]	Energy	1.15E-01	MJ
GLO: resource correction, PbZn, cadmium, negative [Benefication]	Mass	1.09E-01	kg
GLO: resource correction, PbZn, cadmium, positive [Benefication]	Mass	1.09E-01	kg
GLO: resource correction, PbZn, indium, negative [Benefication]	Mass	1.81E-03	kg
GLO: resource correction, PbZn, indium, positive [Benefication]	Mass	1.81E-03	kg

GLO: resource correction, PbZn, zinc, negative [Benefication]	Mass	4.56E-03	kg
GLO: resource correction, PbZn, zinc, positive [Benefication]	Mass	4.56E-03	kg
Oxygen liquid [Inorganic intermediate products]	Mass	2.97E-01	kg
RER: hard coal, burned in industrial furnace [Heating systems]	Energy	1.90E+01	MJ
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	4.38E+00	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	3.00E+00	kg
RER: electricity, at grid [Production mix]	Energy	9.56E+00	MJ
Water [Water]	Mass	1.07E-01	kg
Zinc scrap [Waste for recovery]	Mass	1.31E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	3.46E-05	kg
Arsenic [Heavy metals to freshwater]	Mass	3.23E-06	kg
Biological oxygen demand (BOD) [Analytical measures to freshwater]	Mass	8.52E-04	kg
Cadmium [Heavy metals to freshwater]	Mass	1.01E-05	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	1.28E-03	kg
Copper [Heavy metals to freshwater]	Mass	1.10E-05	kg
Dioxins (unspecified) [Halogenated organic emissions to air]	Mass	1.37E-10	kg
DOC, Dissolved Organic Carbon [Ecoinvent long-term to freshwater]	Mass	5.00E-04	kg
Dust (> PM10) [Particles to air]	Mass	9.86E-05	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	9.86E-05	kg
Dust (PM2.5) [Particles to air]	Mass	5.15E-04	kg
Fluoride [Inorganic emissions to freshwater]	Mass	8.17E-05	kg
GLO: cadmium sludge, from zinc electrolysis, at plant [Benefication]	Mass	2.31E-02	kg
GLO: leaching residues, indium rich, from zinc circuit, at smelter [Benefication]	Mass	2.32E+00	kg
GLO: zinc , from Imperial smelting furnace [Benefication]	Mass	6.85E+00	kg
Lead [Heavy metals to air]	Mass	2.85E-04	kg
Lead [Heavy metals to freshwater]	Mass	1.15E-04	kg
Mercury [Heavy metals to air]	Mass	1.10E-05	kg
Mercury [Heavy metals to freshwater]	Mass	4.72E-07	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.96E-02	kg

Sulphur dioxide [Inorganic emissions to air]	Mass	4.79E-02	kg
Total organic carbon, TOC (Ecoinvent) [Ecoinvent long-term to freshwater]	Mass	5.00E-04	kg
Waste heat [Other emissions to air]	Energy	3.44E+01	MJ
Zinc [Heavy metals to air]	Mass	5.70E-03	kg
Zinc [Heavy metals to freshwater]	Mass	1.26E-04	kg

Disposing metallic waste of a bow thruster to incineration plants [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.08E+03	MJ
CH: heat from waste [Incineration]	Energy	1.56E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	4.66E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.95E+03	kg
CH: slag compartment [Incineration]	Number of pieces	5.26E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	1.86E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.52E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.52E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.64E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.23E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	7.78E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.86E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	6.47E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	1.86E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	3.95E+02	kg
Iron [Heavy metals to freshwater]	Mass	6.36E-03	kg
Lead (+II) [Ecoinvent long-term to freshwater]	Mass	7.09E-01	kg
Lead (+II) [Heavy metals to freshwater]	Mass	1.29E-05	kg
Manganese (+II) [Ecoinvent long-term to freshwater]	Mass	4.48E+00	kg

Manganese (+II) [Heavy metals to freshwater]	Mass	2.29E-04	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.20E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	4.72E-03	kg
Nickel (+II) [Heavy metals to freshwater]	Mass	1.96E+00	kg
Solids [Ecoinvent long-term to freshwater]	Mass	4.94E-01	kg
Solids [Particles to freshwater]	Mass	2.13E-03	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	2.00E-05	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.24E+00	kg
Waste heat [Other emissions to air]	Energy	9.27E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	1.52E+02	MJ
Zinc (+II) [Heavy metals to freshwater]	Mass	1.12E-05	kg
Zinc, ion [Ecoinvent long-term to freshwater]	Mass	3.77E-01	kg

Disposing metallic waste of a bow thruster to landfill [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	4.79E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	1.20E+01	kg
CH: disposal, paper [Incineration]	Mass	7.24E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	7.24E-02	kg
CH: electricity from waste [Incineration]	Energy	6.40E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	7.05E+01	MJ
CH: heat from waste [Incineration]	Energy	1.04E+02	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	1.85E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	4.36E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	3.10E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	1.24E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	1.20E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	6.96E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	2.50E-08	pcs.

CH: landfill facility [Landfill facility]	Number of pieces	1.04E-06	pcs.
CH: sewer grid [Wastewater treatment]	Length	1.04E-06	m
CH: slag compartment [Incineration]	Number of pieces	1.24E-07	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	2.65E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.50E-04	kg
GLO: chemicals organic, at plant [Organics]	Mass	7.53E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.86E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	8.99E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	8.56E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	7.96E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.85E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.76E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	9.01E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	8.88E+00	kg
Copper (+II) [Heavy metals to air]	Mass	3.71E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	2.65E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.35E-04	kg
Iron [Heavy metals to air]	Mass	1.32E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	3.39E-03	kg
Iron [Heavy metals to freshwater]	Mass	6.47E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	1.86E+03	kg
Lead (+II) [Heavy metals to air]	Mass	7.07E-01	kg
Lead (+II) [Ecoinvent long-term to freshwater]	Mass	7.65E-07	kg
Lead (+II) [Heavy metals to freshwater]	Mass	2.29E-04	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.89E-04	kg
Tin (+IV) [Heavy metals to air]	Mass	7.25E+00	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	8.97E-03	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	2.18E-05	kg

Waste heat [Other emissions to air]	Energy	7.09E+01	MJ
Zinc (+II) [Heavy metals to air]	Mass	3.04E-01	kg
Zinc (+II) [Heavy metals to freshwater]	Mass	2.76E-03	kg
Zinc, ion [Ecoinvent long-term to freshwater]	Mass	2.07E-06	kg

Manufacturing a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	2.28E+03	kg
Copper [Metals]	Mass	1.92E+04	kg
Crude steel [Metals]	Mass	1.60E+03	kg
Lead [Metals]	Mass	7.20E+00	kg
Manganese [Metals]	Mass	2.09E+02	kg
Nickel [Metals]	Mass	1.01E+03	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	2.72E+02	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	2.16E+04	MJ
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	5.68E+04	MJ
RER: tap water, at user [Appropriation]	Mass	7.43E+05	kg
Silicon (99%) [Metals]	Mass	2.40E+01	kg
Tin (99.92%) [Metals]	Mass	2.40E+01	kg
RER: electricity, at grid [Production mix]	Energy	1.09E+04	MJ
Zinc [Metals]	Mass	2.40E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	1.46E+03	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	8.14E+03	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	3.71E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	7.19E+02	m^3
Propeller and shaft [Assemblies]	Mass	5.94E+04	kg
Waste heat [Other emissions to air]	Energy	1.09E+04	MJ

Operating and maintaining a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	3.66E+08	MJ
Propeller and shaft [Assemblies]	Mass	5.94E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Propeller and shaft [Assemblies]	Mass	5.94E+04	kg

Dismantling a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	8.86E+02	MJ
Propeller and shaft [Assemblies]	Mass	5.94E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	7.59E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.58E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.51E+00	kg
Copper scrap [Waste for recovery]	Mass	6.39E+03	kg
Dust (PM10) [Particles to air]	Mass	6.55E-01	kg
Lead scrap [Waste for recovery]	Mass	2.40E+00	kg
manganese scrap [Waste for recovery]	Mass	6.95E+01	kg
Metallic waste for incineration [Waste for disposal]	Mass	1.98E+04	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.98E+04	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.39E-01	kg
nickel scrap [Waste for recovery]	Mass	3.36E+02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.78E+01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	8.90E-03	kg
silicon waste [Hazardous non organic waste for disposal]	Mass	7.99E+00	kg
Steel scrap [Waste for recovery]	Mass	1.22E+04	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.90E+00	kg
Tin scrap [Waste for recovery]	Mass	7.99E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	5.94E+01	kg
Zinc scrap [Waste for recovery]	Mass	7.99E+00	kg

Recycling aluminium scrap of a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.41E+01	kg
Aluminium scrap [Waste for recovery]	Mass	7.59E+02	kg
CH: anionic resin [Organics]	Mass	2.68E+00	kg
CH: cationic resin [Organics]	Mass	2.68E+00	kg
RER: natural gas [Fuels]	Energy	7.76E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	6.03E+00	kg
RER: electricity, at grid [Production mix]	Energy	7.24E+01	MJ
Water [Water]	Mass	6.45E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	6.70E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.13E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.70E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.70E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.01E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.35E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.24E+01	kg

Recycling copper scrap of a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	6.39E+03	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	5.49E+03	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	3.73E-08	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	4.36E-09	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	4.40E-06	kg
Acetic acid [NMVOC Group to air]	Mass	6.65E-04	kg
Arsenic [Heavy metals to air]	Mass	8.95E-03	kg
Benzene [NMVOC Group to air]	Mass	5.09E-06	kg
Benzo{a}pyrene [PAH group to air]	Mass	2.91E-09	kg

Butane [NMVOC Group to air]	Mass	5.09E-03	kg
Cadmium [Heavy metals to air]	Mass	1.47E-02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.10E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.24E-02	kg
Copper [Heavy metals to air]	Mass	1.79E-01	kg
Dust (> PM10) [Particles to air]	Mass	2.89E-01	kg
Dust (PM2.5) [Particles to air]	Mass	1.66E+00	kg
Ethane [NMVOC Group to air]	Mass	7.53E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.82E-04	kg
Heat, waste [unspecified]	Energy	4.18E+03	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	4.36E-03	kg
Lead [Heavy metals to air]	Mass	7.03E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.49E-03	kg
Nickel [Heavy metals to air]	Mass	8.31E-04	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.85E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	5.49E-03	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	6.32E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	4.11E-03	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.59E-13	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	4.40E-05	kg
Propane [NMVOC Group to air]	Mass	3.87E-03	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	8.79E-05	kg
RER: copper, secondary [Benefication]	Mass	6.39E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.10E-01	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	8.24E-06	kg

Recycling lead scrap of a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Lead scrap [Waste for recovery]	Mass	2.40E+00	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	1.68E+01	MJ

RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.63E-11	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	5.55E-12	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	5.60E-09	kg
Acetic acid [NMVOC Group to air]	Mass	8.47E-07	kg
Arsenic [Heavy metals to air]	Mass	1.01E-04	kg
Benzene [NMVOC Group to air]	Mass	6.48E-09	kg
Benzo{a}pyrene [PAH group to air]	Mass	3.70E-12	kg
Butane [NMVOC Group to air]	Mass	6.48E-06	kg
Cadmium [Heavy metals to air]	Mass	3.36E-05	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.40E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.05E-04	kg
Dust (> PM10) [Particles to air]	Mass	2.54E-02	kg
Dust (PM2.5) [Particles to air]	Mass	1.89E-02	kg
Ethane [NMVOC Group to air]	Mass	9.59E-06	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	2.32E-07	kg
Heat, waste [unspecified]	Energy	5.32E+00	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	5.55E-06	kg
Lead [Heavy metals to air]	Mass	1.25E-02	kg
Lead secondary [Metals]	Mass	2.40E+00	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.00E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.90E-04	kg
Nitrous oxide [Inorganic emissions to air]	Mass	7.00E-06	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	8.05E-06	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	7.67E-06	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	2.03E-16	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.60E-08	kg
Propane [NMVOC Group to air]	Mass	4.94E-06	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	1.12E-07	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.40E-04	kg

Toluene (methyl benzene) [NMVOC Group to air]	Mass	1.05E-08	kg
Zinc [Heavy metals to air]	Mass	7.43E-05	kg

Recycling manganese scrap of a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: manganese concentrate, at beneficiation [Benefication]	Mass	7.27E+01	kg
GLO: non-ferrous metal smelter [Benefication]	Number of pieces	7.37E-13	pcs.
manganese scrap [Waste for recovery]	Mass	6.95E+01	kg
RER: ferromanganese, high-coal, 74.5% Mn, at regional storage [Benefication]	Mass	8.95E+01	kg
RER: electricity, at grid [Production mix]	Energy	6.58E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Heat, waste [unspecified]	Energy	6.58E+02	MJ
RER: manganese, at regional storage [Benefication]	Mass	1.06E+02	kg

Recycling nickel scrap of a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Blasting abrasive [Operating materials]	Mass	2.31E-02	kg
CH: disposal, nickel smelter slag, 0% water [Residual material landfill facility]	Mass	2.44E+02	kg
CH: limestone, milled, packed, at plant [others]	Mass	9.05E+00	kg
GLO: diesel, burned in building machine [Machines]	Energy	3.68E+01	MJ
GLO: non-ferrous metal mine, surface [Benefication]	Number of pieces	3.86E-08	pcs.
GLO: non-ferrous metal smelter [Benefication]	Number of pieces	1.25E-09	pcs.
nickel scrap [Waste for recovery]	Mass	3.36E+02	kg
Occupation, mineral extraction site [Hemerobie Ecoinvent]	Area time	3.18E-02	m2*yr
RER: conveyor belt, at plant [Machines]	Length	1.54E-05	m
RER: hard coal, burned in industrial furnace [Heating systems]	Energy	7.71E+02	MJ
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	7.23E+01	MJ

RER: natural gas, burned in industrial furnace [Heating systems]	Energy	5.74E+02	MJ
Transformation, from unspecified [Hemerobie Ecoinvent]	Area	1.06E-03	m^2
Transformation, to mineral extraction site [Hemerobie Ecoinvent]	Area	1.06E-03	m^2
RER: electricity, at grid [Production mix]	Energy	6.44E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.33E-05	kg
Antimony [Heavy metals to air]	Mass	3.90E-08	kg
Arsenic [Heavy metals to air]	Mass	2.94E-06	kg
Arsenic [Heavy metals to freshwater]	Mass	2.77E-04	kg
Beryllium [Inorganic emissions to air]	Mass	5.07E-07	kg
Biological oxygen demand (BOD) [Analytical measures to freshwater]	Mass	1.61E-03	kg
Boron [Inorganic emissions to air]	Mass	1.95E-06	kg
Cadmium [Heavy metals to air]	Mass	4.12E-07	kg
Cadmium [Heavy metals to freshwater]	Mass	2.14E-08	kg
Calcium (+II) [Inorganic emissions to freshwater]	Mass	1.06E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.98E+00	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	1.61E-03	kg
Chromium [Heavy metals to air]	Mass	1.95E-05	kg
Chromium [Heavy metals to freshwater]	Mass	3.89E-06	kg
Cobalt [Heavy metals to air]	Mass	5.82E-04	kg
Cobalt [Heavy metals to freshwater]	Mass	1.21E-07	kg
Copper [Heavy metals to freshwater]	Mass	8.23E-06	kg
Dioxins (unspecified) [Halogenated organic emissions to air]	Mass	1.93E-10	kg
DOC, Dissolved Organic Carbon [Ecoinvent long-term to freshwater]	Mass	6.28E-04	kg
Dust (> PM10) [Particles to air]	Mass	1.44E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.01E-01	kg
Dust (PM2.5) [Particles to air]	Mass	9.92E-02	kg
Fluorine [Inorganic emissions to air]	Mass	1.85E-04	kg
GLO: ferronickel, 25% Ni, at plant [Benefication]	Mass	1.93E+02	kg
Iron [Heavy metals to freshwater]	Mass	4.48E-05	kg
Lead [Heavy metals to air]	Mass	1.48E-03	kg
Lead [Heavy metals to freshwater]	Mass	1.48E-03	kg

Manganese [Heavy metals to air]	Mass	1.85E-04	kg
Manganese [Heavy metals to freshwater]	Mass	3.81E-06	kg
Mercury [Heavy metals to air]	Mass	9.75E-09	kg
Mercury [Heavy metals to freshwater]	Mass	4.38E-08	kg
Nickel [Heavy metals to air]	Mass	6.13E-04	kg
Nickel [Heavy metals to freshwater]	Mass	6.58E-06	kg
Nitrogen [Inorganic emissions to freshwater]	Mass	3.51E-03	kg
Selenium [Heavy metals to air]	Mass	9.75E-09	kg
Sulphate [Inorganic emissions to freshwater]	Mass	3.64E-01	kg
Tin [Heavy metals to air]	Mass	3.10E-04	kg
Tin [Heavy metals to freshwater]	Mass	3.80E-06	kg
Total organic carbon, TOC (Ecoinvent) [Ecoinvent long-term to freshwater]	Mass	6.28E-04	kg
Waste heat [Other emissions to air]	Energy	6.44E+02	MJ
Zinc [Heavy metals to air]	Mass	4.83E-03	kg
Zinc [Heavy metals to freshwater]	Mass	2.30E-05	kg

Recycling silicon scrap of a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, slag from MG silicon production, 0% water [Landfill facility]	Mass	2.96E-02	kg
DE: silica sand, at plant [Additives]	Mass	3.20E+00	kg
GLO: charcoal, at plant [Fuels]	Mass	2.01E-01	kg
RER: graphite, at plant [Inorganics]	Mass	1.18E-01	kg
RER: hard coal coke, at plant [Fuels]	Energy	2.74E+01	MJ
RER: oxygen, liquid, at plant [Inorganics]	Mass	2.37E-02	kg
RER: petroleum coke, at refinery [Fuels]	Mass	5.92E-01	kg
RER: silicone plant [Inorganics]	Number of pieces	1.18E-11	pcs.
RER: wood chips, mixed, u=120%, at forest [Fuels]	Volume	3.85E-03	m^3
silicon waste [Hazardous non organic waste for disposal]	Mass	7.99E+00	kg
RER: electricity, at grid [Production mix]	Energy	4.69E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	1.84E-06	kg
Antimony [Heavy metals to air]	Mass	9.30E-09	kg
Arsenic [Heavy metals to air]	Mass	1.12E-08	kg
Boron [Inorganic emissions to air]	Mass	3.31E-07	kg
Cadmium [Heavy metals to air]	Mass	3.72E-10	kg

Calcium [Consumer waste]	Mass	9.18E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.15E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.37E-03	kg
Chlorine [Inorganic emissions to air]	Mass	9.30E-08	kg
Chromium [Heavy metals to air]	Mass	9.30E-09	kg
Cyanide (unspecified) [Inorganic emissions to air]	Mass	8.13E-06	kg
Dust (> PM10) [Particles to air]	Mass	9.18E-03	kg
Fluorine [Inorganic emissions to air]	Mass	4.59E-08	kg
Heat, waste [unspecified]	Energy	8.44E+01	MJ
Hydrogen fluoride [Inorganic emissions to air]	Mass	5.92E-04	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	5.92E-04	kg
Iron [Heavy metals to air]	Mass	4.59E-06	kg
Lead [Heavy metals to air]	Mass	4.07E-07	kg
Mercury [Heavy metals to air]	Mass	9.30E-09	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.15E-02	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	1.14E-04	kg
NO: MG-silicon, at plant [Benefication]	Mass	2.96E+00	kg
Silicon dust [Particles to air]	Mass	8.90E-03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.45E-02	kg
Tin [Heavy metals to air]	Mass	9.30E-09	kg

Recycling steel scrap of a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.96E+02	kg
Argon [Inorganic intermediate products]	Mass	1.09E+01	kg
GLO: charcoal, at plant [Fuels]	Mass	4.86E+02	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.69E+02	kg
Dolomite [Minerals]	Mass	2.38E+02	kg
Graphite [Inorganic intermediate products]	Mass	3.89E+01	kg
Lime finelime (ground) [Minerals]	Mass	8.02E+02	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	4.31E+02	kg
Oxygen liquid [Inorganic intermediate products]	Mass	4.87E+02	kg

Pig iron (Fe carrier) [Metals]	Mass	1.83E+02	kg
Refractory [Minerals]	Mass	1.99E+02	kg
RER: natural gas [Fuels]	Energy	7.54E+03	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.38E+03	kg
Steel scrap [Waste for recovery]	Mass	1.22E+04	kg
RER: electricity, at grid [Production mix]	Energy	2.08E+04	MJ
Water [Water]	Mass	2.26E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.28E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.92E+01	kg
Chromium [Heavy metals to air]	Mass	2.09E-02	kg
Dust (> PM10) [Particles to air]	Mass	2.45E+00	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.95E+02	kg
Lead [Heavy metals to air]	Mass	1.42E+01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.92E+00	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	4.76E-03	kg
Refractory [Hazardous waste]	Mass	1.19E+02	kg
RER: steel, unalloyed [Benefication]	Mass	9.73E+03	kg
Sludge [Waste for disposal]	Mass	4.18E+01	kg
Steel works slag [Waste for recovery]	Mass	2.01E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.24E+00	kg

Recycling tin scrap of a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Blasting abrasive [Operating materials]	Mass	5.19E-01	kg
CH: disposal, dust, unalloyed EAF steel [Residual material landfill facility]	Mass	3.72E-01	kg
CH: gypsum, mineral, at mine [others]	Mass	3.25E-02	kg
CH: limestone, at mine [Additives]	Mass	9.40E-01	kg
GLO: diesel, burned in building machine [Machines]	Energy	1.11E+02	MJ
GLO: mine, iron [Benefication]	Number of pieces	2.69E-10	pcs.
GLO: non-ferrous metal mine, underground [Benefication]	Number of pieces	1.46E-13	pcs.

RER: anode, aluminium electrolysis [Benefication]	Mass	2.67E-03	kg
RER: heat, heavy fuel oil, at industrial furnace [Heating systems]	Energy	1.46E+01	MJ
Tin scrap [Waste for recovery]	Mass	7.99E+00	kg
RER: electricity, at grid [Production mix]	Energy	2.07E+02	MJ
UCTE: hard coal mix, at regional storage [Fuels]	Mass	7.68E-01	kg
Water [Water]	Mass	2.84E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	2.54E+00	kg
Dust (> PM10) [Particles to air]	Mass	4.89E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.40E-01	kg
Dust (PM2.5) [Particles to air]	Mass	4.89E-02	kg
Heat, waste [unspecified]	Energy	2.31E+02	MJ
RER: tin, at regional storage [Benefication]	Mass	6.83E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	7.60E-01	kg

Recycling zinc scrap of a CuNiAl propeller and a shaft [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, inert waste, 5% water [Landfill facility]	Mass	9.31E-01	kg
CH: treatment, sewage, unpolluted [Wastewater treatment]	Volume	1.13E+00	m^3
GLO: diesel, burned in building machine [Machines]	Energy	1.22E+00	MJ
GLO: resource correction, PbZn, cadmium, negative [Benefication]	Mass	1.15E+00	kg
GLO: resource correction, PbZn, cadmium, positive [Benefication]	Mass	1.15E+00	kg
GLO: resource correction, PbZn, indium, negative [Benefication]	Mass	1.92E-02	kg
GLO: resource correction, PbZn, indium, positive [Benefication]	Mass	1.92E-02	kg
GLO: resource correction, PbZn, zinc, negative [Benefication]	Mass	4.84E-02	kg
GLO: resource correction, PbZn, zinc, positive [Benefication]	Mass	4.84E-02	kg

Oxygen liquid [Inorganic intermediate products]	Mass	3.15E+00	kg
RER: hard coal, burned in industrial furnace [Heating systems]	Energy	2.01E+02	MJ
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	4.64E+01	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	3.18E+01	kg
RER: electricity, at grid [Production mix]	Energy	1.01E+02	MJ
Water [Water]	Mass	1.13E+03	kg
Zinc scrap [Waste for recovery]	Mass	1.38E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	3.67E-04	kg
Arsenic [Heavy metals to freshwater]	Mass	3.43E-05	kg
Biological oxygen demand (BOD) [Analytical measures to freshwater]	Mass	9.04E-03	kg
Cadmium [Heavy metals to freshwater]	Mass	1.07E-04	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	1.36E-02	kg
Copper [Heavy metals to freshwater]	Mass	1.16E-04	kg
Dioxins (unspecified) [Halogenated organic emissions to air]	Mass	1.45E-09	kg
DOC, Dissolved Organic Carbon [Ecoinvent long-term to freshwater]	Mass	5.30E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.05E-03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.05E-03	kg
Dust (PM2.5) [Particles to air]	Mass	5.46E-03	kg
Fluoride [Inorganic emissions to freshwater]	Mass	8.66E-04	kg
GLO: cadmium sludge, from zinc electrolysis, at plant [Benefication]	Mass	2.45E-01	kg
GLO: leaching residues, indium rich, from zinc circuit, at smelter [Benefication]	Mass	2.47E+01	kg
GLO: zinc , from Imperial smelting furnace [Benefication]	Mass	7.27E+01	kg
Lead [Heavy metals to air]	Mass	3.02E-03	kg
Lead [Heavy metals to freshwater]	Mass	1.22E-03	kg
Mercury [Heavy metals to air]	Mass	1.16E-04	kg
Mercury [Heavy metals to freshwater]	Mass	5.01E-06	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.08E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.08E-01	kg

Total organic carbon, TOC (Ecoinvent) [Ecoinvent long-term to freshwater]	Mass	5.30E-03	kg
Waste heat [Other emissions to air]	Energy	3.65E+02	MJ
Zinc [Heavy metals to air]	Mass	6.05E-02	kg
Zinc [Heavy metals to freshwater]	Mass	1.33E-03	kg

Disposing metallic waste of a CuNiAl propeller and a shaft to incineration plants [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.15E+04	MJ
CH: heat from waste [Incineration]	Energy	1.66E+04	MJ
CH: waste incineration plant [Incineration]	Number of pieces	4.95E-06	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	3.13E+04	kg
CH: slag compartment [Incineration]	Number of pieces	5.58E-05	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	1.98E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.61E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.67E+00	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.74E+00	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.30E+01	kg
Chloride [Inorganic emissions to freshwater]	Mass	8.25E+01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.98E+04	kg
Copper (+II) [Heavy metals to freshwater]	Mass	6.86E-01	kg
Incineration of metallic waste [Waste for disposal]	Mass	1.98E+04	kg
Iron [Ecoinvent long-term to freshwater]	Mass	4.19E+03	kg
Iron [Heavy metals to freshwater]	Mass	6.75E-02	kg
Lead (+II) [Ecoinvent long-term to freshwater]	Mass	7.52E+00	kg
Lead (+II) [Heavy metals to freshwater]	Mass	1.37E-04	kg
Manganese (+II) [Ecoinvent long-term to freshwater]	Mass	4.75E+01	kg

Manganese (+II) [Heavy metals to freshwater]	Mass	2.43E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.64E-02	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	5.00E-02	kg
Nickel (+II) [Heavy metals to freshwater]	Mass	2.08E+01	kg
Solids [Ecoinvent long-term to freshwater]	Mass	5.24E+00	kg
Solids [Particles to freshwater]	Mass	2.25E-02	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	2.12E-04	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.32E+01	kg
Waste heat [Other emissions to air]	Energy	9.83E+03	MJ
Waste heat [Other emissions to freshwater]	Energy	1.62E+03	MJ
Zinc (+II) [Heavy metals to freshwater]	Mass	1.19E-04	kg
Zinc, ion [Ecoinvent long-term to freshwater]	Mass	4.00E+00	kg

Disposing metallic waste of a CuNiAl propeller and a shaft to landfill [C, R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	5.08E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	1.27E+02	kg
CH: disposal, paper [Incineration]	Mass	7.67E-01	kg
CH: disposal, plastics, mixture [Incineration]	Mass	7.67E-01	kg
CH: electricity from waste [Incineration]	Energy	6.79E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	7.48E+02	MJ
CH: heat from waste [Incineration]	Energy	1.10E+03	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	1.97E-02	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	4.63E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	3.28E-07	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	1.31E+03	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	1.27E+02	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	7.38E+02	kg

CH: landfill facility [Landfill facility]	Number of pieces	1.10E-05	pcs.
CH: sewer grid [Wastewater treatment]	Length	1.10E-05	m
CH: slag compartment [Incineration]	Number of pieces	1.31E-06	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	2.81E-07	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.59E-03	kg
GLO: chemicals organic, at plant [Organics]	Mass	7.99E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.98E+04	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	9.53E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	9.08E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	8.45E-01	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.96E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.93E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	9.55E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	9.42E+01	kg
Copper (+II) [Heavy metals to air]	Mass	3.94E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	2.81E-06	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.49E-03	kg
Iron [Heavy metals to air]	Mass	1.40E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	3.60E-02	kg
Iron [Heavy metals to freshwater]	Mass	6.86E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	1.98E+04	kg
Lead (+II) [Heavy metals to air]	Mass	7.50E+00	kg
Lead (+II) [Ecoinvent long-term to freshwater]	Mass	8.11E-06	kg
Lead (+II) [Heavy metals to freshwater]	Mass	2.43E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	8.37E-03	kg

Tin (+IV) [Heavy metals to air]	Mass	7.69E+01	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	9.51E-02	kg
Tin, ion [Ecoinvent long-term to freshwater	Mass	2.31E-04	kg
Waste heat [Other emissions to air]	Energy	7.52E+02	MJ
Zinc (+II) [Heavy metals to air]	Mass	3.22E+00	kg
Zinc (+II) [Heavy metals to freshwater]	Mass	2.93E-02	kg
Zinc, ion [Ecoinvent long-term to freshwater]	Mass	2.20E-05	kg

Manufacturing a stainless steel propeller and a shaft [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: chromium steel, at plant [Benefication]	Mass	1.25E+04	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	5.70E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	4.52E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	1.19E+04	MJ
RER: tap water, at user [Appropriation]	Mass	1.56E+05	kg
RER: electricity, at grid [Production mix]	Energy	2.28E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	3.05E+02	kg
Propeller and shaft [Assemblies]	Mass	1.25E+04	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	1.71E+03	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	7.77E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	1.51E+02	m^3
Waste heat [Other emissions to air]	Energy	2.28E+03	MJ

Operating a stainless steel propeller and a shaft [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	3.66E+08	MJ
Propeller and shaft [Assemblies]	Mass	1.25E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Propeller and shaft [Assemblies]	Mass	1.25E+04	kg

Dismantling a stainless steel propeller and a shaft [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	1.86E+02	MJ
Propeller [Assemblies]	Mass	1.25E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.30E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.15E+00	kg
Dust (PM10) [Particles to air]	Mass	1.37E-01	kg
Metallic waste for incineration [Waste for disposal]	Mass	4.15E+03	kg
Metallic waste for landfill [Waste for disposal]	Mass	4.15E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.51E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	5.83E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.87E-03	kg
Stainless steel scrap [Waste for recovery]	Mass	4.15E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.98E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	8.71E+00	kg

Recovering stainless steel scrap of a propeller and a shaft [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.80E+02	kg
Argon [Inorganic intermediate products]	Mass	1.56E+01	kg
GLO: charcoal, at plant [Fuels]	Mass	6.96E+02	kg
Coke, metallurgic [Organic intermediate products]	Mass	2.42E+02	kg
Dolomite [Minerals]	Mass	3.41E+02	kg
Graphite [Inorganic intermediate products]	Mass	5.56E+01	kg
Lime finelime (ground) [Minerals]	Mass	1.15E+03	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	6.16E+02	kg
Oxygen liquid [Inorganic intermediate products]	Mass	6.96E+02	kg
Pig iron (Fe carrier) [Metals]	Mass	2.62E+02	kg
Refractory [Minerals]	Mass	2.85E+02	kg

RER: natural gas [Fuels]	Energy	1.08E+04	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.98E+03	kg
Stainless steel scrap [Waste for recovery]	Mass	4.15E+03	kg
RER: electricity, at grid [Production mix]	Energy	2.97E+04	MJ
Water [Water]	Mass	3.24E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.83E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.17E+01	kg
Chromium [Heavy metals to air]	Mass	2.99E-02	kg
Dust (> PM10) [Particles to air]	Mass	3.51E+00	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.78E+02	kg
Lead [Heavy metals to air]	Mass	2.03E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.43E-02	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	6.81E-03	kg
Refractory [Hazardous waste]	Mass	1.70E+02	kg
Sludge [Waste for disposal]	Mass	5.98E+01	kg
Stainless steel (slab) [Metals]	Mass	4.08E+03	kg
Steel works slag [Waste for recovery]	Mass	2.87E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.77E+00	kg

Disposing metallic waste of a stainless steel propeller and a shaft to incineration plants [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	2.40E+03	MJ
CH: heat from waste [Incineration]	Energy	3.48E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.04E-06	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	6.55E+03	kg
CH: slag compartment [Incineration]	Number of pieces	1.17E-05	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	4.15E+03	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon monoxide [Inorganic emissions to air]	Mass	5.60E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	3.66E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.72E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.73E+01	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	3.25E-02	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	1.42E-04	kg
Incineration of metallic waste [Waste for disposal]	Mass	4.15E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	8.79E+02	kg
Iron [Heavy metals to freshwater]	Mass	1.41E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.60E-02	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.05E-02	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.10E+00	kg
Solids [Particles to freshwater]	Mass	4.73E-03	kg
Waste heat [Other emissions to air]	Energy	2.06E+03	MJ
Waste heat [Other emissions to freshwater]	Energy	3.39E+02	MJ

Disposing metallic waste of a stainless steel propeller and a shaft to landfill [C]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.07E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	2.66E+01	kg
CH: disposal, paper [Incineration]	Mass	1.61E-01	kg
CH: disposal, plastics, mixture [Incineration]	Mass	1.61E-01	kg
CH: electricity from waste [Incineration]	Energy	1.42E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	1.57E+02	MJ
CH: heat from waste [Incineration]	Energy	2.31E+02	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	4.12E-03	kg

CH: light fuel oil, burned in boiler [Heating systems]	Energy	9.70E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	6.88E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	2.75E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	2.66E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	4.15E+03	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.55E+02	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	5.56E-08	pcs.
CH: sewer grid [Wastewater treatment]	Length	2.31E-06	m
CH: slag compartment [Incineration]	Number of pieces	2.31E-06	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	2.75E-07	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	5.89E-08	kg
GLO: chemicals organic, at plant [Organics]	Mass	3.33E-04	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.67E-02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	2.00E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.90E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon monoxide [Inorganic emissions to air]	Mass	6.14E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.00E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.97E+01	kg
Iron [Heavy metals to air]	Mass	2.94E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	7.55E-03	kg
Iron [Heavy metals to freshwater]	Mass	1.44E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	4.15E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.75E-03	kg
Waste heat [Other emissions to air]	Energy	1.58E+02	MJ

Manufacturing a gearbox [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	1.42E+02	kg
Cast iron [Metals]	Mass	2.83E+02	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.35E+03	MJ
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	6.48E+00	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	5.14E+02	MJ
RER: tap water, at user [Appropriation]	Mass	1.77E+04	kg
Steel cast part [Metal parts]	Mass	9.91E+02	kg
RER: electricity, at grid [Production mix]	Energy	2.59E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	3.47E+01	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	1.94E+02	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	8.83E+00	kg
CH: treatment, sewage [Wastewater treatment]	Volume	1.71E+01	m^3
Gearbox [Assemblies]	Mass	1.42E+03	kg
Waste heat [Other emissions to air]	Energy	2.59E+02	MJ

Operating a gearbox [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Gearbox [Assemblies]	Mass	1.42E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Gearbox [Assemblies]	Mass	1.42E+03	kg

Dismantling a gearbox [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	2.11E+01	MJ
Gearbox [Assemblies]	Mass	1.42E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	4.71E+01	kg

Carbon dioxide [Inorganic emissions to air]	Mass	3.75E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.31E-01	kg
Cast iron scrap [Waste for recovery]	Mass	9.42E+01	kg
Dust (PM10) [Particles to air]	Mass	1.56E-02	kg
Metallic waste for incineration [Waste for disposal]	Mass	4.71E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	4.71E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.71E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	6.63E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	2.12E-04	kg
Steel scrap [Waste for recovery]	Mass	3.30E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.52E-02	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.41E+00	kg

Recycling aluminium scrap of a gearbox [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	8.73E-01	kg
Aluminium scrap [Waste for recovery]	Mass	4.71E+01	kg
CH: anionic resin [Organics]	Mass	1.66E-01	kg
CH: cationic resin [Organics]	Mass	1.66E-01	kg
RER: natural gas [Fuels]	Energy	4.82E+02	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	3.74E-01	kg
RER: electricity, at grid [Production mix]	Energy	4.49E+00	MJ
Water [Water]	Mass	4.00E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	4.16E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.57E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.16E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.16E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.25E-01	kg

Sulphur dioxide [Inorganic emissions to air]	Mass	2.08E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	7.71E-01	kg

Recycling cast iron scrap of a gearbox [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.51E+00	kg
Argon [Inorganic intermediate products]	Mass	8.42E-02	kg
Cast iron scrap [Waste for recovery]	Mass	9.42E+01	kg
GLO: charcoal, at plant [Fuels]	Mass	3.76E+00	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.31E+00	kg
Dolomite [Minerals]	Mass	1.84E+00	kg
Graphite [Inorganic intermediate products]	Mass	3.01E-01	kg
Lime finelime (ground) [Minerals]	Mass	6.20E+00	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	3.33E+00	kg
Oxygen liquid [Inorganic intermediate products]	Mass	3.76E+00	kg
Pig iron (Fe carrier) [Metals]	Mass	1.41E+00	kg
Refractory [Minerals]	Mass	1.54E+00	kg
RER: natural gas [Fuels]	Energy	5.82E+01	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.07E+01	kg
RER: electricity, at grid [Production mix]	Energy	1.61E+02	MJ
Water [Water]	Mass	1.75E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	9.89E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.25E-01	kg
Cast iron [Metals]	Mass	7.52E+01	kg
Chromium [Heavy metals to air]	Mass	1.62E-04	kg
Dust (> PM10) [Particles to air]	Mass	1.50E+00	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.50E+00	kg
Lead [Heavy metals to air]	Mass	1.10E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.26E-02	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	3.68E-05	kg
Refractory [Hazardous waste]	Mass	9.17E-01	kg

Sludge [Waste for disposal]	Mass	3.23E-01	kg
Steel works slag [Waste for recovery]	Mass	1.55E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	9.59E-03	kg

Recycling steel scrap of a gearbox [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	5.30E+00	kg
Argon [Inorganic intermediate products]	Mass	2.95E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	1.32E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	4.58E+00	kg
Dolomite [Minerals]	Mass	6.44E+00	kg
Graphite [Inorganic intermediate products]	Mass	1.05E+00	kg
Lime finelime (ground) [Minerals]	Mass	2.17E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.17E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	1.32E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	4.94E+00	kg
Refractory [Minerals]	Mass	5.39E+00	kg
RER: natural gas [Fuels]	Energy	2.04E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	3.73E+01	kg
Steel scrap [Waste for recovery]	Mass	3.30E+02	kg
RER: electricity, at grid [Production mix]	Energy	5.62E+02	MJ
Water [Water]	Mass	6.12E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.46E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.89E-01	kg
Chromium [Heavy metals to air]	Mass	5.66E-04	kg
Dust (> PM10) [Particles to air]	Mass	6.63E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.26E+00	kg
Lead [Heavy metals to air]	Mass	3.85E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	7.90E-02	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.29E-04	kg
Refractory [Hazardous waste]	Mass	3.21E+00	kg
RER: steel, unalloyed [Benefication]	Mass	2.63E+02	kg

Sludge [Waste for disposal]	Mass	1.13E+00	kg
Steel works slag [Waste for recovery]	Mass	5.43E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.36E-02	kg

Disposing metallic waste of a gearbox to incineration plants [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	2.73E+02	MJ
CH: heat from waste [Incineration]	Energy	3.95E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.18E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	7.44E+02	kg
CH: slag compartment [Incineration]	Number of pieces	1.33E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	4.71E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	3.83E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.36E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	4.16E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	3.10E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.96E+00	kg
Incineration of metallic waste [Waste for disposal]	Mass	4.71E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	9.99E+01	kg
Iron [Heavy metals to freshwater]	Mass	1.61E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.82E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.19E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.25E-01	kg
Solids [Particles to freshwater]	Mass	5.37E-04	kg
Waste heat [Other emissions to air]	Energy	2.34E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	3.85E+01	MJ

Disposing metallic waste of a gearbox to landfill [C, R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.21E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	3.03E+00	kg
CH: disposal, paper [Incineration]	Mass	1.83E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	1.83E-02	kg
CH: electricity from waste [Incineration]	Energy	1.62E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	1.78E+01	MJ
CH: heat from waste [Incineration]	Energy	2.62E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	4.68E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	1.10E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	7.82E-09	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	3.12E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	3.03E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.76E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	6.31E-09	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	2.62E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	2.62E-07	m
CH: slag compartment [Incineration]	Number of pieces	3.12E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	6.69E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	3.79E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	1.90E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	4.71E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	2.27E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	2.16E+00	MJ

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	2.01E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	4.66E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.97E-03	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.28E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	2.24E+00	kg
Iron [Heavy metals to air]	Mass	3.34E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	8.58E-04	kg
Iron [Heavy metals to freshwater]	Mass	1.64E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	4.71E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.99E-04	kg
Waste heat [Other emissions to air]	Energy	1.79E+01	MJ

Manufacturing a frequency converter [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: brass, at plant [Benefication]	Mass	9.43E+01	kg
GLO: butyrolactone [Organics]	Mass	2.09E+01	kg
GLO: nickel, 99.5%, at plant [Benefication]	Mass	8.61E-02	kg
GLO: printed wiring board mounting plant [Module]	Number of pieces	4.37E-05	pcs.
Paper for corrugated board [Materials from renewable raw materials]	Mass	2.27E+02	kg
Polypropylene compound (PP) [Plastics]	Mass	1.28E+01	kg
Polyvinylchloride compound (PVC) [Plastics]	Mass	8.49E+00	kg
RER: aluminium, primary [Benefication]	Mass	6.06E+02	kg
RER: copper, primary [Benefication]	Mass	1.28E+02	kg
RER: epoxy resin, liquid [monomers]	Mass	2.78E+01	kg
RER: glass fibre, at plant [construction]	Mass	3.31E+01	kg
RER: gold, at regional storage [Benefication]	Mass	8.61E-02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	6.46E+00	MJ

RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	5.12E+02	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	1.35E+03	MJ
RER: nylon 66, at plant [polymers]	Mass	6.67E+01	kg
RER: steel, low-alloyed [Benefication]	Mass	1.84E+02	kg
RER: tap water, at user [Appropriation]	Mass	1.76E+04	kg
RER: electricity, at grid [Production mix]	Energy	3.14E+04	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	3.45E+01	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	1.93E+02	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	8.80E+00	kg
CH: treatment, sewage [Wastewater treatment]	Volume	1.71E+01	m^3
Frequency converter [Components]	Mass	1.41E+03	kg
Waste heat [Other emissions to air]	Energy	5.14E+03	MJ

Operating a frequency converter [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	1.94E+07	MJ
Frequency converter [Components]	Mass	1.41E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Frequency converter [Components]	Mass	1.41E+03	kg

Dismantling a frequency converter [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Frequency converter [Components]	Mass	1.41E+03	kg
RER: electricity, at grid [Production mix]	Energy	2.11E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	2.02E+02	kg
Brass scrap [Waste for recovery]	Mass	3.14E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.74E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.31E-01	kg

CH: disposal, packaging paper, 13.7% water [Incineration]	Mass	1.59E+02	kg
CH: disposal, packaging paper, 13.7% water [Landfill facility]	Mass	6.82E+01	kg
Copper scrap [Waste for recovery]	Mass	4.26E+01	kg
Dust (PM10) [Particles to air]	Mass	1.56E-02	kg
gold scrap [Waste for recovery]	Mass	2.87E-02	kg
Landfill of glass/inert waste [Consumer waste]	Mass	2.32E+01	kg
Landfill of plastic waste [Consumer waste]	Mass	6.61E+01	kg
Metallic waste for incineration [Waste for disposal]	Mass	3.37E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	3.37E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.71E-02	kg
nickel scrap [Waste for recovery]	Mass	2.87E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	6.61E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	2.12E-04	kg
Pieces of broken glass [Waste for recovery]	Mass	9.93E+00	kg
Plastic (unspecified) [Waste for recovery]	Mass	2.83E+01	kg
polypropylene (PP) [Waste for disposal]	Mass	8.97E+00	kg
Polypropylene (PP) [Waste for recovery]	Mass	3.84E+00	kg
Polyvinyl chloride (PVC) [Waste for disposal]	Mass	5.94E+00	kg
Polyvinyl chloride (PVC) [Waste for recovery]	Mass	2.55E+00	kg
Printed wiring board scrap [Waste for recovery]	Mass	4.37E-05	kg
Steel scrap [Waste for recovery]	Mass	6.13E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.51E-02	kg

Recycling aluminium scrap of a frequency converter - ingot production [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	3.74E+00	kg
Aluminium scrap [Waste for recovery]	Mass	2.02E+02	kg
CH: anionic resin [Organics]	Mass	7.13E-01	kg
CH: cationic resin [Organics]	Mass	7.13E-01	kg
RER: natural gas [Fuels]	Energy	2.06E+03	MJ

Sodium chloride (rock salt) [Non renewable resources]	Mass	1.60E+00	kg
RER: electricity, at grid [Production mix]	Energy	1.92E+01	MJ
Water [Water]	Mass	1.72E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	1.78E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.10E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.78E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.78E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	5.35E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.91E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	3.30E+00	kg

Recycling brass scrap of a frequency converter [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Brass scrap [Waste for recovery]	Mass	3.14E+01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	1.55E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.06E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	1.23E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.24E-07	kg
Acetic acid [NMVOC Group to air]	Mass	1.88E-05	kg
Arsenic [Heavy metals to air]	Mass	4.40E-05	kg
Benzene [NMVOC Group to air]	Mass	1.44E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	8.22E-11	kg
Butane [NMVOC Group to air]	Mass	1.44E-04	kg
Cadmium [Heavy metals to air]	Mass	7.22E-05	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.11E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.33E-03	kg
Copper [Heavy metals to air]	Mass	8.79E-04	kg
Copper [Metals]	Mass	2.20E+01	kg
Dust (> PM10) [Particles to air]	Mass	8.16E-03	kg
Dust (PM2.5) [Particles to air]	Mass	2.95E-02	kg

Ethane [NMVOC Group to air]	Mass	2.13E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	5.14E-06	kg
Heat, waste [unspecified]	Energy	1.18E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.23E-04	kg
Lead [Heavy metals to air]	Mass	3.45E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.55E-04	kg
Nickel [Heavy metals to air]	Mass	4.08E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.09E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.55E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	1.79E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.16E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	4.51E-15	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.24E-06	kg
Propane [NMVOC Group to air]	Mass	1.10E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	2.49E-06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.11E-03	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	2.33E-07	kg
Zinc [Metals]	Mass	9.42E+00	kg

Recycling copper scrap of a frequency converter R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	4.26E+01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	2.11E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.43E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	1.67E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.69E-07	kg
Acetic acid [NMVOC Group to air]	Mass	2.55E-05	kg
Arsenic [Heavy metals to air]	Mass	5.97E-05	kg

Benzene [NMVOC Group to air]	Mass	1.95E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.12E-10	kg
Butane [NMVOC Group to air]	Mass	1.95E-04	kg
Cadmium [Heavy metals to air]	Mass	9.81E-05	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.22E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.17E-03	kg
Copper [Heavy metals to air]	Mass	1.19E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.11E-02	kg
Dust (PM2.5) [Particles to air]	Mass	4.01E-02	kg
Ethane [NMVOC Group to air]	Mass	2.89E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	6.98E-06	kg
Heat, waste [unspecified]	Energy	1.60E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.67E-04	kg
Lead [Heavy metals to air]	Mass	4.69E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.11E-04	kg
Nickel [Heavy metals to air]	Mass	5.54E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.48E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	2.11E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	2.43E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.58E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	6.12E-15	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.69E-06	kg
Propane [NMVOC Group to air]	Mass	1.49E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	3.38E-06	kg
RER: copper, secondary [Benefication]	Mass	4.26E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.22E-03	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	3.17E-07	kg

Recycling nickel scrap of a frequency converter [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Blasting abrasive [Operating materials]	Mass	1.98E-06	kg
CH: disposal, nickel smelter slag, 0% water [Residual material landfill facility]	Mass	2.09E-02	kg
CH: limestone, milled, packed, at plant [others]	Mass	7.73E-04	kg
GLO: diesel, burned in building machine [Machines]	Energy	3.14E-03	MJ
GLO: non-ferrous metal mine, surface [Benefication]	Number of pieces	3.29E-12	pcs.
GLO: non-ferrous metal smelter [Benefication]	Number of pieces	1.07E-13	pcs.
nickel scrap [Waste for recovery]	Mass	2.87E-02	kg
Occupation, mineral extraction site [Hemerobie Ecoinvent]	Area time	2.72E-06	m2*yr
RER: conveyor belt, at plant [Machines]	Length	1.32E-09	m
RER: hard coal, burned in industrial furnace [Heating systems]	Energy	6.59E-02	MJ
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	6.18E-03	MJ
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	4.90E-02	MJ
Transformation, from unspecified [Hemerobie Ecoinvent]	Area	9.05E-08	m^2
Transformation, to mineral extraction site [Hemerobie Ecoinvent]	Area	9.05E-08	m^2
RER: electricity, at grid [Production mix]	Energy	5.50E-02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.14E-09	kg
Antimony [Heavy metals to air]	Mass	3.33E-12	kg
Arsenic [Heavy metals to freshwater]	Mass	2.51E-10	kg
Arsenic [Heavy metals to air]	Mass	2.37E-08	kg
Beryllium [Inorganic emissions to air]	Mass	4.33E-11	kg
Biological oxygen demand (BOD) [Analytical measures to freshwater]	Mass	1.37E-07	kg
Boron [Inorganic emissions to air]	Mass	1.67E-10	kg
Cadmium [Heavy metals to freshwater]	Mass	3.52E-11	kg
Cadmium [Heavy metals to air]	Mass	1.83E-12	kg
Calcium (+II) [Inorganic emissions to freshwater]	Mass	9.04E-06	kg

Carbon dioxide [Inorganic emissions to air]	Mass	3.40E-04	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	1.37E-07	kg
Chromium [Heavy metals to freshwater]	Mass	3.32E-10	kg
Chromium [Heavy metals to air]	Mass	1.67E-09	kg
Cobalt [Heavy metals to freshwater]	Mass	1.03E-11	kg
Cobalt [Heavy metals to air]	Mass	4.98E-08	kg
Copper [Heavy metals to freshwater]	Mass	7.03E-10	kg
Dioxins (unspecified) [Halogenated organic emissions to air]	Mass	1.65E-14	kg
DOC, Dissolved Organic Carbon [Ecoinvent long-term to freshwater]	Mass	5.36E-08	kg
Dust (> PM10) [Particles to air]	Mass	1.23E-06	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	8.60E-06	kg
Dust (PM2.5) [Particles to air]	Mass	8.47E-06	kg
Fluorine [Inorganic emissions to air]	Mass	1.58E-08	kg
GLO: ferronickel, 25% Ni, at plant [Benefication]	Mass	1.65E-02	kg
Iron [Heavy metals to freshwater]	Mass	3.83E-09	kg
Lead [Heavy metals to freshwater]	Mass	2.19E-10	kg
Lead [Heavy metals to air]	Mass	1.26E-07	kg
Manganese [Heavy metals to freshwater]	Mass	3.25E-10	kg
Manganese [Heavy metals to air]	Mass	1.58E-08	kg
Mercury [Heavy metals to freshwater]	Mass	3.74E-12	kg
Mercury [Heavy metals to air]	Mass	8.33E-13	kg
Nickel [Heavy metals to freshwater]	Mass	5.62E-10	kg
Nickel [Heavy metals to air]	Mass	5.24E-08	kg
Nitrogen [Inorganic emissions to freshwater]	Mass	3.00E-07	kg
Selenium [Heavy metals to air]	Mass	8.33E-13	kg
Sulphate [Inorganic emissions to freshwater]	Mass	3.11E-05	kg
Tin [Heavy metals to freshwater]	Mass	3.25E-10	kg
Tin [Heavy metals to air]	Mass	2.64E-08	kg
Total organic carbon, TOC (Ecoinvent) [Ecoinvent long-term to freshwater]	Mass	5.36E-08	kg
Waste heat [Other emissions to air]	Energy	5.50E-02	MJ
Zinc [Heavy metals to freshwater]	Mass	1.96E-09	kg
Zinc [Heavy metals to air]	Mass	4.12E-07	kg

Recycling steel scrap of a frequency converter with EAF [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	9.85E-01	kg
Argon [Inorganic intermediate products]	Mass	5.48E-02	kg
GLO: charcoal, at plant [Fuels]	Mass	2.45E+00	kg
Coke, metallurgic [Organic intermediate products]	Mass	8.51E-01	kg
Dolomite [Minerals]	Mass	1.20E+00	kg
Graphite [Inorganic intermediate products]	Mass	1.96E-01	kg
Lime finelime (ground) [Minerals]	Mass	4.03E+00	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	2.17E+00	kg
Oxygen liquid [Inorganic intermediate products]	Mass	2.45E+00	kg
Pig iron (Fe carrier) [Metals]	Mass	9.19E-01	kg
Refractory [Minerals]	Mass	1.00E+00	kg
RER: natural gas [Fuels]	Energy	3.79E+01	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	6.94E+00	kg
Steel scrap [Waste for recovery]	Mass	6.13E+01	kg
RER: electricity, at grid [Production mix]	Energy	1.05E+02	MJ
Water [Water]	Mass	1.14E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	6.43E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.47E-01	kg
Chromium [Heavy metals to air]	Mass	1.05E-04	kg
Dust (> PM10) [Particles to air]	Mass	1.23E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	9.78E-01	kg
Lead [Heavy metals to air]	Mass	7.15E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.47E-02	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.39E-05	kg
Refractory [Hazardous waste]	Mass	5.97E-01	kg
RER: steel, unalloyed [Benefication]	Mass	4.89E+01	kg
Sludge [Waste for disposal]	Mass	2.10E-01	kg
Steel works slag [Waste for recovery]	Mass	1.01E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.24E-03	kg

Disposal and treatment of printed wiring boards of a frequency converter [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: manual treatment plant, WEEE scrap [Recycling]	Number of pieces	1.75E-14	pcs.
Printed wiring board scrap [Waste for recovery]	Mass	4.37E-05	kg
RER: electricity, at grid [Production mix]	Energy	6.29E-06	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: disposal, treatment of printed wiring boards [Recycling]	Mass	4.37E-05	kg
Waste heat [Other emissions to air]	Energy	6.29E-06	MJ

Disposing metallic waste of a frequency converter to incineration plants [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.95E+02	MJ
CH: heat from waste [Incineration]	Energy	2.83E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	8.43E-08	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	5.33E+02	kg
CH: slag compartment [Incineration]	Number of pieces	9.51E-07	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	3.37E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	2.74E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.55E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	2.97E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.22E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.41E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	3.37E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.17E-02	kg

Incineration of metallic waste [Waste for disposal]	Mass	3.37E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	7.15E+01	kg
Iron [Heavy metals to freshwater]	Mass	1.15E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.30E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	8.53E-04	kg
Nickel (+II) [Heavy metals to freshwater]	Mass	3.54E-01	kg
Solids [Ecoinvent long-term to freshwater]	Mass	8.94E-02	kg
Solids [Particles to freshwater]	Mass	3.85E-04	kg
Waste heat [Other emissions to air]	Energy	1.68E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	2.76E+01	MJ

Disposing metallic waste of a frequency converter to landfill [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	8.67E-01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	2.17E+00	kg
CH: disposal, paper [Incineration]	Mass	1.31E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	1.31E-02	kg
CH: electricity from waste [Incineration]	Energy	1.16E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	1.27E+01	MJ
CH: heat from waste [Incineration]	Energy	1.88E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	3.35E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	7.89E+00	MJ
CH: waste incineration plant [Incineration]	Number of pieces	5.60E-09	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	2.24E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	2.17E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.26E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	4.52E-09	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	1.88E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	1.88E-07	m

CH: slag compartment [Incineration]	Number of pieces	2.24E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	4.79E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	2.71E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	1.36E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	3.37E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	1.63E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.55E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	1.44E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	3.34E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.99E-03	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.63E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.61E+00	kg
Copper (+II) [Heavy metals to air]	Mass	6.71E-02	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	4.79E-08	kg
Copper (+II) [Heavy metals to freshwater]	Mass	4.25E-05	kg
Iron [Heavy metals to air]	Mass	2.39E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	6.14E-04	kg
Iron [Heavy metals to freshwater]	Mass	1.17E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	3.37E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.43E-04	kg
Waste heat [Other emissions to air]	Energy	1.28E+01	MJ

Manufacturing a variable frequency drive [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: butyrolactone [Organics]	Mass	6.26E+01	kg
Paper for corrugated board [Materials from renewable raw materials]	Mass	6.82E+02	kg

Polypropylene compound (PP) [Plastics]	Mass	3.84E+01	kg
Polyvinylchloride compound (PVC) [Plastics]	Mass	2.55E+01	kg
RER: aluminium, primary [Benefication]	Mass	1.82E+03	kg
RER: copper, primary [Benefication]	Mass	3.59E+02	kg
RER: epoxy resin, liquid [monomers]	Mass	8.33E+01	kg
RER: glass fibre, at plant [construction]	Mass	9.93E+01	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.65E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.31E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	3.45E+03	MJ
RER: nylon 66, at plant [polymers]	Mass	3.76E+01	kg
RER: steel, low-alloyed [Benefication]	Mass	3.94E+02	kg
RER: tap water, at user [Appropriation]	Mass	4.50E+04	kg
RER: electricity, at grid [Production mix]	Energy	6.60E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	8.82E+01	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	4.93E+02	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	2.25E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	4.36E+01	m^3
Variable frequency drive [Components]	Mass	3.60E+03	kg
Waste heat [Other emissions to air]	Energy	6.59E+02	MJ

Operating a variable frequency drive [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	1.58E+08	MJ
Variable frequency drive [Components]	Mass	3.60E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	2.15E+08	MJ
Variable frequency drive [Components]	Mass	3.60E+03	kg

Dismantling a variable frequency drive			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Variable frequency drive [Components]	Mass	3.60E+03	kg
RER: electricity, at grid [Production mix]	Energy	5.37E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	6.06E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	9.56E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.34E-01	kg
CH: disposal, packaging paper, 13.7% water [Incineration]	Mass	4.77E+02	kg
CH: disposal, packaging paper, 13.7% water [Landfill facility]	Mass	2.05E+02	kg
Copper scrap [Waste for recovery]	Mass	1.19E+02	kg
Dust (PM10) [Particles to air]	Mass	3.97E-02	kg
Landfill of glass/inert waste [Consumer waste]	Mass	6.95E+01	kg
Landfill of plastic waste [Consumer waste]	Mass	8.46E+01	kg
Metallic waste for incineration [Waste for disposal]	Mass	8.56E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	8.56E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.36E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.69E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	5.40E-04	kg
Pieces of broken glass [Waste for recovery]	Mass	2.98E+01	kg
Plastic (unspecified) [Waste for recovery]	Mass	3.63E+01	kg
polypropylene (PP) [Waste for disposal]	Mass	2.69E+01	kg
Polypropylene (PP) [Waste for recovery]	Mass	1.15E+01	kg
Polyvinyl chloride (PVC) [Waste for disposal]	Mass	1.78E+01	kg
Polyvinyl chloride (PVC) [Waste for recovery]	Mass	7.64E+00	kg
Steel scrap [Waste for recovery]	Mass	1.31E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.15E-01	kg

Recycling aluminium scrap of a variable frequency drive - ingot production [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.12E+01	kg
Aluminium scrap [Waste for recovery]	Mass	6.06E+02	kg
CH: anionic resin [Organics]	Mass	2.14E+00	kg
CH: cationic resin [Organics]	Mass	2.14E+00	kg
RER: natural gas [Fuels]	Energy	6.19E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	4.81E+00	kg
RER: electricity, at grid [Production mix]	Energy	5.77E+01	MJ
Water [Water]	Mass	5.15E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	5.35E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.30E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.35E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.35E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.60E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.67E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	9.91E+00	kg

Recycling copper scrap of a variable frequency drive [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	1.19E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	5.91E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	4.02E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	4.69E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	4.73E-07	kg
Acetic acid [NMVOC Group to air]	Mass	7.16E-05	kg
Arsenic [Heavy metals to air]	Mass	1.67E-04	kg
Benzene [NMVOC Group to air]	Mass	5.48E-07	kg

Benzo{a}pyrene [PAH group to air]	Mass	3.13E-10	kg
Butane [NMVOC Group to air]	Mass	5.48E-04	kg
Cadmium [Heavy metals to air]	Mass	2.75E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.18E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.87E-03	kg
Copper [Heavy metals to air]	Mass	3.34E-03	kg
Dust (> PM10) [Particles to air]	Mass	3.11E-02	kg
Dust (PM2.5) [Particles to air]	Mass	1.12E-01	kg
Ethane [NMVOC Group to air]	Mass	8.10E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.96E-05	kg
Heat, waste [unspecified]	Energy	4.49E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	4.69E-04	kg
Lead [Heavy metals to air]	Mass	1.31E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.91E-04	kg
Nickel [Heavy metals to air]	Mass	1.55E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.14E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	5.91E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	6.80E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	4.42E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.71E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	4.73E-06	kg
Propane [NMVOC Group to air]	Mass	4.17E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	9.46E-06	kg
RER: copper, secondary [Benefication]	Mass	1.19E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.18E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	8.87E-07	kg

Recycling steel scrap of a variable frequency drive with EAF [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.11E+00	kg
Argon [Inorganic intermediate products]	Mass	1.17E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	5.23E+00	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.82E+00	kg
Dolomite [Minerals]	Mass	2.56E+00	kg
Graphite [Inorganic intermediate products]	Mass	4.18E-01	kg
Lime finelime (ground) [Minerals]	Mass	8.63E+00	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	4.63E+00	kg
Oxygen liquid [Inorganic intermediate products]	Mass	5.23E+00	kg
Pig iron (Fe carrier) [Metals]	Mass	1.97E+00	kg
Refractory [Minerals]	Mass	2.14E+00	kg
RER: natural gas [Fuels]	Energy	8.10E+01	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.48E+01	kg
Steel scrap [Waste for recovery]	Mass	1.31E+02	kg
RER: electricity, at grid [Production mix]	Energy	2.24E+02	MJ
Water [Water]	Mass	2.43E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.38E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.14E-01	kg
Chromium [Heavy metals to air]	Mass	2.25E-04	kg
Dust (> PM10) [Particles to air]	Mass	2.63E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.09E+00	kg
Lead [Heavy metals to air]	Mass	1.53E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.14E-02	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.12E-05	kg
Refractory [Hazardous waste]	Mass	1.28E+00	kg
RER: steel, unalloyed [Benefication]	Mass	1.05E+02	kg
Sludge [Waste for disposal]	Mass	4.50E-01	kg
Steel works slag [Waste for recovery]	Mass	2.16E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.33E-02	kg

Disposing metallic waste of a variable frequency drive to incineration plants [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	4.96E+02	MJ
CH: heat from waste [Incineration]	Energy	7.18E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.14E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.35E+03	kg
CH: slag compartment [Incineration]	Number of pieces	2.41E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	8.56E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	6.96E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.16E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	7.55E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	5.63E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.57E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	8.56E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.97E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	8.56E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.82E+02	kg
Iron [Heavy metals to freshwater]	Mass	2.92E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.31E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	2.17E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	2.27E-01	kg
Solids [Particles to freshwater]	Mass	9.76E-04	kg
Waste heat [Other emissions to air]	Energy	4.26E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	7.00E+01	MJ

Disposing metallic waste of a variable frequency drive to landfill [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	2.20E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	5.50E+00	kg
CH: disposal, paper [Incineration]	Mass	3.32E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	3.32E-02	kg
CH: electricity from waste [Incineration]	Energy	2.94E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	3.24E+01	MJ
CH: heat from waste [Incineration]	Energy	4.76E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	8.51E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	2.00E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.42E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	5.68E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	5.50E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	3.19E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.15E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	4.76E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	4.76E-07	m
CH: slag compartment [Incineration]	Number of pieces	5.68E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.22E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	6.88E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	3.46E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	8.56E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	4.13E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	3.93E+00	MJ

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	3.66E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	8.47E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.27E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.14E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	4.08E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.70E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.22E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.08E-04	kg
Iron [Heavy metals to air]	Mass	6.06E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.56E-03	kg
Iron [Heavy metals to freshwater]	Mass	2.97E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	8.56E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.62E-04	kg
Waste heat [Other emissions to air]	Energy	3.25E+01	MJ

Manufacturing a photovoltaic system (single-array) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper [Metals]	Mass	1.47E+02	kg
DE: photovoltaic cell factory [production of components]	Number of pieces	7.98E-04	pcs.
Frame, aluminium, powder coated [Metal parts]	Mass	2.65E+03	kg
Glass (Sheet glass) [Minerals]	Mass	1.91E+04	kg
Lead [Metals]	Mass	9.00E+00	kg
Plastic compound (unspecified) [Plastics]	Mass	9.26E+02	kg
RER: ethylene vinyl acetate copolymer, at plant [polymers]	Mass	1.69E+03	kg
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	2.32E+03	MJ
RER: metallization paste, back side, aluminium, at plant [production of components]	Mass	1.43E+02	kg
RER: metallization paste, back side, at plant [production of components]	Mass	9.83E+00	kg

RER: metallization paste, front side, at plant [production of components]	Mass	1.47E+01	kg
RER: multi-Si wafer, at plant [production of components]	Area	2.11E+03	m^2
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	9.50E+03	MJ
RER: water, completely softened, at plant [Appropriation]	Mass	2.74E+05	kg
Silicon (99%) [Metals]	Mass	8.95E+02	kg
Silver [Metals]	Mass	2.06E+01	kg
Tin (99.92%) [Metals]	Mass	3.60E+01	kg
RER: electricity, at grid [Production mix]	Energy	6.03E+04	MJ
Water (cooling water) [Operating materials]	Mass	1.99E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (unspecified) [Consumer waste]	Mass	1.54E+00	kg
CH: disposal, waste, Si waferprod., inorg, 9.4% water, to residual material landfill [Residual material landfill facility]	Mass	5.50E+02	kg
CH: treatment, PV cell production effluent [Wastewater treatment]	Volume	4.33E+02	m^3
Dust (PM2.5) [Particles to air]	Mass	5.31E+00	kg
Heat, waste [unspecified]	Energy	2.17E+05	MJ
Hydrogen chloride [Inorganic emissions to industrial soil]	Mass	5.31E-01	kg
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to industrial soil]	Mass	9.67E-03	kg
Lead scrap [Waste for recovery]	Mass	1.54E+00	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	9.97E-02	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	3.86E+02	kg
photovoltaic panel, multi-Si, at plant [Assemblies]	Mass	2.55E+04	kg
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	Mass	4.94E-01	kg
R 116 (hexafluoroethane) [Halogenated organic emissions to air]	Mass	2.37E-01	kg
Silicon dust [Particles to air]	Mass	1.45E-01	kg
Silver [Heavy metals to industrial soil]	Mass	1.54E+00	kg
Sodium (+I) [Inorganic emissions to industrial soil]	Mass	9.67E-02	kg
Tin [Waste for recovery]	Mass	1.54E+00	kg

Operating a photovoltaic system (single-array) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	2.44E+02	MJ
photovoltaic panel, multi-Si, at plant [Assemblies]	Mass	2.55E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	4.19E+07	MJ
photovoltaic panel, multi-Si, at plant [Assemblies]	Mass	2.55E+04	kg

Dismantling a photovoltaic system (single-array) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	3.80E+02	MJ
photovoltaic panel, multi-Si, at plant [Assemblies]	Mass	2.55E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	8.82E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.76E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.36E+00	kg
Copper scrap [Waste for recovery]	Mass	4.88E+01	kg
Dust (PM10) [Particles to air]	Mass	2.81E-01	kg
Landfill of glass/inert waste [Consumer waste]	Mass	1.34E+04	kg
Landfill of plastic waste [Consumer waste]	Mass	1.83E+03	kg
Lead scrap [Waste for recovery]	Mass	3.00E+00	kg
Metallic waste for incineration [Waste for disposal]	Mass	1.25E+03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.25E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.08E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.19E+01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	3.82E-03	kg
Pieces of broken glass [Waste for recovery]	Mass	5.72E+03	kg
Plastic (unspecified) [Waste for recovery]	Mass	7.83E+02	kg

silicon waste [Hazardous non organic waste for disposal]	Mass	2.98E+02	kg
silver [Waste for recovery]	Mass	6.85E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.14E-01	kg
Tin scrap [Waste for recovery]	Mass	1.20E+01	kg

Recycling aluminium scrap of a photovoltaic system (single-array) - ingot production [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.64E+01	kg
Aluminium scrap [Waste for recovery]	Mass	8.82E+02	kg
CH: anionic resin [Organics]	Mass	3.12E+00	kg
CH: cationic resin [Organics]	Mass	3.12E+00	kg
RER: natural gas [Fuels]	Energy	9.02E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	7.01E+00	kg
RER: electricity, at grid [Production mix]	Energy	8.41E+01	MJ
Water [Water]	Mass	7.50E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	7.79E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.81E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.79E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	7.79E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.34E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.89E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.44E+01	kg

Recycling copper scrap of a photovoltaic system (single-array) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	4.88E+01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	2.42E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.64E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**

Acenaphthene [NMVOC Group to air]	Mass	1.92E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.93E-07	kg
Acetic acid [NMVOC Group to air]	Mass	2.92E-05	kg
Arsenic [Heavy metals to air]	Mass	6.84E-05	kg
Benzene [NMVOC Group to air]	Mass	2.24E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.28E-10	kg
Butane [NMVOC Group to air]	Mass	2.24E-04	kg
Cadmium [Heavy metals to air]	Mass	1.12E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.83E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.63E-03	kg
Copper [Heavy metals to air]	Mass	1.37E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.27E-02	kg
Dust (PM2.5) [Particles to air]	Mass	4.59E-02	kg
Ethane [NMVOC Group to air]	Mass	3.31E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	8.00E-06	kg
Heat, waste [unspecified]	Energy	1.84E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.92E-04	kg
Lead [Heavy metals to air]	Mass	5.37E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.42E-04	kg
Nickel [Heavy metals to air]	Mass	6.35E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.69E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	2.42E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	2.78E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.81E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	7.01E-15	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.93E-06	kg
Propane [NMVOC Group to air]	Mass	1.70E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	3.87E-06	kg
RER: copper, secondary [Benefication]	Mass	4.88E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.83E-03	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	3.63E-07	kg

Recycling lead scrap of a photovoltaic system (single-array) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Lead scrap [Waste for recovery]	Mass	3.00E+00	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	2.10E+01	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	2.04E-11	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	5.55E-12	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	5.60E-09	kg
Acetic acid [NMVOC Group to air]	Mass	8.47E-07	kg
Arsenic [Heavy metals to air]	Mass	1.26E-04	kg
Benzene [NMVOC Group to air]	Mass	6.48E-09	kg
Benzo{a}pyrene [PAH group to air]	Mass	3.70E-12	kg
Butane [NMVOC Group to air]	Mass	6.48E-06	kg
Cadmium [Heavy metals to air]	Mass	4.20E-05	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.40E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.05E-04	kg
Dust (> PM10) [Particles to air]	Mass	3.18E-02	kg
Dust (PM2.5) [Particles to air]	Mass	2.37E-02	kg
Ethane [NMVOC Group to air]	Mass	9.59E-06	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	2.32E-07	kg
Heat, waste [unspecified]	Energy	5.32E+00	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	5.55E-06	kg
Lead [Heavy metals to air]	Mass	1.57E-02	kg
Lead secondary [Metals]	Mass	3.00E+00	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.00E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.90E-04	kg
Nitrous oxide [Inorganic emissions to air]	Mass	7.00E-06	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	8.05E-06	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	9.60E-06	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	2.03E-16	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.60E-08	kg

Propane [NMVOC Group to air]	Mass	4.94E-06	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	1.12E-07	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.40E-04	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	1.05E-08	kg
Zinc [Heavy metals to air]	Mass	9.30E-05	kg

Recycling silicon scrap of a photovoltaic system (single-array) R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, slag from MG silicon production, 0% water [Landfill facility]	Mass	1.10E+00	kg
DE: silica sand, at plant [Additives]	Mass	1.19E+02	kg
GLO: charcoal, at plant [Fuels]	Mass	7.51E+00	kg
RER: graphite, at plant [Inorganics]	Mass	4.42E+00	kg
RER: hard coal coke, at plant [Fuels]	Energy	1.02E+03	MJ
RER: oxygen, liquid, at plant [Inorganics]	Mass	8.83E-01	kg
RER: petroleum coke, at refinery [Fuels]	Mass	2.21E+01	kg
RER: silicone plant [Inorganics]	Number of pieces	4.42E-10	pcs.
RER: wood chips, mixed, u=120%, at forest [Fuels]	Volume	1.44E-01	m^3
silicon waste [Hazardous non organic waste for disposal]	Mass	2.98E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.75E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	6.85E-05	kg
Antimony [Heavy metals to air]	Mass	3.47E-07	kg
Arsenic [Heavy metals to air]	Mass	4.16E-07	kg
Boron [Inorganic emissions to air]	Mass	1.23E-05	kg
Cadmium [Heavy metals to air]	Mass	1.39E-08	kg
Calcium [Consumer waste]	Mass	3.42E-05	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.29E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.83E-02	kg
Chlorine [Inorganic emissions to air]	Mass	3.47E-06	kg
Chromium [Heavy metals to air]	Mass	3.47E-07	kg
Cyanide (unspecified) [Inorganic emissions to air]	Mass	3.03E-04	kg
Dust (> PM10) [Particles to air]	Mass	3.42E-01	kg
Fluorine [Inorganic emissions to air]	Mass	1.71E-06	kg

Heat, waste [unspecified]	Energy	3.15E+03	MJ
Hydrogen fluoride [Inorganic emissions to air]	Mass	2.21E-02	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	2.21E-02	kg
Iron [Heavy metals to air]	Mass	1.71E-04	kg
Lead [Heavy metals to air]	Mass	1.52E-05	kg
Mercury [Heavy metals to air]	Mass	3.47E-07	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.30E-01	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	4.24E-03	kg
NO: MG-silicon, at plant [Benefication]	Mass	1.10E+02	kg
Silicon dust [Particles to air]	Mass	3.32E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.41E-01	kg
Tin [Heavy metals to air]	Mass	3.47E-07	kg

Recycling tin scrap of a photovoltaic system (single-array) [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Blasting abrasive [Operating materials]	Mass	7.79E-01	kg
CH: disposal, dust, unalloyed EAF steel [Residual material landfill facility]	Mass	5.58E-01	kg
CH: gypsum, mineral, at mine [others]	Mass	4.88E-02	kg
CH: limestone, at mine [Additives]	Mass	1.41E+00	kg
GLO: diesel, burned in building machine [Machines]	Energy	1.67E+02	MJ
GLO: mine, iron [Benefication]	Number of pieces	4.04E-10	pcs.
GLO: non-ferrous metal mine, underground [Benefication]	Number of pieces	2.19E-13	pcs.
RER: anode, aluminium electrolysis [Benefication]	Mass	4.01E-03	kg
RER: heat, heavy fuel oil, at industrial furnace [Heating systems]	Energy	2.19E+01	MJ
Tin scrap [Waste for recovery]	Mass	1.20E+01	kg
RER: electricity, at grid [Production mix]	Energy	3.10E+02	MJ
UCTE: hard coal mix, at regional storage [Fuels]	Mass	1.15E+00	kg
Water [Water]	Mass	4.26E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.81E+00	kg
Dust (> PM10) [Particles to air]	Mass	7.34E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.60E-01	kg

Dust (PM2.5) [Particles to air]	Mass	7.34E-02	kg
Heat, waste [unspecified]	Energy	3.47E+02	MJ
RER: tin, at regional storage [Benefication]	Mass	1.03E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.14E+00	kg

Disposing metallic waste of a photovoltaic system (single-array) to incineration plants [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	7.25E+02	MJ
CH: heat from waste [Incineration]	Energy	1.05E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	3.13E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.98E+03	kg
CH: slag compartment [Incineration]	Number of pieces	3.53E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	1.25E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.02E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.69E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.10E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	8.22E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	5.22E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.25E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	4.34E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	1.25E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.65E+02	kg
Iron [Heavy metals to freshwater]	Mass	4.27E-03	kg
Lead (+II) [Ecoinvent long-term to freshwater]	Mass	4.75E-01	kg
Lead (+II) [Heavy metals to freshwater]	Mass	8.68E-06	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.83E-03	kg

Methane (biotic) [Organic emissions to air (VOC group)]	Mass	3.17E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	3.32E-01	kg
Solids [Particles to freshwater]	Mass	1.43E-03	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	1.34E-05	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	8.33E-01	kg
Waste heat [Other emissions to air]	Energy	6.22E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	1.02E+02	MJ

Disposing metallic waste of a photovoltaic system (single-array) to landfill R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	3.22E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	8.03E+00	kg
CH: disposal, paper [Incineration]	Mass	4.85E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	4.85E-02	kg
CH: electricity from waste [Incineration]	Energy	4.30E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	4.73E+01	MJ
CH: heat from waste [Incineration]	Energy	6.96E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	1.24E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	2.93E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.08E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	8.30E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	8.03E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	4.67E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.68E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	6.96E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	6.96E-07	m
CH: slag compartment [Incineration]	Number of pieces	8.30E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.78E-08	pcs.

GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.01E-04	kg
GLO: chemicals organic, at plant [Organics]	Mass	5.06E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.25E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	6.03E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	5.74E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	5.34E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.24E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.85E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	6.04E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	5.96E+00	kg
Copper (+II) [Heavy metals to air]	Mass	2.49E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.78E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.58E-04	kg
Iron [Heavy metals to air]	Mass	8.86E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.28E-03	kg
Iron [Heavy metals to freshwater]	Mass	4.34E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	1.25E+03	kg
Lead (+II) [Heavy metals to air]	Mass	4.74E-01	kg
Lead (+II) [Ecoinvent long-term to freshwater]	Mass	5.13E-07	kg
Lead (+II) [Heavy metals to freshwater]	Mass	1.54E-04	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.29E-04	kg
Tin (+IV) [Heavy metals to air]	Mass	4.87E+00	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	6.02E-03	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.46E-05	kg
Waste heat [Other emissions to air]	Energy	4.75E+01	MJ

Manufacturing an inverter for a single-array photovoltaic system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: capacitor, electrolyte type, > 2cm height, at plant [Parts]	Mass	2.47E+01	kg
GLO: capacitor, film, through-hole mounting, at plant [Parts]	Mass	3.29E+01	kg
GLO: capacitor, Tantalum-, through-hole mounting, at plant [Parts]	Mass	2.22E+00	kg
GLO: connector, clamp connection, at plant [Parts]	Mass	2.29E+01	kg
GLO: diode, glass-, through-hole mounting, at plant [Parts]	Mass	4.53E+00	kg
GLO: inductor, ring core choke type, at plant [Parts]	Mass	3.39E+01	kg
GLO: integrated circuit, IC, logic type, at plant [Parts]	Mass	2.70E+00	kg
GLO: printed wiring board, through-hole, at plant [Module]	Area	2.17E+01	m^2
GLO: resistor, metal film type, through-hole mounting, at plant [Parts]	Mass	4.82E-01	kg
GLO: transistor, wired, small size, through-hole mounting, at plant [Parts]	Mass	3.67E+00	kg
RER: corrugated board, mixed fibre [cardboard & corrugated board]	Mass	2.41E+02	kg
RER: fleece, polyethylene, at plant [polymers]	Mass	5.79E+00	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	9.24E+00	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	7.33E+02	MJ
RER: metal working factory [General manufacturing]	Number of pieces	8.66E-07	pcs.
RER: natural gas, burned in boiler [Heating systems]	Energy	1.93E+03	MJ
RER: polystyrene foam slab, at plant [Manufacturing]	Mass	2.89E+01	kg
RER: polyvinylchloride, at regional storage [polymers]	Mass	9.65E-01	kg
RER: section bar extrusion, aluminium [Processing]	Mass	1.35E+02	kg
RER: sheet rolling, steel [Processing]	Mass	9.46E+02	kg
RER: styrene-acrylonitrile copolymer, SAN, at plant [polymers]	Mass	9.65E-01	kg
RER: tap water, at user [Appropriation]	Mass	2.52E+04	kg
RER: wire drawing, copper [Processing]	Mass	5.32E+02	kg
RER: electricity, at grid [Production mix]	Energy	2.05E+03	MJ

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, packaging cardboard, 19.6% water [Incineration]	Mass	2.41E+02	kg
CH: disposal, polyethylene, 0.4% water [Incineration]	Mass	2.99E+01	kg
CH: disposal, polystyrene, 0.2% water [Incineration]	Mass	5.79E+00	kg
GLO: disposal, treatment of printed wiring boards [Recycling]	Mass	1.64E+02	kg
Heat, waste [unspecified]	Energy	7.36E+03	MJ
Inverter, 250 kW [Components]	Mass	2.02E+03	kg

Operating an inverter for a single-array photovoltaic system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Inverter, 250 kW [Components]	Mass	2.02E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Inverter, 250 kW [Components]	Mass	2.02E+03	kg

Dismantling an inverter for a single-array photovoltaic system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: mechanical treatment plant, WEEE scrap [Recycling]	Number of pieces	1.08E-07	pcs.
Inverter, 250 kW [Components]	Mass	2.02E+03	kg
RER: electricity, at grid [Production mix]	Energy	6.21E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	1.89E-04	kg
Aluminium scrap [Waste for recovery]	Mass	4.50E+01	kg
Antimony [Heavy metals to air]	Mass	1.60E-05	kg
Bromine [Inorganic emissions to air]	Mass	3.21E-05	kg
Cadmium [Heavy metals to air]	Mass	3.21E-06	kg
Carbon dioxide [Inorganic emissions to air]	Mass	5.36E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.87E-01	kg
CH: disposal, packaging paper, 13.7% water [Incineration]	Mass	1.69E+02	kg
CH: disposal, packaging paper, 13.7% water [Landfill facility]	Mass	7.24E+01	kg
CH: disposal, polyvinylchloride, 0.2% water [Incineration]	Mass	2.89E-01	kg

Chlorine [Inorganic emissions to air]	Mass	4.34E-05	kg
Chromium [Heavy metals to air]	Mass	6.98E-06	kg
Copper [Heavy metals to air]	Mass	5.66E-05	kg
Copper scrap [Waste for recovery]	Mass	1.77E+02	kg
Dust (PM10) [Particles to air]	Mass	2.23E-02	kg
electronic scrap [Waste for recovery]	Mass	1.35E+02	kg
Iron [Heavy metals to air]	Mass	6.51E-04	kg
Lead [Heavy metals to air]	Mass	5.56E-05	kg
Mercury [Heavy metals to air]	Mass	1.60E-08	kg
Metallic waste for incineration [Waste for disposal]	Mass	5.37E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	5.37E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.44E-02	kg
Nickel [Heavy metals to air]	Mass	2.17E-05	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	9.46E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	3.03E-04	kg
Phosphorus [Inorganic emissions to air]	Mass	1.89E-06	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	2.55E-07	kg
Polystyrene (PS) [Waste for recovery]	Mass	8.68E+00	kg
Polystyrene (PS, unspecified) [Consumer waste]	Mass	2.03E+01	kg
Polyvinylchloride (PVC, unspecified) [Consumer waste]	Mass	6.75E-01	kg
Steel scrap [Waste for recovery]	Mass	3.15E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.46E-02	kg
Tin [Heavy metals to air]	Mass	4.05E-05	kg
Waste heat [Other emissions to air]	Energy	3.20E+01	MJ
Zinc [Heavy metals to air]	Mass	1.76E-04	kg

Recycling aluminium scrap of an inverter for a single-array photovoltaic system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	8.34E-01	kg
Aluminium scrap [Waste for recovery]	Mass	4.50E+01	kg
CH: anionic resin [Organics]	Mass	1.59E-01	kg
CH: cationic resin [Organics]	Mass	1.59E-01	kg
RER: natural gas [Fuels]	Energy	4.60E+02	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	3.57E-01	kg

RER: electricity, at grid [Production mix]	Energy	4.29E+00	MJ
Water [Water]	Mass	3.82E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	3.97E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.45E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.97E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.97E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.19E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.98E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	7.36E-01	kg

Recycling copper scrap of an inverter for a single-array photovoltaic system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	1.77E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	8.76E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	5.95E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	6.95E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	7.01E-07	kg
Acetic acid [NMVOC Group to air]	Mass	1.06E-04	kg
Arsenic [Heavy metals to air]	Mass	2.48E-04	kg
Benzene [NMVOC Group to air]	Mass	8.11E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	4.64E-10	kg
Butane [NMVOC Group to air]	Mass	8.11E-04	kg
Cadmium [Heavy metals to air]	Mass	4.07E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.75E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.31E-02	kg
Copper [Heavy metals to air]	Mass	4.96E-03	kg
Dust (> PM10) [Particles to air]	Mass	4.60E-02	kg
Dust (PM2.5) [Particles to air]	Mass	1.66E-01	kg
Ethane [NMVOC Group to air]	Mass	1.20E-03	kg

Formaldehyde (methanal) [NMVOC Group to air]	Mass	2.90E-05	kg
Heat, waste [unspecified]	Energy	6.66E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	6.95E-04	kg
Lead [Heavy metals to air]	Mass	1.95E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	8.76E-04	kg
Nickel [Heavy metals to air]	Mass	2.30E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	6.13E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	8.76E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	1.01E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	6.55E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	2.54E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	7.01E-06	kg
Propane [NMVOC Group to air]	Mass	6.18E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	1.40E-05	kg
RER: copper, secondary [Benefication]	Mass	1.77E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.75E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	1.31E-06	kg

Recycling steel scrap of an inverter for a single-array photovoltaic system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.52E+01	kg
Argon [Inorganic intermediate products]	Mass	8.44E-01	kg
Charcoal [Materials from renewable raw materials]	Mass	3.77E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.31E+01	kg
Dolomite [Minerals]	Mass	1.85E+01	kg
Graphite [Inorganic intermediate products]	Mass	3.02E+00	kg
Lime finelime (ground) [Minerals]	Mass	6.22E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	3.34E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	3.77E+01	kg

Pig iron (Fe carrier) [Metals]	Mass	1.42E+01	kg
Refractory [Minerals]	Mass	1.55E+01	kg
RER: natural gas, high pressure, at consumer [Fuels]	Energy	5.84E+02	MJ
RER: steam, for chemical processes, at plant [Auxiliary material]	Mass	1.07E+02	kg
Steel scrap [Waste for recovery]	Mass	9.46E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.61E+03	MJ
Water [Water]	Mass	1.75E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	9.92E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.26E+00	kg
Chromium [Heavy metals to air]	Mass	1.62E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.90E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.51E+01	kg
Lead [Heavy metals to air]	Mass	1.10E+00	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.27E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	3.69E-04	kg
Refractory [Hazardous waste]	Mass	9.20E+00	kg
RER: steel, unalloyed [Benefication]	Mass	7.54E+02	kg
Sludge [Waste for disposal]	Mass	3.24E+00	kg
Steel works slag [Waste for recovery]	Mass	1.56E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	9.62E-02	kg

Disposing metallic waste of an inverter for a single-array photovoltaic system to incineration plants [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	3.11E+02	MJ
CH: heat from waste [Incineration]	Energy	4.50E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.34E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	8.48E+02	kg
CH: slag compartment [Incineration]	Number of pieces	1.51E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	5.37E+02	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	4.36E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.25E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	4.74E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	3.53E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	2.24E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	5.37E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.86E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	5.37E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.14E+02	kg
Iron [Heavy metals to freshwater]	Mass	1.83E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.07E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.36E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.42E-01	kg
Solids [Particles to freshwater]	Mass	6.12E-04	kg
Waste heat [Other emissions to air]	Energy	2.67E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	4.39E+01	MJ

Disposing metallic waste of an inverter for a single-array photovoltaic system to landfill [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.38E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	3.45E+00	kg
CH: disposal, paper [Incineration]	Mass	2.08E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	2.08E-02	kg
CH: electricity from waste [Incineration]	Energy	1.84E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	2.03E+01	MJ
CH: heat from waste [Incineration]	Energy	2.98E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	5.34E-04	kg

CH: light fuel oil, burned in boiler [Heating systems]	Energy	1.26E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	8.91E-09	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	3.56E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	3.45E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.00E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	7.19E-09	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	2.98E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	2.98E-07	m
CH: slag compartment [Incineration]	Number of pieces	3.56E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	7.62E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	4.32E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	2.17E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	5.37E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	2.59E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	2.46E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	2.29E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	5.31E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.95E-03	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.59E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	2.56E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.07E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	7.62E-08	kg
Copper (+II) [Heavy metals to freshwater]	Mass	6.76E-05	kg
Iron [Heavy metals to air]	Mass	3.80E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	9.77E-04	kg
Iron [Heavy metals to freshwater]	Mass	1.86E+00	kg

Landfill of metallic waste [Waste for disposal]	Mass	5.37E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.27E-04	kg
Waste heat [Other emissions to air]	Energy	2.04E+01	MJ

Manufacturing cathodes of a lithium ion battery system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium foil [Metals]	Mass	6.14E+02	kg
CH: water, deionised, at plant [Appropriation]	Mass	2.54E+02	kg
GLO: lithium hydroxide, at plant [Inorganics]	Mass	2.93E+02	kg
Iron sulphate dissolution [Inorganic intermediate products]	Mass	7.18E+02	kg
RER: chemical plant, organics [Organics]	Number of pieces	5.06E-07	pcs.
RER: ethylene glycol, at plant [Organics]	Mass	9.36E+01	kg
RER: heat, natural gas, at industrial furnace [Heating systems]	Energy	8.17E+02	MJ
RER: phosphoric acid, industrial grade [Inorganics]	Mass	2.53E+02	kg
RER: electricity, at grid [Production mix]	Energy	9.11E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
cathode, lithium ion battery, lithium iron phosphate [Intermediate products]	Mass	1.26E+03	kg
Sewage sludge [Waste for disposal]	Mass	1.33E-01	kg
Waste heat [Other emissions to industrial soil]	Energy	9.11E+00	MJ

Manufacturing graphite anodes of a lithium ion battery system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: treatment, sewage [Wastewater treatment]	Volume	1.04E-01	m^3
CH: water, deionised, at plant [Appropriation]	Mass	4.13E+02	kg
CN: electricity, at grid [Supply mix]	Energy	7.02E+00	MJ
CN: graphite, battery grade, at plant [Inorganics]	Mass	4.82E+02	kg
GLO: Carbon black, at plant [Inorganics]	Mass	1.55E+01	kg
RER: chemical plant, organics [Organics]	Number of pieces	3.90E-07	pcs.

RER: heat, natural gas, at industrial furnace [Heating systems]	Energy	1.19E+03	MJ
RER: sheet rolling, copper [Processing]	Mass	8.53E+02	kg
RER: sulphuric acid, liquid, at plant [Inorganics]	Mass	7.88E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CN: Anode, lithium-ion battery, graphite, at plant [Parts]	Mass	9.76E+02	kg
Waste heat [Other emissions to air]	Energy	7.02E+00	MJ
Water vapour [Inorganic emissions to air]	Mass	4.13E+02	kg

Manufacturing separators of a lithium ion battery system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, residues, shredder fraction from manual dismantling, in MSWI [Incineration]	Mass	1.21E+01	kg
CN: electricity, at grid [Supply mix]	Energy	1.61E+00	MJ
DE: silica sand, at plant [Additives]	Mass	4.89E+01	kg
GLO: hexafluorethane, at plant [Organics]	Mass	5.87E+00	kg
RER: acetone, liquid, at plant [Organics]	Mass	3.22E+00	kg
RER: chemical plant, organics [Organics]	Number of pieces	8.96E-08	pcs.
RER: fleece, polyethylene, at plant [polymers]	Mass	7.86E+01	kg
RER: heat, natural gas, at industrial furnace [Heating systems]	Energy	4.33E+01	MJ
RER: phthalic anhydride, at plant [Organics]	Mass	6.52E+01	kg
US: polyvinylfluoride, at plant [Organics]	Mass	4.31E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acetone (dimethylcetone) [NMVOC Group to air]	Mass	3.22E+00	kg
CN: separator, lithium-ion battery, at plant [Parts]	Mass	2.24E+02	kg
Waste heat [Other emissions to air]	Energy	1.61E+00	MJ

Manufacturing casings of a lithium ion battery system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.71E+01	MJ

RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.35E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	3.56E+03	MJ
RER: tap water, at user [Appropriation]	Mass	4.65E+04	kg
Steel cast part [Metal parts]	Mass	3.72E+03	kg
RER: electricity, at grid [Production mix]	Energy	1.90E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	9.12E+01	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	5.10E+02	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	2.32E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	4.50E+01	m^3
steel casing [Valuable substances]	Mass	3.72E+03	kg
Waste heat [Other emissions to air]	Energy	6.81E+02	MJ

Manufacturing a lithium ion battery system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Casing [Metal parts]	Mass	3.72E+03	kg
cathode, lithium ion battery, lithium iron phosphate [Intermediate products]	Mass	1.26E+03	kg
CN: Anode, lithium-ion battery, graphite, at plant [Parts]	Mass	9.76E+02	kg
CN: lithium hexafluorophosphate, at plant [Inorganics]	Mass	8.38E+02	kg
CN: separator, lithium-ion battery, at plant [Parts]	Mass	2.24E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Lithium ion battery (Type LiFePO4) [Valuable substances]	Mass	7.23E+03	kg

Operating a lithium ion battery system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	8.15E+07	MJ
Lithium ion battery (Type LiFePO4) [Valuable substances]	Mass	7.23E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	8.20E+07	MJ

Lithium ion battery (Type LiFePO4) [Valuable substances]	Mass	7.23E+03	kg

Dismantling and treating a lithium ion battery system R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Lithium ion battery (Type LiFePO4) [Valuable substances]	Mass	7.23E+03	kg
RER: sodium hydroxide, 50% in H2O, production mix, at plant [Inorganics]	Mass	2.53E+03	kg
RER: electricity, at grid [Production mix]	Energy	2.08E+04	MJ
Water [Water]	Mass	7.23E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	2.05E+02	kg
CH: disposal, carbon SPL, Al elec.lysis, 0% water, to residual material landfill [Residual material landfill facility]	Mass	4.98E+02	kg
CH: disposal, inert waste, 5% water [Landfill facility]	Mass	4.89E+01	kg
CH: disposal, polyvinylfluoride, 0.2% water [Incineration]	Mass	4.31E+01	kg
Chloride [Inorganic emissions to freshwater]	Mass	2.89E+02	kg
Copper scrap [Waste for recovery]	Mass	2.84E+02	kg
Dust (> PM10) [Particles to air]	Mass	7.52E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.76E-01	kg
Dust (PM2.5) [Particles to air]	Mass	7.52E-01	kg
Landfill of plastic waste [Consumer waste]	Mass	1.01E+02	kg
Metallic waste for incineration [Waste for disposal]	Mass	1.73E+03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.73E+03	kg
Plastic (unspecified) [Waste for recovery]	Mass	4.32E+01	kg
Steel scrap [Waste for recovery]	Mass	1.24E+03	kg
Sulphate [Inorganic emissions to freshwater]	Mass	4.34E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.47E-01	kg
Waste heat [Other emissions to air]	Energy	2.08E+04	MJ

Recycling aluminium scrap of a lithium ion battery system - ingot production [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	3.79E+00	kg
Aluminium scrap [Waste for recovery]	Mass	2.05E+02	kg
CH: anionic resin [Organics]	Mass	7.22E-01	kg
CH: cationic resin [Organics]	Mass	7.22E-01	kg
RER: natural gas [Fuels]	Energy	2.09E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	1.62E+00	kg
RER: electricity, at grid [Production mix]	Energy	1.95E+01	MJ
Water [Water]	Mass	1.74E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	1.81E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.11E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.81E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.81E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	5.42E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	9.03E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	3.35E+00	kg

Recycling copper scrap of a lithium ion battery system [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	2.84E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	1.41E+03	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	9.54E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	1.11E-09	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.12E-06	kg
Acetic acid [NMVOC Group to air]	Mass	1.70E-04	kg
Arsenic [Heavy metals to air]	Mass	3.98E-04	kg
Benzene [NMVOC Group to air]	Mass	1.30E-06	kg
Benzo{a}pyrene [PAH group to air]	Mass	7.44E-10	kg
Butane [NMVOC Group to air]	Mass	1.30E-03	kg

Cadmium [Heavy metals to air]	Mass	6.53E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.81E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.11E-02	kg
Copper [Heavy metals to air]	Mass	7.95E-03	kg
Dust (> PM10) [Particles to air]	Mass	7.38E-02	kg
Dust (PM2.5) [Particles to air]	Mass	2.67E-01	kg
Ethane [NMVOC Group to air]	Mass	1.93E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	4.65E-05	kg
Heat, waste [unspecified]	Energy	1.07E+03	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.11E-03	kg
Lead [Heavy metals to air]	Mass	3.12E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.41E-03	kg
Nickel [Heavy metals to air]	Mass	3.69E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	9.84E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.41E-03	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	1.62E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.05E-03	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	4.08E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.12E-05	kg
Propane [NMVOC Group to air]	Mass	9.91E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	2.25E-05	kg
RER: copper, secondary [Benefication]	Mass	2.84E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.81E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	2.11E-06	kg

Recycling steel scrap of a lithium ion battery system with EAF R			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.99E+01	kg
Argon [Inorganic intermediate products]	Mass	1.11E+00	kg
GLO: charcoal, at plant [Fuels]	Mass	4.94E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.72E+01	kg

Dolomite [Minerals]	Mass	2.42E+01	kg
Graphite [Inorganic intermediate products]	Mass	3.95E+00	kg
Lime finelime (ground) [Minerals]	Mass	8.16E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	4.38E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	4.95E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	1.86E+01	kg
Refractory [Minerals]	Mass	2.03E+01	kg
RER: natural gas [Fuels]	Energy	7.66E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.40E+02	kg
Steel scrap [Waste for recovery]	Mass	1.24E+03	kg
RER: electricity, at grid [Production mix]	Energy	2.11E+03	MJ
Water [Water]	Mass	2.30E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.30E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.97E+00	kg
Chromium [Heavy metals to air]	Mass	2.13E-03	kg
Dust (> PM10) [Particles to air]	Mass	2.49E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.98E+01	kg
Lead [Heavy metals to air]	Mass	1.45E+00	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.97E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	4.84E-04	kg
Refractory [Hazardous waste]	Mass	1.21E+01	kg
RER: steel, unalloyed [Benefication]	Mass	9.89E+02	kg
Sludge [Waste for disposal]	Mass	4.25E+00	kg
Steel works slag [Waste for recovery]	Mass	2.04E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.26E-01	kg

Disposing metallic scrap of a lithium ion battery system to incineration plants [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.00E+03	MJ
CH: heat from waste [Incineration]	Energy	1.45E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	4.32E-07	pcs.

CH: process-specific burdens, slag compartment [Incineration]	Mass	2.73E+03	kg
CH: slag compartment [Incineration]	Number of pieces	4.87E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	1.73E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.41E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.33E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.52E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.14E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	7.21E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.73E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	6.00E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	1.73E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	3.66E+02	kg
Iron [Heavy metals to freshwater]	Mass	5.89E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	6.67E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	4.37E-03	kg
Phosphate [Ecoinvent long-term to freshwater]	Mass	5.60E-02	kg
Phosphate [Inorganic emissions to freshwater]	Mass	9.33E-05	kg
Solids [Ecoinvent long-term to freshwater]	Mass	4.58E-01	kg
Solids [Particles to freshwater]	Mass	1.97E-03	kg
Sulphate [Ecoinvent long-term to freshwater]	Mass	3.58E+00	kg
Sulphate [Inorganic emissions to freshwater]	Mass	3.59E-01	kg
Waste heat [Other emissions to air]	Energy	8.59E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	1.41E+02	MJ

Disposing metallic scrap of a lithium ion battery system to landfill [R]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	4.44E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	1.11E+01	kg
CH: disposal, paper [Incineration]	Mass	6.71E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	6.71E-02	kg
CH: electricity from waste [Incineration]	Energy	5.94E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	6.53E+01	MJ
CH: heat from waste [Incineration]	Energy	9.61E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	1.72E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	4.04E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.87E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	1.15E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	1.11E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	6.45E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	2.32E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	9.61E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	9.61E-07	m
CH: slag compartment [Incineration]	Number of pieces	1.15E-07	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	2.45E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.39E-04	kg
GLO: chemicals organic, at plant [Organics]	Mass	6.98E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.73E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	8.33E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	7.93E+00	MJ

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	7.38E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.71E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.56E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	8.35E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	8.23E+00	kg
Copper (+II) [Heavy metals to air]	Mass	3.44E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	2.45E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.18E-04	kg
Iron [Heavy metals to air]	Mass	1.22E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	3.15E-03	kg
Iron [Heavy metals to freshwater]	Mass	6.00E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	1.73E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.31E-04	kg
Waste heat [Other emissions to air]	Energy	6.57E+01	MJ

Manufacturing a transformer (used for cold-ironing) [R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: ferrite, at plant [Parts]	Mass	1.23E+03	kg
RER: copper, primary [Benefication]	Mass	2.58E+02	kg
RER: epoxy resin, liquid [monomers]	Mass	9.08E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.44E+01	MJ
RER: injection moulding [Processing]	Mass	1.25E+03	kg
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.14E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	3.01E+03	MJ
RER: polycarbonate, at plant [polymers]	Mass	3.44E+02	kg
RER: steel, low-alloyed [Benefication]	Mass	4.12E+02	kg
RER: tap water, at user [Appropriation]	Mass	3.94E+04	kg
RER: wire drawing, copper [Processing]	Mass	2.70E+02	kg
RER: electricity, at grid [Production mix]	Energy	5.77E+02	MJ

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	7.72E+01	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	1.58E+02	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	1.97E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	3.81E+01	m^3
GLO: transformer, high voltage use, at plant [Parts]	Mass	3.15E+03	kg
Heat, waste [unspecified]	Energy	5.76E+02	MJ

Operating a transformer (used for cold-ironing) [R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	1.52E+08	MJ
GLO: transformer, high voltage use, at plant [Parts]	Mass	3.15E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	3.15E+03	kg

Dismantling a transformer (used for cold-ironing) [R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	3.15E+03	kg
RER: electricity, at grid [Production mix]	Energy	4.70E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	8.37E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.92E-01	kg
Copper scrap [Waste for recovery]	Mass	8.58E+01	kg
Dust (PM10) [Particles to air]	Mass	3.48E-02	kg
Landfill of plastic waste [Consumer waste]	Mass	8.77E+02	kg
Metallic waste for incineration [Waste for disposal]	Mass	6.32E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	6.32E+02	kg

Methane [Organic emissions to air (VOC group)]	Mass	3.81E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.48E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	4.73E-04	kg
Plastic (unspecified) [Waste for recovery]	Mass	3.76E+02	kg
Steel scrap [Waste for recovery]	Mass	5.46E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.01E-01	kg

Recycling copper scrap of a transformer (used for cold-ironing) [R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	8.58E+01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	4.25E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	2.89E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	3.37E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	3.40E-07	kg
Acetic acid [NMVOC Group to air]	Mass	5.14E-05	kg
Arsenic [Heavy metals to air]	Mass	1.20E-04	kg
Benzene [NMVOC Group to air]	Mass	3.93E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	2.25E-10	kg
Butane [NMVOC Group to air]	Mass	3.93E-04	kg
Cadmium [Heavy metals to air]	Mass	1.97E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	8.50E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.37E-03	kg
Copper [Heavy metals to air]	Mass	2.40E-03	kg
Dust (> PM10) [Particles to air]	Mass	2.23E-02	kg
Dust (PM2.5) [Particles to air]	Mass	8.07E-02	kg
Ethane [NMVOC Group to air]	Mass	5.82E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.41E-05	kg
Heat, waste [unspecified]	Energy	3.23E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	3.37E-04	kg
Lead [Heavy metals to air]	Mass	9.44E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.25E-04	kg

Nickel [Heavy metals to air]	Mass	1.12E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.97E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	4.25E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	4.89E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	3.18E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.23E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	3.40E-06	kg
Propane [NMVOC Group to air]	Mass	3.00E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	6.80E-06	kg
RER: copper, secondary [Benefication]	Mass	8.58E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.50E-03	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	6.37E-07	kg

Recycling steel scrap of a transformer (used for cold-ironing) [R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	8.78E+00	kg
Argon [Inorganic intermediate products]	Mass	4.88E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	2.18E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	7.58E+00	kg
Dolomite [Minerals]	Mass	1.07E+01	kg
Graphite [Inorganic intermediate products]	Mass	1.74E+00	kg
Lime finelime (ground) [Minerals]	Mass	3.59E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.93E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	2.18E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	8.19E+00	kg
Refractory [Minerals]	Mass	8.93E+00	kg
RER: natural gas [Fuels]	Energy	3.38E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	6.18E+01	kg
Steel scrap [Waste for recovery]	Mass	5.46E+02	kg
RER: electricity, at grid [Production mix]	Energy	9.31E+02	MJ
Water [Water]	Mass	1.01E+01	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	5.73E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.31E+00	kg
Chromium [Heavy metals to air]	Mass	9.37E-04	kg
Dust (> PM10) [Particles to air]	Mass	1.10E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	8.71E+00	kg
Lead [Heavy metals to air]	Mass	6.37E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.31E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.13E-04	kg
Refractory [Hazardous waste]	Mass	5.31E+00	kg
RER: steel, unalloyed [Benefication]	Mass	4.35E+02	kg
Sludge [Waste for disposal]	Mass	1.87E+00	kg
Steel works slag [Waste for recovery]	Mass	8.99E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.56E-02	kg

Disposing metallic waste of a transformer (used for cold-ironing) to incineration plants [R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	3.66E+02	MJ
CH: heat from waste [Incineration]	Energy	5.30E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.58E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	9.98E+02	kg
CH: slag compartment [Incineration]	Number of pieces	1.78E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	6.32E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon monoxide [Inorganic emissions to air]	Mass	8.53E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	5.57E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.15E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	2.64E+00	kg

Copper (+II) [Ecoinvent long-term to freshwater]	Mass	6.32E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.19E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	6.32E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.34E+02	kg
Iron [Heavy metals to freshwater]	Mass	2.15E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.44E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.60E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.67E-01	kg
Solids [Particles to freshwater]	Mass	7.20E-04	kg
Waste heat [Other emissions to air]	Energy	3.14E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	5.16E+01	MJ

Disposing metallic waste of a transformer (used for cold-ironing) to landfill [R, N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.62E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	4.06E+00	kg
CH: disposal, paper [Incineration]	Mass	2.45E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	2.45E-02	kg
CH: electricity from waste [Incineration]	Energy	2.17E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	2.39E+01	MJ
CH: heat from waste [Incineration]	Energy	3.51E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	6.28E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	1.48E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.05E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	4.19E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	4.06E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.36E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	8.47E-09	pcs.

CH: landfill facility [Landfill facility]	Number of pieces	3.51E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	3.51E-07	m
CH: slag compartment [Incineration]	Number of pieces	4.19E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	8.97E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	5.08E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	2.55E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	6.32E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	2.90E+00	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	3.05E-05	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon monoxide [Inorganic emissions to air]	Mass	9.35E-03	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	3.05E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.01E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.26E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	8.97E-08	kg
Copper (+II) [Heavy metals to freshwater]	Mass	7.96E-05	kg
Iron [Heavy metals to air]	Mass	4.47E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.15E-03	kg
Iron [Heavy metals to freshwater]	Mass	2.19E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	6.32E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.67E-04	kg
Waste heat [Other emissions to air]	Energy	2.40E+01	MJ

Manufacturing a diesel genset (1) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	1.27E+03	kg
Carbon [Organic intermediate products]	Mass	1.03E+03	kg
Cast iron part [Metal parts]	Mass	3.27E+04	kg
Chromium [Metals]	Mass	9.40E+02	kg

RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	2.15E+02	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.71E+04	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	4.50E+04	MJ
RER: tap water, at user [Appropriation]	Mass	5.88E+05	kg
Steel part [Metal parts]	Mass	1.00E+04	kg
Tin (99.92%) [Metals]	Mass	9.40E+02	kg
RER: electricity, at grid [Production mix]	Energy	8.61E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	1.15E+03	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	6.44E+03	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	2.93E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	5.69E+02	m^3
Main diesel genset [Metal parts]	Mass	4.70E+04	kg
Waste heat [Other emissions to air]	Energy	8.60E+03	MJ

Operating a diesel genset (1) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel generator [Metal parts]	Mass	4.70E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	3.26E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.04E+08	kg
Carbon monoxide [Inorganic emissions to air]	Mass	9.01E+04	kg
Diesel generator [Metal parts]	Mass	4.70E+04	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.51E+04	kg
Energy unspecific [Energy resources]	Energy	8.99E+08	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	6.01E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.09E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.46E+05	kg

Maintaining a diesel genset (1) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	4.70E+04	kg
RER: lubricating oil [Organics]	Mass	1.50E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	4.70E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	1.50E+04	kg

Used lubricating oil treatment of a diesel genset (1) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	4.03E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	3.04E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	3.62E+01	kg
RER: electricity [Production mix]	Energy	7.76E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	6.04E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	1.50E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.14E+03	kg
Sludge [Hazardous waste]	Mass	4.86E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	1.34E+04	kg

Used lubricating oil treatment of a diesel genset (1) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	4.03E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	3.04E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	3.62E+01	kg
RER: electricity [Production mix]	Energy	7.76E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	6.04E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	1.50E+04	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.14E+03	kg
Sludge [Hazardous waste]	Mass	4.86E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	1.34E+04	kg

Recovering used lubricating oil after treatment (1) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	6.99E+00	kg
Propane [Organic intermediate products]	Mass	9.84E+00	kg
RER: electricity [Production mix]	Energy	3.35E+03	MJ
RER: natural gas [Fuels]	Energy	6.94E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	3.88E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	1.34E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	1.76E-08	kg
Asphalt flux [Organic intermediate products]	Mass	4.54E+03	kg
Base oil from re-refining [Other fuels]	Mass	3.23E+03	kg
Cadmium [Heavy metals to air]	Mass	1.19E-06	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.87E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.43E+01	kg
Chromium [Heavy metals to air]	Mass	3.78E-08	kg
Electricity from waste to energy [System-dependent]	Energy	8.10E+04	MJ
Expanded clay [Minerals]	Mass	8.80E+00	kg
Flux and gas [Operating materials]	Mass	3.18E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	1.96E+02	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	3.51E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.74E-07	kg
Marine diesel oil [Other fuels]	Mass	3.47E+03	kg
Nickel [Heavy metals to air]	Mass	5.82E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	5.05E+00	kg

NMVOC (unspecified) [NMVOC Group to air]	Mass	4.40E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	1.74E+02	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	3.53E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.61E-01	kg
Waste heat [Other emissions to air]	Energy	3.55E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	1.96E+02	kg

Recycling aluminium scrap of diesel genset (1) - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	7.06E+00	kg
Aluminium scrap [Waste for recovery]	Mass	3.81E+02	kg
CH: anionic resin [Organics]	Mass	1.34E+00	kg
CH: cationic resin [Organics]	Mass	1.34E+00	kg
RER: natural gas [Fuels]	Energy	3.89E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	3.02E+00	kg
RER: electricity, at grid [Production mix]	Energy	3.63E+01	MJ
Water [Water]	Mass	3.24E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	3.36E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.07E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.36E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.36E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.01E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.68E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	6.23E+00	kg

Recovering cast iron scrap of diesel genset (1) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Cast iron scrap [Waste for recovery]	Mass	9.80E+03	kg
Crude oil [Crude oil, at consumer]	Mass	4.82E+01	kg
Electricity [Electric power]	Energy	9.78E+02	MJ
Hard coal [Resource]	Mass	4.16E+02	kg

RER: natural gas, burned in industrial furnace [Heating systems]	Energy	3.92E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	7.15E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	5.76E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	7.35E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.46E+00	kg
Cast iron [Metals]	Mass	9.80E+03	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	6.92E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.92E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	1.81E-01	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	3.18E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.65E+00	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.88E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	7.38E+00	kg

Recovering steel scrap of diesel genset (1) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Crude oil [Crude oil, at consumer]	Mass	1.48E+01	kg
Electricity [Electric power]	Energy	3.00E+02	MJ
Hard coal [Resource]	Mass	1.27E+02	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	1.20E+00	MJ
Steel scrap [Waste for recovery]	Mass	3.00E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	2.19E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	1.77E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.25E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.98E+00	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	2.12E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.12E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	5.55E-02	kg

Hydrogen sulphide [Inorganic emissions to air]	Mass	9.75E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	8.13E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	8.83E-01	kg
RER: steel, unalloyed [Benefication]	Mass	3.00E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.26E+00	kg

Disposing metallic waste of diesel genset (1) to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	5.37E+03	MJ
CH: heat from waste [Incineration]	Energy	7.77E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.31E-06	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.46E+04	kg
CH: slag compartment [Incineration]	Number of pieces	2.61E-05	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	9.26E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	7.53E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.25E+00	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	8.17E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	6.08E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.86E+01	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	7.27E-02	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	3.18E-04	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	9.26E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	3.21E-01	kg
Incineration of metallic waste [Waste for disposal]	Mass	9.26E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.96E+03	kg
Iron [Heavy metals to freshwater]	Mass	3.16E-02	kg

Methane (biotic) [Organic emissions to air (VOC group)]	Mass	3.57E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.34E-02	kg
Solids [Ecoinvent long-term to freshwater]	Mass	2.45E+00	kg
Solids [Particles to freshwater]	Mass	1.06E-02	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	9.91E-05	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	6.17E+00	kg
Waste heat [Other emissions to air]	Energy	4.60E+03	MJ
Waste heat [Other emissions to freshwater]	Energy	7.56E+02	MJ

Disposing metallic waste of diesel genset (1) to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	2.38E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	5.94E+01	kg
CH: electricity from waste [Incineration]	Energy	3.18E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	3.50E+02	MJ
CH: heat from waste [Incineration]	Energy	5.15E+02	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	9.20E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	2.17E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.54E-07	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	6.14E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	5.94E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	3.45E+02	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.24E-07	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	5.15E-06	pcs.
CH: sewer grid [Wastewater treatment]	Length	5.15E-06	m
CH: slag compartment [Incineration]	Number of pieces	6.14E-07	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.31E-07	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	7.44E-04	kg

GLO: chemicals organic, at plant [Organics]	Mass	3.74E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	9.26E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	4.46E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	4.25E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	3.95E-01	kg
Aluminium [Particles to air]	Mass	9.16E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.37E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.47E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	4.41E+01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.84E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.31E-06	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.17E-03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	6.56E+02	kg
Iron [Heavy metals to air]	Mass	1.69E-02	kg
Iron [Heavy metals to freshwater]	Mass	3.21E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	9.26E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.92E-03	kg
Tin (+IV) [Heavy metals to air]	Mass	3.60E+01	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	4.45E-02	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.08E-04	kg
Waste heat [Other emissions to air]	Energy	3.52E+02	MJ

Manufacturing a diesel genset (2) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	1.17E+03	kg
Carbon [Organic intermediate products]	Mass	9.57E+02	kg
Cast iron part [Metal parts]	Mass	3.02E+04	kg
Chromium [Metals]	Mass	8.70E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.99E+02	MJ

RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.58E+04	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	4.16E+04	MJ
RER: tap water, at user [Appropriation]	Mass	5.44E+05	kg
Steel part [Metal parts]	Mass	9.27E+03	kg
Tin (99.92%) [Metals]	Mass	8.70E+02	kg
RER: electricity, at grid [Production mix]	Energy	7.97E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	1.07E+03	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	5.96E+03	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	2.71E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	5.26E+02	m^3
Main diesel genset [Metal parts]	Mass	4.35E+04	kg
Waste heat [Other emissions to air]	Energy	7.96E+03	MJ

Operating a diesel genset (2) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel generator [Metal parts]	Mass	4.35E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	2.78E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	8.83E+07	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.68E+04	kg
Diesel generator [Metal parts]	Mass	4.35E+04	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.84E+04	kg
Energy unspecific [Energy resources]	Energy	1.01E+09	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	5.12E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.78E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.50E+05	kg

Maintaining a diesel genset (2) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	4.35E+04	kg
RER: lubricating oil [Organics]	Mass	1.22E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	4.35E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	1.22E+04	kg

Used lubricating oil treatment of a diesel genset (2) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	3.27E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	2.46E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	2.94E+01	kg
RER: electricity [Production mix]	Energy	6.30E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	4.90E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	1.22E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	9.24E+02	kg
Sludge [Hazardous waste]	Mass	3.94E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	1.08E+04	kg

Recovering used lubricating oil after treatment (2) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	5.67E+00	kg
Propane [Organic intermediate products]	Mass	7.98E+00	kg
RER: electricity [Production mix]	Energy	2.72E+03	MJ
RER: natural gas [Fuels]	Energy	5.63E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	3.15E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	1.08E+04	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	1.43E-08	kg
Asphalt flux [Organic intermediate products]	Mass	3.68E+03	kg
Base oil from re-refining [Other fuels]	Mass	2.62E+03	kg
Cadmium [Heavy metals to air]	Mass	9.68E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.33E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.16E+01	kg
Chromium [Heavy metals to air]	Mass	3.07E-08	kg
Electricity from waste to energy [System-dependent]	Energy	6.57E+04	MJ
Expanded clay [Minerals]	Mass	7.14E+00	kg
Flux and gas [Operating materials]	Mass	2.58E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	1.59E+02	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	2.85E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.41E-07	kg
Marine diesel oil [Other fuels]	Mass	2.82E+03	kg
Nickel [Heavy metals to air]	Mass	4.72E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.10E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	3.57E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	1.41E+02	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	2.87E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.99E-01	kg
Waste heat [Other emissions to air]	Energy	2.88E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	1.59E+02	kg

Recycling aluminium scrap of diesel genset (2) - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	6.53E+00	kg
Aluminium scrap [Waste for recovery]	Mass	3.52E+02	kg
CH: anionic resin [Organics]	Mass	1.24E+00	kg
CH: cationic resin [Organics]	Mass	1.24E+00	kg
RER: natural gas [Fuels]	Energy	3.60E+03	MJ

Sodium chloride (rock salt) [Non renewable resources]	Mass	2.80E+00	kg
RER: electricity, at grid [Production mix]	Energy	3.36E+01	MJ
Water [Water]	Mass	2.99E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	3.11E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.92E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.11E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.11E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	9.33E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.55E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	5.76E+00	kg

Recovering cast iron scrap of diesel genset (2) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Cast iron scrap [Waste for recovery]	Mass	9.07E+03	kg
Crude oil [Crude oil, at consumer]	Mass	4.46E+01	kg
Electricity [Electric power]	Energy	9.05E+02	MJ
Hard coal [Resource]	Mass	3.85E+02	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	3.63E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	6.62E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	5.34E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.80E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.98E+00	kg
Cast iron [Metals]	Mass	9.07E+03	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	6.40E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.40E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	1.68E-01	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	2.95E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.45E+00	kg

Nitrogen dioxide [Inorganic emissions to air]	Mass	2.67E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.83E+00	kg

Recovering steel scrap of diesel genset (2) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Crude oil [Crude oil, at consumer]	Mass	1.37E+01	kg
Electricity [Electric power]	Energy	2.77E+02	MJ
Hard coal [Resource]	Mass	1.18E+02	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	1.11E+00	MJ
Steel scrap [Waste for recovery]	Mass	2.78E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	2.03E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	1.64E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.08E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.83E+00	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	1.96E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.96E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	5.13E-02	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	9.03E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.52E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	8.18E-01	kg
RER: steel, unalloyed [Benefication]	Mass	2.78E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.09E+00	kg

Disposing metallic waste of diesel genset (2) to incineration plants N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	4.97E+03	MJ
CH: heat from waste [Incineration]	Energy	7.19E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.14E-06	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.35E+04	kg

CH: slag compartment [Incineration]	Number of pieces	2.42E-05	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	8.57E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	6.97E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.16E+00	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	7.56E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	5.63E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.57E+01	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	6.73E-02	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	2.94E-04	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	8.57E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.97E-01	kg
Incineration of metallic waste [Waste for disposal]	Mass	8.57E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.82E+03	kg
Iron [Heavy metals to freshwater]	Mass	2.92E-02	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	3.31E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.17E-02	kg
Solids [Ecoinvent long-term to freshwater]	Mass	2.27E+00	kg
Solids [Particles to freshwater]	Mass	9.77E-03	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	9.17E-05	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	5.71E+00	kg
Waste heat [Other emissions to air]	Energy	4.26E+03	MJ
Waste heat [Other emissions to freshwater]	Energy	7.00E+02	MJ

Disposing metallic waste of diesel genset (2) to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	2.20E+01	kg

CH: disposal, cement [Residual material landfill facility]	Mass	5.50E+01	kg
CH: electricity from waste [Incineration]	Energy	2.94E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	3.24E+02	MJ
CH: heat from waste [Incineration]	Energy	4.76E+02	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	8.52E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	2.01E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.42E-07	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	5.68E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	5.50E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	3.20E+02	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.15E-07	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	4.76E-06	pcs.
CH: sewer grid [Wastewater treatment]	Length	4.76E-06	m
CH: slag compartment [Incineration]	Number of pieces	5.68E-07	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.22E-07	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	6.89E-04	kg
GLO: chemicals organic, at plant [Organics]	Mass	3.46E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	8.57E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	4.13E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	3.93E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	3.66E-01	kg
Aluminium [Particles to air]	Mass	8.48E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.27E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.14E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	4.08E+01	kg

Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.71E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.22E-06	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.08E-03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	6.07E+02	kg
Iron [Heavy metals to air]	Mass	1.56E-02	kg
Iron [Heavy metals to freshwater]	Mass	2.97E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	8.57E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.62E-03	kg
Tin (+IV) [Heavy metals to air]	Mass	3.33E+01	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	4.12E-02	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.00E-04	kg
Waste heat [Other emissions to air]	Energy	3.26E+02	MJ

Manufacturing a diesel genset (3) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	9.05E+02	kg
Carbon [Organic intermediate products]	Mass	7.37E+02	kg
Cast iron part [Metal parts]	Mass	2.33E+04	kg
Chromium [Metals]	Mass	6.70E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.53E+02	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.22E+04	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	3.21E+04	MJ
RER: tap water, at user [Appropriation]	Mass	4.19E+05	kg
Steel part [Metal parts]	Mass	7.14E+03	kg
Tin (99.92%) [Metals]	Mass	6.70E+02	kg
RER: electricity, at grid [Production mix]	Energy	6.14E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	8.21E+02	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	4.59E+03	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	2.09E+02	kg
CH: treatment, sewage	Volume	4.05E+02	m^3
Main diesel genset [Metal parts]	Mass	3.35E+04	kg
Waste heat [Other emissions to air]	Energy	6.13E+03	MJ

Operating a diesel genset (3) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel generator [Metal parts]	Mass	3.35E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	3.20E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.02E+08	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.85E+04	kg
Diesel generator [Metal parts]	Mass	3.35E+04	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.43E+04	kg
Energy unspecific [Energy resources]	Energy	1.01E+09	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	5.90E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.05E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.34E+05	kg

Maintaining a diesel genset (3) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	3.35E+04	kg
RER: lubricating oil [Organics]	Mass	1.13E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	3.35E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	1.13E+04	kg

Used lubricating oil treatment of a diesel genset (3) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	3.04E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	2.29E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	2.74E+01	kg
RER: electricity [Production mix]	Energy	5.87E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	4.56E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	1.13E+04	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	8.61E+02	kg
Sludge [Hazardous waste]	Mass	3.67E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	1.01E+04	kg

Recovering used lubricating oil after treatment (3) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	5.28E+00	kg
Propane [Organic intermediate products]	Mass	7.44E+00	kg
RER: electricity [Production mix]	Energy	2.53E+03	MJ
RER: natural gas [Fuels]	Energy	5.24E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	2.93E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	1.01E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	1.33E-08	kg
Asphalt flux [Organic intermediate products]	Mass	3.43E+03	kg
Base oil from re-refining [Other fuels]	Mass	2.44E+03	kg
Cadmium [Heavy metals to air]	Mass	9.02E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.17E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.08E+01	kg
Chromium [Heavy metals to air]	Mass	2.86E-08	kg
Electricity from waste to energy [System-dependent]	Energy	6.12E+04	MJ
Expanded clay [Minerals]	Mass	6.65E+00	kg
Flux and gas [Operating materials]	Mass	2.40E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	1.48E+02	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	2.66E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.31E-07	kg
Marine diesel oil [Other fuels]	Mass	2.62E+03	kg
Nickel [Heavy metals to air]	Mass	4.40E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.82E+00	kg

NMVOC (unspecified) [NMVOC Group to air]	Mass	3.32E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	1.32E+02	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	2.67E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.51E-01	kg
Waste heat [Other emissions to air]	Energy	2.68E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	1.48E+02	kg

Recycling aluminium scrap of diesel genset (3) - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	5.03E+00	kg
Aluminium scrap [Waste for recovery]	Mass	2.71E+02	kg
CH: anionic resin [Organics]	Mass	9.58E-01	kg
CH: cationic resin [Organics]	Mass	9.58E-01	kg
RER: natural gas [Fuels]	Energy	2.77E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	2.16E+00	kg
RER: electricity, at grid [Production mix]	Energy	2.59E+01	MJ
Water [Water]	Mass	2.31E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	2.39E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.48E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.39E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.39E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	7.18E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.20E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	4.44E+00	kg

Recovering cast iron scrap of diesel genset (3) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Cast iron scrap [Waste for recovery]	Mass	6.98E+03	kg
Crude oil [Crude oil, at consumer]	Mass	3.43E+01	kg
Electricity [Electric power]	Energy	6.97E+02	MJ
Hard coal [Resource]	Mass	2.96E+02	kg

RER: natural gas, burned in industrial furnace [Heating systems]	Energy	2.79E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	5.09E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	4.11E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	5.24E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.60E+00	kg
Cast iron [Metals]	Mass	6.98E+03	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	4.93E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.93E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	1.29E-01	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	2.27E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.89E+00	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.05E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.26E+00	kg

Recovering steel scrap of diesel genset (3) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Crude oil [Crude oil, at consumer]	Mass	1.05E+01	kg
Electricity [Electric power]	Energy	2.14E+02	MJ
Hard coal [Resource]	Mass	9.08E+01	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	8.56E-01	MJ
Steel scrap [Waste for recovery]	Mass	2.14E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	1.56E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	1.26E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.61E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.41E+00	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	1.51E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.51E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	3.95E-02	kg

Hydrogen sulphide [Inorganic emissions to air]	Mass	6.95E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.79E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	6.30E-01	kg
RER: steel, unalloyed [Benefication]	Mass	2.14E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.61E+00	kg

Disposing metallic waste of diesel genset (3) to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	3.83E+03	MJ
CH: heat from waste [Incineration]	Energy	5.54E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.65E-06	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.04E+04	kg
CH: slag compartment [Incineration]	Number of pieces	1.86E-05	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	6.60E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	5.37E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.91E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	5.82E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.34E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	2.75E+01	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	5.18E-02	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	2.26E-04	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	6.60E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.29E-01	kg
Incineration of metallic waste [Waste for disposal]	Mass	6.60E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.40E+03	kg
Iron [Heavy metals to freshwater]	Mass	2.25E-02	kg

Methane (biotic) [Organic emissions to air (VOC group)]	Mass	2.55E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.67E-02	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.75E+00	kg
Solids [Particles to freshwater]	Mass	7.52E-03	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	7.06E-05	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	4.40E+00	kg
Waste heat [Other emissions to air]	Energy	3.28E+03	MJ
Waste heat [Other emissions to freshwater]	Energy	5.39E+02	MJ

Disposing metallic waste of diesel genset (3) to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.70E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	4.24E+01	kg
CH: electricity from waste [Incineration]	Energy	2.27E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	2.49E+02	MJ
CH: heat from waste [Incineration]	Energy	3.67E+02	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	6.56E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	1.54E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.10E-07	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	4.38E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	4.24E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.46E+02	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	8.84E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	3.67E-06	pcs.
CH: sewer grid [Wastewater treatment]	Length	3.67E-06	m
CH: slag compartment [Incineration]	Number of pieces	4.38E-07	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	9.37E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	5.31E-04	kg

GLO: chemicals organic, at plant [Organics]	Mass	2.67E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	6.60E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	3.18E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	3.03E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	2.82E-01	kg
Aluminium [Particles to air]	Mass	6.53E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	9.77E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	3.19E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.14E+01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.31E+00	kg
Copper (+II) [Heavy metals to air]	Mass	9.37E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	8.32E-04	kg
Iron [Ecoinvent long-term to freshwater]	Mass	4.67E+02	kg
Iron [Heavy metals to air]	Mass	1.20E-02	kg
Iron [Heavy metals to freshwater]	Mass	2.29E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	6.60E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.79E-03	kg
Tin (+IV) [Heavy metals to air]	Mass	2.57E+01	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	3.17E-02	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	7.72E-05	kg
Waste heat [Other emissions to air]	Energy	2.51E+02	MJ

Manufacturing a diesel genset (4) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	4.59E+02	kg
Carbon [Organic intermediate products]	Mass	3.74E+02	kg
Cast iron part [Metal parts]	Mass	1.18E+04	kg
Chromium [Metals]	Mass	3.40E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	7.79E+01	MJ

RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	6.17E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	1.63E+04	MJ
RER: tap water, at user [Appropriation]	Mass	2.13E+05	kg
Steel part [Metal parts]	Mass	3.62E+03	kg
Tin (99.92%) [Metals]	Mass	3.40E+02	kg
RER: electricity, at grid [Production mix]	Energy	3.12E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	4.17E+02	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	2.33E+03	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	1.06E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	2.06E+02	m^3
Main diesel genset [Metal parts]	Mass	1.70E+04	kg
Waste heat [Other emissions to air]	Energy	3.11E+03	MJ

Operating a diesel genset (4) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel generator [Metal parts]	Mass	1.70E+04	kg
RER: diesel, low-sulphur [Fuels]	Mass	3.20E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.02E+08	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.85E+04	kg
Diesel generator [Metal parts]	Mass	1.70E+04	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	4.43E+04	kg
Energy unspecific [Energy resources]	Energy	1.01E+09	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	5.90E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.05E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.34E+05	kg

Maintaining a diesel genset (4) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	1.70E+04	kg
RER: lubricating oil [Organics]	Mass	1.13E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	1.70E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	1.13E+04	kg

Used lubricating oil treatment of a diesel genset (4) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	3.04E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	2.29E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	2.74E+01	kg
RER: electricity [Production mix]	Energy	5.87E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	4.56E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	1.13E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	8.61E+02	kg
Sludge [Hazardous waste]	Mass	3.67E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	1.01E+04	kg

Recovering used lubricating oil after treatment (4) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	5.28E+00	kg
Propane [Organic intermediate products]	Mass	7.44E+00	kg
RER: electricity [Production mix]	Energy	2.53E+03	MJ
RER: natural gas [Fuels]	Energy	5.24E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	2.93E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	1.01E+04	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	1.33E-08	kg
Asphalt flux [Organic intermediate products]	Mass	3.43E+03	kg
Base oil from re-refining [Other fuels]	Mass	2.44E+03	kg
Cadmium [Heavy metals to air]	Mass	9.02E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.17E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.08E+01	kg
Chromium [Heavy metals to air]	Mass	2.86E-08	kg
Electricity from waste to energy [System-dependent]	Energy	6.12E+04	MJ
Expanded clay [Minerals]	Mass	6.65E+00	kg
Flux and gas [Operating materials]	Mass	2.40E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	1.48E+02	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	2.66E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.31E-07	kg
Marine diesel oil [Other fuels]	Mass	2.62E+03	kg
Nickel [Heavy metals to air]	Mass	4.40E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.82E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	3.32E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	1.32E+02	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	2.67E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.51E-01	kg
Waste heat [Other emissions to air]	Energy	2.68E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	1.48E+02	kg

Recycling aluminium scrap of diesel genset (4) - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.55E+00	kg
Aluminium scrap [Waste for recovery]	Mass	1.38E+02	kg
CH: anionic resin [Organics]	Mass	4.86E-01	kg
CH: cationic resin [Organics]	Mass	4.86E-01	kg
RER: natural gas [Fuels]	Energy	1.41E+03	MJ

Sodium chloride (rock salt) [Non renewable resources]	Mass	1.09E+00	kg
RER: electricity, at grid [Production mix]	Energy	1.31E+01	MJ
Water [Water]	Mass	1.17E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	1.22E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	7.50E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.22E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.22E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.65E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.08E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	2.25E+00	kg

Recovering cast iron scrap of diesel genset (4) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Cast iron scrap [Waste for recovery]	Mass	3.54E+03	kg
Crude oil [Crude oil, at consumer]	Mass	1.74E+01	kg
Electricity [Electric power]	Energy	3.54E+02	MJ
Hard coal [Resource]	Mass	1.50E+02	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	1.42E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	2.59E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	2.09E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.66E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.34E+00	kg
Cast iron [Metals]	Mass	3.54E+03	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	2.50E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.50E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	6.55E-02	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.15E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	9.59E-01	kg

Nitrogen dioxide [Inorganic emissions to air]	Mass	1.04E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.67E+00	kg

Recovering steel scrap of diesel genset (4) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Crude oil [Crude oil, at consumer]	Mass	5.34E+00	kg
Electricity [Electric power]	Energy	1.08E+02	MJ
Hard coal [Resource]	Mass	4.61E+01	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	4.35E-01	MJ
Steel scrap [Waste for recovery]	Mass	1.09E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	7.92E-04	kg
BOD in waste water [Production residues in life cycle]	Mass	6.39E-02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	8.15E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.16E-01	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	7.67E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	7.67E-01	kg
Hydrochloric acid [Waste for recovery]	Mass	2.01E-02	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	3.53E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.94E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	3.20E-01	kg
RER: steel, unalloyed [Benefication]	Mass	1.09E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.18E-01	kg

Disposing metallic waste of diesel genset (4) to incineration plants N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.94E+03	MJ
CH: heat from waste [Incineration]	Energy	2.81E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	8.37E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	5.29E+03	kg

CH: slag compartment [Incineration]	Number of pieces	9.44E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	3.35E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	2.72E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.52E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	2.95E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.20E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.40E+01	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	2.63E-02	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	1.15E-04	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	3.35E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.16E-01	kg
Incineration of metallic waste [Waste for disposal]	Mass	3.35E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	7.10E+02	kg
Iron [Heavy metals to freshwater]	Mass	1.14E-02	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.29E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	8.47E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	8.87E-01	kg
Solids [Particles to freshwater]	Mass	3.82E-03	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	3.58E-05	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	2.23E+00	kg
Waste heat [Other emissions to air]	Energy	1.66E+03	MJ
Waste heat [Other emissions to freshwater]	Energy	2.74E+02	MJ

Disposing metallic waste of diesel genset (4) to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	8.61E+00	kg

CH: disposal, cement [Residual material landfill facility]	Mass	2.15E+01	kg
CH: electricity from waste [Incineration]	Energy	1.15E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	1.27E+02	MJ
CH: heat from waste [Incineration]	Energy	1.86E+02	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	3.33E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	7.84E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	5.56E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	2.22E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	2.15E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.25E+02	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	4.49E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	1.86E-06	pcs.
CH: sewer grid [Wastewater treatment]	Length	1.86E-06	m
CH: slag compartment [Incineration]	Number of pieces	2.22E-07	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	4.76E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	2.69E-04	kg
GLO: chemicals organic, at plant [Organics]	Mass	1.35E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	3.35E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	1.61E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.54E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.43E-01	kg
Aluminium [Particles to air]	Mass	3.31E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.96E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.62E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.59E+01	kg

Copper (+II) [Ecoinvent long-term to freshwater]	Mass	6.66E-01	kg
Copper (+II) [Heavy metals to air]	Mass	4.76E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	4.22E-04	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.37E+02	kg
Iron [Heavy metals to air]	Mass	6.10E-03	kg
Iron [Heavy metals to freshwater]	Mass	1.16E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	3.35E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.42E-03	kg
Tin (+IV) [Heavy metals to air]	Mass	1.30E+01	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	1.61E-02	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	3.92E-05	kg
Waste heat [Other emissions to air]	Energy	1.27E+02	MJ

Manufacturing a diesel genset (5) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	2.51E+02	kg
Carbon [Organic intermediate products]	Mass	2.05E+02	kg
Cast iron part [Metal parts]	Mass	6.46E+03	kg
Chromium [Metals]	Mass	1.86E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	4.26E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	3.38E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	8.90E+03	MJ
RER: tap water, at user [Appropriation]	Mass	1.16E+05	kg
Steel part [Metal parts]	Mass	1.98E+03	kg
Tin (99.92%) [Metals]	Mass	1.86E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.70E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	2.28E+02	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	1.27E+03	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	5.80E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	1.13E+02	m^3
Main diesel genset [Metal parts]	Mass	9.30E+03	kg

Waste heat [Other emissions to air]	Energy	1.70E+03	MJ

Operating a diesel genset (5) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel generator [Metal parts]	Mass	9.30E+03	kg
RER: diesel, low-sulphur [Fuels]	Mass	1.91E+07	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	6.07E+07	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.28E+04	kg
Diesel generator [Metal parts]	Mass	9.30E+03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.64E+04	kg
Energy unspecific [Energy resources]	Energy	1.01E+09	MJ
Hydrocarbons [Organic emissions to air (VOC group)]	Mass	3.52E+04	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.22E+06	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.78E+05	kg

Maintaining a diesel genset (5) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	9.30E+03	kg
RER: lubricating oil [Organics]	Mass	5.16E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Main diesel genset [Metal parts]	Mass	9.30E+03	kg
Unspecified oil waste [Hazardous waste]	Mass	5.16E+03	kg

Used lubricating oil treatment of a diesel genset (5) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	1.39E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	1.05E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	1.25E+01	kg
RER: electricity [Production mix]	Energy	2.67E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	2.08E+01	kg

Unspecified oil waste [Hazardous waste]	Mass	5.16E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	3.92E+02	kg
Sludge [Hazardous waste]	Mass	1.67E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	4.60E+03	kg

Recovering used lubricating oil after treatment (5) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	2.41E+00	kg
Propane [Organic intermediate products]	Mass	3.39E+00	kg
RER: electricity [Production mix]	Energy	1.15E+03	MJ
RER: natural gas [Fuels]	Energy	2.39E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	1.34E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	4.60E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	6.06E-09	kg
Asphalt flux [Organic intermediate products]	Mass	1.56E+03	kg
Base oil from re-refining [Other fuels]	Mass	1.11E+03	kg
Cadmium [Heavy metals to air]	Mass	4.11E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	9.90E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.93E+00	kg
Chromium [Heavy metals to air]	Mass	1.30E-08	kg
Electricity from waste to energy [System-dependent]	Energy	2.79E+04	MJ
Expanded clay [Minerals]	Mass	3.03E+00	kg
Flux and gas [Operating materials]	Mass	1.10E+02	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	6.76E+01	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	1.21E-03	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	5.98E-08	kg
Marine diesel oil [Other fuels]	Mass	1.20E+03	kg
Nickel [Heavy metals to air]	Mass	2.00E-06	kg

Nitrogen oxides [Inorganic emissions to air]	Mass	1.74E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	1.52E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	6.00E+01	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	1.22E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.97E-01	kg
Waste heat [Other emissions to air]	Energy	1.22E+04	MJ
Waste water - untreated [Production residues in life cycle]	Mass	6.76E+01	kg

Recycling aluminium scrap of diesel genset (5) - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.40E+00	kg
Aluminium scrap [Waste for recovery]	Mass	7.53E+01	kg
CH: anionic resin [Organics]	Mass	2.66E-01	kg
CH: cationic resin [Organics]	Mass	2.66E-01	kg
RER: natural gas [Fuels]	Energy	7.70E+02	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	5.98E-01	kg
RER: electricity, at grid [Production mix]	Energy	7.18E+00	MJ
Water [Water]	Mass	6.40E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	6.65E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.10E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.65E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.65E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.99E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.32E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.23E+00	kg

Recovering cast iron scrap of diesel genset (5) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Cast iron scrap [Waste for recovery]	Mass	1.94E+03	kg
Crude oil [Crude oil, at consumer]	Mass	9.54E+00	kg

Electricity [Electric power]	Energy	1.93E+02	MJ
Hard coal [Resource]	Mass	8.23E+01	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	7.76E-01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	1.41E-03	kg
BOD in waste water [Production residues in life cycle]	Mass	1.14E-01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.45E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.28E+00	kg
Cast iron [Metals]	Mass	1.94E+03	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	1.37E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.37E+00	kg
Hydrochloric acid [Waste for recovery]	Mass	3.58E-02	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	6.30E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.25E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	5.70E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.46E+00	kg

Recovering steel scrap of diesel genset (5) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Crude oil [Crude oil, at consumer]	Mass	2.92E+00	kg
Electricity [Electric power]	Energy	5.93E+01	MJ
Hard coal [Resource]	Mass	2.52E+01	kg
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	2.38E-01	MJ
Steel scrap [Waste for recovery]	Mass	5.94E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Ammonium [Inorganic emissions to air]	Mass	4.33E-04	kg
BOD in waste water [Production residues in life cycle]	Mass	3.50E-02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.46E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.92E-01	kg
Chemical oxygen demand (COD) [Analytical measures to freshwater]	Mass	4.19E-02	kg

Dust (PM2,5 - PM10) [Particles to air]	Mass	4.19E-01	kg
Hydrochloric acid [Waste for recovery]	Mass	1.10E-02	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	1.93E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.61E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.75E-01	kg
RER: steel, unalloyed [Benefication]	Mass	5.94E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.47E-01	kg

Disposing metallic waste of diesel genset (5) to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.06E+03	MJ
CH: heat from waste [Incineration]	Energy	1.54E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	4.58E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.89E+03	kg
CH: slag compartment [Incineration]	Number of pieces	5.17E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	1.83E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.49E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.47E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.62E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.20E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	7.64E+00	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	1.44E-02	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	6.28E-05	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.83E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	6.36E-02	kg

Incineration of metallic waste [Waste for disposal]	Mass	1.83E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	3.88E+02	kg
Iron [Heavy metals to freshwater]	Mass	6.25E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	7.07E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.64E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	4.86E-01	kg
Solids [Particles to freshwater]	Mass	2.09E-03	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	1.96E-05	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.22E+00	kg
Waste heat [Other emissions to air]	Energy	9.11E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	1.50E+02	MJ

Disposing metallic waste of diesel genset (5) to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	3.95E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	9.86E+01	kg
CH: electricity from waste [Incineration]	Energy	5.28E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	5.81E+02	MJ
CH: heat from waste [Incineration]	Energy	8.54E+02	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	1.53E-02	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	3.60E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.55E-07	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	1.02E+03	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	9.86E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	5.73E+02	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	2.06E-07	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	8.54E-06	pcs.
CH: sewer grid [Wastewater treatment]	Length	8.54E-06	m
CH: slag compartment [Incineration]	Number of pieces	1.02E-06	pcs.

CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	2.18E-07	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.24E-03	kg
GLO: chemicals organic, at plant [Organics]	Mass	6.21E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.54E+04	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	7.41E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	7.05E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.52E+04	kg
Aluminium [Particles to air]	Mass	6.56E-01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.27E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	7.42E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	7.31E+01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	2.18E-06	kg
Copper (+II) [Heavy metals to air]	Mass	3.06E+00	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.94E-03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.80E-02	kg
Iron [Heavy metals to air]	Mass	1.09E+03	kg
Iron [Heavy metals to freshwater]	Mass	5.33E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	1.54E+04	kg
Methane [Organic emissions to air (VOC group)]	Mass	6.50E-03	kg
Tin (+IV) [Heavy metals to air]	Mass	5.98E+01	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	7.39E-02	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.80E-04	kg
Waste heat [Other emissions to air]	Energy	5.84E+02	MJ

Manufacturing a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	1.10E+03	kg
Cast iron part [Metal parts]	Mass	3.30E+03	kg
Copper [Metals]	Mass	1.21E+04	kg

Plastic compound (unspecified) [Plastics]	Mass	2.20E+03	kg
RER: chromium steel, at plant [Benefication]	Mass	1.10E+03	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	5.04E+02	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	3.99E+04	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	1.05E+05	MJ
RER: tap water, at user [Appropriation]	Mass	1.38E+06	kg
Steel part [Metal parts]	Mass	9.02E+04	kg
RER: electricity, at grid [Production mix]	Energy	2.02E+04	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	2.70E+03	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	1.51E+04	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	6.86E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	1.33E+03	m^3
Propulsion motor [Metal parts]	Mass	1.10E+05	kg
Waste heat [Other emissions to air]	Energy	2.01E+04	MJ

Operating and maintaining a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	6.74E+06	MJ
Lubricating oil [Operating materials]	Mass	5.28E+03	kg
Propulsion motor [Metal parts]	Mass	1.10E+05	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Propulsion motor [Metal parts]	Mass	1.10E+05	kg
Unspecified oil waste [Hazardous waste]	Mass	5.28E+03	kg

Used lubricating oil treatment of a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	1.42E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	1.07E+01	kg
Liquefied petroleum gas [LPG, at production]	Mass	1.28E+01	kg

RER: electricity [Production mix]	Energy	2.73E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	2.13E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	5.28E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	4.01E+02	kg
Sludge [Hazardous waste]	Mass	1.71E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	4.70E+03	kg

Recovering used lubricating oil of a propulsion motor after treatment [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	1.85E+00	kg
Propane [Organic intermediate products]	Mass	2.60E+00	kg
RER: electricity [Production mix]	Energy	8.85E+02	MJ
RER: natural gas [Fuels]	Energy	1.83E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	1.03E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	3.53E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	4.65E-09	kg
Asphalt flux [Organic intermediate products]	Mass	1.20E+03	kg
Base oil from re-refining [Other fuels]	Mass	8.54E+02	kg
Cadmium [Heavy metals to air]	Mass	3.15E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	7.59E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.78E+00	kg
Chromium [Heavy metals to air]	Mass	9.99E-09	kg
Electricity from waste to energy [System-dependent]	Energy	2.14E+04	MJ
Expanded clay [Minerals]	Mass	2.32E+00	kg
Flux and gas [Operating materials]	Mass	8.40E+01	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	5.19E+01	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	9.28E-04	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	4.59E-08	kg

Marine diesel oil [Other fuels]	Mass	9.17E+02	kg
Nickel [Heavy metals to air]	Mass	1.54E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.33E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	1.16E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	4.60E+01	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	9.34E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.28E-01	kg
Waste heat [Other emissions to air]	Energy	9.37E+03	MJ
Waste water - untreated [Production residues in life cycle]	Mass	5.19E+01	kg

Dismantling a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	1.64E+03	MJ
Propulsion motor [Metal parts]	Mass	1.10E+05	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	1.10E+03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.92E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.02E+01	kg
Cast iron scrap [Waste for recovery]	Mass	3.30E+03	kg
Copper scrap [Waste for recovery]	Mass	1.21E+04	kg
Dust (PM10) [Particles to air]	Mass	1.21E+00	kg
Landfill of plastic waste [Consumer waste]	Mass	0.00E+00	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.33E+00	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	5.16E+01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.65E-02	kg
Plastic (unspecified) [Waste for recovery]	Mass	2.20E+03	kg
Stainless steel scrap [Waste for recovery]	Mass	1.10E+03	kg
Steel scrap [Waste for recovery]	Mass	9.02E+04	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.52E+00	kg

Waste for disposal (unspecified) [Waste for disposal]	Mass	0.00E+00	kg

Recycling aluminium scrap of a propulsion motor - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.04E+01	kg
Aluminium scrap [Waste for recovery]	Mass	1.10E+03	kg
CH: anionic resin [Organics]	Mass	3.88E+00	kg
CH: cationic resin [Organics]	Mass	3.88E+00	kg
RER: natural gas [Fuels]	Energy	1.12E+04	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	8.74E+00	kg
RER: electricity, at grid [Production mix]	Energy	1.05E+02	MJ
Water [Water]	Mass	9.35E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	9.71E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	5.99E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	9.71E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	9.71E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.91E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.85E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.80E+01	kg

Recycling cast iron scrap of a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	5.30E+01	kg
Argon [Inorganic intermediate products]	Mass	2.95E+00	kg
Cast iron scrap [Waste for recovery]	Mass	3.30E+03	kg
GLO: charcoal, at plant [Fuels]	Mass	1.32E+02	kg
Coke, metallurgic [Organic intermediate products]	Mass	4.58E+01	kg
Dolomite [Minerals]	Mass	6.45E+01	kg
Graphite [Inorganic intermediate products]	Mass	1.05E+01	kg
Lime finelime (ground) [Minerals]	Mass	2.17E+02	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.17E+02	kg

Oxygen liquid [Inorganic intermediate products]	Mass	1.32E+02	kg
Pig iron (Fe carrier) [Metals]	Mass	4.95E+01	kg
Refractory [Minerals]	Mass	5.39E+01	kg
RER: natural gas [Fuels]	Energy	2.04E+03	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	3.74E+02	kg
RER: electricity, at grid [Production mix]	Energy	5.63E+03	MJ
Water [Water]	Mass	6.12E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.46E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.89E+00	kg
Cast iron [Metals]	Mass	5.66E-03	kg
Chromium [Heavy metals to air]	Mass	6.63E-01	kg
Dust (> PM10) [Particles to air]	Mass	5.26E+01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.85E+00	kg
Lead [Heavy metals to air]	Mass	7.91E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.29E-03	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	3.21E+01	kg
Refractory [Hazardous waste]	Mass	2.63E+03	kg
Sludge [Waste for disposal]	Mass	1.13E+01	kg
Steel works slag [Waste for recovery]	Mass	5.43E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.36E-01	kg

Recycling copper scrap of a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	1.21E+04	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	5.99E+04	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	4.07E-07	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	4.75E-08	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	4.79E-05	kg
Acetic acid [NMVOC Group to air]	Mass	7.25E-03	kg
Arsenic [Heavy metals to air]	Mass	1.69E-02	kg
Benzene [NMVOC Group to air]	Mass	5.55E-05	kg

Benzo{a}pyrene [PAH group to air]	Mass	3.17E-08	kg
Butane [NMVOC Group to air]	Mass	5.55E-02	kg
Cadmium [Heavy metals to air]	Mass	2.78E-02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.20E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.98E-01	kg
Copper [Heavy metals to air]	Mass	3.39E-01	kg
Dust (> PM10) [Particles to air]	Mass	3.15E+00	kg
Dust (PM2.5) [Particles to air]	Mass	1.14E+01	kg
Ethane [NMVOC Group to air]	Mass	8.21E-02	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.98E-03	kg
Heat, waste [unspecified]	Energy	4.55E+04	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	4.75E-02	kg
Lead [Heavy metals to air]	Mass	1.33E+00	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.99E-02	kg
Nickel [Heavy metals to air]	Mass	1.57E-03	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.19E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	5.99E-02	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	6.89E-02	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	4.48E-02	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.74E-12	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	4.79E-04	kg
Propane [NMVOC Group to air]	Mass	4.22E-02	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	9.58E-04	kg
RER: copper, secondary [Benefication]	Mass	1.21E+04	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.20E+00	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	8.98E-05	kg

Recycling stainless steel scrap of a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	7.44E+01	kg
Argon [Inorganic intermediate products]	Mass	4.13E+00	kg
GLO: charcoal, at plant [Fuels]	Mass	1.85E+02	kg

Coke, metallurgic [Organic intermediate products]	Mass	6.42E+01	kg
Dolomite [Minerals]	Mass	9.04E+01	kg
Graphite [Inorganic intermediate products]	Mass	1.48E+01	kg
Lime finelime (ground) [Minerals]	Mass	3.04E+02	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.64E+02	kg
Oxygen liquid [Inorganic intermediate products]	Mass	1.85E+02	kg
Pig iron (Fe carrier) [Metals]	Mass	6.94E+01	kg
Refractory [Minerals]	Mass	7.57E+01	kg
RER: natural gas [Fuels]	Energy	2.86E+03	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	5.24E+02	kg
Stainless steel scrap [Waste for recovery]	Mass	1.10E+03	kg
RER: electricity, at grid [Production mix]	Energy	7.89E+03	MJ
Water [Water]	Mass	8.59E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	4.86E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.11E+01	kg
Chromium [Heavy metals to air]	Mass	7.94E-03	kg
Dust (> PM10) [Particles to air]	Mass	9.30E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	7.38E+01	kg
Lead [Heavy metals to air]	Mass	5.40E-03	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	9.10E-03	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.81E-03	kg
Refractory [Hazardous waste]	Mass	4.50E+01	kg
Sludge [Waste for disposal]	Mass	1.59E+01	kg
Stainless steel (slab) [Metals]	Mass	1.08E+03	kg
Steel works slag [Waste for recovery]	Mass	7.62E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.71E-01	kg

Recycling steel scrap of a propulsion motor with EAF [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.45E+03	kg
Argon [Inorganic intermediate products]	Mass	8.06E+01	kg
GLO: charcoal, at plant [Fuels]	Mass	3.60E+03	kg

Coke, metallurgic [Organic intermediate products]	Mass	1.25E+03	kg
Dolomite [Minerals]	Mass	1.76E+03	kg
Graphite [Inorganic intermediate products]	Mass	2.88E+02	kg
Lime finelime (ground) [Minerals]	Mass	5.93E+03	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	3.19E+03	kg
Oxygen liquid [Inorganic intermediate products]	Mass	3.60E+03	kg
Pig iron (Fe carrier) [Metals]	Mass	1.35E+03	kg
Refractory [Minerals]	Mass	1.47E+03	kg
RER: natural gas [Fuels]	Energy	5.57E+04	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.02E+04	kg
Steel scrap [Waste for recovery]	Mass	9.02E+04	kg
RER: electricity, at grid [Production mix]	Energy	1.54E+05	MJ
Water [Water]	Mass	1.67E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	9.46E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.16E+02	kg
Chromium [Heavy metals to air]	Mass	1.55E-01	kg
Dust (> PM10) [Particles to air]	Mass	1.81E+01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.44E+03	kg
Lead [Heavy metals to air]	Mass	1.05E+02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.16E+01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	3.52E-02	kg
Refractory [Hazardous waste]	Mass	8.78E+02	kg
RER: steel, unalloyed [Benefication]	Mass	7.19E+04	kg
Sludge [Waste for disposal]	Mass	3.09E+02	kg
Steel works slag [Waste for recovery]	Mass	1.49E+04	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	9.18E+00	kg

Disposing metallic waste of a propulsion motor to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	2.08E+04	MJ
CH: heat from waste [Incineration]	Energy	3.01E+04	MJ
CH: waste incineration plant [Incineration]	Number of pieces	8.97E-06	pcs.

CH: process-specific burdens, slag compartment [Incineration]	Mass	5.67E+04	kg
CH: slag compartment [Incineration]	Number of pieces	1.01E-04	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	3.59E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	2.92E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.85E+00	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	3.17E+00	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.36E+01	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.50E+02	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	2.82E-01	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	1.23E-03	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	3.59E+04	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.25E+00	kg
Incineration of metallic waste [Waste for disposal]	Mass	3.59E+04	kg
Iron [Ecoinvent long-term to freshwater]	Mass	7.61E+03	kg
Iron [Heavy metals to freshwater]	Mass	1.22E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.39E-01	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	9.08E-02	kg
Solids [Ecoinvent long-term to freshwater]	Mass	9.51E+00	kg
Solids [Particles to freshwater]	Mass	4.09E-02	kg
Waste heat [Other emissions to air]	Energy	1.78E+04	MJ
Waste heat [Other emissions to freshwater]	Energy	2.93E+03	MJ

Disposing metallic waste of a propulsion motor to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	9.23E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	2.30E+02	kg

CH: disposal, paper [Incineration]	Mass	1.39E+00	kg
CH: disposal, plastics, mixture [Incineration]	Mass	1.39E+00	kg
CH: electricity from waste [Incineration]	Energy	1.23E+03	MJ
CH: electricity, at grid [Supply mix]	Energy	1.36E+03	MJ
CH: heat from waste [Incineration]	Energy	2.00E+03	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	3.57E-02	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	8.40E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	5.96E-07	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	2.38E+03	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	2.30E+02	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.34E+03	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	4.81E-07	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	2.00E-05	pcs.
CH: sewer grid [Wastewater treatment]	Length	2.00E-05	m
CH: slag compartment [Incineration]	Number of pieces	2.38E-06	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	5.10E-07	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	2.89E-03	kg
GLO: chemicals organic, at plant [Organics]	Mass	1.45E-01	kg
Metallic waste for landfill [Waste for disposal]	Mass	3.59E+04	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	1.73E-03	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.65E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	1.53E+00	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	3.55E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.31E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.73E-07	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.71E+02	kg

Copper (+II) [Heavy metals to air]	Mass	7.14E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	5.10E-06	kg
Copper (+II) [Heavy metals to freshwater]	Mass	4.52E-03	kg
Iron [Heavy metals to air]	Mass	2.54E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	6.53E-02	kg
Iron [Heavy metals to freshwater]	Mass	1.25E+02	kg
Landfill of metallic waste [Waste for disposal]	Mass	3.59E+04	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.52E-02	kg
Waste heat [Other emissions to air]	Energy	1.36E+03	MJ

Manufacturing a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Metals]	Mass	7.50E+02	kg
Cast iron part [Metal parts]	Mass	2.25E+03	kg
Copper [Metals]	Mass	8.25E+03	kg
Plastic compound (unspecified) [Plastics]	Mass	1.50E+03	kg
RER: chromium steel, at plant [Benefication]	Mass	7.50E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	3.44E+02	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	2.72E+04	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	7.18E+04	MJ
RER: tap water, at user [Appropriation]	Mass	9.38E+05	kg
Steel part [Metal parts]	Mass	6.15E+04	kg
RER: electricity, at grid [Production mix]	Energy	1.37E+04	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	1.84E+03	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	1.03E+04	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	4.68E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	9.08E+02	m^3
Thruster motor [Metal parts]	Mass	7.50E+04	kg
Waste heat [Other emissions to air]	Energy	1.37E+04	MJ

Operating and maintaining a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	6.74E+06	MJ
Lubricating oil [Operating materials]	Mass	3.96E+03	kg
Thruster motor [Metal parts]	Mass	7.50E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Thruster motor [Metal parts]	Mass	7.50E+04	kg
Unspecified oil waste [Hazardous waste]	Mass	3.96E+03	kg

Used lubricating oil treatment of a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Diesel [Refinery products]	Mass	1.06E+01	kg
Light fuel oil (0.05 wt.% S) [Refinery products]	Mass	8.02E+00	kg
Liquefied petroleum gas [LPG, at production]	Mass	9.58E+00	kg
RER: electricity [Production mix]	Energy	2.05E+05	MJ
Sulphuric acid [Inorganic intermediate products]	Mass	1.60E+01	kg
Unspecified oil waste [Hazardous waste]	Mass	3.96E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Sewage sludge (waste water processing) [Hazardous waste]	Mass	3.01E+02	kg
Sludge [Hazardous waste]	Mass	1.28E+02	kg
Treated lubricating oil [Waste for recovery]	Mass	3.53E+03	kg

Recovering used lubricating oil of a thruster motor after treatment [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Hydrogen [Inorganic intermediate products]	Mass	1.85E+00	kg
Propane [Organic intermediate products]	Mass	2.60E+00	kg
RER: electricity [Production mix]	Energy	8.85E+02	MJ
RER: natural gas [Fuels]	Energy	1.83E+04	MJ
Sodium hydroxide [Inorganic intermediate products]	Mass	1.03E+01	kg
Treated lubricating oil [Waste for recovery]	Mass	3.53E+03	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Arsenic [Heavy metals to air]	Mass	4.65E-09	kg
Asphalt flux [Organic intermediate products]	Mass	1.20E+03	kg
Base oil from re-refining [Other fuels]	Mass	8.54E+02	kg
Cadmium [Heavy metals to air]	Mass	3.15E-07	kg
Carbon dioxide [Inorganic emissions to air]	Mass	7.59E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.78E+00	kg
Chromium [Heavy metals to air]	Mass	9.99E-09	kg
Electricity from waste to energy [System-dependent]	Energy	2.14E+04	MJ
Expanded clay [Minerals]	Mass	2.32E+00	kg
Flux and gas [Operating materials]	Mass	8.40E+01	kg
Hazardous waste (unspecified) [Hazardous waste]	Mass	5.19E+01	kg
Hydrogen fluoride [Inorganic emissions to air]	Mass	9.28E-04	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	4.59E-08	kg
Marine diesel oil [Other fuels]	Mass	9.17E+02	kg
Nickel [Heavy metals to air]	Mass	1.54E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.33E+00	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	1.16E+00	kg
Production residues (unspecified) [Waste for recovery]	Mass	4.60E+01	kg
Sewage sludge (waste water processing) [Hazardous waste]	Mass	9.34E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.28E-01	kg
Waste heat [Other emissions to air]	Energy	9.37E+03	MJ
Waste water - untreated [Production residues in life cycle]	Mass	5.19E+01	kg

Dismantling a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	1.12E+03	MJ
Thruster motor [Metal parts]	Mass	7.50E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	7.50E+02	kg

Carbon dioxide [Inorganic emissions to air]	Mass	1.99E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.96E+00	kg
Cast iron scrap [Waste for recovery]	Mass	2.25E+03	kg
Copper scrap [Waste for recovery]	Mass	8.25E+03	kg
Dust (PM10) [Particles to air]	Mass	8.28E-01	kg
Landfill of plastic waste [Consumer waste]	Mass	0.00E+00	kg
Methane [Organic emissions to air (VOC group)]	Mass	9.08E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	3.52E+01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.13E-02	kg
Plastic (unspecified) [Waste for recovery]	Mass	1.50E+03	kg
Stainless steel scrap [Waste for recovery]	Mass	7.50E+02	kg
Steel scrap [Waste for recovery]	Mass	6.15E+04	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.40E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	0.00E+00	kg

Recycling aluminium scrap of a thruster motor - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.39E+01	kg
Aluminium scrap [Waste for recovery]	Mass	7.50E+02	kg
CH: anionic resin [Organics]	Mass	2.65E+00	kg
CH: cationic resin [Organics]	Mass	2.65E+00	kg
RER: natural gas [Fuels]	Energy	7.67E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	5.96E+00	kg
RER: electricity, at grid [Production mix]	Energy	7.15E+01	MJ
Water [Water]	Mass	6.37E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	6.62E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.08E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.62E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.62E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.99E+00	kg

Sulphur dioxide [Inorganic emissions to air]	Mass	3.31E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.23E+01	kg

Recycling cast iron scrap of a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	3.62E+01	kg
Argon [Inorganic intermediate products]	Mass	2.01E+00	kg
Cast iron scrap [Waste for recovery]	Mass	2.25E+03	kg
GLO: charcoal, at plant [Fuels]	Mass	8.97E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	3.12E+01	kg
Dolomite [Minerals]	Mass	4.40E+01	kg
Graphite [Inorganic intermediate products]	Mass	7.18E+00	kg
Lime finelime (ground) [Minerals]	Mass	1.48E+02	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	7.95E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	8.98E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	3.37E+01	kg
Refractory [Minerals]	Mass	3.68E+01	kg
RER: natural gas [Fuels]	Energy	1.39E+03	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	2.55E+02	kg
RER: electricity, at grid [Production mix]	Energy	3.84E+03	MJ
Water [Water]	Mass	4.18E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	2.36E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.38E+00	kg
Cast iron [Metals]	Mass	3.86E-03	kg
Chromium [Heavy metals to air]	Mass	4.52E-01	kg
Dust (> PM10) [Particles to air]	Mass	3.59E+01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.62E+00	kg
Lead [Heavy metals to air]	Mass	5.39E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	8.78E-04	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.19E+01	kg
Refractory [Hazardous waste]	Mass	1.79E+03	kg
Sludge [Waste for disposal]	Mass	7.72E+00	kg

Steel works slag [Waste for recovery]	Mass	3.71E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.29E-01	kg

Recycling copper scrap of a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	8.25E+03	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	4.08E+04	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	2.77E-07	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	3.24E-08	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	3.27E-05	kg
Acetic acid [NMVOC Group to air]	Mass	4.94E-03	kg
Arsenic [Heavy metals to air]	Mass	1.16E-02	kg
Benzene [NMVOC Group to air]	Mass	3.78E-05	kg
Benzo{a}pyrene [PAH group to air]	Mass	2.16E-08	kg
Butane [NMVOC Group to air]	Mass	3.78E-02	kg
Cadmium [Heavy metals to air]	Mass	1.90E-02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	8.17E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.13E-01	kg
Copper [Heavy metals to air]	Mass	2.31E-01	kg
Dust (> PM10) [Particles to air]	Mass	2.15E+00	kg
Dust (PM2.5) [Particles to air]	Mass	7.76E+00	kg
Ethane [NMVOC Group to air]	Mass	5.59E-02	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.35E-03	kg
Heat, waste [unspecified]	Energy	3.10E+04	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	3.24E-02	kg
Lead [Heavy metals to air]	Mass	9.08E-01	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.08E-02	kg
Nickel [Heavy metals to air]	Mass	1.07E-03	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.86E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	4.08E-02	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	4.70E-02	kg

Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	3.05E-02	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.18E-12	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	3.27E-04	kg
Propane [NMVOC Group to air]	Mass	2.88E-02	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	6.53E-04	kg
RER: copper, secondary [Benefication]	Mass	8.25E+03	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.17E-01	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	6.13E-05	kg

Recycling stainless steel scrap of a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	5.07E+01	kg
Argon [Inorganic intermediate products]	Mass	2.82E+00	kg
GLO: charcoal, at plant [Fuels]	Mass	1.26E+02	kg
Coke, metallurgic [Organic intermediate products]	Mass	4.38E+01	kg
Dolomite [Minerals]	Mass	6.17E+01	kg
Graphite [Inorganic intermediate products]	Mass	1.01E+01	kg
Lime finelime (ground) [Minerals]	Mass	2.08E+02	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.12E+02	kg
Oxygen liquid [Inorganic intermediate products]	Mass	1.26E+02	kg
Pig iron (Fe carrier) [Metals]	Mass	4.73E+01	kg
Refractory [Minerals]	Mass	5.16E+01	kg
RER: natural gas [Fuels]	Energy	1.95E+03	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	3.57E+02	kg
Stainless steel scrap [Waste for recovery]	Mass	7.50E+02	kg
RER: electricity, at grid [Production mix]	Energy	5.38E+03	MJ
Water [Water]	Mass	5.86E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.31E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.55E+00	kg
Chromium [Heavy metals to air]	Mass	5.41E-03	kg

Dust (> PM10) [Particles to air]	Mass	6.34E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.03E+01	kg
Lead [Heavy metals to air]	Mass	3.68E-03	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	6.20E-03	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.23E-03	kg
Refractory [Hazardous waste]	Mass	3.07E+01	kg
Sludge [Waste for disposal]	Mass	1.08E+01	kg
Stainless steel (slab) [Metals]	Mass	7.38E+02	kg
Steel works slag [Waste for recovery]	Mass	5.20E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.21E-01	kg

Recycling steel scrap of a thruster motor with EAF [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	9.88E+02	kg
Argon [Inorganic intermediate products]	Mass	5.49E+01	kg
GLO: charcoal, at plant [Fuels]	Mass	2.45E+03	kg
Coke, metallurgic [Organic intermediate products]	Mass	8.53E+02	kg
Dolomite [Minerals]	Mass	1.20E+03	kg
Graphite [Inorganic intermediate products]	Mass	1.96E+02	kg
Lime finelime (ground) [Minerals]	Mass	4.05E+03	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	2.17E+03	kg
Oxygen liquid [Inorganic intermediate products]	Mass	2.46E+03	kg
Pig iron (Fe carrier) [Metals]	Mass	9.22E+02	kg
Refractory [Minerals]	Mass	1.01E+03	kg
RER: natural gas [Fuels]	Energy	3.80E+04	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	6.96E+03	kg
Steel scrap [Waste for recovery]	Mass	6.15E+04	kg
RER: electricity, at grid [Production mix]	Energy	1.05E+05	MJ
Water [Water]	Mass	1.14E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	6.45E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.47E+02	kg
Chromium [Heavy metals to air]	Mass	1.06E-01	kg

Dust (> PM10) [Particles to air]	Mass	1.24E+01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	9.81E+02	kg
Lead [Heavy metals to air]	Mass	7.17E+01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.47E+01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.40E-02	kg
Refractory [Hazardous waste]	Mass	5.98E+02	kg
RER: steel, unalloyed [Benefication]	Mass	4.90E+04	kg
Sludge [Waste for disposal]	Mass	2.11E+02	kg
Steel works slag [Waste for recovery]	Mass	1.01E+04	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.26E+00	kg

Disposing metallic waste of a thruster motor to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.42E+04	MJ
CH: heat from waste [Incineration]	Energy	2.05E+04	MJ
CH: waste incineration plant [Incineration]	Number of pieces	6.12E-06	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	3.87E+04	kg
CH: slag compartment [Incineration]	Number of pieces	6.90E-05	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	2.45E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.99E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.30E+00	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	2.16E+00	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.61E+01	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.02E+02	kg
Chromium (+VI) [Ecoinvent long-term to freshwater]	Mass	1.92E-01	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	8.40E-04	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	2.45E+04	kg
Copper (+II) [Heavy metals to freshwater]	Mass	8.49E-01	kg

Incineration of metallic waste [Waste for disposal]	Mass	2.45E+04	kg
Iron [Ecoinvent long-term to freshwater]	Mass	5.19E+03	kg
Iron [Heavy metals to freshwater]	Mass	8.35E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	9.45E-02	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	6.19E-02	kg
Solids [Ecoinvent long-term to freshwater]	Mass	6.49E+00	kg
Solids [Particles to freshwater]	Mass	2.79E-02	kg
Waste heat [Other emissions to air]	Energy	1.22E+04	MJ
Waste heat [Other emissions to freshwater]	Energy	2.00E+03	MJ

Disposing metallic waste of a thruster motor to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	6.29E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	1.57E+02	kg
CH: disposal, paper [Incineration]	Mass	9.50E-01	kg
CH: disposal, plastics, mixture [Incineration]	Mass	9.50E-01	kg
CH: electricity from waste [Incineration]	Energy	8.41E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	9.25E+02	MJ
CH: heat from waste [Incineration]	Energy	1.36E+03	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	2.43E-02	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	5.73E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	4.06E-07	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	1.62E+03	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	1.57E+02	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	9.13E+02	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	3.28E-07	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	1.36E-05	pcs.
CH: sewer grid [Wastewater treatment]	Length	1.36E-05	m
CH: slag compartment [Incineration]	Number of pieces	1.62E-06	pcs.

CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	3.48E-07	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.97E-03	kg
GLO: chemicals organic, at plant [Organics]	Mass	9.89E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	2.45E+04	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	1.18E-03	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.12E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	1.05E+00	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	2.42E+04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.62E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.18E-07	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.17E+02	kg
Copper (+II) [Heavy metals to air]	Mass	4.87E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	3.48E-06	kg
Copper (+II) [Heavy metals to freshwater]	Mass	3.08E-03	kg
Iron [Heavy metals to air]	Mass	1.73E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	4.45E-02	kg
Iron [Heavy metals to freshwater]	Mass	8.49E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	2.45E+04	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.04E-02	kg
Waste heat [Other emissions to air]	Energy	9.30E+02	MJ

Manufacturing a variable frequency drive connecting a propulsion motor N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: butyrolactone [Organics]	Mass	1.22E+02	kg
Paper for corrugated board [Materials from renewable raw materials]	Mass	1.33E+03	kg
Polypropylene compound (PP) [Plastics]	Mass	7.47E+01	kg
Polyvinylchloride compound (PVC) [Plastics]	Mass	4.95E+01	kg

RER: aluminium, primary [Benefication]	Mass	3.54E+03	kg
RER: copper, primary [Benefication]	Mass	6.98E+02	kg
RER: epoxy resin, liquid [monomers]	Mass	1.62E+02	kg
RER: glass fibre, at plant [construction]	Mass	1.93E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	3.21E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	2.54E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	6.70E+03	MJ
RER: nylon 66, at plant [polymers]	Mass	7.30E+01	kg
RER: steel, low-alloyed [Benefication]	Mass	7.66E+02	kg
RER: tap water, at user [Appropriation]	Mass	8.75E+04	kg
RER: electricity, at grid [Production mix]	Energy	1.28E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	1.72E+02	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	9.59E+02	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	4.37E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	8.47E+01	m^3
Variable frequency drive [Components]	Mass	7.00E+03	kg
Waste heat [Other emissions to air]	Energy	1.28E+03	MJ

Operating a variable frequency drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Variable frequency drive [Components]	Mass	7.00E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Variable frequency drive [Components]	Mass	7.00E+03	kg

Dismantling a variable frequency drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Production mix]	Energy	1.03E+02	MJ
Variable frequency drive [Components]	Mass	7.00E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	3.54E+03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.83E+02	kg

Carbon monoxide [Inorganic emissions to air]	Mass	6.38E-01	kg
Copper scrap [Waste for recovery]	Mass	6.98E+02	kg
Dust (PM10) [Particles to air]	Mass	7.59E-02	kg
Landfill of glass/inert waste [Consumer waste]	Mass	0.00E+00	kg
Methane [Organic emissions to air (VOC group)]	Mass	8.32E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	3.23E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.03E-03	kg
Pieces of broken glass [Waste for recovery]	Mass	1.93E+02	kg
Plastic (unspecified) [Waste for recovery]	Mass	2.35E+02	kg
polypropylene (PP) [Waste for disposal]	Mass	0.00E+00	kg
Polypropylene (PP) [Waste for recovery]	Mass	7.47E+01	kg
Polyvinyl chloride (PVC) [Waste for disposal]	Mass	0.00E+00	kg
Polyvinyl chloride (PVC) [Waste for recovery]	Mass	4.95E+01	kg
RER: corrugated board, recycling fibre, double wall, at plant [cardboard & corrugated board]	Mass	1.33E+03	kg
Steel scrap [Waste for recovery]	Mass	7.66E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.20E-01	kg

Recycling aluminium scrap of a variable frequency drive connecting a propulsion motor - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	6.55E+01	kg
Aluminium scrap [Waste for recovery]	Mass	3.54E+03	kg
CH: anionic resin [Organics]	Mass	1.25E+01	kg
CH: cationic resin [Organics]	Mass	1.25E+01	kg
RER: natural gas [Fuels]	Energy	3.62E+04	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	2.81E+01	kg
RER: electricity, at grid [Production mix]	Energy	3.37E+02	MJ
Water [Water]	Mass	3.01E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	1.04E+03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.93E+03	kg

Carbon monoxide [Inorganic emissions to air]	Mass	3.12E+00	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.12E+00	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	9.36E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.56E+01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	5.79E+01	kg

Recycling copper scrap of a variable frequency drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	6.98E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	3.45E+03	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	2.34E-08	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	2.74E-09	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	2.76E-06	kg
Acetic acid [NMVOC Group to air]	Mass	4.18E-04	kg
Arsenic [Heavy metals to air]	Mass	9.77E-04	kg
Benzene [NMVOC Group to air]	Mass	3.20E-06	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.83E-09	kg
Butane [NMVOC Group to air]	Mass	3.20E-03	kg
Cadmium [Heavy metals to air]	Mass	1.60E-03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.91E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.18E-02	kg
Copper [Heavy metals to air]	Mass	1.95E-02	kg
Dust (> PM10) [Particles to air]	Mass	1.81E-01	kg
Dust (PM2.5) [Particles to air]	Mass	6.56E-01	kg
Ethane [NMVOC Group to air]	Mass	4.73E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.14E-04	kg
Heat, waste [unspecified]	Energy	2.62E+03	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	2.74E-03	kg
Lead [Heavy metals to air]	Mass	7.67E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.45E-03	kg

Nickel [Heavy metals to air]	Mass	9.07E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.42E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	3.45E-03	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	3.97E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	2.58E-03	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.00E-13	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.76E-05	kg
Propane [NMVOC Group to air]	Mass	2.43E-03	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	5.52E-05	kg
RER: copper, secondary [Benefication]	Mass	2.32E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.91E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	5.18E-06	kg

Recycling steel scrap of a variable frequency drive connecting a propulsion motor with EAF [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.23E+01	kg
Argon [Inorganic intermediate products]	Mass	6.84E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	3.05E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.06E+01	kg
Dolomite [Minerals]	Mass	1.50E+01	kg
Graphite [Inorganic intermediate products]	Mass	2.44E+00	kg
Lime finelime (ground) [Minerals]	Mass	5.04E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	2.71E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	3.06E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	1.15E+01	kg
Refractory [Minerals]	Mass	1.25E+01	kg
RER: natural gas [Fuels]	Energy	4.73E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	8.67E+01	kg
Steel scrap [Waste for recovery]	Mass	7.66E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.31E+03	MJ
Water [Water]	Mass	1.42E+01	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	8.03E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.83E+00	kg
Chromium [Heavy metals to air]	Mass	1.31E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.54E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.22E+01	kg
Lead [Heavy metals to air]	Mass	8.93E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.83E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.99E-04	kg
Refractory [Hazardous waste]	Mass	7.45E+00	kg
RER: steel, unalloyed [Benefication]	Mass	2.03E+02	kg
Sludge [Waste for disposal]	Mass	2.63E+00	kg
Steel works slag [Waste for recovery]	Mass	1.26E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	7.79E-02	kg

Disposing metallic waste of a variable frequency drive connecting a propulsion motor to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	9.65E+02	MJ
CH: heat from waste [Incineration]	Energy	1.40E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	4.16E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.63E+03	kg
CH: slag compartment [Incineration]	Number of pieces	4.69E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	1.66E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.35E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.25E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.47E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.09E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	6.94E+00	kg

Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.66E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	5.78E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	1.66E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	3.53E+02	kg
Iron [Heavy metals to freshwater]	Mass	5.68E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	6.43E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	4.21E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	4.41E-01	kg
Solids [Particles to freshwater]	Mass	1.90E-03	kg
Waste heat [Other emissions to air]	Energy	8.27E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	1.36E+02	MJ

Disposing metallic waste of a variable frequency drive connecting a propulsion motor to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	4.28E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	1.07E+01	kg
CH: disposal, paper [Incineration]	Mass	6.46E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	6.46E-02	kg
CH: electricity from waste [Incineration]	Energy	5.72E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	6.29E+01	MJ
CH: heat from waste [Incineration]	Energy	9.26E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	1.65E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	3.90E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.76E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	1.10E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	1.07E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	6.21E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	2.23E-08	pcs.

CH: landfill facility [Landfill facility]	Number of pieces	9.26E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	9.26E-07	m
CH: slag compartment [Incineration]	Number of pieces	1.10E-07	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	2.36E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.34E-04	kg
GLO: chemicals organic, at plant [Organics]	Mass	6.73E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.66E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	8.02E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	7.64E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	7.11E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.65E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.46E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	8.04E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	7.92E+00	kg
Copper (+II) [Heavy metals to air]	Mass	3.31E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	2.36E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.10E-04	kg
Iron [Heavy metals to air]	Mass	1.18E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	3.03E-03	kg
Iron [Heavy metals to freshwater]	Mass	5.78E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	1.66E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.04E-04	kg
Waste heat [Other emissions to air]	Energy	6.33E+01	MJ

Manufacturing a variable frequency drive connecting a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: butyrolactone [Organics]	Mass	8.69E+01	kg
Paper for corrugated board [Materials from renewable raw materials]	Mass	9.47E+02	kg
Polypropylene compound (PP) [Plastics]	Mass	5.34E+01	kg
Polyvinylchloride compound (PVC) [Plastics]	Mass	3.54E+01	kg
RER: aluminium, primary [Benefication]	Mass	2.53E+03	kg
RER: copper, primary [Benefication]	Mass	4.98E+02	kg
RER: epoxy resin, liquid [monomers]	Mass	1.16E+02	kg
RER: glass fibre, at plant [construction]	Mass	1.38E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	2.29E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.82E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	4.79E+03	MJ
RER: nylon 66, at plant [polymers]	Mass	5.22E+01	kg
RER: steel, low-alloyed [Benefication]	Mass	5.47E+02	kg
RER: tap water, at user [Appropriation]	Mass	6.25E+04	kg
RER: electricity, at grid [Production mix]	Energy	9.16E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	1.23E+02	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	6.85E+02	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	3.12E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	6.05E+01	m^3
Variable frequency drive [Components]	Mass	5.00E+03	kg
Waste heat [Other emissions to air]	Energy	9.15E+02	MJ

Operating a variable frequency drive connecting a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Variable frequency drive [Components]	Mass	5.00E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Variable frequency drive [Components]	Mass	5.00E+03	kg

Dismantling a variable frequency drive connecting a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Production mix]	Energy	7.47E+01	MJ
Variable frequency drive [Components]	Mass	5.00E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	8.41E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.33E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.64E-01	kg
CH: disposal, packaging paper, 13.7% water [Incineration]	Mass	6.63E+02	kg
CH: disposal, packaging paper, 13.7% water [Landfill facility]	Mass	2.84E+02	kg
Copper scrap [Waste for recovery]	Mass	1.66E+02	kg
Dust (PM10) [Particles to air]	Mass	5.52E-02	kg
Landfill of glass/inert waste [Consumer waste]	Mass	9.65E+01	kg
Landfill of plastic waste [Consumer waste]	Mass	1.18E+02	kg
Metallic waste for incineration [Waste for disposal]	Mass	1.19E+03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.19E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	6.05E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	2.34E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	7.50E-04	kg
Pieces of broken glass [Waste for recovery]	Mass	4.14E+01	kg
Plastic (unspecified) [Waste for recovery]	Mass	5.04E+01	kg
polypropylene (PP) [Waste for disposal]	Mass	3.74E+01	kg
Polypropylene (PP) [Waste for recovery]	Mass	1.60E+01	kg
Polyvinyl chloride (PVC) [Waste for disposal]	Mass	2.48E+01	kg
Polyvinyl chloride (PVC) [Waste for recovery]	Mass	1.06E+01	kg
Steel scrap [Waste for recovery]	Mass	1.82E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.60E-01	kg

Recycling aluminium scrap of a variable frequency drive connecting a thruster motor - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.56E+01	kg
Aluminium scrap [Waste for recovery]	Mass	8.41E+02	kg
CH: anionic resin [Organics]	Mass	2.97E+00	kg
CH: cationic resin [Organics]	Mass	2.97E+00	kg
RER: natural gas [Fuels]	Energy	8.60E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	6.68E+00	kg
RER: electricity, at grid [Production mix]	Energy	8.02E+01	MJ
Water [Water]	Mass	7.15E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	7.42E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.58E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.42E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	7.42E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.23E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.71E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.38E+01	kg

Recycling copper scrap of a variable frequency drive connecting a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	1.66E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	8.21E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	5.58E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	6.51E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	6.57E-07	kg
Acetic acid [NMVOC Group to air]	Mass	9.94E-05	kg
Arsenic [Heavy metals to air]	Mass	2.32E-04	kg
Benzene [NMVOC Group to air]	Mass	7.61E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	4.34E-10	kg

Butane [NMVOC Group to air]	Mass	7.61E-04	kg
Cadmium [Heavy metals to air]	Mass	3.82E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.64E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.23E-02	kg
Copper [Heavy metals to air]	Mass	4.65E-03	kg
Dust (> PM10) [Particles to air]	Mass	4.31E-02	kg
Dust (PM2.5) [Particles to air]	Mass	1.56E-01	kg
Ethane [NMVOC Group to air]	Mass	1.13E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	2.72E-05	kg
Heat, waste [unspecified]	Energy	6.24E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	6.51E-04	kg
Lead [Heavy metals to air]	Mass	1.83E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	8.21E-04	kg
Nickel [Heavy metals to air]	Mass	2.16E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	5.75E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	8.21E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	9.45E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	6.14E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	2.38E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	6.57E-06	kg
Propane [NMVOC Group to air]	Mass	5.79E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	1.31E-05	kg
RER: copper, secondary [Benefication]	Mass	1.66E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.64E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	1.23E-06	kg

Recycling steel scrap of a variable frequency drive connecting a thruster motor with EAF [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.93E+00	kg
Argon [Inorganic intermediate products]	Mass	1.63E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	7.26E+00	kg

Coke, metallurgic [Organic intermediate products]	Mass	2.53E+00	kg
Dolomite [Minerals]	Mass	3.56E+00	kg
Graphite [Inorganic intermediate products]	Mass	5.81E-01	kg
Lime finelime (ground) [Minerals]	Mass	1.20E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	6.43E+00	kg
Oxygen liquid [Inorganic intermediate products]	Mass	7.27E+00	kg
Pig iron (Fe carrier) [Metals]	Mass	2.73E+00	kg
Refractory [Minerals]	Mass	2.98E+00	kg
RER: natural gas [Fuels]	Energy	1.13E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	2.06E+01	kg
Steel scrap [Waste for recovery]	Mass	1.82E+02	kg
RER: electricity, at grid [Production mix]	Energy	3.11E+02	MJ
Water [Water]	Mass	3.38E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.91E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	4.36E-01	kg
Chromium [Heavy metals to air]	Mass	3.12E-04	kg
Dust (> PM10) [Particles to air]	Mass	3.66E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.90E+00	kg
Lead [Heavy metals to air]	Mass	2.12E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.36E-02	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	7.11E-05	kg
Refractory [Hazardous waste]	Mass	1.77E+00	kg
RER: steel, unalloyed [Benefication]	Mass	1.45E+02	kg
Sludge [Waste for disposal]	Mass	6.24E-01	kg
Steel works slag [Waste for recovery]	Mass	3.00E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.85E-02	kg

Disposing metallic waste of a variable frequency drive connecting a thruster motor to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	6.89E+02	MJ
CH: heat from waste [Incineration]	Energy	9.98E+02	MJ

CH: waste incineration plant [Incineration]	Number of pieces	2.97E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.88E+03	kg
CH: slag compartment [Incineration]	Number of pieces	3.35E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	1.19E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	9.67E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.61E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.05E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	7.81E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	4.96E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.19E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	4.13E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	1.19E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.52E+02	kg
Iron [Heavy metals to freshwater]	Mass	4.06E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.59E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	3.01E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	3.15E-01	kg
Solids [Particles to freshwater]	Mass	1.36E-03	kg
Waste heat [Other emissions to air]	Energy	5.91E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	9.72E+01	MJ

Disposing metallic waste of a variable frequency drive connecting a thruster motor to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	3.06E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	7.63E+00	kg
CH: disposal, paper [Incineration]	Mass	4.61E-02	kg

CH: disposal, plastics, mixture [Incineration]	Mass	4.61E-02	kg
CH: electricity from waste [Incineration]	Energy	4.08E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	4.50E+01	MJ
CH: heat from waste [Incineration]	Energy	6.61E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	1.18E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	2.78E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.97E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	7.88E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	7.63E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	4.44E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.59E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	6.61E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	6.61E-07	m
CH: slag compartment [Incineration]	Number of pieces	7.88E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.69E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	9.56E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	4.80E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.19E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	5.73E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	5.46E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	5.08E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.18E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.76E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	5.74E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	5.66E+00	kg

Copper (+II) [Heavy metals to air]	Mass	2.37E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.69E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.50E-04	kg
Iron [Heavy metals to air]	Mass	8.42E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.16E-03	kg
Iron [Heavy metals to freshwater]	Mass	4.13E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	1.19E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.03E-04	kg
Waste heat [Other emissions to air]	Energy	4.52E+01	MJ

Manufacturing a photovoltaic system (2 arrays, 1196 modules) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper [Metals]	Mass	1.45E+02	kg
DE: photovoltaic cell factory [production of components]	Number of pieces	7.87E-04	pcs.
Frame, aluminium, powder coated [Metal parts]	Mass	2.62E+03	kg
Glass (Sheet glass) [Minerals]	Mass	1.88E+04	kg
Lead [Metals]	Mass	8.89E+00	kg
Plastic compound (unspecified) [Plastics]	Mass	9.14E+02	kg
RER: ethylene vinyl acetate copolymer, at plant [polymers]	Mass	1.66E+03	kg
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	2.29E+03	MJ
RER: metallization paste, back side, aluminium, at plant [production of components]	Mass	1.42E+02	kg
RER: metallization paste, back side, at plant [production of components]	Mass	9.70E+00	kg
RER: metallization paste, front side, at plant [production of components]	Mass	1.46E+01	kg
RER: multi-Si wafer, at plant [production of components]	Area	2.09E+03	m^2
RER: natural gas, burned in industrial furnace [Heating systems]	Energy	9.38E+03	MJ
RER: water, completely softened, at plant [Appropriation]	Mass	2.70E+05	kg
Silicon (99%) [Metals]	Mass	8.84E+02	kg
Silver [Metals]	Mass	2.03E+01	kg
Tin (99.92%) [Metals]	Mass	3.55E+01	kg
RER: electricity, at grid [Production mix]	Energy	5.95E+04	MJ

Water (cooling water) [Operating materials]	Mass	1.97E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (unspecified) [Consumer waste]	Mass	1.52E+00	kg
CH: disposal, waste, Si waferprod., inorg, 9.4% water, to residual material landfill [Residual material landfill facility]	Mass	5.43E+02	kg
CH: treatment, PV cell production effluent [Wastewater treatment]	Volume	4.28E+02	m^3
Dust (PM2.5) [Particles to air]	Mass	5.24E+00	kg
Heat, waste [unspecified]	Energy	2.14E+05	MJ
Hydrogen chloride [Inorganic emissions to industrial soil]	Mass	5.24E-01	kg
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to industrial soil]	Mass	9.54E-03	kg
Lead scrap [Waste for recovery]	Mass	1.52E+00	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	9.84E-02	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	3.81E+02	kg
photovoltaic panel, multi-Si, at plant [Assemblies]	Mass	2.51E+04	kg
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	Mass	4.87E-01	kg
R 116 (hexafluoroethane) [Halogenated organic emissions to air]	Mass	2.33E-01	kg
Silicon dust [Particles to air]	Mass	1.43E-01	kg
Silver [Heavy metals to industrial soil]	Mass	1.52E+00	kg
Sodium (+I) [Inorganic emissions to industrial soil]	Mass	9.54E-02	kg
Tin [Waste for recovery]	Mass	1.52E+00	kg

Operating a photovoltaic system (2 arrays, 1196 modules) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	2.44E+02	MJ
photovoltaic panel, multi-Si, at plant [Assemblies]	Mass	2.51E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	5.01E+07	MJ
photovoltaic panel, multi-Si, at plant [Assemblies]	Mass	2.51E+04	kg

Dismantling a photovoltaic system (2 arrays, 1196 modules) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: electricity, at grid [Supply mix]	Energy	3.75E+02	MJ
photovoltaic panel, multi-Si, at plant [Assemblies]	Mass	2.51E+04	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	8.71E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.67E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.33E+00	kg
Copper scrap [Waste for recovery]	Mass	4.82E+01	kg
Dust (PM10) [Particles to air]	Mass	2.77E-01	kg
Landfill of glass/inert waste [Consumer waste]	Mass	1.32E+04	kg
Landfill of plastic waste [Consumer waste]	Mass	1.80E+03	kg
Lead scrap [Waste for recovery]	Mass	2.96E+00	kg
Metallic waste for incineration [Waste for disposal]	Mass	1.23E+03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.23E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.04E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.18E+01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	3.77E-03	kg
Pieces of broken glass [Waste for recovery]	Mass	5.65E+03	kg
Plastic (unspecified) [Waste for recovery]	Mass	7.73E+02	kg
silicon waste [Hazardous non organic waste for disposal]	Mass	2.94E+02	kg
silver [Waste for recovery]	Mass	6.76E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.03E-01	kg
Tin scrap [Waste for recovery]	Mass	1.18E+01	kg

Recycling aluminium scrap of a photovoltaic system (2 arrays, 1196 modules) - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.61E+01	kg
Aluminium scrap [Waste for recovery]	Mass	8.71E+02	kg

CH: anionic resin [Organics]	Mass	3.07E+00	kg
CH: cationic resin [Organics]	Mass	3.07E+00	kg
RER: natural gas [Fuels]	Energy	8.90E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	6.92E+00	kg
RER: electricity, at grid [Production mix]	Energy	8.30E+01	MJ
Water [Water]	Mass	7.40E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	7.69E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.74E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.69E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	7.69E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.31E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.84E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.42E+01	kg

Recycling copper scrap of a photovoltaic system (2 arrays, 1196 modules) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	4.82E+01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	2.39E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.62E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	1.89E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.91E-07	kg
Acetic acid [NMVOC Group to air]	Mass	2.89E-05	kg
Arsenic [Heavy metals to air]	Mass	6.75E-05	kg
Benzene [NMVOC Group to air]	Mass	2.21E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.26E-10	kg
Butane [NMVOC Group to air]	Mass	2.21E-04	kg
Cadmium [Heavy metals to air]	Mass	1.11E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.77E+01	kg

Carbon monoxide [Inorganic emissions to air]	Mass	3.58E-03	kg
Copper [Heavy metals to air]	Mass	1.35E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.25E-02	kg
Dust (PM2.5) [Particles to air]	Mass	4.53E-02	kg
Ethane [NMVOC Group to air]	Mass	3.27E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	7.90E-06	kg
Heat, waste [unspecified]	Energy	1.81E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.89E-04	kg
Lead [Heavy metals to air]	Mass	5.30E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.39E-04	kg
Nickel [Heavy metals to air]	Mass	6.26E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.67E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	2.39E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	2.74E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.78E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	6.92E-15	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.91E-06	kg
Propane [NMVOC Group to air]	Mass	1.68E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	3.82E-06	kg
RER: copper, secondary [Benefication]	Mass	4.82E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.77E-03	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	3.58E-07	kg

Recycling lead scrap of a photovoltaic system (2 arrays, 1196 modules) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Lead scrap [Waste for recovery]	Mass	2.96E+00	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	2.07E+01	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	2.01E-11	pcs.

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	5.55E-12	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	5.60E-09	kg
Acetic acid [NMVOC Group to air]	Mass	8.47E-07	kg
Arsenic [Heavy metals to air]	Mass	1.24E-04	kg
Benzene [NMVOC Group to air]	Mass	6.48E-09	kg
Benzo{a}pyrene [PAH group to air]	Mass	3.70E-12	kg
Butane [NMVOC Group to air]	Mass	6.48E-06	kg
Cadmium [Heavy metals to air]	Mass	4.14E-05	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.40E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.05E-04	kg
Dust (> PM10) [Particles to air]	Mass	3.14E-02	kg
Dust (PM2.5) [Particles to air]	Mass	2.34E-02	kg
Ethane [NMVOC Group to air]	Mass	9.59E-06	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	2.32E-07	kg
Heat, waste [unspecified]	Energy	5.32E+00	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	5.55E-06	kg
Lead [Heavy metals to air]	Mass	1.54E-02	kg
Lead secondary [Metals]	Mass	2.96E+00	kg
Methane [Organic emissions to air (VOC group)]	Mass	7.00E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.90E-04	kg
Nitrous oxide [Inorganic emissions to air]	Mass	7.00E-06	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	8.05E-06	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	9.47E-06	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	2.03E-16	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.60E-08	kg
Propane [NMVOC Group to air]	Mass	4.94E-06	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	1.12E-07	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.40E-04	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	1.05E-08	kg
Zinc [Heavy metals to air]	Mass	9.17E-05	kg

Recycling silicon scrap of a photovoltaic system (2 arrays, 1196 modules) N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, slag from MG silicon production, 0% water [Landfill facility]	Mass	1.09E+00	kg
DE: silica sand, at plant [Additives]	Mass	1.18E+02	kg
GLO: charcoal, at plant [Fuels]	Mass	7.41E+00	kg
RER: graphite, at plant [Inorganics]	Mass	4.36E+00	kg
RER: hard coal coke, at plant [Fuels]	Energy	1.01E+03	MJ
RER: oxygen, liquid, at plant [Inorganics]	Mass	8.72E-01	kg
RER: petroleum coke, at refinery [Fuels]	Mass	2.18E+01	kg
RER: silicone plant [Inorganics]	Number of pieces	4.36E-10	pcs.
RER: wood chips, mixed, u=120%, at forest [Fuels]	Volume	1.42E-01	m^3
silicon waste [Hazardous non organic waste for disposal]	Mass	2.94E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.73E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	6.76E-05	kg
Antimony [Heavy metals to air]	Mass	3.42E-07	kg
Arsenic [Heavy metals to air]	Mass	4.11E-07	kg
Boron [Inorganic emissions to air]	Mass	1.22E-05	kg
Cadmium [Heavy metals to air]	Mass	1.37E-08	kg
Calcium [Consumer waste]	Mass	3.38E-05	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.26E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.72E-02	kg
Chlorine [Inorganic emissions to air]	Mass	3.42E-06	kg
Chromium [Heavy metals to air]	Mass	3.42E-07	kg
Cyanide (unspecified) [Inorganic emissions to air]	Mass	2.99E-04	kg
Dust (> PM10) [Particles to air]	Mass	3.38E-01	kg
Fluorine [Inorganic emissions to air]	Mass	1.69E-06	kg
Heat, waste [unspecified]	Energy	3.11E+03	MJ
Hydrogen fluoride [Inorganic emissions to air]	Mass	2.18E-02	kg
Hydrogen sulphide [Inorganic emissions to air]	Mass	2.18E-02	kg
Iron [Heavy metals to air]	Mass	1.69E-04	kg
Lead [Heavy metals to air]	Mass	1.50E-05	kg
Mercury [Heavy metals to air]	Mass	3.42E-07	kg

Nitrogen oxides [Inorganic emissions to air]	Mass	4.25E-01	kg
NMVOC (unspecified) [NMVOC Group to air]	Mass	4.18E-03	kg
NO: MG-silicon, at plant [Benefication]	Mass	1.09E+02	kg
Silicon dust [Particles to air]	Mass	3.27E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.34E-01	kg
Tin [Heavy metals to air]	Mass	3.42E-07	kg

Recycling tin scrap of a photovoltaic system (2 arrays, 1196 modules) [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Blasting abrasive [Operating materials]	Mass	7.69E-01	kg
CH: disposal, dust, unalloyed EAF steel [Residual material landfill facility]	Mass	5.50E-01	kg
CH: gypsum, mineral, at mine [others]	Mass	4.82E-02	kg
CH: limestone, at mine [Additives]	Mass	1.39E+00	kg
GLO: diesel, burned in building machine [Machines]	Energy	1.65E+02	MJ
GLO: mine, iron [Benefication]	Number of pieces	3.99E-10	pcs.
GLO: non-ferrous metal mine, underground [Benefication]	Number of pieces	2.16E-13	pcs.
RER: anode, aluminium electrolysis [Benefication]	Mass	3.95E-03	kg
RER: heat, heavy fuel oil, at industrial furnace [Heating systems]	Energy	2.16E+01	MJ
Tin scrap [Waste for recovery]	Mass	1.18E+01	kg
RER: electricity, at grid [Production mix]	Energy	3.06E+02	MJ
UCTE: hard coal mix, at regional storage [Fuels]	Mass	1.14E+00	kg
Water [Water]	Mass	4.21E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.76E+00	kg
Dust (> PM10) [Particles to air]	Mass	7.24E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.51E-01	kg
Dust (PM2.5) [Particles to air]	Mass	7.24E-02	kg
Heat, waste [unspecified]	Energy	3.42E+02	MJ
RER: tin, at regional storage [Benefication]	Mass	1.01E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.12E+00	kg

Disposing metallic waste of a photovoltaic system (2 arrays, 1196 modules) to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	7.16E+02	MJ
CH: heat from waste [Incineration]	Energy	1.04E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	3.09E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.95E+03	kg
CH: slag compartment [Incineration]	Number of pieces	3.48E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	1.23E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.00E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.67E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.09E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	8.11E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	5.15E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.23E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	4.28E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	1.23E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.62E+02	kg
Iron [Heavy metals to freshwater]	Mass	4.21E-03	kg
Lead (+II) [Ecoinvent long-term to freshwater]	Mass	4.69E-01	kg
Lead (+II) [Heavy metals to freshwater]	Mass	8.57E-06	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.77E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	3.12E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	3.27E-01	kg
Solids [Particles to freshwater]	Mass	1.41E-03	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	1.32E-05	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	8.22E-01	kg
Waste heat [Other emissions to air]	Energy	6.14E+02	MJ

Waste heat [Other emissions to freshwater]	Energy	1.01E+02	MJ

Disposing metallic waste of a photovoltaic system (2 arrays, 1196 modules) to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	3.17E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	7.93E+00	kg
CH: disposal, paper [Incineration]	Mass	4.79E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	4.79E-02	kg
CH: electricity from waste [Incineration]	Energy	4.24E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	4.67E+01	MJ
CH: heat from waste [Incineration]	Energy	6.87E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	1.23E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	2.89E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.05E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	8.19E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	7.93E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	4.61E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.65E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	6.87E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	6.87E-07	m
CH: slag compartment [Incineration]	Number of pieces	8.19E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.75E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	9.93E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	4.99E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.23E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	5.95E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	5.67E+00	MJ

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	5.27E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.22E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.83E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	5.96E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	5.88E+00	kg
Copper (+II) [Heavy metals to air]	Mass	2.46E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.75E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.56E-04	kg
Iron [Heavy metals to air]	Mass	8.74E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	2.25E-03	kg
Iron [Heavy metals to freshwater]	Mass	4.28E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	1.23E+03	kg
Lead (+II) [Heavy metals to air]	Mass	4.68E-01	kg
Lead (+II) [Ecoinvent long-term to freshwater]	Mass	5.06E-07	kg
Lead (+II) [Heavy metals to freshwater]	Mass	1.52E-04	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.22E-04	kg
Tin (+IV) [Heavy metals to air]	Mass	4.80E+00	kg
Tin (+IV) [Heavy metals to freshwater]	Mass	5.94E-03	kg
Tin, ion [Ecoinvent long-term to freshwater]	Mass	1.44E-05	kg
Waste heat [Other emissions to air]	Energy	4.69E+01	MJ

Manufacturing an inverter for a photovoltaic system with 2 arrays, 1196 modules [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: capacitor, electrolyte type, > 2cm height, at plant [Parts]	Mass	3.33E+01	kg
GLO: capacitor, film, through-hole mounting, at plant [Parts]	Mass	4.44E+01	kg
GLO: capacitor, Tantalum-, through-hole mounting, at plant [Parts]	Mass	2.99E+00	kg
GLO: connector, clamp connection, at plant [Parts]	Mass	3.08E+01	kg
GLO: diode, glass-, through-hole mounting, at plant [Parts]	Mass	6.12E+00	kg

GLO: inductor, ring core choke type, at plant [Parts]	Mass	4.57E+01	kg
GLO: integrated circuit, IC, logic type, at plant [Parts]	Mass	3.64E+00	kg
GLO: printed wiring board, through-hole, at plant [Module]	Area	2.92E+01	m^2
GLO: resistor, metal film type, through-hole mounting, at plant [Parts]	Mass	6.51E-01	kg
GLO: transistor, wired, small size, through-hole mounting, at plant [Parts]	Mass	4.95E+00	kg
RER: corrugated board, mixed fibre [cardboard & corrugated board]	Mass	3.25E+02	kg
RER: fleece, polyethylene, at plant [polymers]	Mass	7.81E+00	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.25E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	9.88E+02	MJ
RER: metal working factory [General manufacturing]	Number of pieces	1.17E-06	pcs.
RER: natural gas, burned in boiler [Heating systems]	Energy	2.60E+03	MJ
RER: polystyrene foam slab, at plant [Manufacturing]	Mass	3.90E+01	kg
RER: polyvinylchloride, at regional storage [polymers]	Mass	1.30E+00	kg
RER: section bar extrusion, aluminium [Processing]	Mass	1.82E+02	kg
RER: sheet rolling, steel [Processing]	Mass	1.28E+03	kg
RER: styrene-acrylonitrile copolymer, SAN, at plant [polymers]	Mass	1.30E+00	kg
RER: tap water, at user [Appropriation]	Mass	3.40E+04	kg
RER: wire drawing, copper [Processing]	Mass	7.17E+02	kg
RER: electricity, at grid [Production mix]	Energy	2.76E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, packaging cardboard, 19.6% water [Incineration]	Mass	3.25E+02	kg
CH: disposal, polyethylene, 0.4% water [Incineration]	Mass	4.03E+01	kg
CH: disposal, polystyrene, 0.2% water [Incineration]	Mass	7.81E+00	kg
GLO: disposal, treatment of printed wiring boards [Recycling]	Mass	2.22E+02	kg
Heat, waste [unspecified]	Energy	9.93E+03	MJ
inverter, 100kW [Components]	Mass	2.72E+03	kg

Operating an inverter for a photovoltaic system with 2 arrays, 1196 modules N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Inverter, 250 kW [Components]	Mass	2.72E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Inverter, 250 kW [Components]	Mass	2.72E+03	kg

Dismantling an inverter for a photovoltaic system with 2 arrays, 1196 modules N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: mechanical treatment plant, WEEE scrap [Recycling]	Number of pieces	1.45E-07	pcs.
inverter, 100kW [Components]	Mass	2.72E+03	kg
RER: electricity, at grid [Production mix]	Energy	8.38E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	2.54E-04	kg
Aluminium scrap [Waste for recovery]	Mass	6.07E+01	kg
Antimony [Heavy metals to air]	Mass	2.16E-05	kg
Bromine [Inorganic emissions to air]	Mass	4.32E-05	kg
Cadmium [Heavy metals to air]	Mass	4.32E-06	kg
Carbon dioxide [Inorganic emissions to air]	Mass	7.23E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.53E-01	kg
CH: disposal, packaging paper, 13.7% water [Incineration]	Mass	2.28E+02	kg
CH: disposal, packaging paper, 13.7% water [Landfill facility]	Mass	9.76E+01	kg
CH: disposal, polyvinylchloride, 0.2% water [Incineration]	Mass	3.90E-01	kg
Chlorine [Inorganic emissions to air]	Mass	5.85E-05	kg
Chromium [Heavy metals to air]	Mass	9.41E-06	kg
Copper [Heavy metals to air]	Mass	7.63E-05	kg
Copper scrap [Waste for recovery]	Mass	2.39E+02	kg
Dust (PM10) [Particles to air]	Mass	3.01E-02	kg
electronic scrap [Waste for recovery]	Mass	1.82E+02	kg
Iron [Heavy metals to air]	Mass	8.77E-04	kg
Lead [Heavy metals to air]	Mass	7.50E-05	kg
Mercury [Heavy metals to air]	Mass	2.16E-08	kg
Metallic waste for incineration [Waste for disposal]	Mass	7.24E+02	kg

Metallic waste for landfill [Waste for disposal]	Mass	7.24E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.29E-02	kg
Nickel [Heavy metals to air]	Mass	2.92E-05	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.28E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	4.08E-04	kg
Phosphorus [Inorganic emissions to air]	Mass	2.54E-06	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	3.43E-07	kg
Polystyrene (PS) [Waste for recovery]	Mass	1.17E+01	kg
Polystyrene (PS, unspecified) [Consumer waste]	Mass	2.73E+01	kg
Polyvinylchloride (PVC, unspecified) [Consumer waste]	Mass	9.11E-01	kg
Steel scrap [Waste for recovery]	Mass	4.25E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.71E-02	kg
Tin [Heavy metals to air]	Mass	5.47E-05	kg
Waste heat [Other emissions to air]	Energy	4.32E+01	MJ
Zinc [Heavy metals to air]	Mass	2.38E-04	kg

Recycling aluminium scrap of an inverter for a photovoltaic system with 2 arrays, 1196 modules [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.12E+00	kg
Aluminium scrap [Waste for recovery]	Mass	6.07E+01	kg
CH: anionic resin [Organics]	Mass	2.14E-01	kg
CH: cationic resin [Organics]	Mass	2.14E-01	kg
RER: natural gas [Fuels]	Energy	6.20E+02	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	4.82E-01	kg
RER: electricity, at grid [Production mix]	Energy	5.78E+00	MJ
Water [Water]	Mass	5.16E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	5.35E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.30E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.35E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.35E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.61E-01	kg

Sulphur dioxide [Inorganic emissions to air]	Mass	2.68E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	9.93E-01	kg

Recycling copper scrap of an inverter for a photovoltaic system with 2 arrays, 1196 modules [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	2.39E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	1.18E+03	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	8.03E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	9.37E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	9.46E-07	kg
Acetic acid [NMVOC Group to air]	Mass	1.43E-04	kg
Arsenic [Heavy metals to air]	Mass	3.34E-04	kg
Benzene [NMVOC Group to air]	Mass	1.09E-06	kg
Benzo{a}pyrene [PAH group to air]	Mass	6.25E-10	kg
Butane [NMVOC Group to air]	Mass	1.09E-03	kg
Cadmium [Heavy metals to air]	Mass	5.49E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.36E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.77E-02	kg
Copper [Heavy metals to air]	Mass	6.69E-03	kg
Dust (> PM10) [Particles to air]	Mass	6.21E-02	kg
Dust (PM2.5) [Particles to air]	Mass	2.25E-01	kg
Ethane [NMVOC Group to air]	Mass	1.62E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	3.91E-05	kg
Heat, waste [unspecified]	Energy	8.98E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	9.37E-04	kg
Lead [Heavy metals to air]	Mass	2.63E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.18E-03	kg
Nickel [Heavy metals to air]	Mass	3.10E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	8.27E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.18E-03	kg

Pentane (n-pentane) [NMVOC Group to air]	Mass	1.36E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	8.84E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	3.43E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	9.46E-06	kg
Propane [NMVOC Group to air]	Mass	8.33E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	1.89E-05	kg
RER: copper, secondary [Benefication]	Mass	2.39E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.36E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	1.77E-06	kg

Recycling steel scrap of an inverter for a photovoltaic system with 2 arrays, 1196 modules [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	6.82E+00	kg
Argon [Inorganic intermediate products]	Mass	3.79E-01	kg
Charcoal [Materials from renewable raw materials]	Mass	1.69E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	5.89E+00	kg
Dolomite [Minerals]	Mass	8.30E+00	kg
Graphite [Inorganic intermediate products]	Mass	1.35E+00	kg
Lime finelime (ground) [Minerals]	Mass	2.79E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.50E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	1.70E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	6.37E+00	kg
Refractory [Minerals]	Mass	6.94E+00	kg
RER: natural gas, high pressure, at consumer [Fuels]	Energy	2.62E+02	MJ
RER: steam, for chemical processes, at plant [Auxiliary material]	Mass	4.81E+01	kg
Steel scrap [Waste for recovery]	Mass	4.25E+02	kg
RER: electricity, at grid [Production mix]	Energy	7.24E+02	MJ
Water [Water]	Mass	7.88E+00	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	4.46E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.02E+00	kg
Chromium [Heavy metals to air]	Mass	7.29E-04	kg
Dust (> PM10) [Particles to air]	Mass	8.53E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.77E+00	kg
Lead [Heavy metals to air]	Mass	4.95E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.02E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.66E-04	kg
Refractory [Hazardous waste]	Mass	4.13E+00	kg
RER: steel, unalloyed [Benefication]	Mass	3.39E+02	kg
Sludge [Waste for disposal]	Mass	1.46E+00	kg
Steel works slag [Waste for recovery]	Mass	6.99E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.32E-02	kg

Disposing metallic waste of an inverter for a photovoltaic system with 2 arrays, 1196 modules to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	4.20E+02	MJ
CH: heat from waste [Incineration]	Energy	6.08E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.81E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.14E+03	kg
CH: slag compartment [Incineration]	Number of pieces	2.04E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	7.24E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	5.89E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	9.78E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	6.39E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.76E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.02E+00	kg

Copper (+II) [Ecoinvent long-term to freshwater]	Mass	7.24E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.51E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	7.24E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.54E+02	kg
Iron [Heavy metals to freshwater]	Mass	2.47E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.80E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.83E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.92E-01	kg
Solids [Particles to freshwater]	Mass	8.26E-04	kg
Waste heat [Other emissions to air]	Energy	3.60E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	5.92E+01	MJ

Disposing metallic waste of an inverter for a photovoltaic system with 2 arrays, 1196 modules to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.86E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	4.65E+00	kg
CH: disposal, paper [Incineration]	Mass	2.81E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	2.81E-02	kg
CH: electricity from waste [Incineration]	Energy	2.49E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	2.74E+01	MJ
CH: heat from waste [Incineration]	Energy	4.03E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	7.20E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	1.69E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.20E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	4.80E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	4.65E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.70E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	9.70E-09	pcs.

CH: landfill facility [Landfill facility]	Number of pieces	4.03E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	4.03E-07	m
CH: slag compartment [Incineration]	Number of pieces	4.80E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.03E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	5.82E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	2.93E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	7.24E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	3.49E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	3.32E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	3.09E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	7.17E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.07E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	3.50E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.45E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.44E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.03E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	9.12E-05	kg
Iron [Heavy metals to air]	Mass	5.13E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.32E-03	kg
Iron [Heavy metals to freshwater]	Mass	2.51E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	7.24E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.06E-04	kg
Waste heat [Other emissions to air]	Energy	2.75E+01	MJ

Manufacturing cathodes of a 1MW lithium ion battery system [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium foil [Metals]	Mass	3.28E+02	kg

CH: water, deionised, at plant [Appropriation]	Mass	1.35E+02	kg
GLO: lithium hydroxide, at plant [Inorganics]	Mass	1.56E+02	kg
Iron sulphate dissolution [Inorganic intermediate products]	Mass	3.83E+02	kg
RER: chemical plant, organics [Organics]	Number of pieces	2.70E-07	pcs.
RER: ethylene glycol, at plant [Organics]	Mass	9.36E+01	kg
RER: heat, natural gas, at industrial furnace [Heating systems]	Energy	4.36E+02	MJ
RER: phosphoric acid, industrial grade [Inorganics]	Mass	1.35E+02	kg
RER: electricity, at grid [Production mix]	Energy	4.86E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
cathode, lithium ion battery, lithium iron phosphate [Intermediate products]	Mass	6.75E+02	kg
Sewage sludge [Waste for disposal]	Mass	7.11E-02	kg
Waste heat [Other emissions to industrial soil]	Energy	4.86E+00	MJ

Manufacturing graphite anodes of a 1MW lithium ion battery system [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: treatment, sewage [Wastewater treatment]	Volume	5.53E-02	m^3
CH: water, deionised, at plant [Appropriation]	Mass	2.20E+02	kg
CN: electricity, at grid [Supply mix]	Energy	3.75E+00	MJ
CN: graphite, battery grade, at plant [Inorganics]	Mass	2.57E+02	kg
GLO: Carbon black, at plant [Inorganics]	Mass	8.25E+00	kg
RER: chemical plant, organics [Organics]	Number of pieces	2.08E-07	pcs.
RER: heat, natural gas, at industrial furnace [Heating systems]	Energy	6.33E+02	MJ
RER: sheet rolling, copper [Processing]	Mass	4.55E+02	kg
RER: sulphuric acid, liquid, at plant [Inorganics]	Mass	4.20E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CN: Anode, lithium-ion battery, graphite, at plant [Parts]	Mass	5.20E+02	kg
Waste heat [Other emissions to air]	Energy	3.75E+00	MJ
Water vapour [Inorganic emissions to air]	Mass	2.20E+02	kg

Manufacturing separators of a 1MW lithium ion battery system [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, residues, shredder fraction from manual dismantling, in MSWI [Incineration]	Mass	6.45E+00	kg
CN: electricity, at grid [Supply mix]	Energy	8.60E-01	MJ
DE: silica sand, at plant [Additives]	Mass	2.61E+01	kg
GLO: hexafluorethane, at plant [Organics]	Mass	3.13E+00	kg
RER: acetone, liquid, at plant [Organics]	Mass	1.72E+00	kg
RER: chemical plant, organics [Organics]	Number of pieces	4.78E-08	pcs.
RER: fleece, polyethylene, at plant [polymers]	Mass	4.19E+01	kg
RER: heat, natural gas, at industrial furnace [Heating systems]	Energy	2.31E+01	MJ
RER: phthalic anhydride, at plant [Organics]	Mass	3.48E+01	kg
US: polyvinylfluoride, at plant [Organics]	Mass	2.30E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acetone (dimethylcetone) [NMVOC Group to air]	Mass	1.72E+00	kg
CN: separator, lithium-ion battery, at plant [Parts]	Mass	1.19E+02	kg
Waste heat [Other emissions to air]	Energy	8.60E-01	MJ

Manufacturing casings of a 1MW lithium ion battery system			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	9.09E+00	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	7.21E+02	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	1.90E+03	MJ
RER: tap water, at user [Appropriation]	Mass	2.48E+04	kg
Steel cast part [Metal parts]	Mass	1.99E+03	kg
RER: electricity, at grid [Production mix]	Energy	1.01E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	4.86E+01	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	2.72E+02	kg

CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	1.24E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	2.40E+01	m^3
steel casing [Valuable substances]	Mass	1.99E+03	kg
Waste heat [Other emissions to air]	Energy	3.63E+02	MJ

Manufacturing a 1MW lithium ion battery system [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Casing [Metal parts]	Mass	1.99E+03	kg
cathode, lithium ion battery, lithium iron phosphate [Intermediate products]	Mass	6.75E+02	kg
CN: Anode, lithium-ion battery, graphite, at plant [Parts]	Mass	5.20E+02	kg
CN: lithium hexafluorophosphate, at plant [Inorganics]	Mass	4.47E+02	kg
CN: separator, lithium-ion battery, at plant [Parts]	Mass	1.19E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Lithium ion battery (Type LiFePO4) [Valuable substances]	Mass	3.85E+03	kg

Operating a 1MW lithium ion battery system [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	4.10E+07	MJ
Lithium ion battery (Type LiFePO4) [Valuable substances]	Mass	3.85E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Energy unspecific [Energy resources]	Energy	4.08E+07	MJ
Lithium ion battery (Type LiFePO4) [Valuable substances]	Mass	3.85E+03	kg

Dismantling and treating a 1MW lithium ion battery system [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, plastics, mixture [Incineration]	Mass	7.71E+02	kg
Lithium ion battery (Type LiFePO4) [Valuable substances]	Mass	3.85E+03	kg
RER: sodium hydroxide, 50% in H2O, production mix, at plant [Inorganics]	Mass	1.35E+03	kg

SE: facilities blister-copper conversion, secondary copper [Benefication]	Number of pieces	1.93E-06	pcs.
RER: electricity, at grid [Production mix]	Energy	1.11E+04	MJ
Water [Water]	Mass	3.85E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	3.28E+02	kg
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	2.30E+01	kg
CH: disposal, polyvinylfluoride, 0.2% water [Incineration]	Mass	1.25E+02	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.26E-01	kg
Copper scrap [Waste for recovery]	Mass	4.55E+02	kg
Dust (> PM10) [Particles to air]	Mass	3.42E+02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.99E+03	kg
Dust (PM2.5) [Particles to air]	Mass	1.88E+02	kg
Steel scrap [Waste for recovery]	Mass	3.26E-02	kg
Sulphate [Inorganic emissions to freshwater]	Mass	1.50E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	7.21E+02	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	2.93E-01	kg
Waste heat [Other emissions to air]	Energy	9.02E+03	MJ

Recycling aluminium scrap of a 1MW lithium ion battery system - ingot production [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	6.07E+00	kg
Aluminium scrap [Waste for recovery]	Mass	3.28E+02	kg
CH: anionic resin [Organics]	Mass	1.16E+00	kg
CH: cationic resin [Organics]	Mass	1.16E+00	kg
RER: natural gas [Fuels]	Energy	3.35E+03	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	2.60E+00	kg
RER: electricity, at grid [Production mix]	Energy	3.12E+01	MJ
Water [Water]	Mass	2.78E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	2.89E+02	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.78E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.89E-01	kg

Dust (PM2,5 - PM10) [Particles to air]	Mass	2.89E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	8.67E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.45E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	5.36E+00	kg

Recycling copper scrap of a 1MW lithium ion battery system [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	4.55E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	2.25E+03	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.53E-08	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	1.79E-09	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.80E-06	kg
Acetic acid [NMVOC Group to air]	Mass	2.72E-04	kg
Arsenic [Heavy metals to air]	Mass	6.37E-04	kg
Benzene [NMVOC Group to air]	Mass	2.08E-06	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.19E-09	kg
Butane [NMVOC Group to air]	Mass	2.08E-03	kg
Cadmium [Heavy metals to air]	Mass	1.05E-03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	4.50E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.38E-02	kg
Copper [Heavy metals to air]	Mass	1.27E-02	kg
Dust (> PM10) [Particles to air]	Mass	1.18E-01	kg
Dust (PM2.5) [Particles to air]	Mass	4.28E-01	kg
Ethane [NMVOC Group to air]	Mass	3.08E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	7.45E-05	kg
Heat, waste [unspecified]	Energy	1.71E+03	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.79E-03	kg
Lead [Heavy metals to air]	Mass	5.00E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.25E-03	kg
Nickel [Heavy metals to air]	Mass	5.91E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.58E-01	kg

Nitrous oxide [Inorganic emissions to air]	Mass	2.25E-03	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	2.59E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.68E-03	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	6.53E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.80E-05	kg
Propane [NMVOC Group to air]	Mass	1.59E-03	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	3.60E-05	kg
RER: copper, secondary [Benefication]	Mass	4.55E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.50E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	3.38E-06	kg

Recycling steel scrap of a 1MW lithium ion battery system with EAF [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	3.19E+01	kg
Argon [Inorganic intermediate products]	Mass	1.77E+00	kg
GLO: charcoal, at plant [Fuels]	Mass	7.92E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	2.76E+01	kg
Dolomite [Minerals]	Mass	3.88E+01	kg
Graphite [Inorganic intermediate products]	Mass	6.33E+00	kg
Lime fineline (ground) [Minerals]	Mass	1.31E+02	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	7.02E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	7.93E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	2.98E+01	kg
Refractory [Minerals]	Mass	3.25E+01	kg
RER: natural gas [Fuels]	Energy	1.23E+03	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	2.25E+02	kg
Steel scrap [Waste for recovery]	Mass	1.99E+03	kg
RER: electricity, at grid [Production mix]	Energy	3.39E+03	MJ
Water [Water]	Mass	3.69E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	2.08E+02	kg

Carbon monoxide [Inorganic emissions to air]	Mass	4.75E+00	kg
Chromium [Heavy metals to air]	Mass	3.41E-03	kg
Dust (> PM10) [Particles to air]	Mass	3.99E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	3.17E+01	kg
Lead [Heavy metals to air]	Mass	2.32E+00	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.76E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	7.75E-04	kg
Refractory [Hazardous waste]	Mass	1.93E+01	kg
RER: steel, unalloyed [Benefication]	Mass	1.58E+03	kg
Sludge [Waste for disposal]	Mass	6.81E+00	kg
Steel works slag [Waste for recovery]	Mass	3.27E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.02E-01	kg

Disposing metallic scrap of a 1MW lithium ion battery system to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	5.34E+02	MJ
CH: heat from waste [Incineration]	Energy	7.73E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.30E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.46E+03	kg
CH: slag compartment [Incineration]	Number of pieces	2.60E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	9.22E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	7.49E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.24E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	8.13E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	6.06E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.84E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	9.22E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	3.20E-02	kg

Incineration of metallic waste [Waste for disposal]	Mass	9.22E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.95E+02	kg
Iron [Heavy metals to freshwater]	Mass	3.14E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.56E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	2.33E-03	kg
Phosphate [Ecoinvent long-term to freshwater]	Mass	2.99E-02	kg
Phosphate [Inorganic emissions to freshwater]	Mass	4.98E-05	kg
Solids [Ecoinvent long-term to freshwater]	Mass	2.44E-01	kg
Solids [Particles to freshwater]	Mass	1.05E-03	kg
Sulphate [Ecoinvent long-term to freshwater]	Mass	1.91E+00	kg
Sulphate [Inorganic emissions to freshwater]	Mass	1.92E-01	kg
Waste heat [Other emissions to air]	Energy	4.58E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	7.53E+01	MJ

Disposing metallic scrap of a 1MW lithium ion battery system to landfill N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	2.37E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	5.92E+00	kg
CH: disposal, paper [Incineration]	Mass	3.58E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	3.58E-02	kg
CH: electricity from waste [Incineration]	Energy	3.17E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	3.48E+01	MJ
CH: heat from waste [Incineration]	Energy	5.12E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	9.16E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	2.16E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.53E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	6.11E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	5.92E+00	kg

CH: process-specific burdens, slag compartment [Incineration]	Mass	3.44E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.24E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	5.12E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	5.12E-07	m
CH: slag compartment [Incineration]	Number of pieces	6.11E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.31E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	7.41E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	3.72E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	9.22E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	4.44E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	4.23E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	3.94E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	9.12E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.36E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.45E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	4.39E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.83E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.31E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.16E-04	kg
Iron [Heavy metals to air]	Mass	6.53E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.68E-03	kg
Iron [Heavy metals to freshwater]	Mass	3.20E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	9.22E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.90E-04	kg
Waste heat [Other emissions to air]	Energy	3.50E+01	MJ

Manufacturing a rectifier [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: capacitor, electrolyte type, > 2cm height, at plant [Parts]	Mass	1.04E+01	kg
GLO: capacitor, film, through-hole mounting, at plant [Parts]	Mass	1.39E+01	kg
GLO: capacitor, Tantalum-, through-hole mounting, at plant [Parts]	Mass	9.35E-01	kg
GLO: connector, clamp connection, at plant [Parts]	Mass	9.63E+00	kg
GLO: diode, glass-, through-hole mounting, at plant [Parts]	Mass	1.91E+00	kg
GLO: inductor, ring core choke type, at plant [Parts]	Mass	1.43E+01	kg
GLO: integrated circuit, IC, logic type, at plant [Parts]	Mass	1.14E+00	kg
GLO: printed wiring board, through-hole, at plant [Module]	Area	9.13E+00	m^2
GLO: resistor, metal film type, through-hole mounting, at plant [Parts]	Mass	2.03E-01	kg
GLO: transistor, wired, small size, through-hole mounting, at plant [Parts]	Mass	1.54E+00	kg
RER: corrugated board, mixed fibre [cardboard & corrugated board]	Mass	1.02E+02	kg
RER: fleece, polyethylene, at plant [polymers]	Mass	2.44E+00	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	3.89E+00	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	3.09E+02	MJ
RER: metal working factory [General manufacturing]	Number of pieces	3.65E-07	pcs.
RER: natural gas, burned in boiler [Heating systems]	Energy	8.13E+02	MJ
RER: polystyrene foam slab, at plant [Manufacturing]	Mass	1.22E+01	kg
RER: polyvinylchloride, at regional storage [polymers]	Mass	4.06E-01	kg
RER: section bar extrusion, aluminium [Processing]	Mass	5.69E+01	kg
RER: sheet rolling, steel [Processing]	Mass	3.98E+02	kg
RER: styrene-acrylonitrile copolymer, SAN, at plant [polymers]	Mass	4.06E-01	kg
RER: tap water, at user [Appropriation]	Mass	1.06E+04	kg
RER: wire drawing, copper [Processing]	Mass	2.24E+02	kg
RER: electricity, at grid [Production mix]	Energy	8.62E+02	MJ

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, packaging cardboard, 19.6% water [Incineration]	Mass	1.02E+02	kg
CH: disposal, polyethylene, 0.4% water [Incineration]	Mass	1.26E+01	kg
CH: disposal, polystyrene, 0.2% water [Incineration]	Mass	2.44E+00	kg
GLO: disposal, treatment of printed wiring boards [Recycling]	Mass	6.92E+01	kg
Heat, waste [unspecified]	Energy	3.10E+03	MJ
Rectifier [Components]	Mass	8.50E+02	kg

Operating a rectifier [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Rectifier [Components]	Mass	8.50E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Rectifier [Components]	Mass	8.50E+02	kg

Dismantling a rectifier [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: mechanical treatment plant, WEEE scrap [Recycling]	Number of pieces	4.54E-08	pcs.
Rectifier [Components]	Mass	8.50E+02	kg
RER: electricity, at grid [Production mix]	Energy	2.62E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	7.94E-05	kg
Aluminium scrap [Waste for recovery]	Mass	1.89E+01	kg
Antimony [Heavy metals to air]	Mass	6.75E-06	kg
Bromine [Inorganic emissions to air]	Mass	1.35E-05	kg
Cadmium [Heavy metals to air]	Mass	1.35E-06	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.26E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.89E-02	kg
CH: disposal, packaging paper, 13.7% water [Incineration]	Mass	7.11E+01	kg
CH: disposal, packaging paper, 13.7% water [Landfill facility]	Mass	3.05E+01	kg
CH: disposal, polyvinylchloride, 0.2% water [Incineration]	Mass	1.22E-01	kg

Chlorine [Inorganic emissions to air]	Mass	1.83E-05	kg
Chromium [Heavy metals to air]	Mass	2.94E-06	kg
Copper [Heavy metals to air]	Mass	2.38E-05	kg
Copper scrap [Waste for recovery]	Mass	7.46E+01	kg
Dust (PM10) [Particles to air]	Mass	9.38E-03	kg
electronic scrap [Waste for recovery]	Mass	5.67E+01	kg
Iron [Heavy metals to air]	Mass	2.74E-04	kg
Lead [Heavy metals to air]	Mass	2.34E-05	kg
Mercury [Heavy metals to air]	Mass	6.75E-09	kg
Metallic waste for incineration [Waste for disposal]	Mass	2.26E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	2.26E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.03E-02	kg
Nickel [Heavy metals to air]	Mass	9.13E-06	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	3.99E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.28E-04	kg
Phosphorus [Inorganic emissions to air]	Mass	7.94E-07	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.07E-07	kg
Polystyrene (PS) [Waste for recovery]	Mass	3.66E+00	kg
Polystyrene (PS, unspecified) [Consumer waste]	Mass	8.53E+00	kg
Polyvinylchloride (PVC, unspecified) [Consumer waste]	Mass	2.84E-01	kg
Steel scrap [Waste for recovery]	Mass	1.33E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	2.72E-02	kg
Tin [Heavy metals to air]	Mass	1.71E-05	kg
Waste heat [Other emissions to air]	Energy	1.35E+01	MJ
Zinc [Heavy metals to air]	Mass	7.43E-05	kg

Recycling aluminium scrap of a rectifier [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	3.51E-01	kg
Aluminium scrap [Waste for recovery]	Mass	1.89E+01	kg
CH: anionic resin [Organics]	Mass	6.69E-02	kg
CH: cationic resin [Organics]	Mass	6.69E-02	kg
RER: natural gas [Fuels]	Energy	1.94E+02	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	1.50E-01	kg
RER: electricity, at grid [Production mix]	Energy	1.81E+00	MJ

Water [Water]	Mass	1.61E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	1.67E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.03E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.67E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.67E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	5.02E-02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.36E-02	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	3.10E-01	kg

Recycling copper scrap of a rectifier [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	7.46E+01	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	3.69E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	2.51E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	2.93E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	2.95E-07	kg
Acetic acid [NMVOC Group to air]	Mass	4.47E-05	kg
Arsenic [Heavy metals to air]	Mass	1.04E-04	kg
Benzene [NMVOC Group to air]	Mass	3.42E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.95E-10	kg
Butane [NMVOC Group to air]	Mass	3.42E-04	kg
Cadmium [Heavy metals to air]	Mass	1.71E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	7.38E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.54E-03	kg
Copper [Heavy metals to air]	Mass	2.09E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.94E-02	kg
Dust (PM2.5) [Particles to air]	Mass	7.01E-02	kg
Ethane [NMVOC Group to air]	Mass	5.06E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.22E-05	kg
Heat, waste [unspecified]	Energy	2.81E+02	MJ

Hexane (isomers) [NMVOC Group to air]	Mass	2.93E-04	kg
Lead [Heavy metals to air]	Mass	8.20E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.69E-04	kg
Nickel [Heavy metals to air]	Mass	9.69E-06	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.58E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	3.69E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	4.24E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	2.76E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.07E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.95E-06	kg
Propane [NMVOC Group to air]	Mass	2.60E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	5.91E-06	kg
RER: copper, secondary [Benefication]	Mass	7.46E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	7.38E-03	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	5.54E-07	kg

Recycling steel scrap of a rectifier [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.13E+00	kg
Argon [Inorganic intermediate products]	Mass	1.18E-01	kg
Charcoal [Materials from renewable raw materials]	Mass	5.29E+00	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.84E+00	kg
Dolomite [Minerals]	Mass	2.59E+00	kg
Graphite [Inorganic intermediate products]	Mass	4.23E-01	kg
Lime finelime (ground) [Minerals]	Mass	8.73E+00	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	4.69E+00	kg
Oxygen liquid [Inorganic intermediate products]	Mass	5.29E+00	kg
Pig iron (Fe carrier) [Metals]	Mass	1.99E+00	kg
Refractory [Minerals]	Mass	2.17E+00	kg

RER: natural gas, high pressure, at consumer [Fuels]	Energy	8.20E+01	MJ
RER: steam, for chemical processes, at plant [Auxiliary material]	Mass	1.50E+01	kg
Steel scrap [Waste for recovery]	Mass	1.33E+02	kg
RER: electricity, at grid [Production mix]	Energy	2.26E+02	MJ
Water [Water]	Mass	2.46E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.39E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.17E-01	kg
Chromium [Heavy metals to air]	Mass	2.28E-04	kg
Dust (> PM10) [Particles to air]	Mass	2.67E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.12E+00	kg
Lead [Heavy metals to air]	Mass	1.55E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.18E-02	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.18E-05	kg
Refractory [Hazardous waste]	Mass	1.29E+00	kg
RER: steel, unalloyed [Benefication]	Mass	3.52E+01	kg
Sludge [Waste for disposal]	Mass	4.55E-01	kg
Steel works slag [Waste for recovery]	Mass	2.18E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.35E-02	kg

Disposing metallic waste of a rectifier to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.31E+02	MJ
CH: heat from waste [Incineration]	Energy	1.90E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	5.65E-08	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	3.57E+02	kg
CH: slag compartment [Incineration]	Number of pieces	6.38E-07	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	2.26E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	1.84E+02	kg

Carbon monoxide [Inorganic emissions to air]	Mass	3.05E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	1.99E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.49E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	9.43E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	2.26E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	7.85E-03	kg
Incineration of metallic waste [Waste for disposal]	Mass	2.26E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	4.79E+01	kg
Iron [Heavy metals to freshwater]	Mass	7.71E-04	kg
Methane [Organic emissions to air (VOC group)]	Mass	8.73E-04	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	5.72E-04	kg
Solids [Ecoinvent long-term to freshwater]	Mass	5.99E-02	kg
Solids [Particles to freshwater]	Mass	2.58E-04	kg
Waste heat [Other emissions to air]	Energy	1.12E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	1.85E+01	MJ
Zinc (+II) [Heavy metals to freshwater]	Mass	1.36E-06	kg
Zinc, ion [Ecoinvent long-term to freshwater]	Mass	4.57E-02	kg

Disposing metallic waste of a rectifier to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	5.81E-01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	1.45E+00	kg
CH: disposal, paper [Incineration]	Mass	8.77E-03	kg
CH: disposal, plastics, mixture [Incineration]	Mass	8.77E-03	kg
CH: electricity from waste [Incineration]	Energy	7.77E+00	MJ
CH: electricity, at grid [Supply mix]	Energy	8.55E+00	MJ
CH: heat from waste [Incineration]	Energy	1.26E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	2.25E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	5.29E+00	MJ

CH: waste incineration plant [Incineration]	Number of pieces	3.75E-09	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	1.50E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	1.45E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	8.43E+00	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	3.03E-09	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	1.26E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	1.26E-07	m
CH: slag compartment [Incineration]	Number of pieces	1.50E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	3.21E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.82E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	9.14E-04	kg
Metallic waste for landfill [Waste for disposal]	Mass	2.26E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	1.09E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.04E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	9.66E-03	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	2.24E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.35E-03	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.09E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.08E+00	kg
Copper (+II) [Heavy metals to air]	Mass	4.50E-02	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	3.21E-08	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.85E-05	kg
Iron [Heavy metals to air]	Mass	1.60E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	4.12E-04	kg
Iron [Heavy metals to freshwater]	Mass	7.85E-01	kg
Landfill of metallic waste [Waste for disposal]	Mass	2.26E+02	kg

Methane [Organic emissions to air (VOC group)]	Mass	9.57E-05	kg
Waste heat [Other emissions to air]	Energy	8.59E+00	MJ

Manufacturing a 24-pulse transformer used together with the drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: aluminium, primary [Benefication]	Mass	9.73E+03	kg
RER: copper, primary [Benefication]	Mass	2.04E+03	kg
RER: epoxy resin, liquid [monomers]	Mass	7.20E+03	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	9.98E+01	MJ
RER: injection moulding [Processing]	Mass	9.93E+03	kg
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	7.91E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	2.09E+04	MJ
RER: polycarbonate, at plant [polymers]	Mass	2.73E+03	kg
RER: steel, low-alloyed [Benefication]	Mass	9.72E+01	kg
RER: tap water, at user [Appropriation]	Mass	2.73E+05	kg
RER: wire drawing, copper [Processing]	Mass	2.14E+03	kg
RER: electricity, at grid [Production mix]	Energy	3.99E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	5.34E+02	kg
CH: disposal, solid waste, 22.9% water [Incineration]	Mass	1.09E+03	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	1.36E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	2.64E+02	m^3
GLO: transformer, high voltage use, at plant [Parts]	Mass	2.18E+04	kg
Heat, waste [unspecified]	Energy	3.99E+03	MJ

Operating a 24-pulse transformer used together with the drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	2.18E+04	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	2.18E+04	kg

Dismantling a 24-pulse transformer used together with the drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	2.18E+04	kg
RER: electricity, at grid [Production mix]	Energy	3.25E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	3.24E+03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	5.79E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.02E+00	kg
Copper scrap [Waste for recovery]	Mass	6.81E+02	kg
Dust (PM10) [Particles to air]	Mass	2.41E-01	kg
Landfill of plastic waste [Consumer waste]	Mass	6.95E+03	kg
Metallic waste for incineration [Waste for disposal]	Mass	3.95E+03	kg
Metallic waste for landfill [Waste for disposal]	Mass	3.95E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.64E-01	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.02E+01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	3.27E-03	kg
Plastic (unspecified) [Waste for recovery]	Mass	2.98E+03	kg
Steel scrap [Waste for recovery]	Mass	3.24E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.98E-01	kg

Recycling aluminium scrap of a 24-pulse transformer used together with the drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	6.01E+01	kg
Aluminium scrap [Waste for recovery]	Mass	3.24E+03	kg

CH: anionic resin [Organics]	Mass	1.14E+01	kg
CH: cationic resin [Organics]	Mass	1.14E+01	kg
RER: natural gas [Fuels]	Energy	3.31E+04	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	2.57E+01	kg
RER: electricity, at grid [Production mix]	Energy	3.09E+02	MJ
Water [Water]	Mass	2.75E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	2.86E+03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.76E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.86E+00	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.86E+00	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	8.58E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.43E+01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	5.30E+01	kg

Recycling copper scrap of a 24-pulse transformer used together with the drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	6.81E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	3.37E+03	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	2.29E-08	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	2.67E-09	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	2.69E-06	kg
Acetic acid [NMVOC Group to air]	Mass	4.08E-04	kg
Arsenic [Heavy metals to air]	Mass	9.53E-04	kg
Benzene [NMVOC Group to air]	Mass	3.12E-06	kg
Benzo{a}pyrene [PAH group to air]	Mass	1.78E-09	kg
Butane [NMVOC Group to air]	Mass	3.12E-03	kg
Cadmium [Heavy metals to air]	Mass	1.57E-03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	6.74E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.05E-02	kg

Copper [Heavy metals to air]	Mass	1.91E-02	kg
Dust (> PM10) [Particles to air]	Mass	1.77E-01	kg
Dust (PM2.5) [Particles to air]	Mass	6.40E-01	kg
Ethane [NMVOC Group to air]	Mass	4.62E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.12E-04	kg
Heat, waste [unspecified]	Energy	2.56E+03	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	2.67E-03	kg
Lead [Heavy metals to air]	Mass	7.49E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.37E-03	kg
Nickel [Heavy metals to air]	Mass	8.85E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	2.36E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	3.37E-03	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	3.87E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	2.52E-03	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	9.77E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.69E-05	kg
Propane [NMVOC Group to air]	Mass	2.37E-03	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	5.39E-05	kg
RER: copper, secondary [Benefication]	Mass	6.81E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.74E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	5.05E-06	kg

Recycling steel scrap of a 24-pulse transformer used together with the drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	5.20E-01	kg
Argon [Inorganic intermediate products]	Mass	2.89E-02	kg
GLO: charcoal, at plant [Fuels]	Mass	1.29E+00	kg
Coke, metallurgic [Organic intermediate products]	Mass	4.49E-01	kg
Dolomite [Minerals]	Mass	6.32E-01	kg
Graphite [Inorganic intermediate products]	Mass	1.03E-01	kg

Lime finelime (ground) [Minerals]	Mass	2.13E+00	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.14E+00	kg
Oxygen liquid [Inorganic intermediate products]	Mass	1.29E+00	kg
Pig iron (Fe carrier) [Metals]	Mass	4.85E-01	kg
Refractory [Minerals]	Mass	5.29E-01	kg
RER: natural gas [Fuels]	Energy	2.00E+01	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	3.67E+00	kg
Steel scrap [Waste for recovery]	Mass	3.24E+01	kg
RER: electricity, at grid [Production mix]	Energy	5.52E+01	MJ
Water [Water]	Mass	6.01E-01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.40E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.74E-02	kg
Chromium [Heavy metals to air]	Mass	5.55E-05	kg
Dust (> PM10) [Particles to air]	Mass	6.51E-03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	5.16E-01	kg
Lead [Heavy metals to air]	Mass	3.78E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	7.76E-03	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.26E-05	kg
Refractory [Hazardous waste]	Mass	3.15E-01	kg
RER: steel, unalloyed [Benefication]	Mass	2.58E+01	kg
Sludge [Waste for disposal]	Mass	1.11E-01	kg
Steel works slag [Waste for recovery]	Mass	5.33E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.29E-03	kg

Disposing metallic waste of a 24-pulse transformer used together with the drive connecting a propulsion motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	2.29E+03	MJ
CH: heat from waste [Incineration]	Energy	3.32E+03	MJ
CH: waste incineration plant [Incineration]	Number of pieces	9.88E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	6.25E+03	kg
CH: slag compartment [Incineration]	Number of pieces	1.11E-05	pcs.

Metallic waste for incineration [Waste for disposal]	Mass	3.95E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	3.21E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.34E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	3.49E-01	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.60E+00	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.65E+01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	3.95E+03	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.37E-01	kg
Incineration of metallic waste [Waste for disposal]	Mass	3.95E+03	kg
Iron [Ecoinvent long-term to freshwater]	Mass	8.38E+02	kg
Iron [Heavy metals to freshwater]	Mass	1.35E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.53E-02	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.00E-02	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.05E+00	kg
Solids [Particles to freshwater]	Mass	4.51E-03	kg
Waste heat [Other emissions to air]	Energy	1.97E+03	MJ
Waste heat [Other emissions to freshwater]	Energy	3.23E+02	MJ

Disposing metallic waste of a 24-pulse transformer used together with the drive connecting a propulsion motor to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.02E+01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	2.54E+01	kg
CH: disposal, paper [Incineration]	Mass	1.53E-01	kg
CH: disposal, plastics, mixture [Incineration]	Mass	1.53E-01	kg
CH: electricity from waste [Incineration]	Energy	1.36E+02	MJ
CH: electricity, at grid [Supply mix]	Energy	1.49E+02	MJ
CH: heat from waste [Incineration]	Energy	2.20E+02	MJ

CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	3.93E-03	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	9.25E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	6.56E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	2.62E+02	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	2.54E+01	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.47E+02	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	5.30E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	2.20E-06	pcs.
CH: sewer grid [Wastewater treatment]	Length	2.20E-06	m
CH: slag compartment [Incineration]	Number of pieces	2.62E-07	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	5.61E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	3.18E-04	kg
GLO: chemicals organic, at plant [Organics]	Mass	1.60E-02	kg
Metallic waste for landfill [Waste for disposal]	Mass	3.95E+03	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	1.91E-04	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.81E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	1.69E-01	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	3.91E+03	kg
Carbon monoxide [Inorganic emissions to air]	Mass	5.85E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.91E-08	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.88E+01	kg
Copper (+II) [Heavy metals to air]	Mass	7.87E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	5.61E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	4.98E-04	kg

Iron [Heavy metals to air]	Mass	2.80E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	7.20E-03	kg
Iron [Heavy metals to freshwater]	Mass	1.37E+01	kg
Landfill of metallic waste [Waste for disposal]	Mass	3.95E+03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.67E-03	kg
Waste heat [Other emissions to air]	Energy	1.50E+02	MJ

Manufacturing a 12-pulse transformer used together with the drive connecting a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
RER: aluminium, primary [Benefication]	Mass	1.61E+03	kg
RER: copper, primary [Benefication]	Mass	3.37E+02	kg
RER: epoxy resin, liquid [monomers]	Mass	1.19E+03	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.65E+01	MJ
RER: injection moulding [Processing]	Mass	1.64E+03	kg
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.31E+03	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	3.45E+03	MJ
RER: polycarbonate, at plant [polymers]	Mass	4.50E+02	kg
RER: steel, low-alloyed [Benefication]	Mass	1.61E+01	kg
RER: tap water, at user [Appropriation]	Mass	4.50E+04	kg
RER: wire drawing, copper [Processing]	Mass	3.54E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.83E+02	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	8.82E+01	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	2.25E+01	kg
CH: disposal, plastics, mixture [Incineration]	Mass	1.80E+02	kg
CH: treatment, sewage [Wastewater treatment]	Volume	4.36E+01	m^3
GLO: transformer, high voltage use, at plant [Parts]	Mass	3.60E+03	kg
Heat, waste [unspecified]	Energy	6.59E+02	MJ

Operating a 12-pulse transformer used together with the drive connecting a thruster motor N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	3.60E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	3.60E+03	kg

Dismantling a 12-pulse transformer used together with the drive connecting a thruster motor N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	3.60E+03	kg
RER: electricity, at grid [Production mix]	Energy	5.37E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium scrap [Waste for recovery]	Mass	1.61E+03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	9.56E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.34E-01	kg
Copper scrap [Waste for recovery]	Mass	3.37E+02	kg
Dust (PM10) [Particles to air]	Mass	3.97E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	4.36E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.69E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	5.40E-04	kg
Plastic (unspecified) [Waste for recovery]	Mass	1.64E+03	kg
Steel scrap [Waste for recovery]	Mass	1.61E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.15E-01	kg

Recycling aluminium scrap of a 12-pulse transformer used together with the drive connecting a thruster motor N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.98E+01	kg
Aluminium scrap [Waste for recovery]	Mass	1.61E+03	kg

CH: anionic resin [Organics]	Mass	5.67E+00	kg
CH: cationic resin [Organics]	Mass	5.67E+00	kg
RER: natural gas [Fuels]	Energy	1.64E+04	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	1.28E+01	kg
RER: electricity, at grid [Production mix]	Energy	1.53E+02	MJ
Water [Water]	Mass	1.37E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	1.42E+03	kg
Carbon dioxide [Inorganic emissions to air]	Mass	8.75E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.42E+00	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.42E+00	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.26E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	7.09E+00	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	2.63E+01	kg

Recycling copper scrap of a 12-pulse transformer used together with the drive connecting a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	3.37E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	1.67E+03	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	1.13E-08	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	1.32E-09	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.34E-06	kg
Acetic acid [NMVOC Group to air]	Mass	2.02E-04	kg
Arsenic [Heavy metals to air]	Mass	4.72E-04	kg
Benzene [NMVOC Group to air]	Mass	1.55E-06	kg
Benzo{a}pyrene [PAH group to air]	Mass	8.84E-10	kg
Butane [NMVOC Group to air]	Mass	1.55E-03	kg
Cadmium [Heavy metals to air]	Mass	7.76E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.34E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.51E-02	kg

Copper [Heavy metals to air]	Mass	9.45E-03	kg
Dust (> PM10) [Particles to air]	Mass	8.77E-02	kg
Dust (PM2.5) [Particles to air]	Mass	3.17E-01	kg
Ethane [NMVOC Group to air]	Mass	2.29E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	5.53E-05	kg
Heat, waste [unspecified]	Energy	1.27E+03	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.32E-03	kg
Lead [Heavy metals to air]	Mass	3.71E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.67E-03	kg
Nickel [Heavy metals to air]	Mass	4.39E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.17E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.67E-03	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	1.92E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	1.25E-03	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	4.84E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.34E-05	kg
Propane [NMVOC Group to air]	Mass	1.18E-03	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	2.67E-05	kg
RER: copper, secondary [Benefication]	Mass	3.37E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.34E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	2.51E-06	kg

Recycling steel scrap of a 12-pulse transformer used together with the drive connecting a thruster motor [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	2.58E-01	kg
Argon [Inorganic intermediate products]	Mass	1.43E-02	kg
GLO: charcoal, at plant [Fuels]	Mass	6.40E-01	kg
Coke, metallurgic [Organic intermediate products]	Mass	2.23E-01	kg
Dolomite [Minerals]	Mass	3.14E-01	kg
Graphite [Inorganic intermediate products]	Mass	5.12E-02	kg
Lime finelime (ground) [Minerals]	Mass	1.06E+00	kg

Nitrogen liquid [Inorganic intermediate products]	Mass	5.67E-01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	6.41E-01	kg
Pig iron (Fe carrier) [Metals]	Mass	2.41E-01	kg
Refractory [Minerals]	Mass	2.62E-01	kg
RER: natural gas [Fuels]	Energy	9.92E+00	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	1.82E+00	kg
Steel scrap [Waste for recovery]	Mass	1.61E+01	kg
RER: electricity, at grid [Production mix]	Energy	2.74E+01	MJ
Water [Water]	Mass	2.98E-01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	1.68E+00	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.84E-02	kg
Chromium [Heavy metals to air]	Mass	2.75E-05	kg
Dust (> PM10) [Particles to air]	Mass	3.23E-03	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	2.56E-01	kg
Lead [Heavy metals to air]	Mass	1.87E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.85E-03	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	6.27E-06	kg
Refractory [Hazardous waste]	Mass	1.56E-01	kg
RER: steel, unalloyed [Benefication]	Mass	4.26E+00	kg
Sludge [Waste for disposal]	Mass	5.50E-02	kg
Steel works slag [Waste for recovery]	Mass	2.64E+00	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.63E-03	kg

Disposing metallic waste of a 12-pulse transformer used together with the drive connecting a thruster motor to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	3.78E+02	MJ
CH: heat from waste [Incineration]	Energy	5.48E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.63E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.03E+03	kg
CH: slag compartment [Incineration]	Number of pieces	1.84E-06	pcs.

Metallic waste for incineration [Waste for disposal]	Mass	6.53E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	5.31E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	8.81E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	5.76E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	4.29E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	2.72E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	6.53E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.27E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	6.53E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.38E+02	kg
Iron [Heavy metals to freshwater]	Mass	2.23E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.52E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	1.65E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	1.73E-01	kg
Solids [Particles to freshwater]	Mass	7.44E-04	kg
Waste heat [Other emissions to air]	Energy	3.24E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	5.33E+01	MJ

Disposing metallic waste of a 12-pulse transformer used together with the drive connecting a thruster motor to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	1.68E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	4.19E+00	kg
CH: disposal, paper [Incineration]	Mass	2.53E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	2.53E-02	kg
CH: electricity from waste [Incineration]	Energy	2.24E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	2.47E+01	MJ
CH: heat from waste [Incineration]	Energy	3.63E+01	MJ

CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	6.49E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	1.53E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.08E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	4.33E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	4.19E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	2.44E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	8.75E-09	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	3.63E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	3.63E-07	m
CH: slag compartment [Incineration]	Number of pieces	4.33E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	9.27E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	5.25E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	2.64E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	6.53E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	3.15E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	3.00E+00	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	2.79E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	6.46E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	9.66E-03	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	3.15E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.11E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.30E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	9.27E-08	kg
Copper (+II) [Heavy metals to freshwater]	Mass	8.23E-05	kg
Iron [Heavy metals to air]	Mass	4.62E+01	kg

Iron [Ecoinvent long-term to freshwater]	Mass	1.19E-03	kg
Iron [Heavy metals to freshwater]	Mass	2.27E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	6.53E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	2.76E-04	kg
Waste heat [Other emissions to air]	Energy	2.48E+01	MJ

Manufacturing a 400kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: ferrite, at plant [Parts]	Mass	6.34E+02	kg
RER: copper, primary [Benefication]	Mass	1.33E+02	kg
RER: epoxy resin, liquid [monomers]	Mass	4.69E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	7.24E+00	MJ
RER: injection moulding [Processing]	Mass	6.47E+02	kg
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	5.74E+02	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	1.51E+03	MJ
RER: polycarbonate, at plant [polymers]	Mass	1.78E+02	kg
RER: steel, low-alloyed [Benefication]	Mass	1.66E+02	kg
RER: tap water, at user [Appropriation]	Mass	1.98E+04	kg
RER: wire drawing, copper [Processing]	Mass	1.39E+02	kg
RER: electricity, at grid [Production mix]	Energy	8.04E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	3.87E+01	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	9.86E+00	kg
CH: disposal, plastics, mixture [Incineration]	Mass	7.91E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	1.91E+01	m^3
GLO: transformer, high voltage use, at plant [Parts]	Mass	1.58E+03	kg
Heat, waste [unspecified]	Energy	2.89E+02	MJ

Operating a 400kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	1.58E+03	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	1.58E+03	kg

Dismantling a 400kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	1.58E+03	kg
RER: electricity, at grid [Production mix]	Energy	2.36E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	4.20E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.47E-01	kg
Copper scrap [Waste for recovery]	Mass	1.33E+02	kg
Dust (PM10) [Particles to air]	Mass	1.74E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.91E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	7.41E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	2.37E-04	kg
Plastic (unspecified) [Waste for recovery]	Mass	6.47E+02	kg
Steel scrap [Waste for recovery]	Mass	8.00E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	5.06E-02	kg

Recycling copper scrap of a 400kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	1.33E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	6.59E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	4.47E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	5.23E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	5.27E-07	kg
Acetic acid [NMVOC Group to air]	Mass	7.97E-05	kg
Arsenic [Heavy metals to air]	Mass	1.86E-04	kg

Benzene [NMVOC Group to air]	Mass	6.10E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	3.49E-10	kg
Butane [NMVOC Group to air]	Mass	6.10E-04	kg
Cadmium [Heavy metals to air]	Mass	3.06E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.32E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	9.88E-03	kg
Copper [Heavy metals to air]	Mass	3.73E-03	kg
Dust (> PM10) [Particles to air]	Mass	3.46E-02	kg
Dust (PM2.5) [Particles to air]	Mass	1.25E-01	kg
Ethane [NMVOC Group to air]	Mass	9.03E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	2.18E-05	kg
Heat, waste [unspecified]	Energy	5.01E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	5.23E-04	kg
Lead [Heavy metals to air]	Mass	1.46E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	6.59E-04	kg
Nickel [Heavy metals to air]	Mass	1.73E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.61E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	6.59E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	7.58E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	4.93E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.91E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	5.27E-06	kg
Propane [NMVOC Group to air]	Mass	4.65E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	1.05E-05	kg
RER: copper, secondary [Benefication]	Mass	4.43E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.32E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	9.88E-07	kg

Recycling steel scrap of a 400kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.29E+01	kg
Argon [Inorganic intermediate products]	Mass	7.15E-01	kg

GLO: charcoal, at plant [Fuels]	Mass	3.19E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	1.11E+01	kg
Dolomite [Minerals]	Mass	1.56E+01	kg
Graphite [Inorganic intermediate products]	Mass	2.55E+00	kg
Lime finelime (ground) [Minerals]	Mass	5.26E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	2.83E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	3.19E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	1.20E+01	kg
Refractory [Minerals]	Mass	1.31E+01	kg
RER: natural gas [Fuels]	Energy	4.95E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	9.06E+01	kg
Steel scrap [Waste for recovery]	Mass	8.00E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.36E+03	MJ
Water [Water]	Mass	1.49E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	8.40E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.91E+00	kg
Chromium [Heavy metals to air]	Mass	1.37E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.61E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	1.28E+01	kg
Lead [Heavy metals to air]	Mass	9.33E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.92E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	3.12E-04	kg
Refractory [Hazardous waste]	Mass	7.79E+00	kg
RER: steel, unalloyed [Benefication]	Mass	2.13E+02	kg
Sludge [Waste for disposal]	Mass	2.74E+00	kg
Steel works slag [Waste for recovery]	Mass	1.32E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	8.14E-02	kg

Disposing metallic waste of a 400kW distribution transformer to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.80E+02	MJ
CH: heat from waste [Incineration]	Energy	2.61E+02	MJ

CH: waste incineration plant [Incineration]	Number of pieces	7.77E-08	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	4.91E+02	kg
CH: slag compartment [Incineration]	Number of pieces	8.77E-07	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	3.11E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon monoxide [Inorganic emissions to air]	Mass	4.20E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	2.74E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	2.04E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.30E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	3.11E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.08E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	3.11E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	6.59E+01	kg
Iron [Heavy metals to freshwater]	Mass	1.06E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.20E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	7.86E-04	kg
Solids [Ecoinvent long-term to freshwater]	Mass	8.24E-02	kg
Solids [Particles to freshwater]	Mass	3.54E-04	kg
Waste heat [Other emissions to air]	Energy	1.54E+02	MJ
Waste heat [Other emissions to freshwater]	Energy	2.54E+01	MJ

Disposing metallic waste of a 400kW distribution transformer to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	7.99E-01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	2.00E+00	kg
CH: disposal, paper [Incineration]	Mass	1.21E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	1.21E-02	kg

CH: electricity from waste [Incineration]	Energy	1.07E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	1.17E+01	MJ
CH: heat from waste [Incineration]	Energy	1.73E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	3.09E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	7.27E+00	MJ
CH: waste incineration plant [Incineration]	Number of pieces	5.16E-09	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	2.06E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	2.00E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.16E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	4.16E-09	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	1.73E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	1.73E-07	m
CH: slag compartment [Incineration]	Number of pieces	2.06E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	4.41E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	2.50E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	1.26E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	3.11E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	1.43E+00	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	1.50E-05	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon monoxide [Inorganic emissions to air]	Mass	4.60E-03	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.50E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.48E+00	kg
Copper (+II) [Heavy metals to air]	Mass	6.19E-02	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	4.41E-08	kg
Copper (+II) [Heavy metals to freshwater]	Mass	3.92E-05	kg
Iron [Heavy metals to air]	Mass	2.20E+01	kg

Iron [Ecoinvent long-term to freshwater]	Mass	5.66E-04	kg
Iron [Heavy metals to freshwater]	Mass	1.08E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	3.11E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.31E-04	kg
Waste heat [Other emissions to air]	Energy	1.18E+01	MJ

Manufacturing a 250kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: ferrite, at plant [Parts]	Mass	5.00E+02	kg
RER: copper, primary [Benefication]	Mass	1.05E+02	kg
RER: epoxy resin, liquid [monomers]	Mass	3.70E+02	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	5.59E+00	MJ
RER: injection moulding [Processing]	Mass	5.10E+02	kg
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	4.43E+02	MJ
RER: natural gas, burned in boiler [Heating systems]	Energy	1.17E+03	MJ
RER: polycarbonate, at plant [polymers]	Mass	1.40E+02	kg
RER: steel, low-alloyed [Benefication]	Mass	1.05E+02	kg
RER: tap water, at user [Appropriation]	Mass	1.53E+04	kg
RER: wire drawing, copper [Processing]	Mass	1.10E+02	kg
RER: electricity, at grid [Production mix]	Energy	6.21E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: disposal, hazardous waste, 25% water [hazardous waste incineration]	Mass	2.99E+01	kg
CH: disposal, solid waste, 22.9% water [Landfill facility]	Mass	7.61E+00	kg
CH: disposal, plastics, mixture [Incineration]	Mass	6.11E+01	kg
CH: treatment, sewage [Wastewater treatment]	Volume	1.48E+01	m^3
GLO: transformer, high voltage use, at plant [Parts]	Mass	1.22E+03	kg
Heat, waste [unspecified]	Energy	2.23E+02	MJ

Operating a 250kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	1.22E+03	kg

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	1.22E+03	kg

Dismantling a 250kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: transformer, high voltage use, at plant [Parts]	Mass	1.22E+03	kg
RER: electricity, at grid [Production mix]	Energy	1.82E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	3.24E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.13E-01	kg
Copper scrap [Waste for recovery]	Mass	1.05E+02	kg
Dust (PM10) [Particles to air]	Mass	1.35E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.48E-02	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	5.72E-01	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.83E-04	kg
Plastic (unspecified) [Waste for recovery]	Mass	5.10E+02	kg
Steel scrap [Waste for recovery]	Mass	6.05E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.90E-02	kg

Recycling copper scrap of a 250kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	1.05E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	5.20E+02	MJ
RER: gas power plant, 100MWe [Power plants]	Number of pieces	3.53E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	4.12E-10	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	4.16E-07	kg
Acetic acid [NMVOC Group to air]	Mass	6.29E-05	kg
Arsenic [Heavy metals to air]	Mass	1.47E-04	kg

Benzene [NMVOC Group to air]	Mass	4.81E-07	kg
Benzo{a}pyrene [PAH group to air]	Mass	2.75E-10	kg
Butane [NMVOC Group to air]	Mass	4.81E-04	kg
Cadmium [Heavy metals to air]	Mass	2.41E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1.04E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	7.80E-03	kg
Copper [Heavy metals to air]	Mass	2.94E-03	kg
Dust (> PM10) [Particles to air]	Mass	2.73E-02	kg
Dust (PM2.5) [Particles to air]	Mass	9.87E-02	kg
Ethane [NMVOC Group to air]	Mass	7.12E-04	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	1.72E-05	kg
Heat, waste [unspecified]	Energy	3.95E+02	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	4.12E-04	kg
Lead [Heavy metals to air]	Mass	1.15E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	5.20E-04	kg
Nickel [Heavy metals to air]	Mass	1.36E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	3.64E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	5.20E-04	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	5.98E-04	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	3.88E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	1.51E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	4.16E-06	kg
Propane [NMVOC Group to air]	Mass	3.66E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	8.32E-06	kg
RER: copper, secondary [Benefication]	Mass	1.05E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	1.04E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	7.80E-07	kg

Recycling steel scrap of a 250kW distribution transformer [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	9.72E+00	kg
Argon [Inorganic intermediate products]	Mass	5.40E-01	kg
GLO: charcoal, at plant [Fuels]	Mass	2.41E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	8.39E+00	kg
Dolomite [Minerals]	Mass	1.18E+01	kg
Graphite [Inorganic intermediate products]	Mass	1.93E+00	kg
Lime finelime (ground) [Minerals]	Mass	3.98E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	2.14E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	2.42E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	9.07E+00	kg
Refractory [Minerals]	Mass	9.89E+00	kg
RER: natural gas [Fuels]	Energy	3.74E+02	MJ
RER: steam, for chemical processes [Auxiliary material]	Mass	6.85E+01	kg
Steel scrap [Waste for recovery]	Mass	6.05E+02	kg
RER: electricity, at grid [Production mix]	Energy	1.03E+03	MJ
Water [Water]	Mass	1.12E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	6.35E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.45E+00	kg
Chromium [Heavy metals to air]	Mass	1.04E-03	kg
Dust (> PM10) [Particles to air]	Mass	1.22E-01	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	9.65E+00	kg
Lead [Heavy metals to air]	Mass	7.06E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.45E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	2.36E-04	kg
Refractory [Hazardous waste]	Mass	5.89E+00	kg
RER: steel, unalloyed [Benefication]	Mass	4.82E+02	kg
Sludge [Waste for disposal]	Mass	2.07E+00	kg
Steel works slag [Waste for recovery]	Mass	9.96E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	6.16E-02	kg

Disposing metallic waste of a 250kW distribution transformer to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	1.37E+02	MJ
CH: heat from waste [Incineration]	Energy	1.98E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	5.91E-08	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	3.74E+02	kg
CH: slag compartment [Incineration]	Number of pieces	6.67E-07	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	2.36E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Cadmium (+II) [Heavy metals to freshwater]	Mass	7.09E-04	kg
Carbon monoxide [Inorganic emissions to air]	Mass	3.19E-02	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	2.09E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.55E-01	kg
Chromium (+VI) [Heavy metals to freshwater]	Mass	8.11E-06	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	2.36E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	8.20E-03	kg
Incineration of metallic waste [Waste for disposal]	Mass	2.36E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	5.01E+01	kg
Manganese (+II) [Heavy metals to freshwater]	Mass	2.91E-05	kg
Methane [Organic emissions to air (VOC group)]	Mass	9.13E-04	kg
Phosphate [Inorganic emissions to freshwater]	Mass	1.28E-05	kg
Solids [Ecoinvent long-term to freshwater]	Mass	6.27E-02	kg
Vanadium, ion [Ecoinvent long-term to freshwater]	Mass	5.77E-03	kg
Waste heat [Other emissions to air]	Energy	1.18E+02	MJ

Disposing metallic waste of a 250kW distribution transformer to landfill N			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	6.08E-01	kg
CH: disposal, cement [Residual material landfill facility]	Mass	1.52E+00	kg
CH: disposal, paper [Incineration]	Mass	9.17E-03	kg
CH: disposal, plastics, mixture [Incineration]	Mass	9.17E-03	kg
CH: electricity from waste [Incineration]	Energy	8.12E+00	MJ
CH: electricity, at grid [Supply mix]	Energy	8.94E+00	MJ
CH: heat from waste [Incineration]	Energy	1.31E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	2.35E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	5.53E+00	MJ
CH: waste incineration plant [Incineration]	Number of pieces	3.92E-09	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	1.57E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	1.52E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	8.82E+00	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	3.17E-09	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	1.31E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	1.31E-07	m
CH: slag compartment [Incineration]	Number of pieces	1.57E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	3.36E-09	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	1.90E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	9.55E-04	kg
Metallic waste for landfill [Waste for disposal]	Mass	1.09E+00	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	1.14E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	2.36E+02	MJ

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon monoxide [Inorganic emissions to air]	Mass	3.50E-03	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	1.14E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	1.13E+00	kg
Copper (+II) [Heavy metals to air]	Mass	4.70E-02	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	3.36E-08	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.98E-05	kg
Iron [Heavy metals to air]	Mass	1.67E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	4.30E-04	kg
Iron [Heavy metals to freshwater]	Mass	8.20E-01	kg
Landfill of metallic waste [Waste for disposal]	Mass	2.36E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.00E-04	kg
Waste heat [Other emissions to air]	Energy	8.98E+00	MJ

Manufacturing an AC-AC converter [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
GLO: capacitor, electrolyte type, > 2cm height, at plant [Parts]	Mass	3.76E+01	kg
GLO: capacitor, film, through-hole mounting, at plant [Parts]	Mass	5.01E+01	kg
GLO: capacitor, Tantalum-, through-hole mounting, at plant [Parts]	Mass	3.38E+00	kg
GLO: connector, clamp connection, at plant [Parts]	Mass	3.48E+01	kg
GLO: diode, glass-, through-hole mounting, at plant [Parts]	Mass	6.90E+00	kg
GLO: inductor, ring core choke type, at plant [Parts]	Mass	5.15E+01	kg
GLO: integrated circuit, IC, logic type, at plant [Parts]	Mass	4.11E+00	kg
GLO: printed wiring board, through-hole, at plant [Module]	Area	3.30E+01	m^2
GLO: resistor, metal film type, through-hole mounting, at plant [Parts]	Mass	7.34E-01	kg
GLO: transistor, wired, small size, through-hole mounting, at plant [Parts]	Mass	5.58E+00	kg
RER: corrugated board, mixed fibre [cardboard & corrugated board]	Mass	3.67E+02	kg

RER: fleece, polyethylene, at plant [polymers]	Mass	8.81E+00	kg
RER: heavy fuel oil, burned in industrial furnace [Heating systems]	Energy	1.41E+01	MJ
RER: light fuel oil, burned in industrial furnace [Heating systems]	Energy	1.11E+03	MJ
RER: metal working factory [General manufacturing]	Number of pieces	1.32E-06	pcs.
RER: natural gas, burned in boiler [Heating systems]	Energy	2.94E+03	MJ
RER: polystyrene foam slab, at plant [Manufacturing]	Mass	4.40E+01	kg
RER: polyvinylchloride, at regional storage [polymers]	Mass	1.47E+00	kg
RER: section bar extrusion, aluminium [Processing]	Mass	2.05E+02	kg
RER: sheet rolling, steel [Processing]	Mass	1.44E+03	kg
RER: styrene-acrylonitrile copolymer, SAN, at plant [polymers]	Mass	1.47E+00	kg
RER: tap water, at user [Appropriation]	Mass	3.84E+04	kg
RER: wire drawing, copper [Processing]	Mass	8.09E+02	kg
RER: electricity, at grid [Production mix]	Energy	3.11E+03	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
AC-AC converter [Components]	Mass	3.07E+03	kg
CH: disposal, packaging cardboard, 19.6% water [Incineration]	Mass	3.67E+02	kg
CH: disposal, polyethylene, 0.4% water [Incineration]	Mass	4.55E+01	kg
CH: disposal, polystyrene, 0.2% water [Incineration]	Mass	8.81E+00	kg
GLO: disposal, treatment of printed wiring boards [Recycling]	Mass	2.50E+02	kg
Heat, waste [unspecified]	Energy	1.12E+04	MJ

Operating an AC-AC converter [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
AC-AC converter [Components]	Mass	3.07E+03	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
AC-AC converter [Components]	Mass	3.07E+03	kg

Dismantling an AC-AC converter [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
AC-AC converter [Components]	Mass	3.07E+03	kg
GLO: mechanical treatment plant, WEEE scrap [Recycling]	Number of pieces	1.64E-07	pcs.
RER: electricity, at grid [Production mix]	Energy	9.45E+01	MJ
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	2.87E-04	kg
Aluminium scrap [Waste for recovery]	Mass	6.84E+01	kg
Antimony [Heavy metals to air]	Mass	2.44E-05	kg
Bromine [Inorganic emissions to air]	Mass	4.88E-05	kg
Cadmium [Heavy metals to air]	Mass	4.88E-06	kg
Carbon dioxide [Inorganic emissions to air]	Mass	8.15E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.85E-01	kg
CH: disposal, packaging paper, 13.7% water [Incineration]	Mass	2.57E+02	kg
CH: disposal, packaging paper, 13.7% water [Landfill facility]	Mass	1.10E+02	kg
CH: disposal, polyvinylchloride, 0.2% water [Incineration]	Mass	4.40E-01	kg
Chlorine [Inorganic emissions to air]	Mass	6.60E-05	kg
Chromium [Heavy metals to air]	Mass	1.06E-05	kg
Copper [Heavy metals to air]	Mass	8.61E-05	kg
Copper scrap [Waste for recovery]	Mass	2.69E+02	kg
Dust (PM10) [Particles to air]	Mass	3.39E-02	kg
electronic scrap [Waste for recovery]	Mass	2.05E+02	kg
Iron [Heavy metals to air]	Mass	9.90E-04	kg
Lead [Heavy metals to air]	Mass	8.46E-05	kg
Mercury [Heavy metals to air]	Mass	2.44E-08	kg
Metallic waste for incineration [Waste for disposal]	Mass	8.17E+02	kg
Metallic waste for landfill [Waste for disposal]	Mass	8.17E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.71E-02	kg
Nickel [Heavy metals to air]	Mass	3.30E-05	kg
Nitrogen dioxide [Inorganic emissions to air]	Mass	1.44E+00	kg
Nitrous oxide [Inorganic emissions to air]	Mass	4.61E-04	kg
Phosphorus [Inorganic emissions to air]	Mass	2.87E-06	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	3.87E-07	kg

Polystyrene (PS) [Waste for recovery]	Mass	1.32E+01	kg
Polystyrene (PS, unspecified) [Consumer waste]	Mass	3.08E+01	kg
Polyvinylchloride (PVC, unspecified) [Consumer waste]	Mass	1.03E+00	kg
Steel scrap [Waste for recovery]	Mass	4.79E+02	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	9.82E-02	kg
Tin [Heavy metals to air]	Mass	6.17E-05	kg
Waste heat [Other emissions to air]	Energy	4.87E+01	MJ
Zinc [Heavy metals to air]	Mass	2.68E-04	kg

Recycling aluminium scrap of an AC-AC converter [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	1.27E+00	kg
Aluminium scrap [Waste for recovery]	Mass	6.84E+01	kg
CH: anionic resin [Organics]	Mass	2.42E-01	kg
CH: cationic resin [Organics]	Mass	2.42E-01	kg
RER: natural gas [Fuels]	Energy	7.00E+02	MJ
Sodium chloride (rock salt) [Non renewable resources]	Mass	5.44E-01	kg
RER: electricity, at grid [Production mix]	Energy	6.52E+00	MJ
Water [Water]	Mass	5.82E+01	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium ingot (secondary) [Metals]	Mass	6.04E+01	kg
Carbon dioxide [Inorganic emissions to air]	Mass	3.73E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	6.04E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	6.04E-02	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.81E-01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	3.02E-01	kg
Waste for disposal (unspecified) [Waste for disposal]	Mass	1.12E+00	kg

Recycling copper scrap of an AC-AC converter [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Copper scrap [Waste for recovery]	Mass	2.69E+02	kg
RER: blast furnace gas, burned in power plant [Power plants]	Energy	1.33E+03	MJ

RER: gas power plant, 100MWe [Power plants]	Number of pieces	9.05E-09	pcs.
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Acenaphthene [NMVOC Group to air]	Mass	1.06E-09	kg
Acetaldehyde (Ethanal) [NMVOC Group to air]	Mass	1.07E-06	kg
Acetic acid [NMVOC Group to air]	Mass	1.61E-04	kg
Arsenic [Heavy metals to air]	Mass	3.77E-04	kg
Benzene [NMVOC Group to air]	Mass	1.23E-06	kg
Benzo{a}pyrene [PAH group to air]	Mass	7.05E-10	kg
Butane [NMVOC Group to air]	Mass	1.23E-03	kg
Cadmium [Heavy metals to air]	Mass	6.19E-04	kg
Carbon dioxide [Inorganic emissions to air]	Mass	2.67E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	2.00E-02	kg
Copper [Heavy metals to air]	Mass	7.54E-03	kg
Dust (> PM10) [Particles to air]	Mass	7.00E-02	kg
Dust (PM2.5) [Particles to air]	Mass	2.53E-01	kg
Ethane [NMVOC Group to air]	Mass	1.83E-03	kg
Formaldehyde (methanal) [NMVOC Group to air]	Mass	4.41E-05	kg
Heat, waste [unspecified]	Energy	1.01E+03	MJ
Hexane (isomers) [NMVOC Group to air]	Mass	1.06E-03	kg
Lead [Heavy metals to air]	Mass	2.96E-02	kg
Methane [Organic emissions to air (VOC group)]	Mass	1.33E-03	kg
Nickel [Heavy metals to air]	Mass	3.50E-05	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	9.33E-02	kg
Nitrous oxide [Inorganic emissions to air]	Mass	1.33E-03	kg
Pentane (n-pentane) [NMVOC Group to air]	Mass	1.53E-03	kg
Polychlorinated biphenyls [Halogenated organic emissions to air]	Mass	9.96E-04	kg
Polychlorinated dibenzo-p-dioxins [Halogenated organic emissions to air]	Mass	3.87E-14	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.07E-05	kg
Propane [NMVOC Group to air]	Mass	9.40E-04	kg
Propionic acid (propane acid) [NMVOC Group to air]	Mass	2.13E-05	kg
RER: copper, secondary [Benefication]	Mass	2.69E+02	kg

Sulphur dioxide [Inorganic emissions to air]	Mass	2.67E-02	kg
Toluene (methyl benzene) [NMVOC Group to air]	Mass	2.00E-06	kg

Recycling steel scrap of an AC-AC converter [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
Alloy components [Metals]	Mass	7.70E+00	kg
Argon [Inorganic intermediate products]	Mass	4.28E-01	kg
Charcoal [Materials from renewable raw materials]	Mass	1.91E+01	kg
Coke, metallurgic [Organic intermediate products]	Mass	6.65E+00	kg
Dolomite [Minerals]	Mass	9.36E+00	kg
Graphite [Inorganic intermediate products]	Mass	1.53E+00	kg
Lime fineline (ground) [Minerals]	Mass	3.15E+01	kg
Nitrogen liquid [Inorganic intermediate products]	Mass	1.69E+01	kg
Oxygen liquid [Inorganic intermediate products]	Mass	1.91E+01	kg
Pig iron (Fe carrier) [Metals]	Mass	7.18E+00	kg
Refractory [Minerals]	Mass	7.83E+00	kg
RER: natural gas, high pressure, at consumer [Fuels]	Energy	2.96E+02	MJ
RER: steam, for chemical processes, at plant [Auxiliary material]	Mass	5.42E+01	kg
Steel scrap [Waste for recovery]	Mass	4.79E+02	kg
RER: electricity, at grid [Production mix]	Energy	8.17E+02	MJ
Water [Water]	Mass	8.89E+00	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Carbon dioxide [Inorganic emissions to air]	Mass	5.02E+01	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.15E+00	kg
Chromium [Heavy metals to air]	Mass	8.22E-04	kg
Dust (> PM10) [Particles to air]	Mass	9.63E-02	kg
Dust (PM2,5 - PM10) [Particles to air]	Mass	7.64E+00	kg
Lead [Heavy metals to air]	Mass	5.59E-01	kg
Nitrogen oxides [Inorganic emissions to air]	Mass	1.15E-01	kg
Polycyclic aromatic hydrocarbons (carcinogenic) [PAH group to air]	Mass	1.87E-04	kg
Refractory [Hazardous waste]	Mass	4.66E+00	kg
RER: steel, unalloyed [Benefication]	Mass	1.27E+02	kg

Sludge [Waste for disposal]	Mass	1.64E+00	kg
Steel works slag [Waste for recovery]	Mass	7.89E+01	kg
Sulphur dioxide [Inorganic emissions to air]	Mass	4.87E-02	kg

Disposing metallic waste of an AC-AC converter to incineration plants [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: electricity from waste [Incineration]	Energy	4.73E+02	MJ
CH: heat from waste [Incineration]	Energy	6.85E+02	MJ
CH: waste incineration plant [Incineration]	Number of pieces	2.04E-07	pcs.
CH: process-specific burdens, slag compartment [Incineration]	Mass	1.29E+03	kg
CH: slag compartment [Incineration]	Number of pieces	2.30E-06	pcs.
Metallic waste for incineration [Waste for disposal]	Mass	8.17E+02	kg
Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	6.64E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.10E-01	kg
Carbon monoxide, non-fossil [Inorganic emissions to air]	Mass	7.20E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	5.37E-01	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.41E+00	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	8.17E+02	kg
Copper (+II) [Heavy metals to freshwater]	Mass	2.83E-02	kg
Incineration of metallic waste [Waste for disposal]	Mass	8.17E+02	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.73E+02	kg
Iron [Heavy metals to freshwater]	Mass	2.79E-03	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.15E-03	kg
Methane (biotic) [Organic emissions to air (VOC group)]	Mass	2.07E-03	kg
Solids [Ecoinvent long-term to freshwater]	Mass	2.16E-01	kg
Solids [Particles to freshwater]	Mass	9.31E-04	kg
Waste heat [Other emissions to air]	Energy	4.06E+02	MJ

Waste heat [Other emissions to freshwater]	Energy	6.67E+01	MJ

Disposing metallic waste of an AC-AC converter to landfill [N]			
Inputs			
Flow	**Quantity**	**Amount**	**Unit**
CH: cement, unspecified, at plant [Binder]	Mass	2.10E+00	kg
CH: disposal, cement [Residual material landfill facility]	Mass	5.24E+00	kg
CH: disposal, paper [Incineration]	Mass	3.17E-02	kg
CH: disposal, plastics, mixture [Incineration]	Mass	3.17E-02	kg
CH: electricity from waste [Incineration]	Energy	2.80E+01	MJ
CH: electricity, at grid [Supply mix]	Energy	3.09E+01	MJ
CH: heat from waste [Incineration]	Energy	4.54E+01	MJ
CH: iron (III) chloride, 40% in H2O, at plant [Inorganics]	Mass	8.12E-04	kg
CH: light fuel oil, burned in boiler [Heating systems]	Energy	1.91E+01	MJ
CH: waste incineration plant [Incineration]	Number of pieces	1.36E-08	pcs.
CH: process-specific burdens, waste incineration [Incineration]	Mass	5.41E+01	kg
CH: process-specific burdens, residual [Residual material landfill facility]	Mass	5.24E+00	kg
CH: process-specific burdens, slag compartment [Incineration]	Mass	3.05E+01	kg
CH: residual material landfill facility [Residual material landfill facility]	Number of pieces	1.09E-08	pcs.
CH: landfill facility [Landfill facility]	Number of pieces	4.54E-07	pcs.
CH: sewer grid [Wastewater treatment]	Length	4.54E-07	m
CH: slag compartment [Incineration]	Number of pieces	5.41E-08	pcs.
CH: wastewater treatment plant [Wastewater treatment]	Number of pieces	1.16E-08	pcs.
GLO: chemicals inorganic, at plant [Inorganics]	Mass	6.57E-05	kg
GLO: chemicals organic, at plant [Organics]	Mass	3.30E-03	kg
Metallic waste for landfill [Waste for disposal]	Mass	8.17E+02	kg
RER: hydrochloric acid, at plant [Inorganics]	Mass	3.94E-05	kg
RER: natural gas, burned in boiler [Heating systems]	Energy	3.75E+00	MJ

Outputs			
Flow	**Quantity**	**Amount**	**Unit**
Aluminium [Particles to air]	Mass	3.49E-02	kg
Aluminium (+III) [Inorganic emissions to freshwater]	Mass	8.08E+02	kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.21E-02	kg
Chloride [Ecoinvent long-term to freshwater]	Mass	3.94E-09	kg
Chloride [Inorganic emissions to freshwater]	Mass	3.89E+00	kg
Copper (+II) [Heavy metals to air]	Mass	1.63E-01	kg
Copper (+II) [Ecoinvent long-term to freshwater]	Mass	1.16E-07	kg
Copper (+II) [Heavy metals to freshwater]	Mass	1.03E-04	kg
Hydrogen chloride [Inorganic emissions to air]	Mass	5.60E-02	kg
Iron [Heavy metals to air]	Mass	5.78E+01	kg
Iron [Ecoinvent long-term to freshwater]	Mass	1.49E-03	kg
Iron [Heavy metals to freshwater]	Mass	2.83E+00	kg
Landfill of metallic waste [Waste for disposal]	Mass	8.17E+02	kg
Methane [Organic emissions to air (VOC group)]	Mass	3.45E-04	kg
Waste heat [Other emissions to air]	Energy	3.10E+01	MJ