Life Cycle Assessment of Waste Management System. The case of Avezzano, Italy

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Life Cycle Assessment of Waste Management System.
The case of Avezzano, Italy

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Summary

Nowadays “waste management” is a topic largely studied and questioned among government and Institutional organizations, as a complex phenomenon with a range of consequences for the involved stakeholders and society. In an European scenario, the Northern countries, where waste is considered as a resource, implement an efficient management of the solid residues, while the Southern countries, like Italy, seem to have a slowly evolution on waste treatment. Although different waste management options are now available the development of a sustainable waste management system needs to be discussed from a broader systems perspective, taking the environmental, social and economic issues into account.

In this study, Life-Cycle Assessment (LCA) in accordance to ISO 14040/44 standards, helps to expand the perspective beyond the waste management system. Scope of this study is using LCA method to compare the environmental performance of two different waste management systems in the municipality of Avezzano (Southern Italy). These are landfilling, the Avezzano's original waste management, and incineration for supplying heat and electricity to household; Waste to Energy is a system largely experimented in Sweden, that has been agreed upon in Avezzano, but not yet implemented. After data collection, models have been developed using GaBi 4, an LCA tool that allows to account material and energy flows and carry out environmental impact assessment from a life cycle perspective.

Life cycle impact assessment has been addressed at mid-point level (i.e. problem-oriented); at the end incineration results to be negative for the air quality, and consequently for human health, due to CO_2 and SO_X emissions in the atmosphere. These substances affect not only the Climatic Change but also phenomena like Acidification that impact flora, fauna, humans and artistic building. Although Landfilling is more toxic for the soil quality. Incineration produces 35% more energy than landfilling and this is ideal for the Avezzano inhabitants, as the city, like the whole Italy, depends strongly of foreign Countries for the energy production. Implementing an incineration plant result 30% less economical than landfilling, and currently in Italy there are no economic incentive to build Waste to Energy plants, and also there are still problem of legality that make incineration project even more difficult to be implemented.

Key words: life cycle assessment, Gabi, incineration, waste management, landfilling, waste to energy.

Symbols/Abbreviations

CO_2	Carbon dioxide
CH_4	Methane
eq.	Equivalence factor
EU	European Union
FAEP	Fresh water aquatic ecotoxicity potential
FU	Functional Unit
GaBi	Ganzheitliche Bilanzierung (holistic balancing)
HCFCs	Hydro chlorofluorocarbons
HCl	Hydrogen chloride
HF	Hydrogen fluoride
HFC	Chlorofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
ISO	International organization for standardization
HTPAU	Human toxicity potential Australia
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LHV	Lower heating value
MAEP	Marine aquatic ecotoxicity potential
NMVOC	Non-methane volatile organic compounds
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides
O_2	Oxygen
P	Phosphorus
P-tot	Total phosphorus
PAH	Polyaromatic hydrocarbons
SCR	Selective Catalytic Reduction
SO_2	Sulphur dioxide
SO_3	Sulphite
T	Temperature of landfill gas
TEP	Terrestrial ecotoxicity potential
WTE	Waste-to-Energy

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1. Introduction

As the world is moving towards a rapid urbanization, quantity of produced solid waste by humans being is one of the most important products of the urban lifestyle; as the increasing of GDP, the waste volumes are growing even faster than the rate of urbanization. For instance, ten years ago there were 2,9 billion urban residents who have been generating 0,68 billion tons per years; currently, the world cities generate about 1,3 billion tons of solid wastes per year (Tahir and Hussain, 2015). According to the World Bank and the publication of the "Global Review of Solid Waste Management" (Hoornweg and Bhada-Tata, 2012), the volume of waste is expected to increase to 2,2 billion tones by 2025.

Solid waste management is a responsibility of local governments and is often their single largest budget item. It is practically the most important municipal service and it is a precondition for the other municipal actions, because his role is leading in a sustainable development that covers economic, social and environmental skills of the municipality. MSW, Municipal Solid Waste, requires a strong social deal between the municipality and community. The waste workers, formal and informal, represent from 1% up to 5% of all urban employment, and workers tend to be younger (World Bank, 2012). This has a strong influence on economy, municipalities need capacities in procurement, management, and often unionized labor management, and ongoing expertise in capital and operating budgeting and finance (World Bank, 2012).

1.1 Waste Hierarchy

On 21 December 2005, the European Commission approved the 6th Environmental Action Plan: ''Taking sustainable use of resources forward: A thematic strategy on the prevention and recycling of waste'', with this Communication, the prevention and the recycling are basically the main strategies planned on European framework.

According to the Waste Framework Directive 2008/98/EC, the basic objectives of current EU waste policy is a waste hierarchy (figure 1), in which preventing wastes and promoting reuse are the first step. The waste hierarchy governs how waste management should take place in Europe and it is made up of five-step as follows; in order are: prevent waste generation if possible, reuse or recycle wastes, energy recovered for what cannot be recycled and finally, the least option, is disposal in landfills.

However, the environmental impact of a waste management system depends on a number of geographic, economic, social and technological factors; for this reason, the waste hierarchy should not be seen as beginning of a rigid prescription, but just a starting order of treatment options for the best way to treat wastes.

Figure 1 Waste Hierarchy (European Union, 2008)

1.2 Life cycle thinking

During the last decade, a number of new waste treatment technologies have come into use and it has begun to be contested as what can be considered the best treatment option in the waste hierarchy. Consequently, new scenarios are evaluated in order to find out the optimal solution and the best combination to improve the energy and material recovering and to have low impacts on the environment.

A new system, where the key phrase is "life cycle thinking" has been introduced in the European context; it moves away from the rigid waste hierarchy and starts to assess alternative scenarios, e.g. what waste treatment is the best option, which alternatives are available, and which system fits better with the surrounding environment. The Waste Framework Directive (European Commission, 2008) does not state which assessment should be used, but introduces Life Cycle Assessment (LCA), just known at the early 1990s, applied to waste management. Furthermore, in some cases there are many differences in the waste management system adopted and the energy system with which it interchanges itself, this stimulates the introduction of LCA models, that are more flexible and manageable, applied to waste system and energy recover.

2. Aim and objectives

The aim of the study is to investigate and discuss the potential life cycle environmental impacts of the hypothetical introduction of an incineration plant in the city of Avezzano (South Italy) in comparison with the actual practice, landfilling. The introduction of a waste to energy system is coherent with the European waste hierarchy, which encourage energy recovering instead than disposal in a landfill. Scope of this report is evaluating the impacts of this scenario (that privilege incineration) on environment and human health, and developing recommendations. For this purpose, LCA has been adopted as decision making analysis.

After explaining how the European sustainable waste hierarchy thinking is conceived in Italy, the following objectives are considered:

- stream line a Life Cycle Assessment, according to ISO, International Organization for Standardization, to compare the two different waste management solutions, landfilling and incineration,

- identify and analyze the process-related impacts on the environment and human health and which phases of the life cycle contribute most to that, using Gabi 4 LCA software tool;

- evaluate pros and cons of the introduction of an incineration plant in Italy in order to increase the Avezzano energy independence;

- Discuss the economical achievability of incineration and how to proceed with a future assessments to have a more detailed sustainable vision of these scenario.

2.1 Current Waste Management Practices in Italy

On July 2012, the European Commission published the document “Screening of waste management performance of EU Member”, with the scope to figure the present municipal waste management situation in Europe. Major discrepancies have been found in the implementation and application of the European Waste Framework Directive into Italian legislation.

Landfilling is nowadays the most common practice of waste management in Italy, in spite of enforced regulations aimed at increasing waste pre-sorting as well as energy and material recovery (Cherubini, 2008). According with ISPRA, the Italian Institute for Environmental Protection and Research, for the unsorted waste management, land-filling represents the 42% and Waste to Energy only the 16%; even if this values are increasing, this data are far from countries like Sweden, in which Waste to energy represents the 50% and land-filling just the 0,7% (Avfall Sverige, Swedish Waste Management 2014). The recycle system increases, especially in those small-scale municipal centers.

2.2 Waste to energy in Italy

In Italy, in 2013, 57 facilities of incineration are surveyed by ISPRA, 55 of those are operating. 24 plants are located in the North, the 42,1% of the national equipment; 20 plants are in the Center and 13 plants in the South, respectively, the 35,1% and 22,8% of the total in the country (ISPRA). Waste to energy is a practice mostly implemented in the North of Italy, since in the South are observed lots of problems of lawfulness, corruption and it is present a bad conduct of the citizens who often leave the garbage in open space with a great impact on environment and life health.

Another benefit connected to incineration is supplying energy that could partly solve the Italian energy problem of strong dependence on other Countries: 43,821 MTOE produced in contrast of 154,114 MTOE imported (Italian Energy Balance, 2013). One of the main problem is the public prejudice about incineration, the greens and the common sense are in contrast and they vindicate the eventual environmental impact and damages on human health.

2.2.1 Avezzano's case

Avezzano is a small city of 42 434 inhabitants (Italian Statistic Institute, INSTAT, Demographic Session), in the south of Italy and it is the main city of the Abruzzo National Park. The city is surrounded by mountains and, since it is located on a drained lake, his economy is basically agriculture.

Currently in Avezzano is present a service door to door, it means that each family is responsible of his own trash, and every day a truck of the company that manage the municipal wastes, (Tekneko), comes to collect the trash. This method is considered an optimal way to educate the inhabitants of the city to respect the environment, to think about the importance of recycling and to generate less wastes.

In the last years, the local administration has been discussing about the introduction of an incineration plant to replace the currently used landfilling method. The introduction of an incineration plant could be also an optimal solution, for the energy supply in the city, that is located in the middle of the mountains and the transportation of energy could be tricky and pollutant.

Avezzano could be a good starting point to evaluate if waste to energy has more impact on environment and human health than landfilling, as supposed by Avezzano inhabitants, greens and ecologist movement.

2.3 Environmental effect of waste management

The Environment is strongly affected by the waste management; globally nature of MSW includes its contribution to GHG emissions, like the methane from the organic fraction of the waste stream, the increasingly global linkages of products, urban practices and recycling industry. Additionally, solid wastes are one of the most pernicious uncollected local pollutants; the solid wastes are usually the leading responsible to local flooding and air and water pollution. (World Bank, 2014)

According with Eurostat (2015) currently, Italy covers one of the first position as emitter of greenhouse gases, which promote climate change, worldwide. Nowadays climate change is of national and international interest.

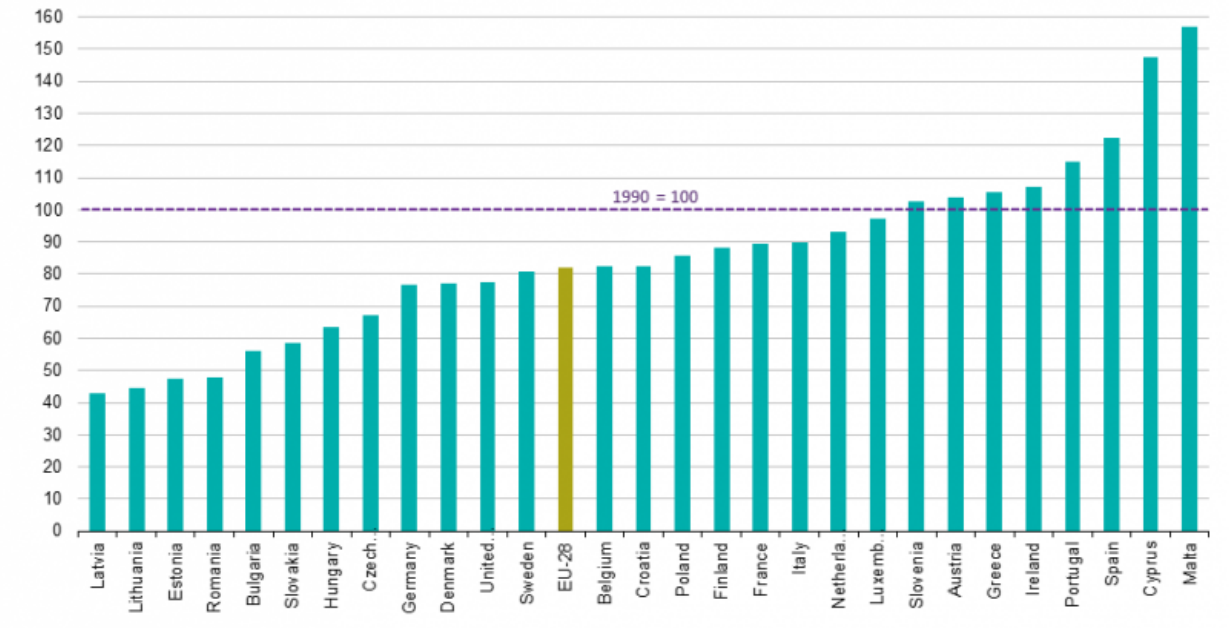


Figure 2 Total greenhouse emissions by European Country 2012 (Eurostat, 2015)

The statistic made by United Nations framework convention on climate change (UNFCCC, 2012) covers trends in emissions of all Kyoto greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6).

2.3.1 Climatic change effect in Italy

Italy, in line with the EU international headline target (international commitments under the Kyoto Protocol's 2013-2020) has the commitment to reduce of 20% the GHG emissions by 2020. Major EU initiatives to reduce greenhouse gas emissions include: implementing legislation to raise the share of energy consumption produced by renewable energy sources to 20%, increase Europe's energy efficiency by 20% by improving the energy efficiency of buildings and of a wide array of equipment and household appliances; reduce CO_2 emissions from new cars and vans.

In Italy, climate changes are noticeable through the "traditional" effect of weather and climate phenomena, due to temperature increasing and consequent desertification, floods and intense rainfall; changing also appear with new intensity and worrying effect: heat waves, summer hail storms. Everything increases risk of hydro-geological landslides (e.g. tornadoes, storm surges, locusts' infestation in southern Italy). Climate changes affect not only the inhabitants but also the activities like trading, agriculture and tourism that are the basis of the Italian economy (Rete Clima Italia, 2013).

3. Methodology

In this chapter the methodology adopted during the study is listed.

3.1 Literature study

In order to obtain a deep background of the topic, a wide literature research has been performed. Database of KTH are been used, and scientific literature within the areas of waste management techniques, Life Cycle Assessment and LCA applied to waste framework. Annual report of International and National (Italian) organism, to investigate Italian and European waste stream situation (ISPRA, ISTAT), and International handbook about organism for the environmental protection.

3.2 Interview

Interview to the companies in charged to the waste management in the city of Avezzano, Tekneco and Aciam, have been necessary to obtain specific data about the composition and quantification of the urban waste and the transportation. The municipal institution have been contacted also, in order to obtain information about the amount of the municipal waste.

3.3 Life Cycle Assessment

Life Cycle Assessment (LCA) has been definite by the International Organization for Standardization (ISO standards). ISO has developed several guideline for the awareness of the importance of environmental protection, and the possible impacts associated; the main one is LCA and is described by ISO 14040-14044, 14040 contains the principles and the framework, and UNI ISO 14044 contains requirements and guidelines. (ISO, 2006)

According to ISO 14044 LCA can assist in

— identifying opportunities to improve the environmental performance of products at various points in their life cycle.

— informing decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign).

— the selection of relevant indicators of environmental performance, including measurement techniques, and

- marketing (e.g. implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration). (UNI ISO 14040:2006)

In this study LCA has ben adopted as decision making in order to compare the two waste management scenarios, and it will be explained in a deeper description in the following chapter.

3.4 Gabi Software

GaBi 4 is a software, developed by the Institute for Polymer Testing and Polymer Sciences (IKP) of the University of Stuttgart, in cooperation with PE International. It is an internationally well-known LCA tool, as it presents databases to perform a LCA inventory and Impact category assessment. It has been used in this study to model the two systems,

and to compare both, evaluating their environmental impacts. All the information about GaBi are taken from the GaBi 4 manual.

3.5 Impact Assessment CML

The so-called CML 1992 (Dutch guidelines) method is the methodology of the Centre for Environmental Studies (CML) of the University of Leiden and it focuses on a series of environmental impact categories expressed in terms of emissions to the environment. The CML method includes classification, characterization, and normalization, and it bases on midpoint modelling (GaBi Manual, 2006). This kind of impact assessment models reflect the relative potency of the stressors at a common midpoint within the cause-effect chain (GaBi manual, 2006). This analysis minimizes the amount of forecasting and effect modeling incorporated into the LCIA, thereby reducing the complexity of the modeling and often simplifying communication. (Bare, 2003). This method contains more than 1700 different flows that can be downloaded from their website of 2011(Acero, 2014). However in this study just 8 impacts have neem chosen, since they most allows a comparison about the human and ecosystem impacts, they are: Climatic Chang, Ozone Depletion Potential, Acidification Potential, Eutrophication Potential, Human Toxicity Potential, Marine, fresh water and industrial soil Ecotoxicity Potential.

Economic ssessment

Many information are indicated in BAT document: where it is guarantee an optimal energy production and utilization, that allows to reach the maximum value of energy with less emissions. A classification is presented by the Best Available technology published by BREF, under the IPPC Directive and the Industrial Emissions Directive with last references from 2006. These documents recommend information about the price of incineration plant and landfill in relation of their capacity. Thereby it has been possible outline an approximate price of both the techniques.

4. Life Cycle Assessment

LCA is a subcomponent of Life Cycle Engineering and it is not an exact scientific tool, but a science-based assessment methodology (Guineè, 2004). LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave) (UNI ISO 14040:2006).

It is increasingly utilized for strategic planning, so it fit also with a solid waste management systems especially in the political decision-making process and in strategy-planning (Abeliotis, 2011). All the processes involved the material and energy flows for the entire life cycle product system are analyzed. However in waste management some exceptions must be taken into account since the extraction of raw materials and the manufacturing of products, that finally result in the domestic waste, can be disregarded because they are the same for all systems under study.

According to ISO 14044 LCA follows four steps:

a) goal and scope definition
b) inventory analysis
c) impact assessment
d) interpretation

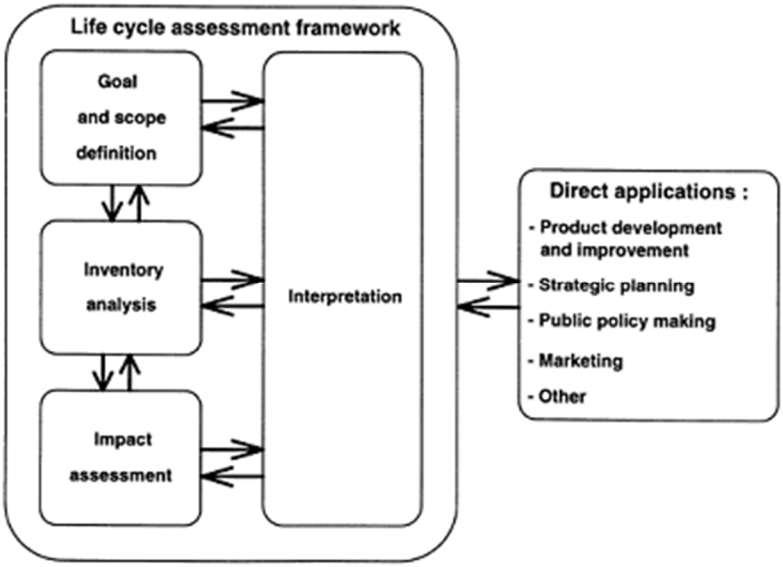


Figure 3 LCA framework (ISO 14040-14044:2006)

4.1 Goal and Scope definition

According to the ISO 14040 standard, the first phase of an LCA is the definition of the goal and scope. In this step all general decisions for setting up the LCA system are made. The goal and scope should be defined clearly and consistently with the intended application. This step consists in "initial choices which determine the working plan of the entire LCA" (Cherubini, 2008) as the objectives and the framework of the investigation.

✓ **Goal Definition**

In the goal definition, the following points need to be determined:

- The intended application of an LCA study
- The purpose of an LCA study
- The intended audience of an LCA report
- Usage for comparative analysis

✓ **Scope Definition**

The scope defines:

- functional unit (FU)
- the associated system to be studied
- the system boundaries
- the quality of data that the system requires
- Impact categories and the impact assessment method

It describes the primary function of the system and it serves as the basis for all calculations in the LCA study.

4.1.1 Functional Unit

According to ISO standard, a functional unit is defined as "the quantified performance of a product". It is a system for the measurement of the performing (function) of a product (or a more complex system), and it helps to define clearly the comparisons of the different systems. The main function of a waste management system is to treat a certain amount of waste from the defined area and provide different kinds of products that can be recovered from waste (The United Nations Environment Program, UNEP).

4.1.2 System Boundaries

The system boundary defines which processes will be included in, or excluded from, the system; It is helpful to describe the system using a process flow diagram showing all processes included in the LCA and their relationships. The system also includes emissions taking place in the extraction of raw materials and generation of energy needed for the waste management (upstream effects and the final disposal of the materials used).

There are four main options to define the system boundaries used

• Cradle to Grave: includes the material and energy production chain and all processes from the raw material extraction through the production, transportation and use phase up to the product's end of life treatment.

• Cradle to Gate: includes all processes from the raw material extraction through the production phase; used to determine the environmental impact of the production of a product.

• Gate to Grave: includes the processes from the use and end-of-life phases; used to determine the environmental impacts of a product once it leaves the factory.

• Gate to Gate: includes the processes from the production phase only; used to determine the environmental impacts of a single production step or process.

4.2 Life Cycle Inventory (LCI)

The Inventory Analysis concerns the modelling of the processes within the system boundaries. This includes the collection of data and the calculations for specification of relevant inputs and outputs for the product system (ISO 14044:2006). The inputs, e.g. raw materials and energy and the outputs e.g. emissions from production, into the air, water and soil. All material and energy flows are recorded and compiled in the inventory and analyzed.

4.3 Life Cycle Impact Assessment (LCIA)

ISO developed a standard for conducting an impact assessment entitled ISO 14042, Life Cycle Impact Assessment refers to the calculation of potential environmental impacts, effects on resource availability and human health impacts. Inputs and outputs, identified in the inventory analysis, are characterized and assessed. For example, an environmental release identified in the LCI may harm human health by causing cancer or sterility, or affect workplace safety. Likewise, a release identified in the LCI could also affect the environment by causing acid rain, global warming, or endangering species of animals.

4.3.1 Selection of Impact Categories, Category Indicators and Models

The first step in the impact assessment is the choice of impact categories from a list of resource use and environmental impacts. Their contribution is quantified by indicators and models. This step should be completed as part of the initial goal and scope definition phase to guide the LCI data collection process and requires reconsideration following the data collection phase. Impacts are calculated based on the inventory results and specific characterization models for each substance in the inventory. Typically, LCIAs focus on the potential impacts on three main endpoint categories: human health, ecosystem quality, and resources.

4.3.2 Assignment of LCI Results (Classification)

The several impacts of the selected categories of the LCI are assigned to their environmental effects, e.g. CO_2 is assigned to climate change and SO_2 to terrestrial aquatic eco-toxicity potential.

4.3.3 Calculation of Category Indicator Results (Characterization)

As many different interventions apply to a certain impact category, the estimation of the effect is expressed by so called equivalence factors. Therefore, for example, CO_2 is an intervention having an effect on climate change. It serves as a reference substance to all other gases within this category. Their impacts are therefore calculated as CO_2-equivalence factors (CO2-eq). Methane is supposed to have a 21 times bigger effect on climate change than CO_2 on a 100 year time scale, therefore each kg of emitted CH_4 is taken into account as 21 kg CO_2-eq.

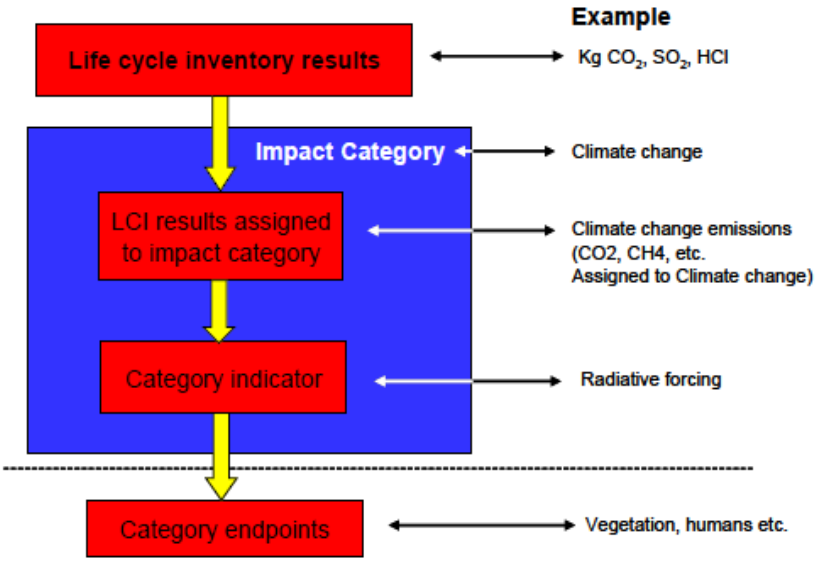


Figure 4 Concept of category indicator (Büning, 2004)

4.4 Results and Interpretation

The calculated LCI and LCIA results are interpreted with respect to the goal of the LCA study and recommendations for decision-making are given.

A sensitivity analysis is part of the interpretation as well as the quantification of the accuracy of the LCA results by evaluating data quality and data gaps (GaBi manual 2003).

4.5 Life Cycle Assessment in Italy

LCA, as a decision-support tool in planning integrated municipal solid waste management, is not yet widely used in Italy, among local authorities, waste management companies and enterprises. (Buttol, 2007). However, some studies about the main city (Roma, Bologna) have been published; university and institutes, especially ENEA, Italian National Agency for New Technologies, Energy and the Environment, are developing and improving the researches about LCA, and spreading the study to all Italian areas.

4.6 GaBi 4 Software

GaBi (GaBi = Ganzheitliche Bilanzierung = holistic balancing) is a software that allows the creation of a Life Cycle Assessment Inventory by modeling the product life cycle and calculating the different balances throughout the system based on the input-output materials and the energy flow.

It is a tool to create life cycle balances and it is able to support the handling of large amounts of data. Balances show the results of a model. Once these balances have been created, they can be analyzed within the program in many different ways.

Each database consists out of objects which have a certain order according to their hierarchy. These objects are balances, plans, processes, flows, quantities, units, users, projects, quality indicators, weighting and global parameters. The hierarchy is shown in Figure 5, that shows the user interface.

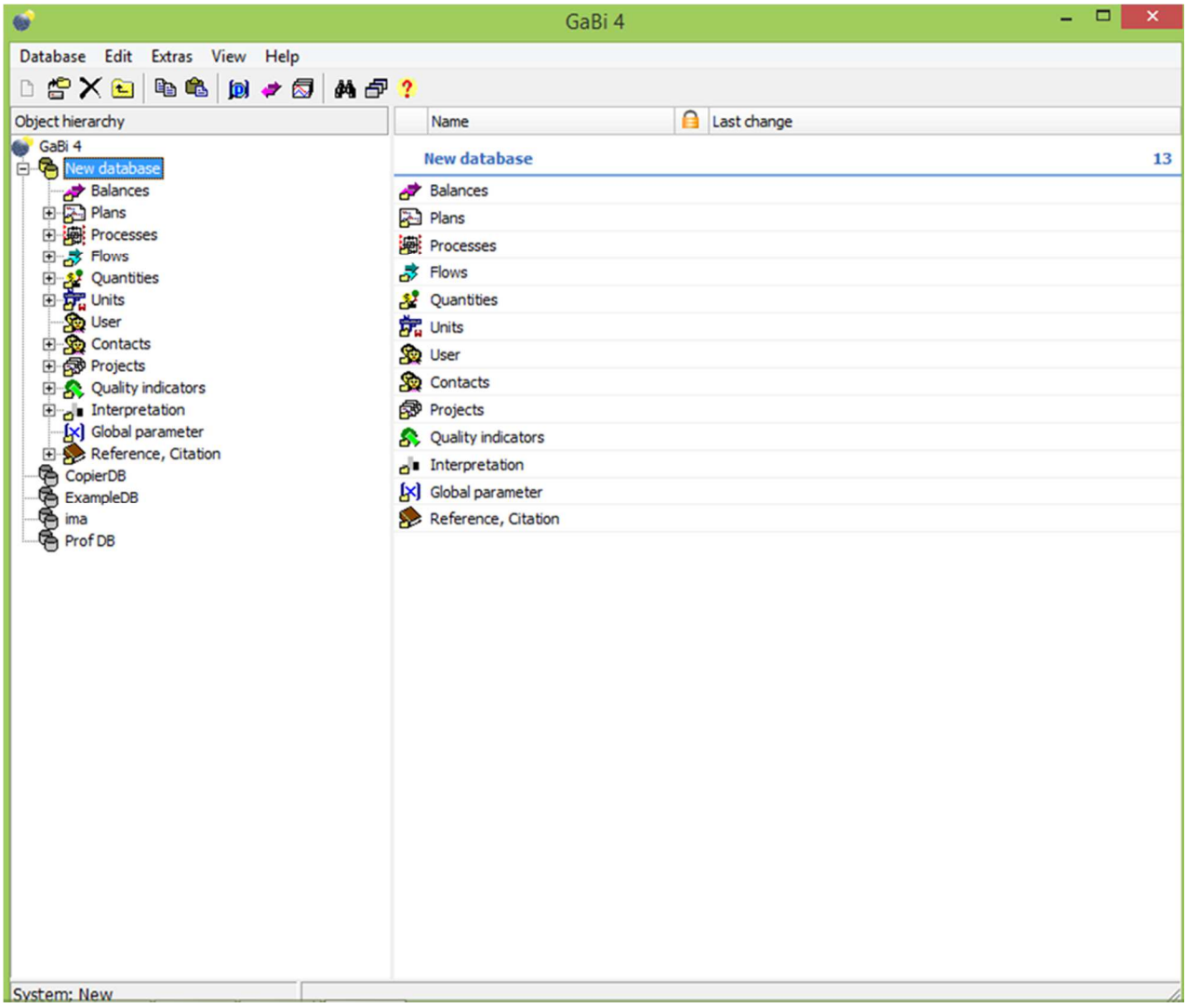


Figure 5 GaBi user face

GaBi calculates the potential environmental impacts and other important quantities of a product system based on plans, the plans is made up by processes and process is characterized by flows. The plan represents the system with its boundaries, processes represent the processes that are taking place in the model and flows are all the inputs and outputs related to the system, which connect plans or processes within the system. The list of input and output flows is referred to the Life Cycle Inventory, LCI, inputs are the flows entering in the system like natural system, energy, resources, and the outputs are the flows leaving the system (emission, ashes); all these flows are called elementary flows.

Flow information are essential in GaBi, because they are characterized by mass, energy and costs with their respective values. For example, GaBi contains flow information for different raw materials, plastics, metals, emissions to air and water and many more. (GaBi manual, 2003)

An extensive database of substance flow analysis, materials and processes has been implemented by many years of experience and based on numerous projects in the fields of life cycle assessment. Several companies and research institutes are now using the software tool GaBi 4 database worldwide.

5. Goal and Scope definition

5.1 Goal Definition

The primary goal of this study is to evaluate and compare the environmental performance of two waste management options in the urban area of Avezzano. The case history of Avezzano, that now it is consisting to collect the unrecyclable waste in a landfilling, is compared with the hypothetical introduction of an incineration plant in the city, for the combustion of waste and the production of energy.

The potential environmental impacts and effect on human health of a change in waste management strategy are shown through a comparison between the procedure of landfilling and waste to energy, by incineration, through LCA. The result of this investigation could be used by the local stakeholders that are involved into the waste management of Avezzano, in order to evaluate if the introduction of the incineration is more or less environmental and human unsafe than landfilling, and if it represents effectively a real available source of energy.

The unsorted waste, things that are not yet recycled, is take uder study. Recycling is not taken in consideration during the analysis as it is considered the same for both scenarios. Therefore, two scenarios are evaluated.

Scenario 1, (present situation): the wastes are picked from Avezzano, transferred to Aielli, 25 km from Avezzano, and deposited into the landfilling. Part of the biogas naturally released by the landfill is collected, treated and burnt to produce electricity. A sorting plant at landfill site separates the organic and inorganic fractions. Ferrous components are also recovered and sent to recycling (Aciam Company).

Scenario 2: Unsorted, not recyclable waste is directly incinerated to produce electricity with no further pre-sorting or pre-treating process, the incineration is located directly outside the city.

5.2 Scope definition

LCA with Gabi can be adapted to waste management, with some differences, since generally all inputs and outputs are based on a “cradle to grave” system approach. In waste management study, the LCA is basically the same, according with international standards; however some differences approaches must be taken (Finnveden, 2000). In this case, the system starts at the point where domestic solid wastes are generated, the extraction of raw materials and the manufacturing of products, that finally result in the domestic waste, can be disregarded because they are the same for all systems under study (Büning, 2004). The LCA starts at the point of waste collection, and it follows with waste deposited in the landfill, the gas generation and consequently electricity produced. In the case of waste, the input is made up by different material, with huge variety of emission that is impossible to allocate precisely. Unfortunately, data like these are not available, neither from landfills nor from incinerators, as all emission profiles are considered for the whole amount of waste (Sundqvist, 1999).

Therefore, the emissions calculated in this study are based on so called “transfer coefficients” (TC) and they are mainly refer to elementary composition. What can be allocated to different fractions, in this study they are taken from Gabi database.

5.2.1 System Boundaries

In figure 6 the geographical location of the system boundaries is shown and figure 7 shows the interaction, material and energy flows between the different steps.

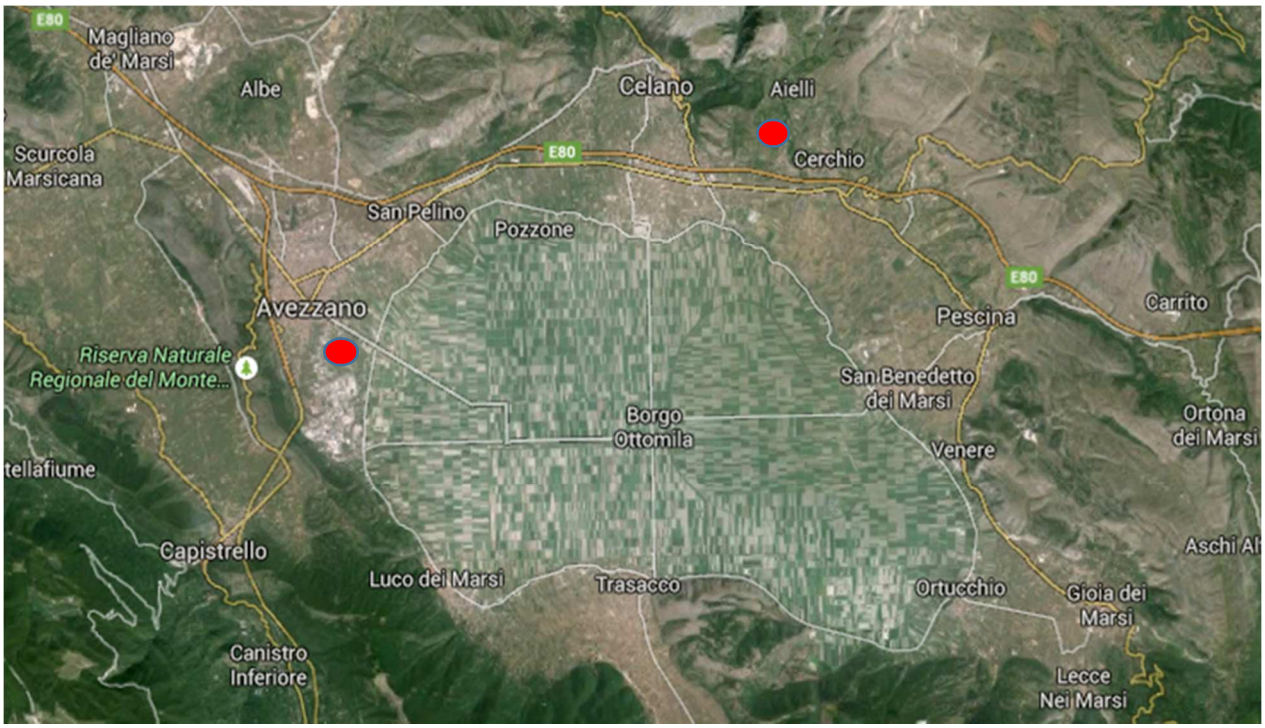


Figure 6 Geographical location of the system boundary of Avezzano (Google Heart)

The study starts from the collection of waste, from the household and from the street bins, and then the wastes are transported to the transfer point. From this point, in the basic case, wastes are transferred to the landfill of Aielli, 25 km far from Avezzano; in the case of incineration, it is supposed to be close to the transfer station, so no transportation is considered.

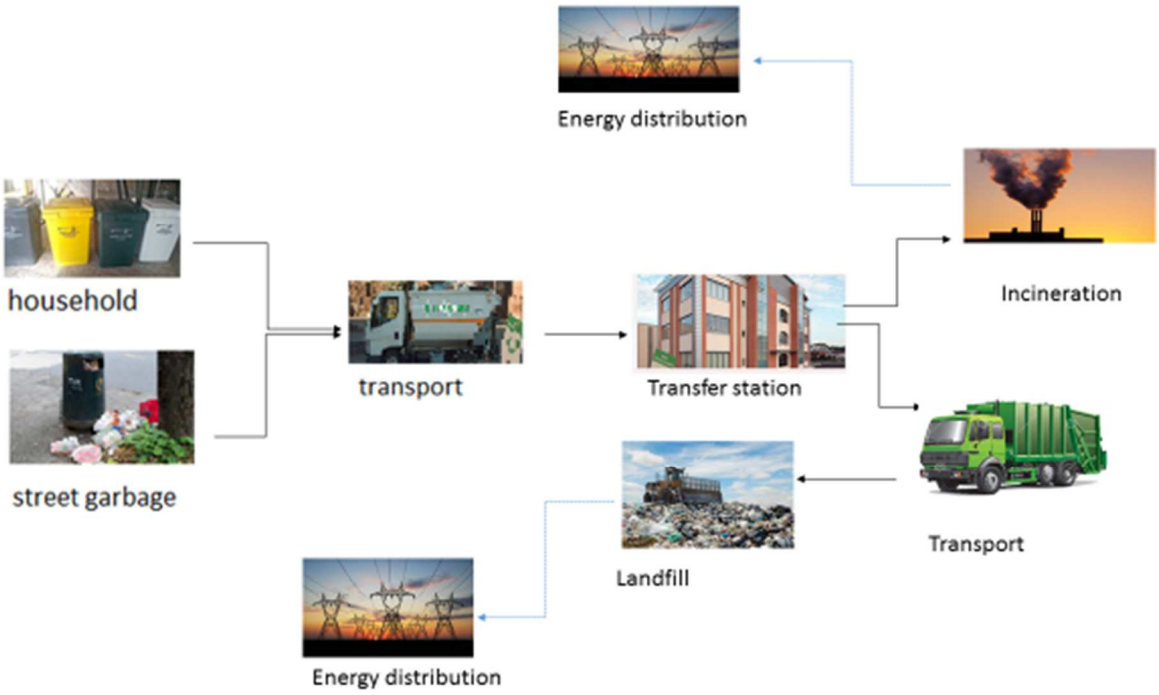


Figure 7 System boundaries

5.2.2 Functional Unit

According to LCA applied to Italian waste management, the fictional unit is the amount of unsorted waste produced in one year (CNR Bologna, 2009). This value is shown in a mandatory document called MUD, that concernes environment declaration that each municipality have to compile.

According to MUD of Avezzano, the amount of waste produced in one year (2012) in the city of Avezzano is 4.930.660 t from the household and 837.160 t from the street garbage; thus the FU adopted in the study is the sum of both values, 5.767.82 t.

5.2.3 Time aspects of Landfilling

Addictional problem connected to waste management is the time expected for the emission; generally, most emissions in LCA are instantaneous. However, things are different for landfilling, where emissions last for centuries, even for thousands of years. In order to compare emissions from a landfill with the ones from an incinerator, a time frame needs to be created (CNR Bologna, 2009).

“The period is called the survey able time period and covers 30 years characterized by high internal activities” (Sundqvist 1999). This, of course, is of importance for landfilled materials considered as inert (glass, metals), hardly degradable (plastics) and materials slowly leaching out (slag), as they are most likely to emit most hazardous substances in the time after this short period (Büning, 2004).

5.2.4 Assumption and limitation

In this study the process have been adapted to the process already present in GaBi, they present some difference with the reality, since they have been adapted to an European average that don’t represent

the specific Italian situation. The time has not been enough to create new databases with the specific features of Italian region.

5.2.5 Impact categories and the impact assessment method

As said in chapter 2, waste management has strong impact on environment system and on human health. The impact categories for this study were obtained using CML method, a method from the university of Leiden, that would be better described in the next chapter. The method has been used by Gabi4 to express emissions at midpoint level. The method consist in impacts such as climate change, Eco toxicity and acidification.

6. Life Cycle Inventory

6.1 Collection and Transportation

The transportation activities are significant contributor to emissions and energy use due to the high tonnages, distances, truck types and load efficiencies and they have to be identified. For the location of the incinerator it is assumed to be next to the collection point, so in scenario 2 is supposed that after the collection the truck goes straight without stopping at the transfer station. However, in the Basic Case, it is also considered the transportation from the transfer station to the landfill. From Avezzano to Aielli, 25 km.

The two different trucks are taken from GaBi database, with the process called “Truck”, Figure 8. For the first route it has been adopted a technology mix, diesel, euro 2, 14-20 total cap/ 11, 4 payload. In the case of landfill route, the track from the transfer station to the landfill is technology mix, diesel, euro 2,

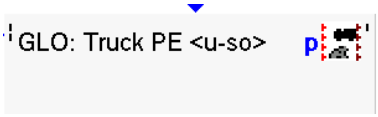


Figure 8 Truck process in GaBi

34-40 total cap/ 27t payload capacity. The label <u-so> of the process, means that represent a unit single process operation referred to a gate to gate process. This process type contains only the data for one specific process step and no LCI (or Life cycle inventory) data.

6.2 Road transport

Transportation systems are found in the using phase, which contains the fuel demand and released emissions.

The formula for the calculation of the transport emission is set in GaBi truck process. However, the parameters have been changed according with the model. Cargo input is equal to FU adopted, 5.767.82 t, over distances listed in the table.

Table 1 trucks and distance values

Path	Average distance (Km)	Truck
Avezzano- transfer station	5	diesel euro 2 cargo 14-20 t
Transfer station - Aielli	25	diesel euro 2 cargo 34-40 t

The formula for the calculation of the emission is related with Emissions Factors (EF) [g/km] for 1 kg of cargo, with the assumption that the utilization ratio behaves linearly.

In this part the basis for the emission assessment as the total payload applies to trucks, the required Sulphur content and the share of biogenic CO2 in fuel, are calculated. The following equation is taken from GaBi manual:

$$\text{Emission Factor} = \frac{EFempty + (EFloaded - EFempty)\ x\ utilisation}{payload\ x\ 1000\ x\ utilisation} \quad \frac{g}{km\ x\ kg} \qquad (1)$$

EF_{empty} = Emission factor for empty run [g/km]

EF_{loaded} = Emission factor for loaded run [g/km]

Utilization = Utilization ratio referred to mass

Payload = Maximum payload capacity [t]

The payload and utilization ratios are variable parameters; they have been adapted to this case.

The total emissions for each pollutant refer to FU cargo; (truck) the transportation distance is calculated based on the driving share of the specific emissions in [g/(km*kg)] and the distance [km] for the transport has been introduced (GaBi Paper Clip Tutorial,2006).

6.3 Gasoline

Gasoline is a flow, and it is referenced as “mass”, it could be assigned also the quantity “energy” because it has a heat values. According to GaBi, Diesel has a volume of 1.36 l and a heat value of 43.5 MJ per kg (GaBi manual, 2004).

The flow can be also determined with a price, determined at the gas station with its current daily price. For the gasoline has been adopted the process Diesel EU-15, taken directly from GaBi dataset.

Figure 9 GaBi Diesel process

6.4 Waste composition

Waste is always homogenized in order to obtain a relative constant calorific value and to comply with the emission standards. However, the used model and the used settings for the average MSW allows to attribute the environmental burden, the emissions and also the resource consumption of auxiliaries, the energy production and the credits (the metal scrap exported) to a single fraction or specific waste incinerated within an average MSW. The average has been adapted to a EU-15 statistic, according with Euro-stat.

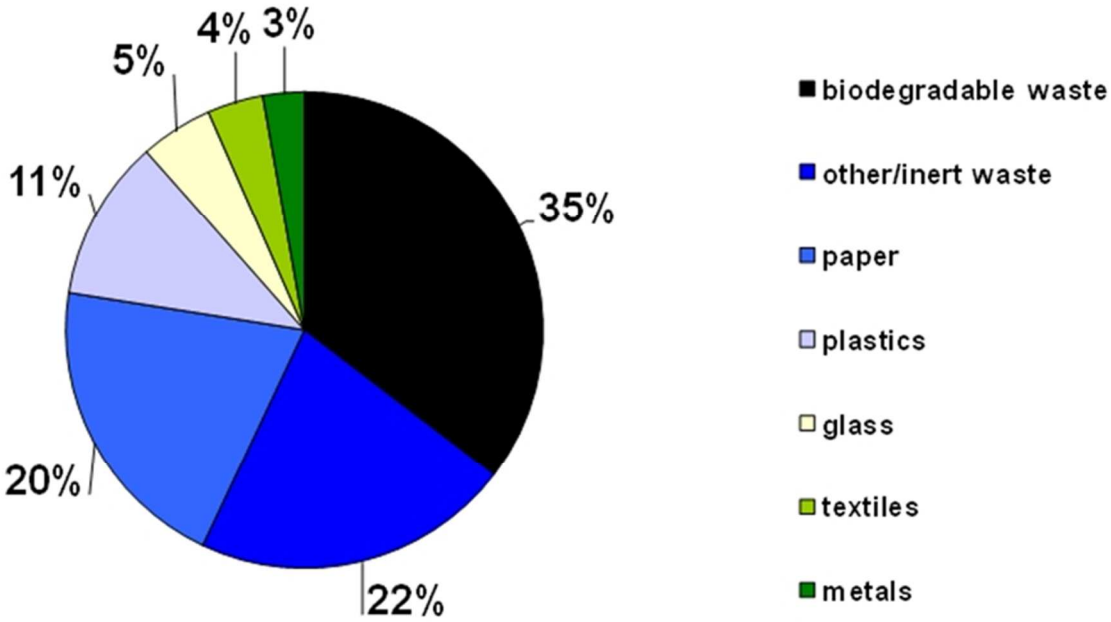


Figure 10 waste composition GaBi Database 2014

6.5 Landfilling

The process of landfill has been taken from GaBi database; the model is adapted to an average of some European Countries (shown in figure 11), including Italy. The label <p-agg> means that is a partly terminated system and it contains all LCI data for the process, except for one or more product flows that require additional modelling. The model refers to the state of art of landfill and takes features from the Best Available Technology for Landfill 2011. Therefore, the data set has been directly performed according with the European limits for emissions of a typical municipal waste landfill with surface and basic sealing.

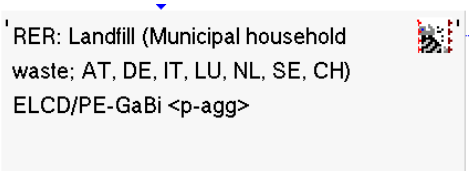


Figure 11 waste composition GaBi Database 2004

The landfill performed by GaBi4 includes the following processes:

1. the construction of the plant (and its land use) of which it is collected the portion of Functional Unit .

2. The provision, compacting and daily covering of waste with shovels, excavators and trucks.

3. The treatment of the biogas (or landfill gas) produced during the life of the landfill. The time is assumed to be equal to 30 years, for the determination of the quantity and composition of the landfill biogas, the moisture content of the waste, the number and distance of fine that captures the biogas. (GaBi4 database information, 2004)

The inside model of the landfill is representing by the following figure 12:

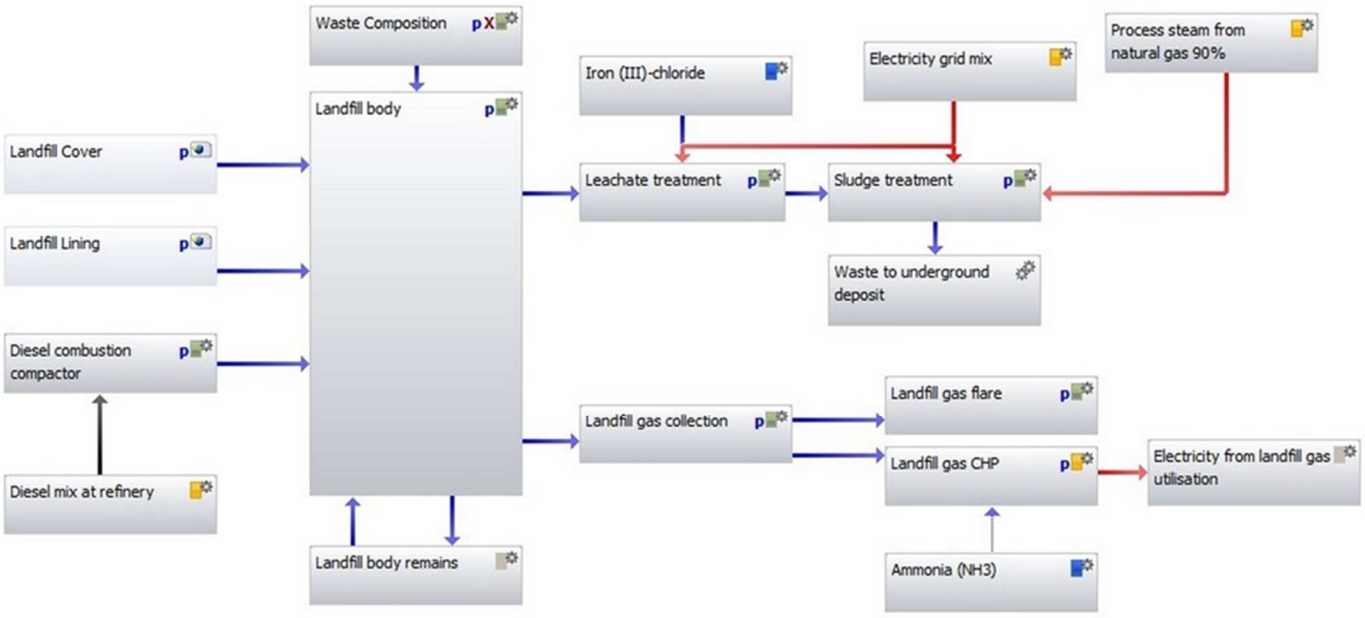


Figure 12 GaBi process landfill model

The size of the Landfill is height 30 m and the area is equal to 40.000 sqm, for 30 years of deposit. As said site includes landfill gas treatment, leachate treatment, sludge treatment and deposition.

The effort for sealing materials (clay, mineral coating, PE film) and diesel for the compactor is included in the data set.

The sealing contains gravel and sand used as filter layer, clay as mineral coverage in the surface and basic sealing and polyethylene film as waterproofed sealing. All manufacturing processes of the sealing materials are considered: The basis for the production of polyethylene film is crude oil. Gravel, sand and clay are mined from dry quarry.

6.5.1 Biogas

Biogas is composed mainly of CH_4, CO_2, and other gases in smaller percentages. Combustion converts CH_4 to CO_2. The tapped biogas can be burned in an engine for the production of energy, and another part of biogas directly into the atmosphere in a percentage, which can be also 40% (Buning, 2004).

Landfill gas production is calculated according to German first order “Weber Model 1990”. With this model, it is assumed that as time goes by, potential amount of LFG is reduced by the 1st order decomposition reaction.

The amount of LFG (landfill gas) at a given certain time (t), after deposition has taken place for an amount of waste (M), in t period, can be calculated as follows:

QLFG (m3 /y) = 1,868 . M . TOC. fao . fa . fo. fs . k . e-kt (2)

Where: TOC: Total organic content (kg/t)

t: Time (y)

k: LFG emission kinetic constant, defines the speed of gas emission (ca. 0,05 to 0,15) (1/y)

a, t : time between the calculated beginning and the considered year of the gas production (y)

fao : opening time factor for consideration of the gas production during the first half year after deposition has taken place (ca. 0,8 to 0,95)

fa: Degradation factor; relation of under optimum conditions of degradable TOC to TC.

fo : Factor of optimization; relation of under practical landfill conditions degradable TOC to under optimum decomposition conditions gasified TC in the test.

fs : Capacity determined by the system; relation of the under landfill conditions captured amount of gas (with ongoing degassing) to actual produced amount; 0-1, normally for vertical gas pipes 0,5.

Landfill gas models calculate methane yield based on three key inputs: (1) Waste amounts deposited in landfill until its closure, (2) Biodegradable total organic content, and (3) Decay rate (k).

Distribution of landfill gas is an average landfill gas industrial country standard: 22 % flare, 28 % used, 50 % emissions (Krümpelbeck, 2000). Use of landfill gas represents composition and amount for stable methane phase. (Thomé-Kozmiensky, 1989).

6.5.2 Leachate treatment

The amount of generated landfill gas is allocated to the organic carbon content in the waste input and represents an average landfill gas composition. (GaBi Modelling Principles, PE International. University of Stuttgart, 2004)

In the process is also contained the treatment of the leachate produced during the life of the landfill. The amount of leachate collected and the part, which enters into the soil is determinate by many factors: the size of the landfill, the layers that constitute it, precipitation, solar radiation and the vegetation that stands on the ground that covers the landfill.

In the case of the landfill waste has an effect that lasts from when the order to end of the period of control and maintenance (30 years after closure). The precipitation data is 660 mm/a and a rate of 60 % transpiration/run off is assumed (Finnveden, 2005)

Leachate and landfill body are assumed homogeneous; landfill body is saturated and there is circulation of leachate. Basic sealing effectively for leachate is 70 % and the leachate treatment includes active carbon and flocculation/precipitation processing. (GaBi database landfill, 2004)

The leachate is treated in a sewage treatment plant for industrial water and the sludge are disposed in a landfill for hazardous waste or non-hazardous according to the classification of leachate. After a chemical and physics purification, the leachate is subjected to biological purification. Sludge treatment and deposition are included. (GaBi database landfill, 2004)

6.5.3 Electricity mix

The data set of electricity mix used by Gabi process database of the process is an average of European specific electricity supply for final consumers, including electricity own consumption, transmission/distribution losses 7% and electricity imports from neighboring countries. The energy mix used for electricity production from the power plant, direct to combine heat and power generation (CHP), efficiency data including transmission/distribution losses and own consumption values, are taken

from International Energy Agency official statistics. The net calorific values associated to the waste is 9,7 MJ/kg (GaBi4 database, 2004). The Gabi inventory is partly based on primary industry data, partly on secondary literature data; the power plant models were used to the calculation of the emission values like gases NOx and particles of heavy metals. Figure 13 and Figure 14 represent the landfilling model implemented with GaBi. They represent the whole process, including transportation from the house and from the street garbage until the transfer station, and then to the landfill. In the figures are represented the material flow (Fig. 13) and the energy flow (Fig. 14) that happen during the process.

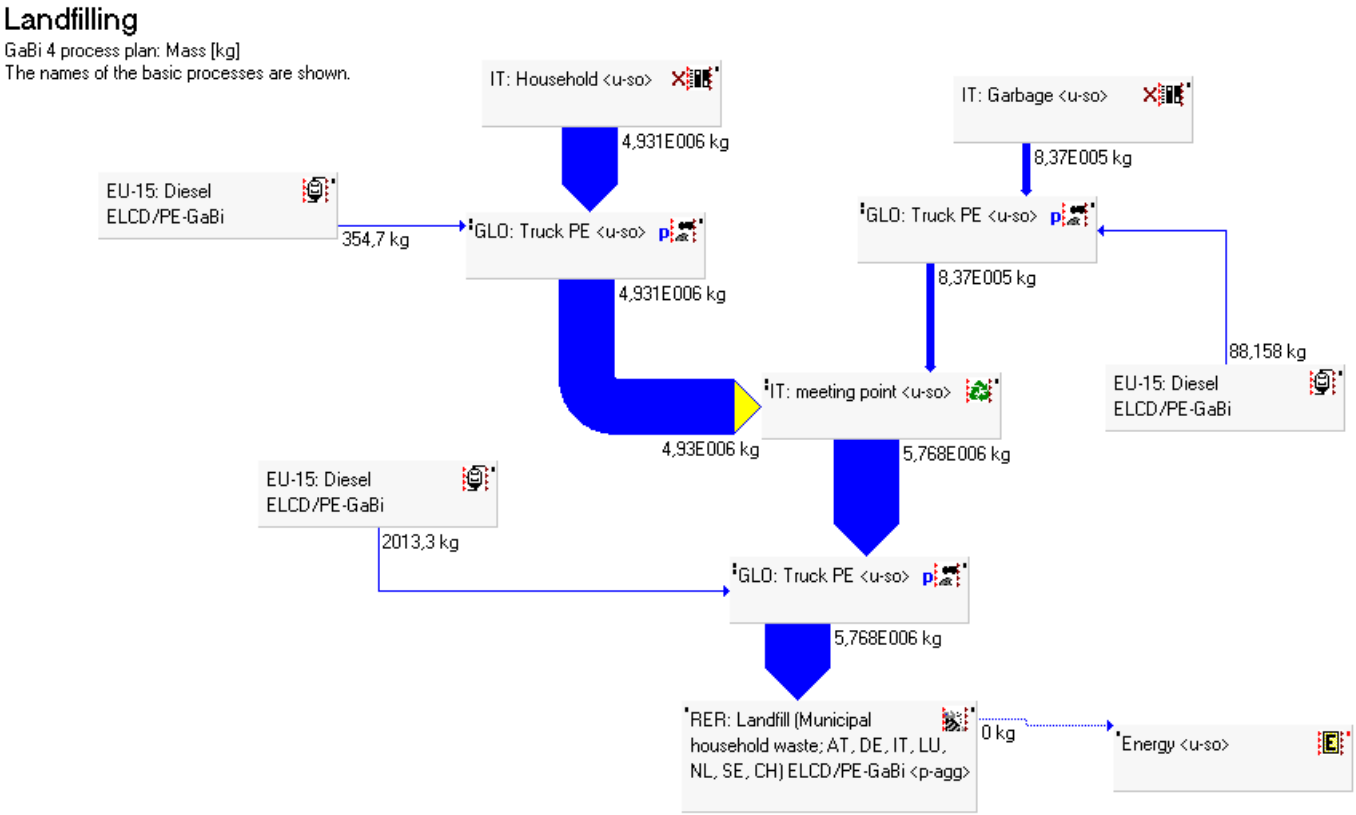


Figure 13 Plan Model Landfill, Mass flow

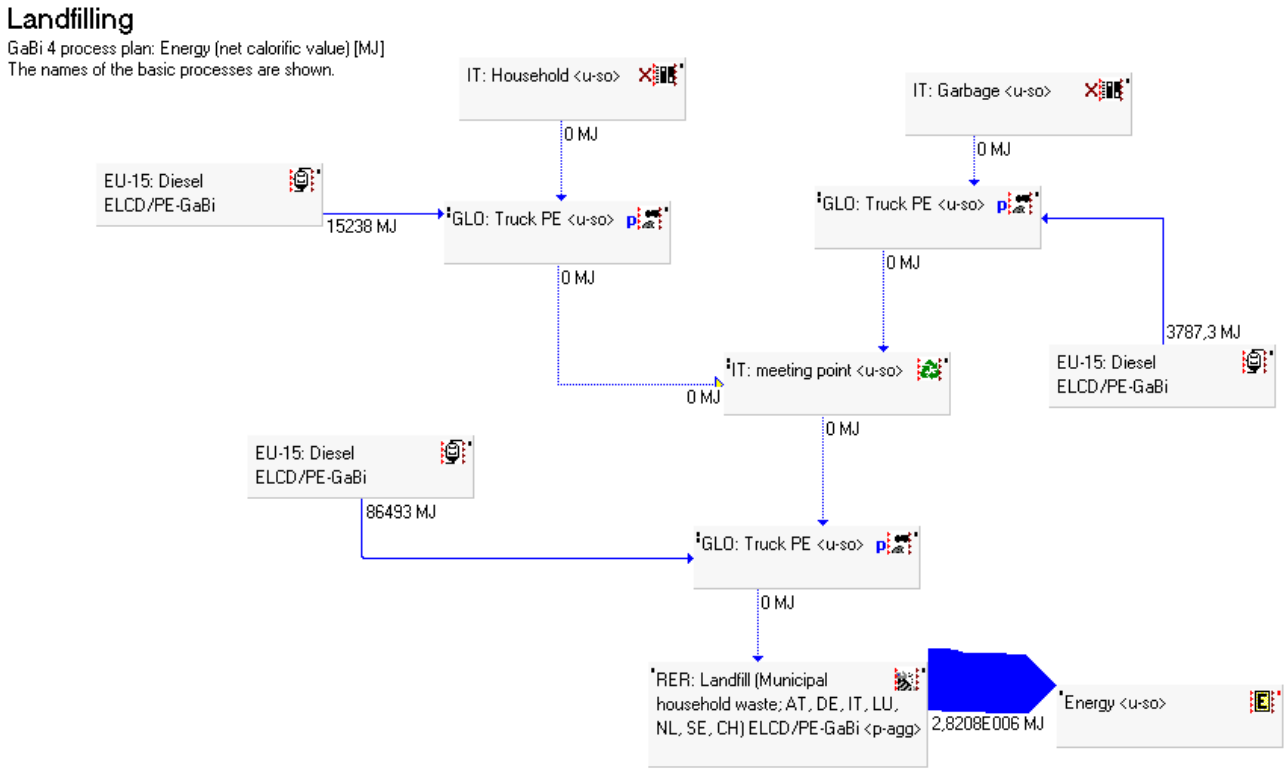


Figure 14 Plan model Landfill Energy flow

6.6 Incineration

The incineration process is included in GaBi4, and the data set represents an average European waste-to-energy plant (WTE) for the thermal treatment of municipal solid waste (MSW) with typical technology used in Europe to meet the legal requirements.
The data set represents a typical European situation (EU-27 + CH and NO), that is composed by a mix of

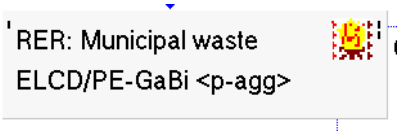


Figure 15 Municipal Waste GaBi4 Process

dry and wet flue gas cleaning and different NOx removal technologies (SCR = Selective Catalytic Reduction and SNCR = Selective Non-Catalytic Reduction) is applied to represent the actual application in the EU-27 countries, Switzerland and Norway. The assumed model is an average of European WTE plant; Generally it doesn't exist a general values of efficiency, of emission as the transfer coefficients and elementary composition will differ for every specific WTE plant.

The emissions and resource consumption for the thermal treatment of waste, the collection of the bottom ash, as the air pollution control residues on a landfill are included in the data set. It should be considered that this data set is an approximation of the reality. Figure 16 and figure 17 represents the

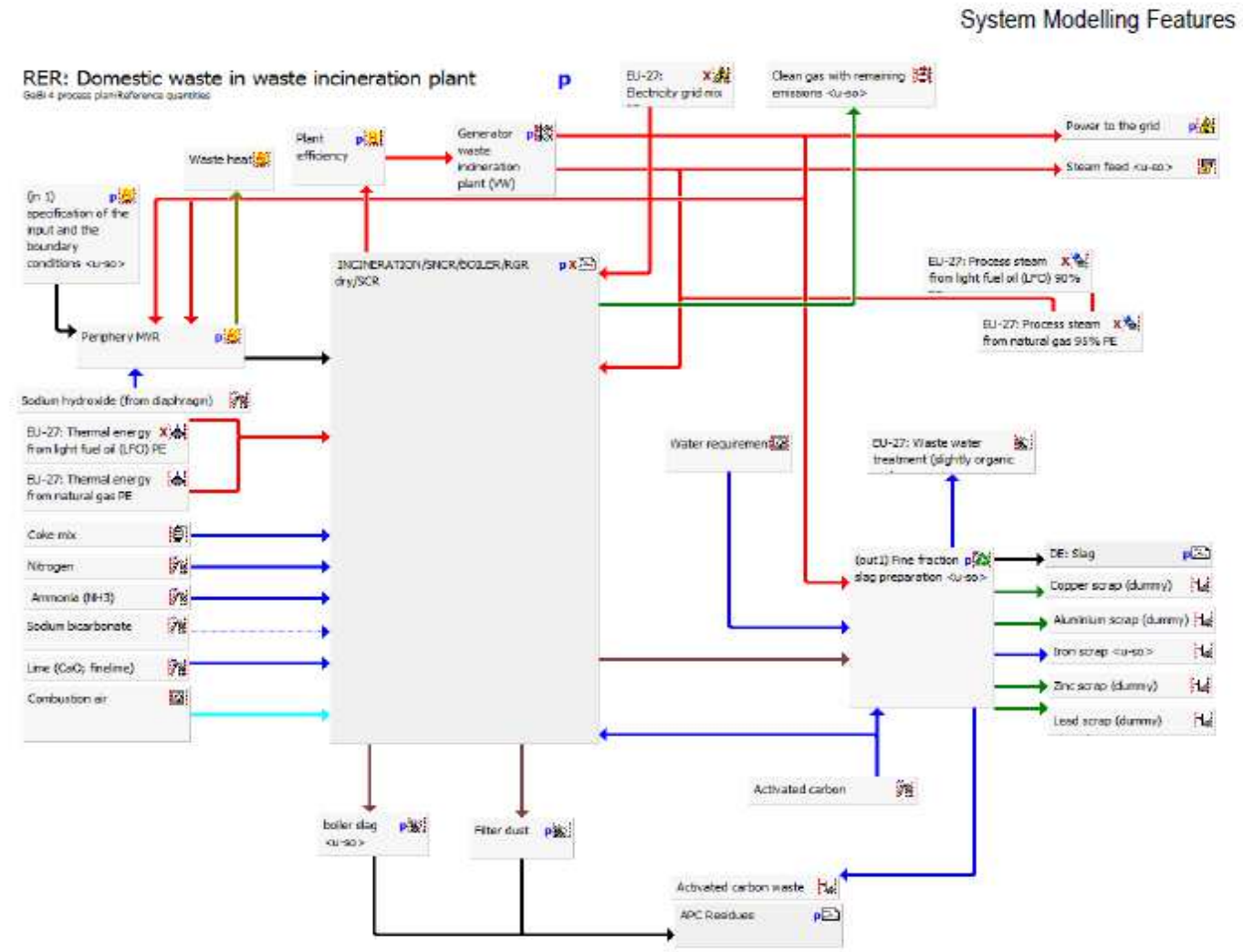


Figure 16 Waste combustion process modelled by GaBi 4, first part (Gabi Manual)

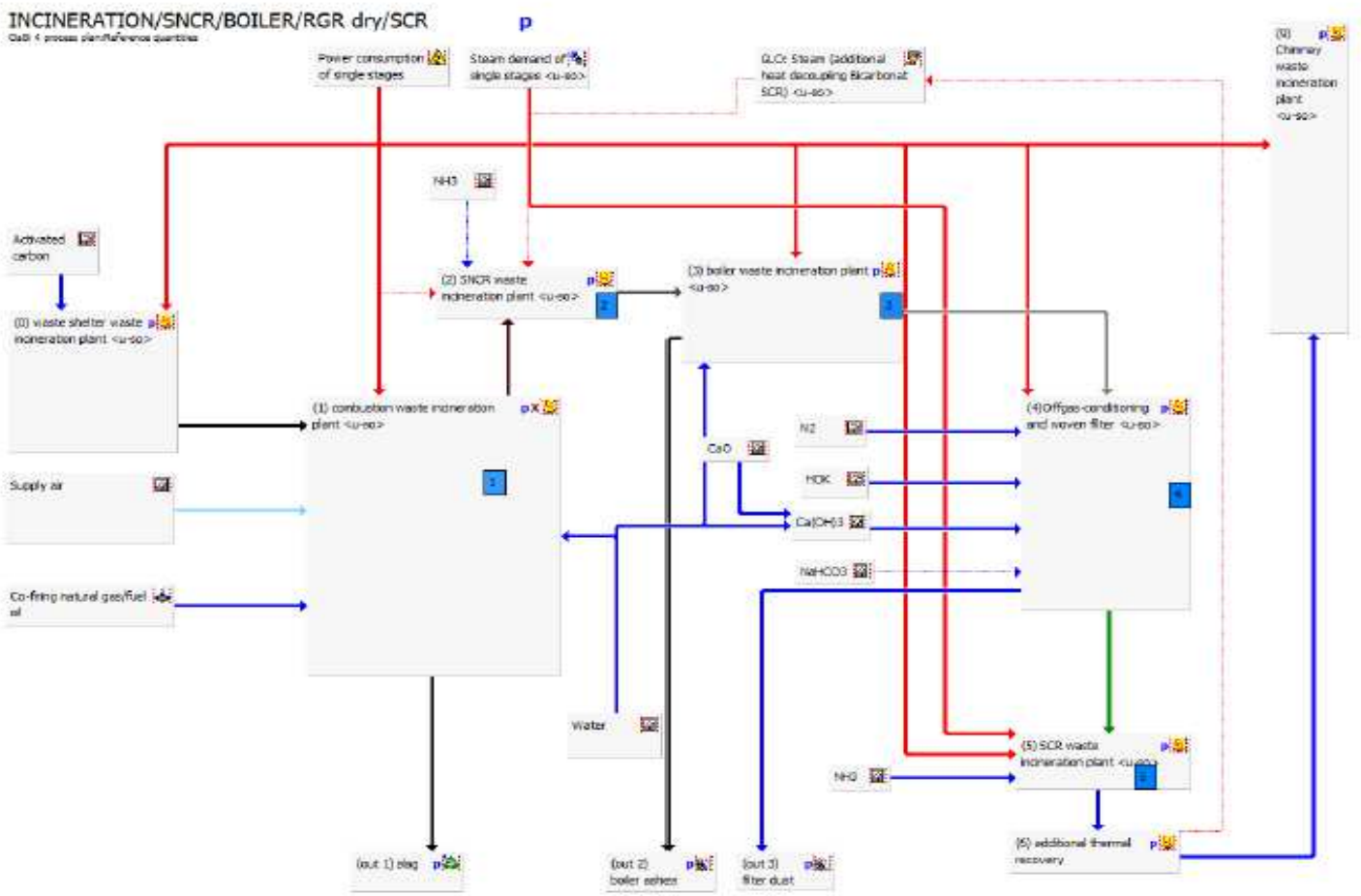


Figure 17 Waste combustion process modelled by GaBi 4, second part (Gabi Manual)

The data set covers all relevant process step technologies over the supply chain of the represented cradle-to-gate inventory process with a good overall data quality. The inventory is mainly based on industry data and is completed, where necessary, by secondary data.

Two different incineration models one with a wet and one with a dry Flue Gas Treatment (FGT) and different NOx-removal technologies are mixed to represent the appliance of the different FGT systems in Europe.

The incineration adopted is according to data published in the BREF document "Waste Incineration" of the European Commission (2006), two-thirds of the MSW are treated within a plant operating with a dry FGT and one-third of the MSW are incinerated within a plant with a wet FGT.

For the NOX reduction, a share of two-third SNCR (Selective Non-Catalytic Reduction) and one-third SCR (Selective Catalytic Reduction) is used. An energy balance for the plant was made using data from the "CEWEP Energy Report" (2006) representing 97 waste-to energy plants in Europe.

The plant consists of an incineration line fitted with a grate and a steam generator. The average efficiency of the steam production is about 81.9%.

Produced steam is used internally as process-steam and the balance is used to generate electricity or exported as heat to industry or households. All the GaBi incineration values for 1t of MSW are shown in table 2, the process is adapted for the FU introduced.

Table 2 MSW efficiency and energy value.

Average efficiency steam production.	**81,90%**
Grid losses	7%
Lower calorific value MSW	10 GJ/t
Electricity distribution	1.09 GJ/t
Thermal energy	3.16 GJ/t

All utilities used in the waste incineration plant, the operation of the underground deposit and the landfill for bottom ash and air pollution control (APC) residues, as well as the meltdown processes for the recovered metals are included in the system (Gabi, database, incineration MSW) that is represented in figure 19.

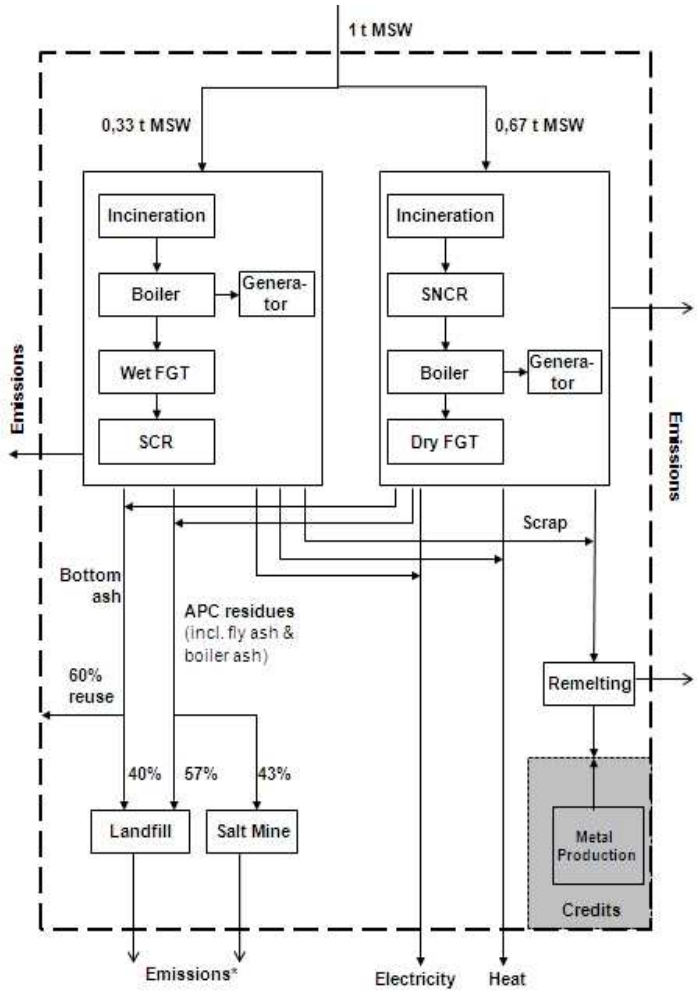


Figure 18 Flow diagram of Waste Incineration, GaBi4

6.6.1 Flue gas treatment system

Dry FGT

The flue gas treatment system uses a dry technology with adsorbent and a SNCR system for NOx-reduction. The NOx reducing agent ammonia is directly injected into the furnace and reacts with the NOx to nitrogen and water. The flue gas is conditioned, with addition of adsorbents and filtered with fabric filters. Lime milk and small parts of hearth furnace coke are used as adsorbents; a part of the adsorbents is re-circulated. The fly ash together with the adsorbent is mixed together with the boiler (CEWEP, 2006)

Wet FGT:

The flue gas treatment system uses a pre-dusting stage and an additional downstream deducted both fabric filters and wet scrubbers to clean the flue gas. After leaving the pre-deducting stage used to reduce the dust load before the wet scrubbers, the flue gas is feed into the water of the first wet scrubber. Mainly HF and HCl are removed in the first stage. The deposition of Sulphur dioxide in very acid medium of the first stage (pH 0-1) is low and requires a second wet scrubber to remove SO2. Lime milk, hearth furnace coke and tress are used as adsorbents in the filters and scrubbers. It hasn't been done a purification of the brine from the first scrubber to hydrochloric acid and the sulphate slurry from the second scrubber to gypsum. All residues are treated together as APC residues. As final treatment stage the flue gas passes a SCR system to reduce NOx. Due to the quenching movement of the flue gas in the wet scrubber and the temperature requirements of the SCR catalyst, the flue gas has to be reheated (Gabi, database, incineration MSW).

6.7 Emissions

For the emissions HCl, HF, NOx, VOC, N_2O, CO, NH_3, SO_2, dust, dioxin and the heavy metals As, Cd, Co, Cr, Ni and Pb mean emission values per cubic meter of cleaned flue gas published in the BREF document "Waste Incineration" of the European Commission are used. Due to the wide range of emissions for some elements and substances the mathematical mean values are adjusted with additional real plant data. The emission of all other elements and the distribution of all elements and substances into the different residues are calculated by means of transfer coefficients (see model description below).

6.8 Treatment of residues

Metals (Fe, Al, Cu, Zn and Pb) are recovered (10% Fe, the 1% Al and Cu, 0.6% Zn and Pb) in the bottom ash) and a three month ageing process is done to stabilize the bottom ash. (CEWEP, 2006)

60% of the produced bottom ash after metal recovery and ageing is reused as construction material (and will leave the system as bottom ash for reuse). The remaining 40% are disposed on a landfill (CEWEP, 2006).

220kg/t of MSW (approximately 195 kg/t of MSW without metals) consist approximately to bottom ash and they are quenched. (CEWEP, 2006).

The tests for bottom ash and standard leakage rates for landfills are used to consider the transfer of elements of the bottom ash into ground water, waters bodies or air leachate. According to the current situation in Europe APC (Air Pollution control), the residues (42kg/t of MSW), including boiler ash, filter cake and slurries, are disposed in salt mines (43%) or landfills (57%). (CEWEP, 2006).

The disposal in salt mines without free water and contact to ground water reservoirs has been modeled as emission free and the operation of the underground deposit is included.

The landfill was modeled similar to the bottom ash using leachate test data for APC residues. Transports for bottom ash and APC residues independent of the different routes are considered. (CEWEP, 2006)

Figure 18 represent the whole incineration process modelled with GaBi tools, it includes transportation form the household and from the street garbage to the transfer station close to the hypothetical incineration plant, the energy generated is distributed to the household as thermal energy or electrical energy.

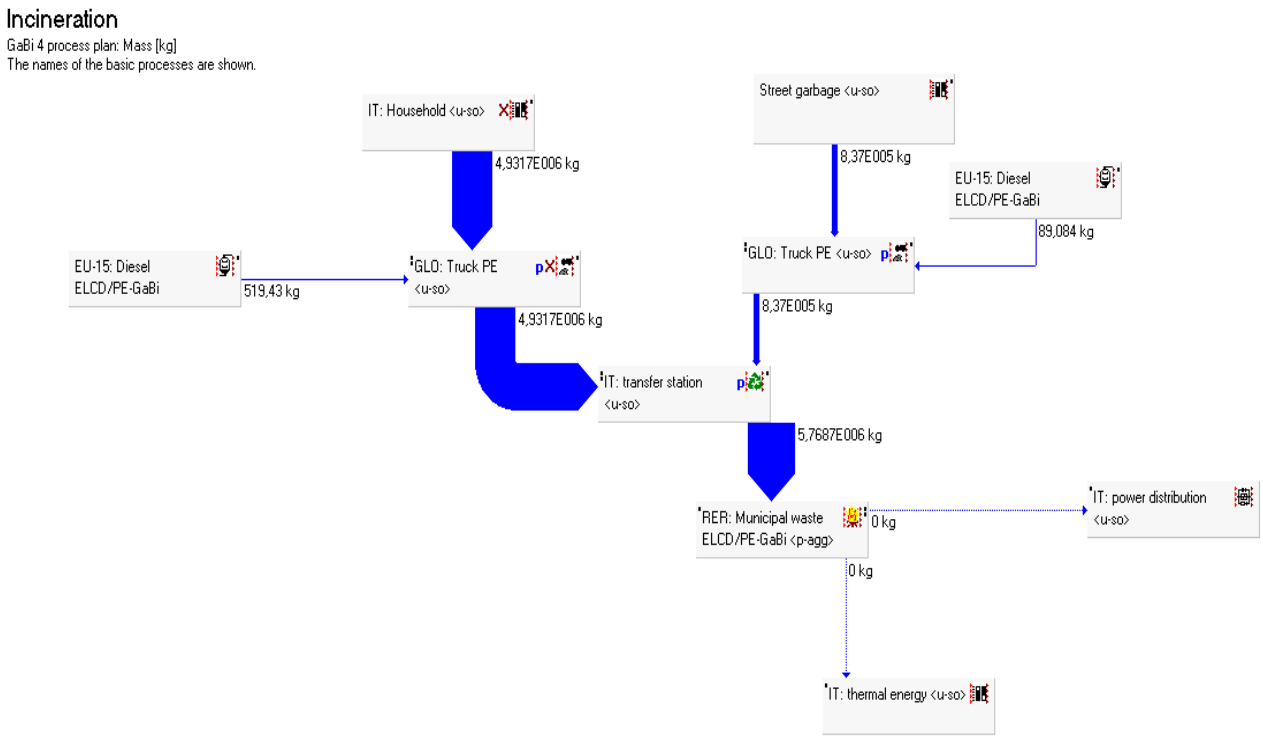


Figure 19 Incineration scenario in GaBi 4, Mass Flow

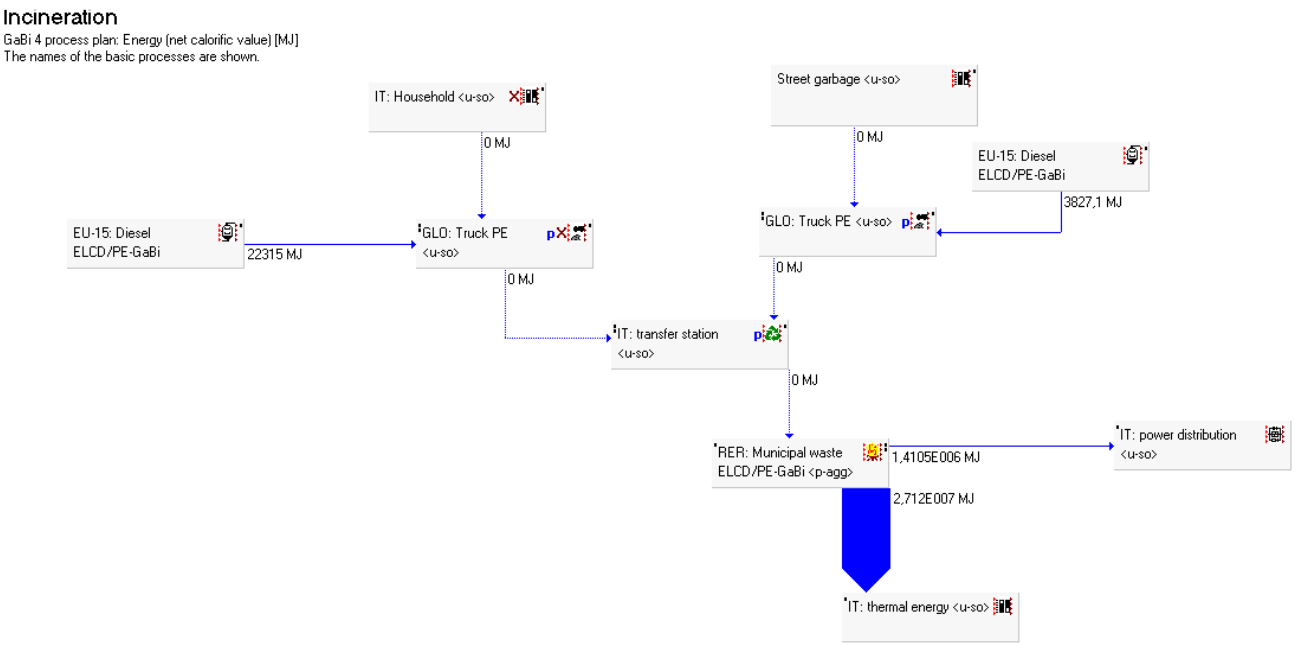


Figure 20 Incineration scenario in GaBi 4, Energy Flow

7. Life Cycle Impact Assessment

As suggested in ISO 14040 norms, after the target and scope definition, a detailed life cycle inventory (LCI) needs to be performed, in which mass and energy flows directly involved in the urban waste system are identified. Results from the LCI are then used for the characterization of impacts (LCIA).

There are different methods that can be used to perform a Life Cycle Impact Assessment. These methods are continually investigated and developed by different scientific groups based on different approaches. GaBi utilizes two main methods for the life cycle impact assessment, TRACI and CML that are used to classify and characterize environmental impacts: the problem-oriented approach, mid-point, and the damage-oriented approach, end point (GaBi manual, 2006).

The midpoint level describes impact such climate change, eco-toxicity and acidification, in contrast to endpoint level where human health and ecosystems damages are described. Liquid, solid and gaseous emissions have been carefully evaluated and classified into impact categories to which they contribute. With CML methods more than a thousand substances are classified and characterized according to the ranch to which they contribute to a list of environmental impact categories. Impact categories such global warming potential and ozone layer depletion are based on IPCC factors the others are elaborated by CML and they are classified in appendix C.

7.1 Total energy

Total energy is not an environmental indicator, but it is a helpful category in order to analyze the efficiency of the waste management systems. In addition, it is useful to provide a more specific data analysis of climate changes and other impact categories.

This category covers renewable and non-renewable energy sources. It can be seen as an indicator for the depletion of energy resources and is expressed with his net calorific value MJ.

7.2 Global Warming Potential (GWP)

As mentioned in chapter 2, the increasing temperature of the troposphere is due to anthropogenic greenhouse gases e.g. from the burning of fossil fuels, and the consequently emission of CO_2. In LCA, Global Warming Potential (GWP) is measured in kg of CO_2 equivalent according with IPCC (Intergovernmental Panel on Climatic Change). This is a measure of how much a unit mass of gas contributes to global warming compared to carbon dioxide. The other gasses as CH_4, N_2O, SF_6, PFC, and HFC values are expressed in CO_2 equivalent. For Global Warming Potential time must always be expressed for a certain time horizon index as 25, 100 or 500 years, because the characteristic effect of greenhouse gases have various atmospheric lifetimes. The reference time horizon for this study is 100.

6.3 Ozone Depletion Potential (ODP)

Another global effect analyzed is Ozone Depletion Potential, which main effect is the reduction of the ozone concentration in the Stratosphere, due to emissions such as Chloro-fluoro-carbons (CFCs). In LCA the Reference Substance is Ozone Depletion Potential (ODP), is a measure of the destructive effects of gases on the ozone layer, measured in Tri-chloro-fluoro-methane-equivalent, R11-equivalent, (Guinee, 2001). The ozone layer is the earth's shield against UV radiation and in this way prevents excessive warming of the earth's surface. Consequences of ozone layer depletion include the growth of tumors in humans and animals as well as photosynthetic disruption in plants. (Gabi tutorial clip 1, 2006)

6.4 Acidification Potential (AP)

Acidification Potential refers to the effects of the acid gases like Sulphur dioxide (SO_2), sulfur trioxide (SO_3), nitrogen oxides(NOx), hydrogen chloride (HCl) and hydrogen fluoride that are released into the air, taken up by atmospheric precipitations and consequently falling like "acid rain". The pH-value of precipitation, due to the wash-out of acid gases, increases, the rain are lately absorbed by plants, soil and surface waters leading to damage and super acidity of the soil, with consequently impact on vegetation, lakes and rivers. Acidification is also harmful for human health especially on the respiratory apparatus; Another big impact is the degradation of monuments, houses, bridges and building products;

The area of Avezzano, Fucino, is an important center in the middle of three national parks; this area is the main center for the agricultural and industrial economy of the region, in addiction, like in all Italy, the place is full of architectural and cultural places, so taking control of the Acidification effect is essential.

In the LCIAI, the effect of other acidifying emissions (e.g. NOx, H_2S) is given in SO_2 equivalents, the reference unit measure of how much the equivalent of a given mass contributes to acidification. (Guinee, 2001).

6.5 Eutrophication Potential (EP)

Eutrophication is a nutrient enrichment culminating in over nourishment in aquatic and terrestrial ecosystems. This may cause the increasing of biomass production, and consequently a shift in the composition of species. In aquatic ecosystems, the increased growth of algae allows less sunlight reaches deeper layers, less photosynthesis occurs and oxygen concentration decreases. Dead plants fall down to deeper layers and are degraded. Finally, the concentration of oxygen is too low for fishes and other animals to survive. Degradation processes happen without oxygen, they are anaerobic and gases like methane are produced.

For terrestrial ecosystems, eutrophication might cause a change in flora and fauna, biodiversity can decrease; this event is negatively critical and significant for a natural area like Abruzzo, where species of fauna and flora are frequently controlled.

In LCAI, The contribution of relevant emissions is expressed in PO_4 equivalent. Eutrophication is caused by excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). The full list of relevant substances and their equivalence factors, determined by the CML, are listed in appendix C.

6.6 Human Toxicity , Marine, Freshwater and Terrestrial Eco-Toxicity Potential

Different toxicity potential are analyzed: Human toxicity, marine, freshwater and terrestrial eco-toxicity. The main contributor are heavy metals, emitted to air, water and soil. The toxicity of a substance is based on several parameters: its chemical composition, physical properties, point source of emission and the time of exposure; Harmful sub-stances can spread to the atmosphere, into water bodies or into the soil. Characterization factors are calculated through the “Centre of Environmental Science (CML), Leiden University”.

Human Toxicity Potential (HTP) assessment aims to estimate the negative impact on humans, Eco-Toxicity potential aims to outline the damaging effects on ecosystem. (GaBi Paper Clip Tutorial, part 1. PE International, 2006). The surface of the model is divided into 3% surface water, 60% natural soil, 27% agricultural soil and 10% industrial soil. 25% of the rainwater is infiltrated into the soil. (GaBi Paper Clip Tutorial, part 1. PE International, 2006). This leads to a division of the toxicity into the groups mentioned above (HTP, AETP, TETP,METP) for which, based on the location of the emission source (air, water, soil), three values are calculated

The potential toxicities (human, aquatic and terrestrial ecosystems) are generated from a proportion based on the reference substance Dichlorbenzol ($C_6H_4Cl_2$). The unit is 1.4 kg Dichlorbenzol-Equivalent kg emission.

8. Result and interpretation

8.1 Global Warming Potential

The model provides a clear overall result regarding the impact category climate change: Table 3 and Figure 19 show that landfilling generates significant savings on CO2 production and emission in the air.

Table 3 GWP comparison each scenario, CO2-Equiv

Global Warming Potential [kg CO2-Equiv./FU]	Incineration	Landfilling
Emissions to air	7462113,037	4043586,574

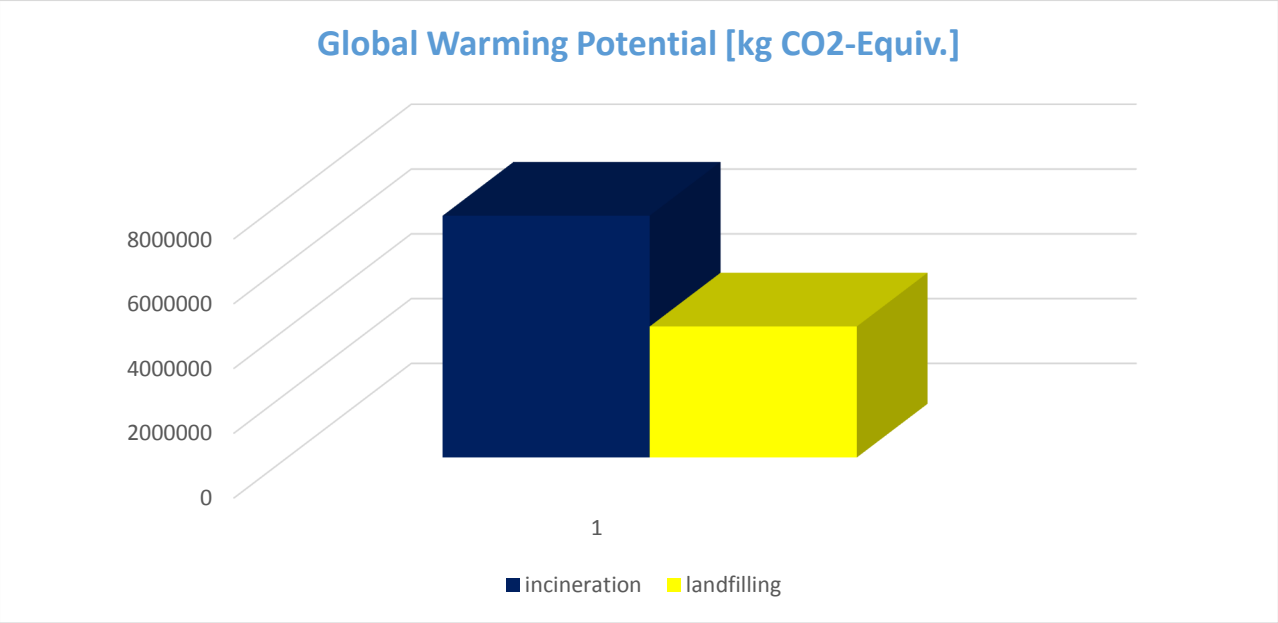


Figure 21 GWP representation for each scenario, CO_2-Equiv.

CO2 are emitted mainly during the combustion, however even landfill have a strong impact on the air quality. The organic material decomposes anaerobically produce LFG is, consisting of 45% to 60% methane gas, 40% to 60% carbon dioxide, and 2% to 9% other gases which are mostly emitted to the atmosphere (Uni Assignment Center, 2006). LFG is a significant contributor to atmospheric methane; this production is a great concern as a great impact on greenhouse effect. Landfills are the largest anthropogenic source of atmospheric methane in many developed countries. In Europe, 23% of anthropogenic emission is methane in 2006 (Capellia, 2014).

Although methane and carbon dioxide are produced in almost equal amounts in landfills, methane is 21 more than carbon dioxide.

Having a deeper analysis the base case, table 4, has a greater emission on transportation, since landfill is located farer than the incineration, from the city.

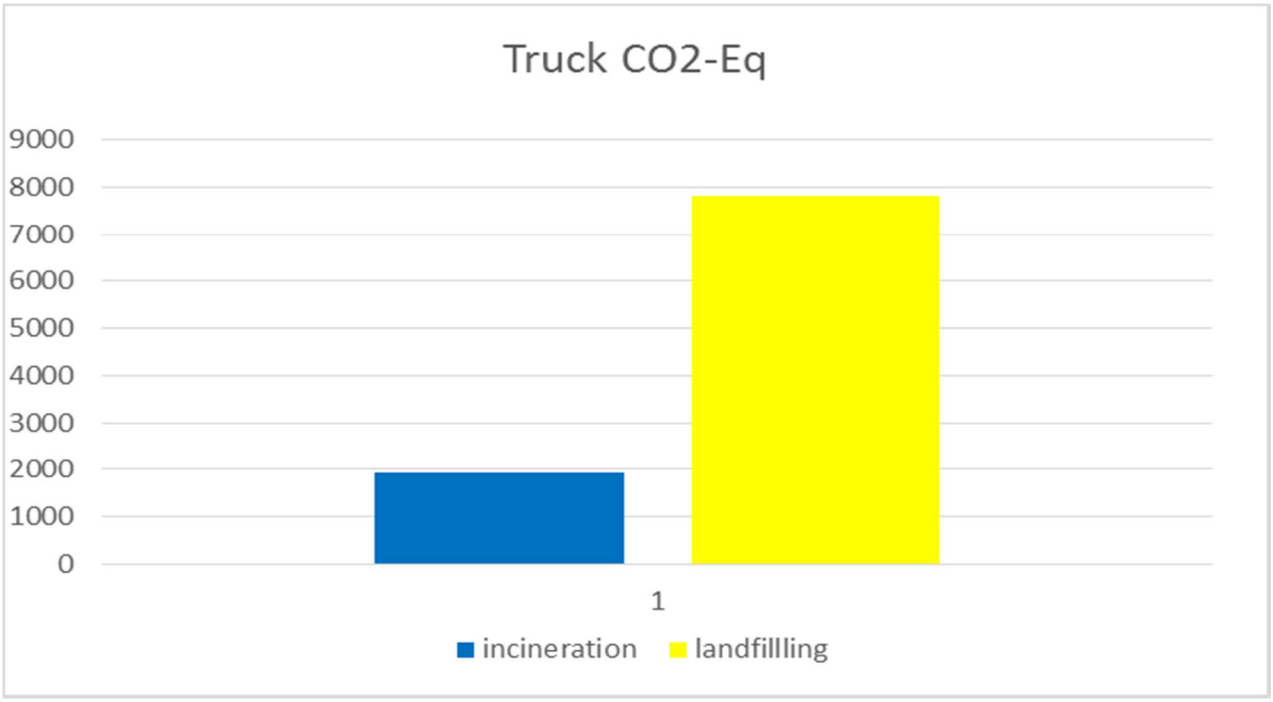


Figure 22 scenario trucks comparison, CO_2-Equiv

The results from the impact category total energy provide useful information for the interpretation of this category. Table 4 shows the emission of CO_2-eq. in relation to the generated energy.

Table 4 ratio of total energy comparison, CO2.equiv

Ratio of total energy and climate change [CO2 equiv/MJ]	
incineration	landfilling
0,237272211	4,617888779

Option 2 shows a production of about 16 times more greenhouse gases per MJ. The result shows a better utilization of the incineration generator. Secondly, the emissions from the combustion plant are largely composed by CO_2; for the landfill, the main part of the emissions is methane and every kg of methane counts 21 kg CO_2-eq.

Here, emissions of combustion have a big impact on climate change; however, incineration produces related IHT energy and guarantees more energy saving and less greenhouse gas emissions.

8.2 Ozone Depletion Potential

Biogas from landfill is a main contributor to ODP as well as the combustion of Diesel due to emissions of CO, NMVOCs and VOCs; therefore transport activities play a major role. Biogas production is the reason because Option 1 gets a slight worse result in CO_2 terms compared with incineration and methane landfills; results are powerful greenhouse gas and effects on the ozone layer they are emitted in the air; however their impact is not big.

Table 5 comparison ODP each scenarios, kg R11-Equiv.

Ozone Layer Depletion Potential [kg R11-Equiv.]	Incineration	Landfilling
Emissions to air	0,011773818	0,006919415

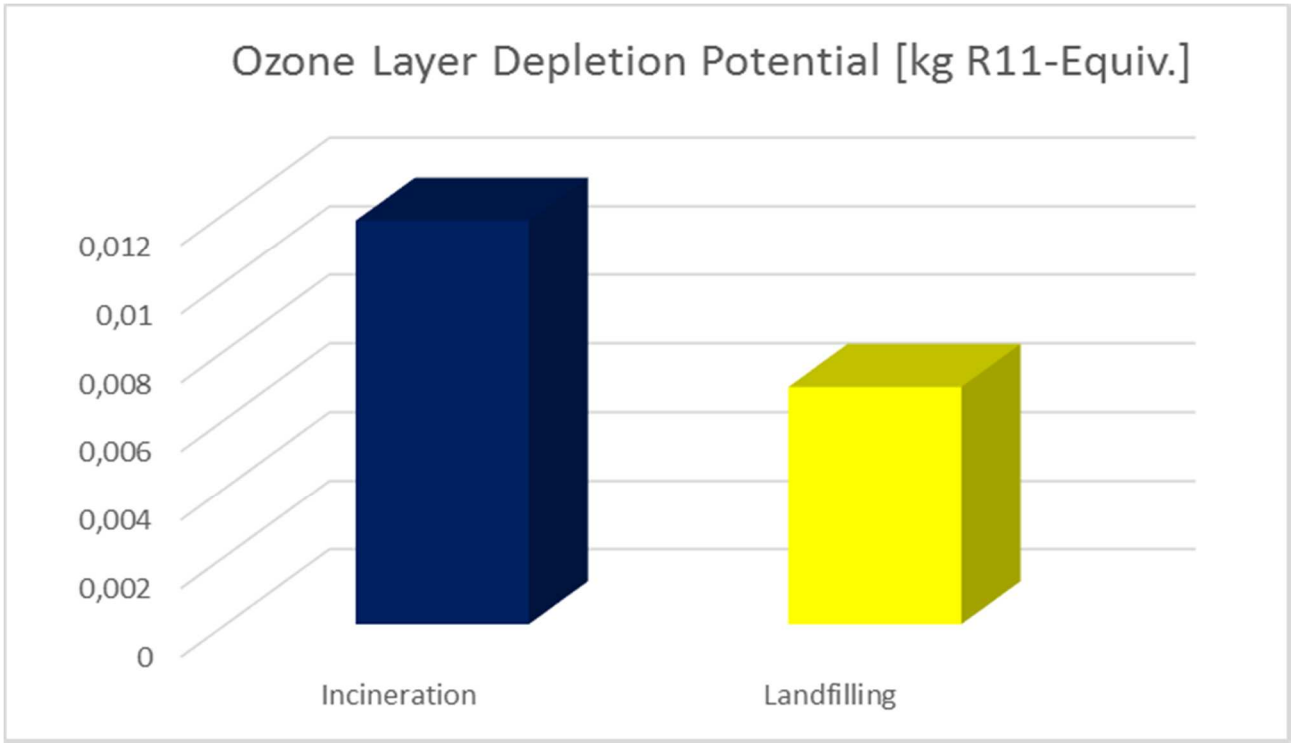


Figure 23 ODP representation for each scenario, kg R11-Equiv

Coherently with what has already been analyzed incineration have a greater impact than landfill on the air quality. But less emission compared on the energy production (table 6).

Table 6 comparison ratio of total energy kg R11-Eq/MJ

Ratio of total energy on ODP [Kg R11-eq/ MJ]	
incineration	landfilling
3,74E-10	7,90E-09

8.3 Acidification Potential

Emission are more pollutant in incineration, the graphic shows the acid compound for FU. Acidification Potential is increased by acidifying compounds from human sources, principally fossil fuel and biomass combustion, other main pollutants involved in acidification are sulfur and nitrogen compounds. However landfilling have a more impact on water quality due hydrochloric acid.

Table 7 AP comparison emissions for each scenario, kg SO2-Equiv

Acidification Potential [kg SO2-Equiv.]	Incineration	Landfilling
Emissions to air	8422,207418	1848,27358
Emissions to fresh water	0,000636786	0,62086425

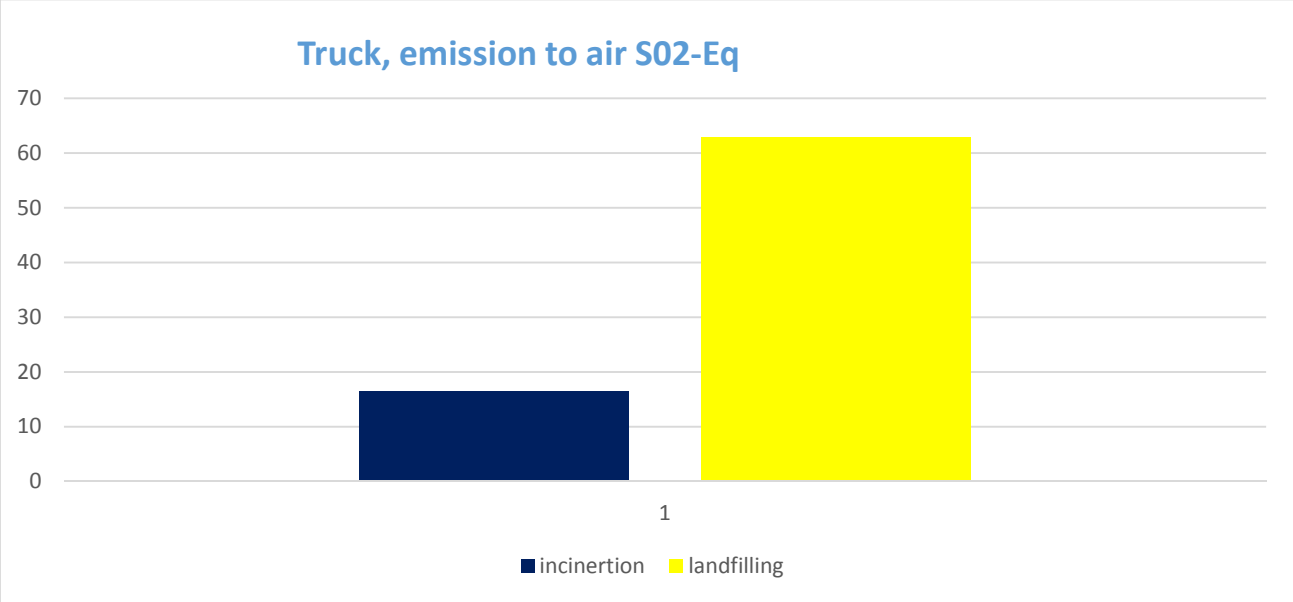


Figure 23 comparison truck each scenario, kg SO2-Equiv.

8.4 Eutrophication Potential

The model presents a clear ranking for the impact category eutrophication potential. Incineration produces a small saving compared to the Base Case. Main impacts are transportation, leachate from landfill and exhaust from WTE. Incineration itself is a big source of nitrogen emission as it is shown in table 8, on fact WTE has the biggest impact on the air quality while the production of leachate is more dangerous for the soil and water quality.

Table 8 EP comparison emissions for each scenario, kg Phosphate-Eq

Eutrophication Potential [kg Phosphate-Equiv.]	Incineration	Landfilling
Emissions to air	1257,225801	250,674494
Emissions to fresh water	23,38650282	997,041128
Emissions to sea water	0,247448282	0,03529596
Emissions to industrial soil	3,684707801	8678,97664

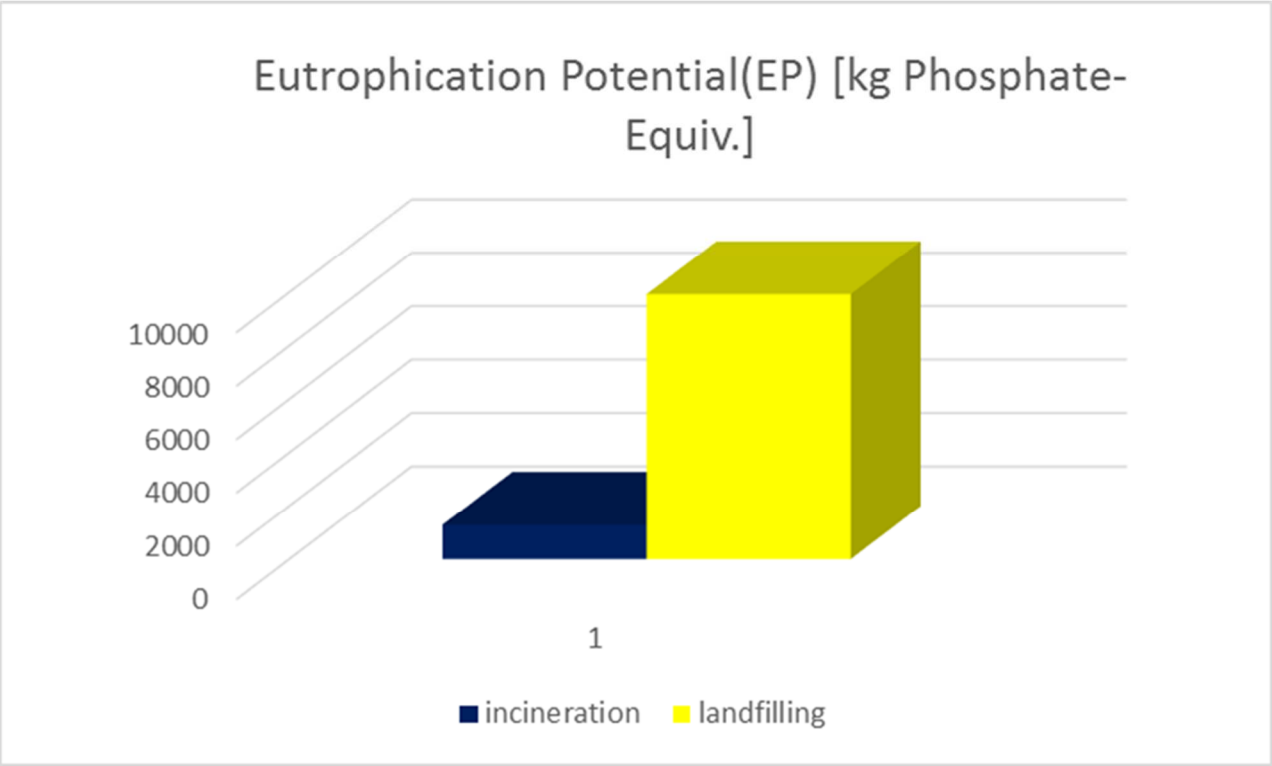


Figure 24 EP comparsion

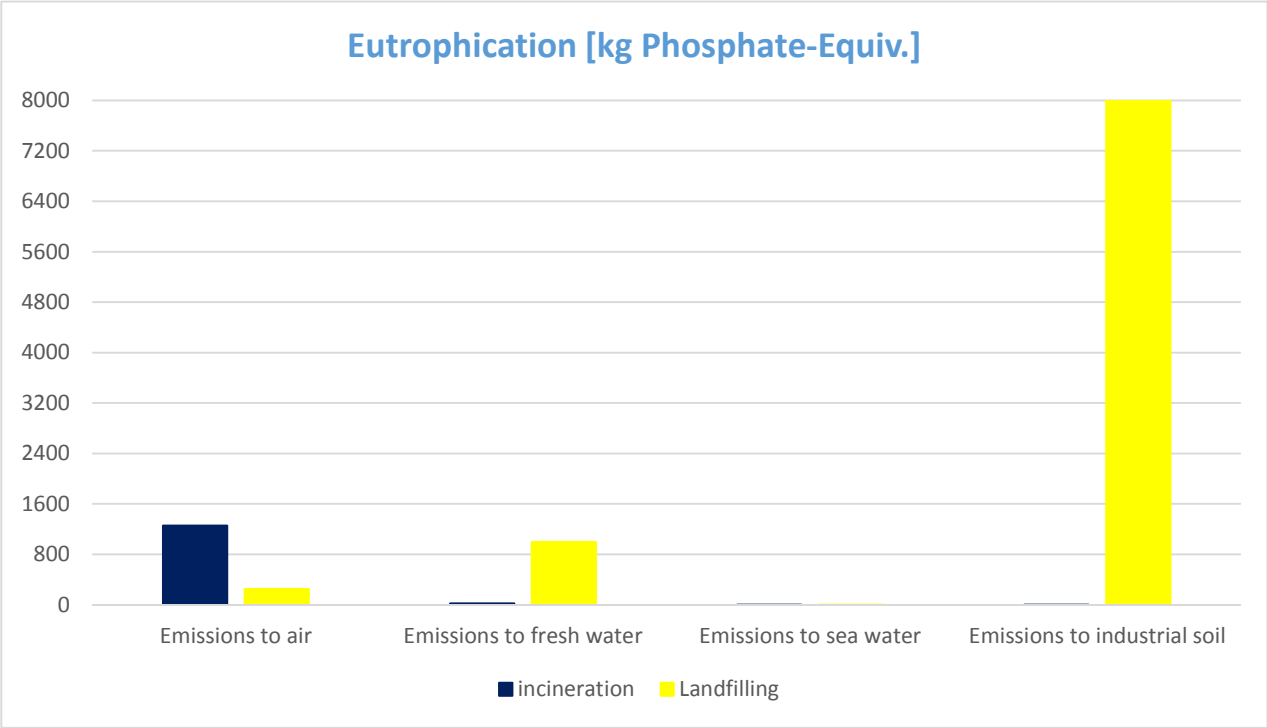


Figure 25 EP, representation of the specific emissions, kg-Phospate-eq

According with the precedent analysis, there is a close connection between total energy and impact category. Benefits from incineration are clearer, WTE guarantees a better production of energy and therefore higher energy utilization; Every MJ of electricity produced in the incineration process contributes to this impact category with 4,08446E-05kg P-eq. that is almost 300 hundred less than the energy produced by landfill.

Table 9 EU comparison total ratio energy Kg P/ MJ

Ratio total energy EP [kg P-Eq]	
incineration	landfilling
4,08E-05	0,01136

8.5 Human Toxicity Potential (HTP)

Main benefits arise out of land-filling. Released biogas, exhaust from the electricity generator at landfill, leachate and exhaust from WTE cause impacts. For the combustion of waste, heavy metals residues are the main contributor.

In the following table 10 and graphics, the effects on human and environment toxicity are shown. It can be seen a sort of coherence in the analysis, incineration emissions have a huge impact on air.

Table 10 HTP comparison emission kg DCB-Equiv.]

Human Toxicity Potential [kg DCB-Equiv.]	Incineration	Landfilling
Emissions to air	30906,1055	6549,78544
Emissions to fresh water	452,439454	1721,61724
Emissions to sea water	866,009435	116,15248
Emissions to industrial soil	3,86107438	273,418236

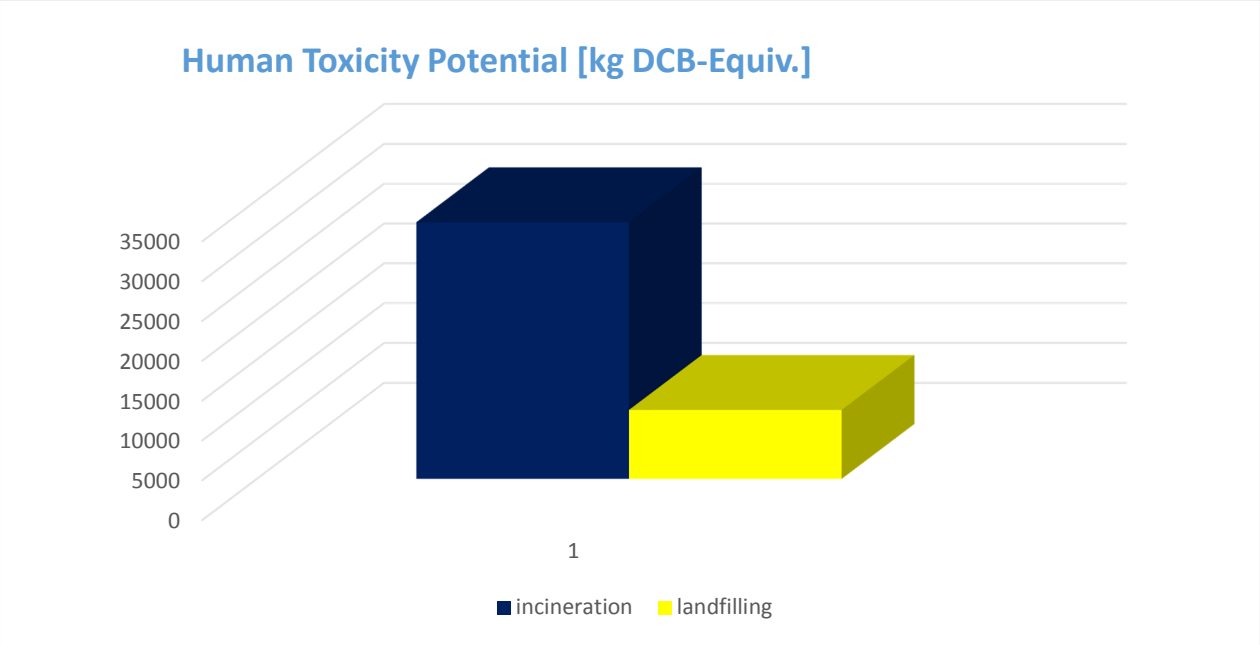


Figure 26 HTP comparison for scenarios

The behavior and effects of atmospheric emissions in soils and plants for both cases are discussed. Incineration has a higher effect on Human toxicity as it could be seen in the graphic of figure 26, due to his biggest effects in the emission to air or the gas emissions which are more intense than land-filling. However land-filling has a major impact on freshwater and industrial soil, especially if the production of leachate, and it is not fine controlled.

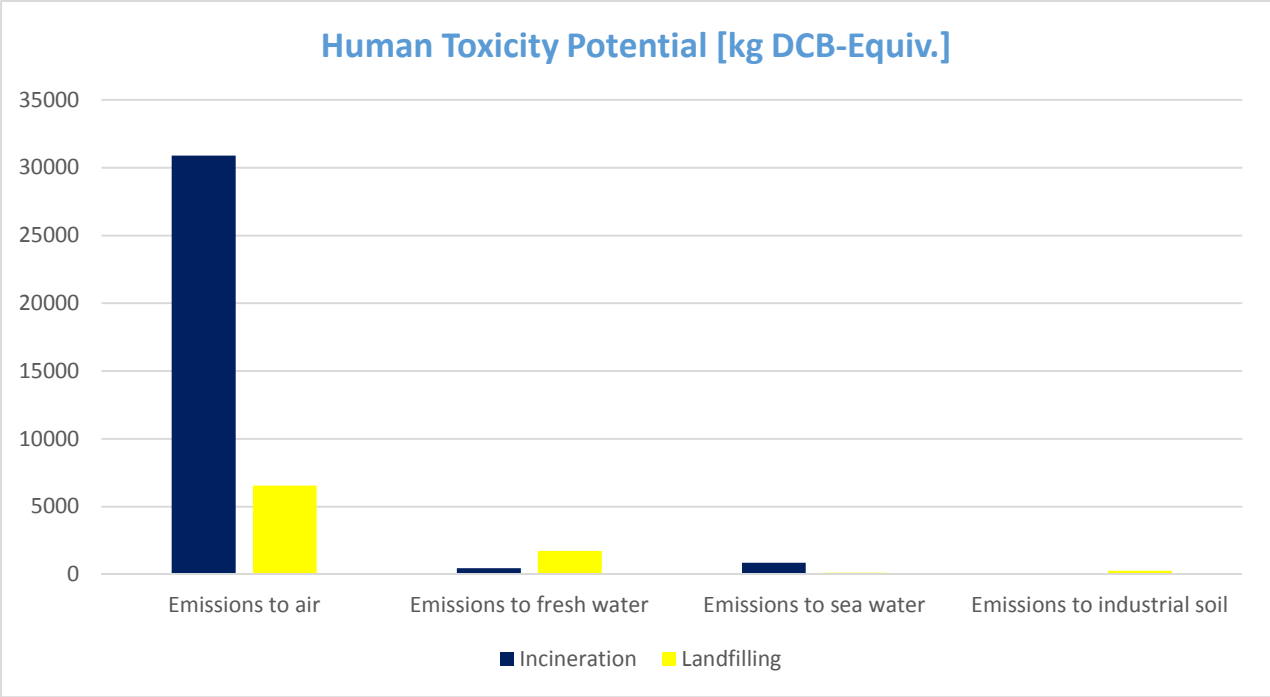


Figure 27 Human Toxicity Potential Emissions

8.6 Marine Aquatic Ecotoxicity Pot. MAETP

The results for this impact category are determined by impacts caused by leachate (emissions to water and soil) and exhaust fumes. Although impacts by exhaust from garbage combustion are of little relevance compared to land-filling emission in the soil, the emissions of Hydrocarbons to the sea water are worst by incineration than by land-filling. For the incineration case, the presence of metals and organics in the incinerator quenches water and in leachates from ash disposed in landfills are reviewed, as well as their toxicity to fish.

Table 11 MAETP comparison of emissions for each scenario, DCB-Eq

Marine Aquatic Ecotoxicity Pot. [kg DCB-Equiv.]	Incineration	Land-filling
Emissions to air	8951691,415	8497352,8
Emissions to fresh water	293246,7114	21060899,9
Emissions to sea water	2335456,34	313950,481
Emissions to industrial soil	4186,129008	211759,463

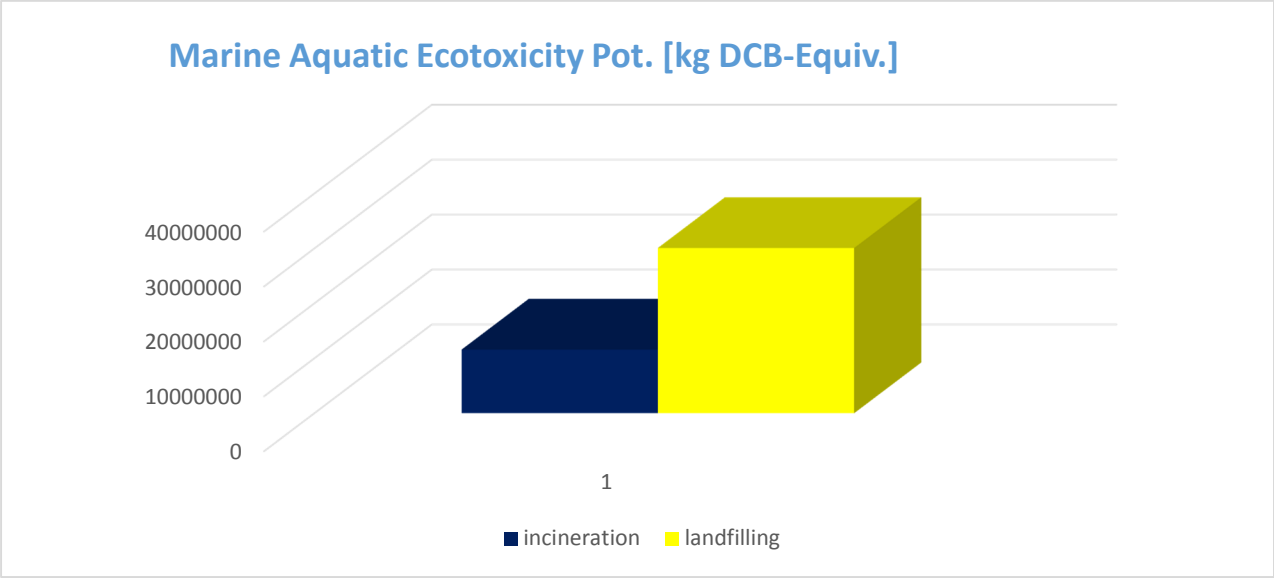


Figure 28 MAETP comparison for each scenario, kg DCB-Eq

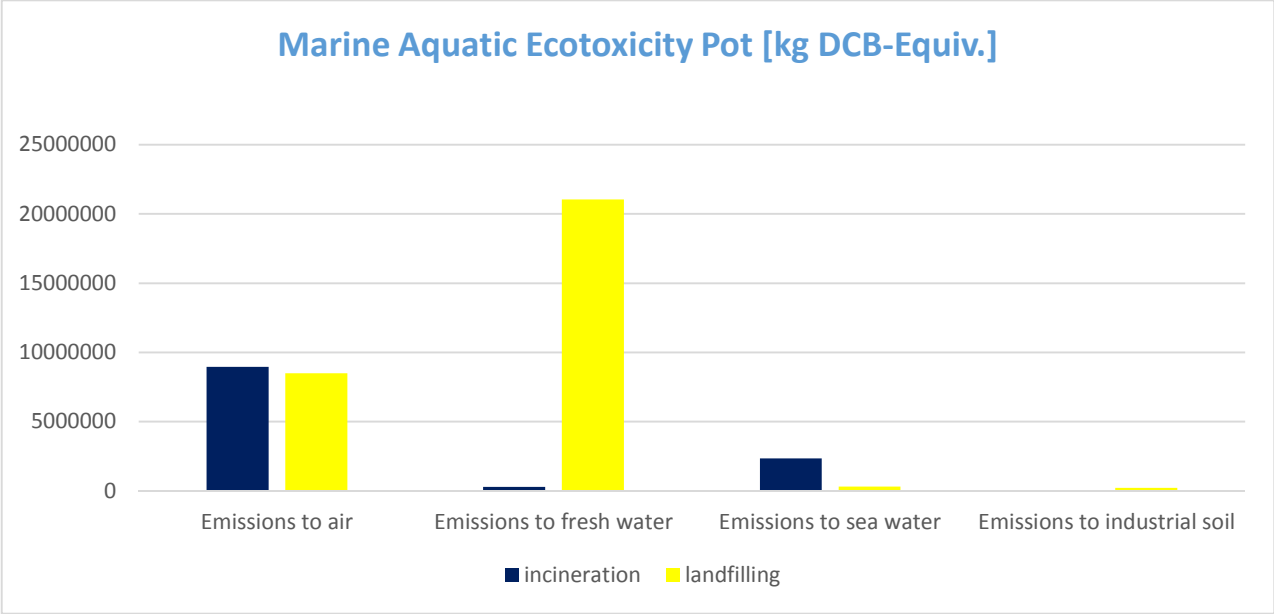


Figure 29 MAETP comparison of emissions for each scenario, kg DCB-Eq

8.7 Freshwater Aquatic Ecotoxicity Potential

The impact for this category arise mainly out of heavy metal emissions from leachate to water. As they are especially high for leachate from slag. This is particularly evident explained in Figure 12

Table 12 FAETP comparison of emissions for each scenario

Freshwater Aquatic Ecotoxicity Pot. [kg 1,4 DCB-Equiv.]	Incineration	Landfilling
Emissions to air	286,3703824	81,20706916
Emissions to fresh water	207,3510955	244,0638025
Emissions to sea water	0,008589247	0,001073517
Emissions to industrial soil	5,906544834	374,9264591

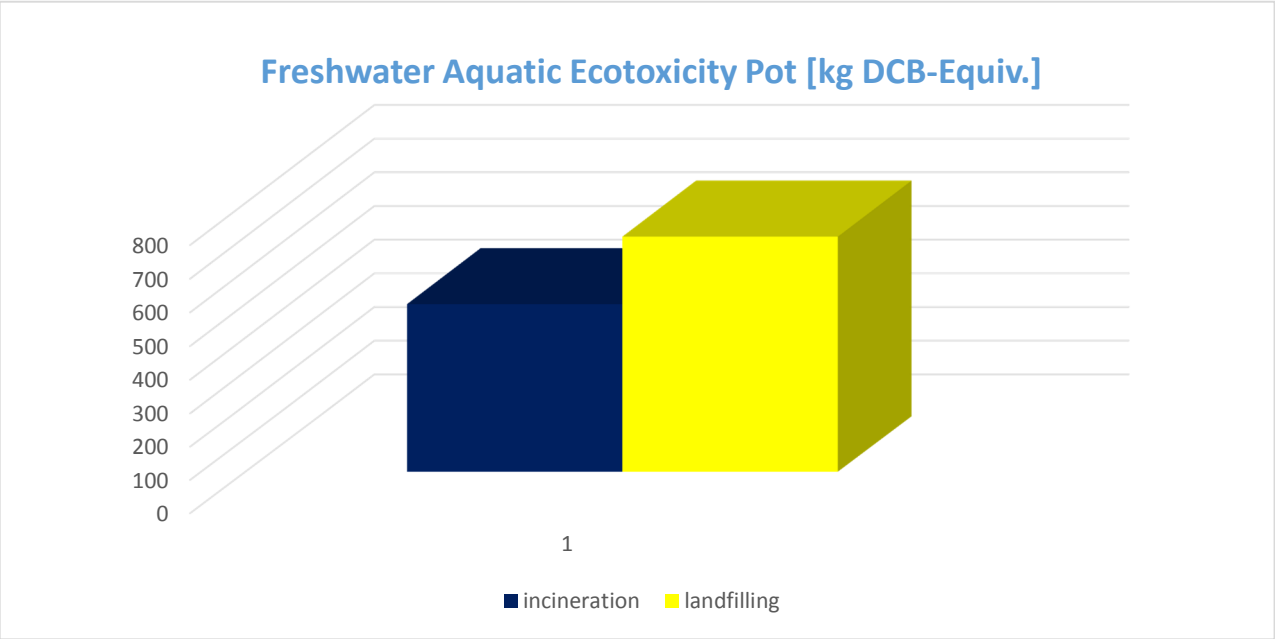


Figure 30 FAEP representation of total impact for each scenario

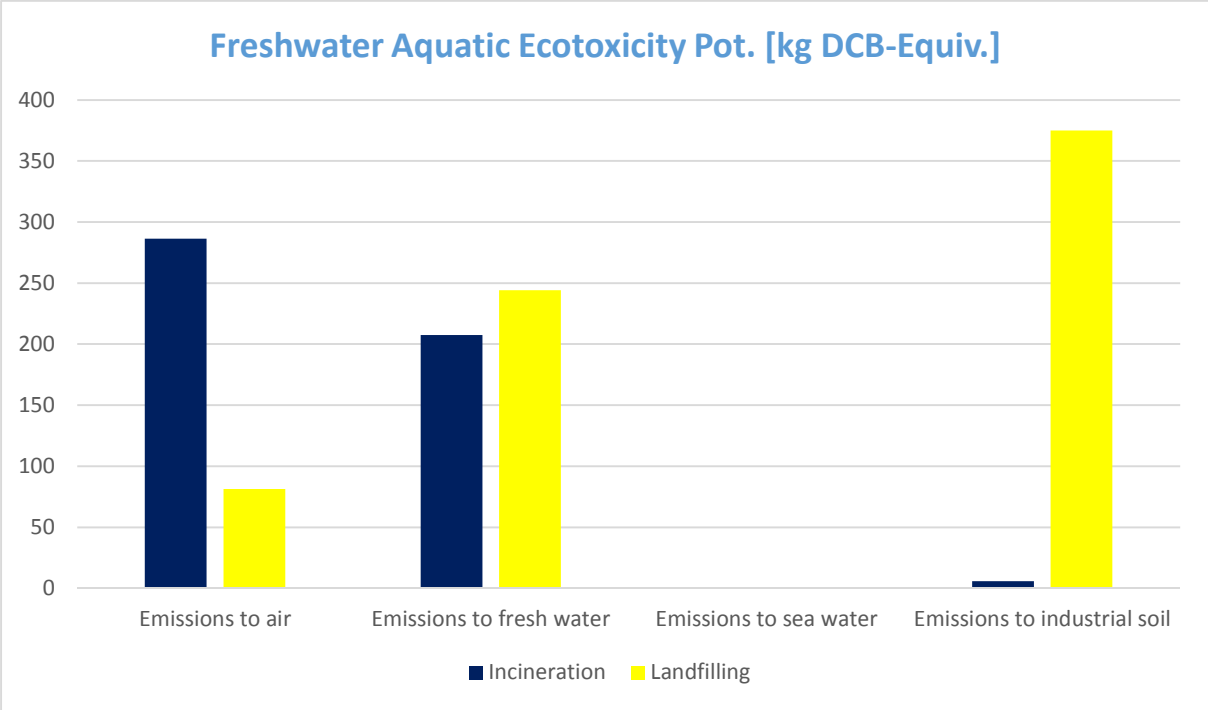


Figure 31 FAETP comparison emissions for each scenario, kgDCB-Eq

Areas near landfills have a greater possibility of groundwater contamination because of the potential pollution source of leachate direct mitigation.

8.8 Terrestric Ecotoxicity Potential

Exhaust from WTE, inorganic particles, diesel consumption (e.g. for transportation) and waste handling are the main factors causing impacts. Incineration still have the main impact on air quality, however landfilling impact is almost 66 times higher than WTE due to more heavy metals toxic for the soil quality.

Table 13 TETP emissions for each scenario

Terrestrial Ecotoxicity Potential [kg DCB-Equiv.]	Incineration	Landfilling
Emissions to air	276,314369	59,00084647
Emissions to fresh water	0,30714169	0,110806082
Emissions to sea water	1,23238309	0,187677422
Emissions to industrial soil	68,371277	4569,390586

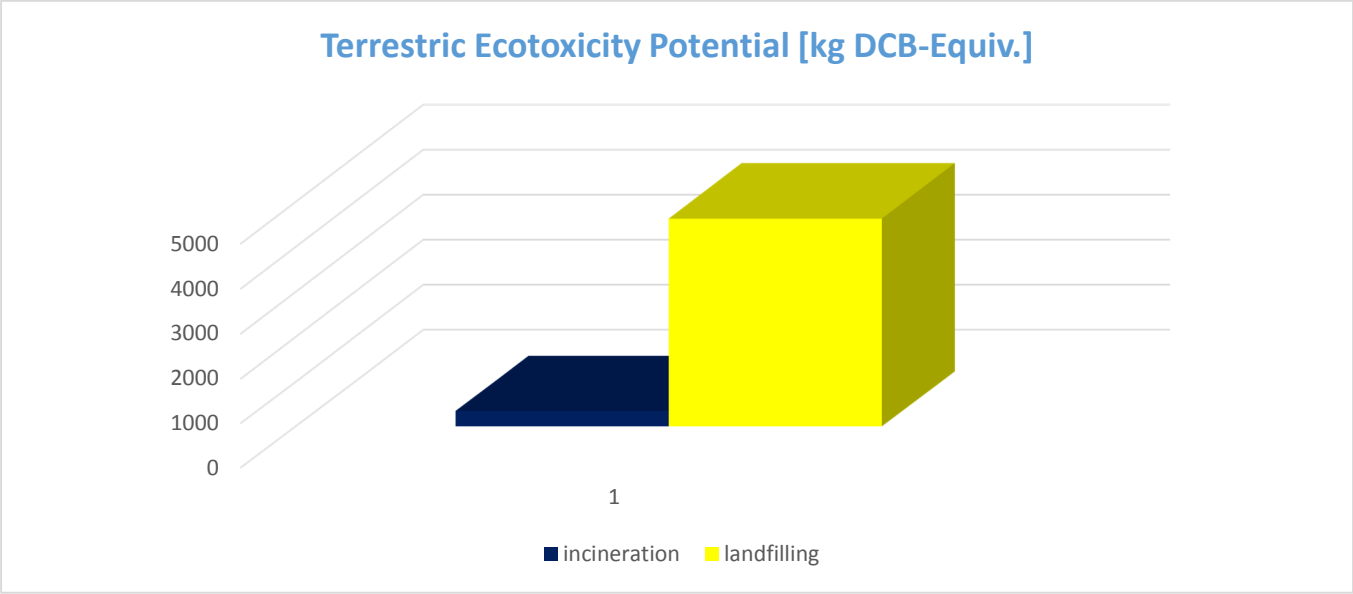


Figure 32 TETP comparison for each scenario, kg DCB-Eq

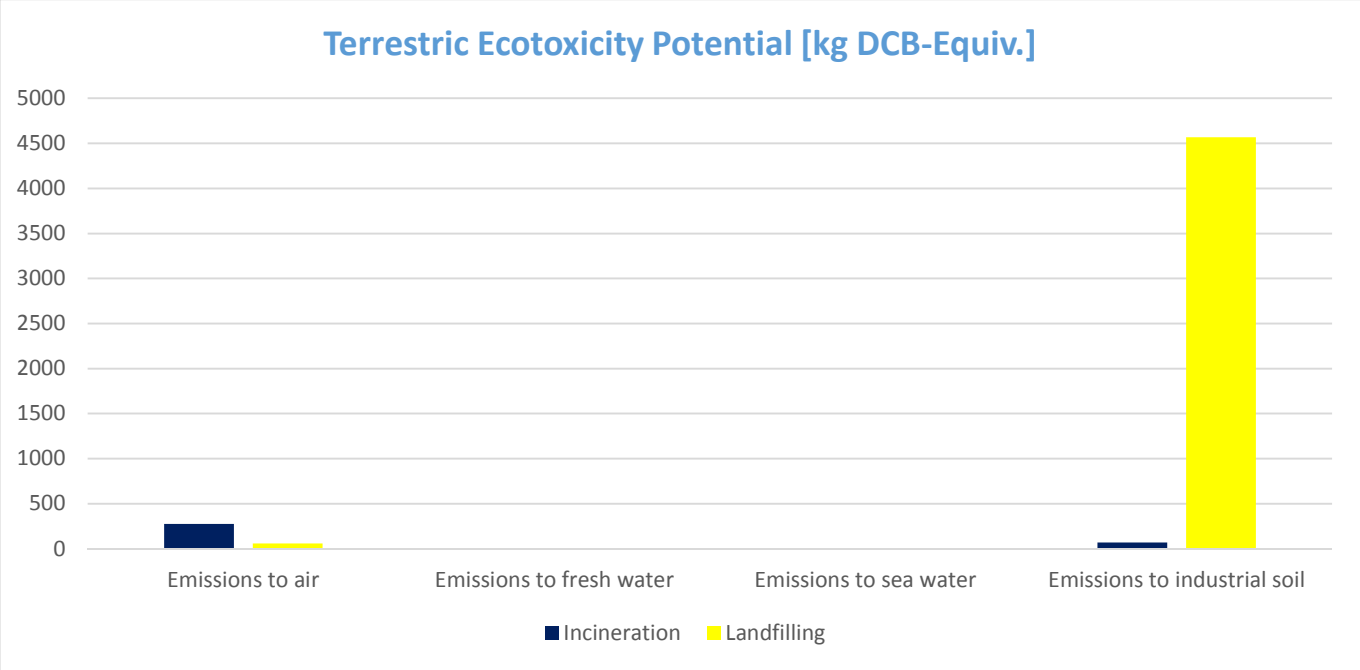


Figure 33 Comparison TETP emissions

8.9 Results comparison

After the presentation and interpretation of the results in the previous paragraphs, it is possible to draw an overall vision in order to obtain conclusions and to give recommendations. In figure 44 all the results of the study are collected and compared. To analyze the incineration impact compared to landfilling, a Value of 1 has been assigned to the Base Case (landfilling), the incineration values are taken as ratio that measure how much the incineration impact is higher than landfilling.

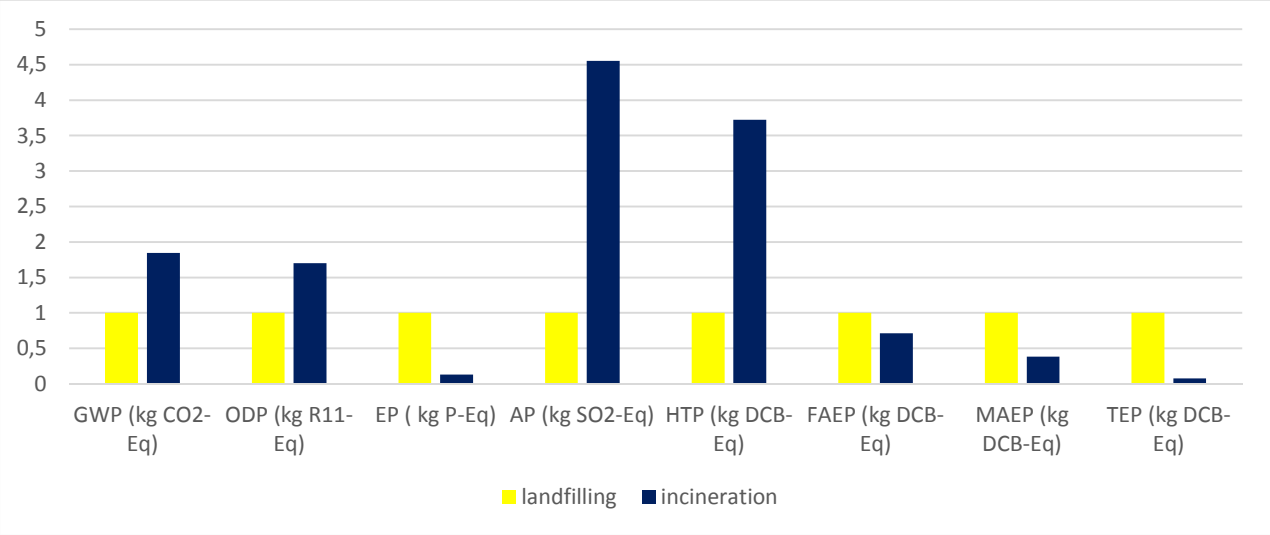


Figure 34 Overall Comparison of the Effects

The analysis shows that incineration has a more dangerous impact than landfilling; however focusing on energy production waste to energy produces almost 35% more energy. (figure 45)

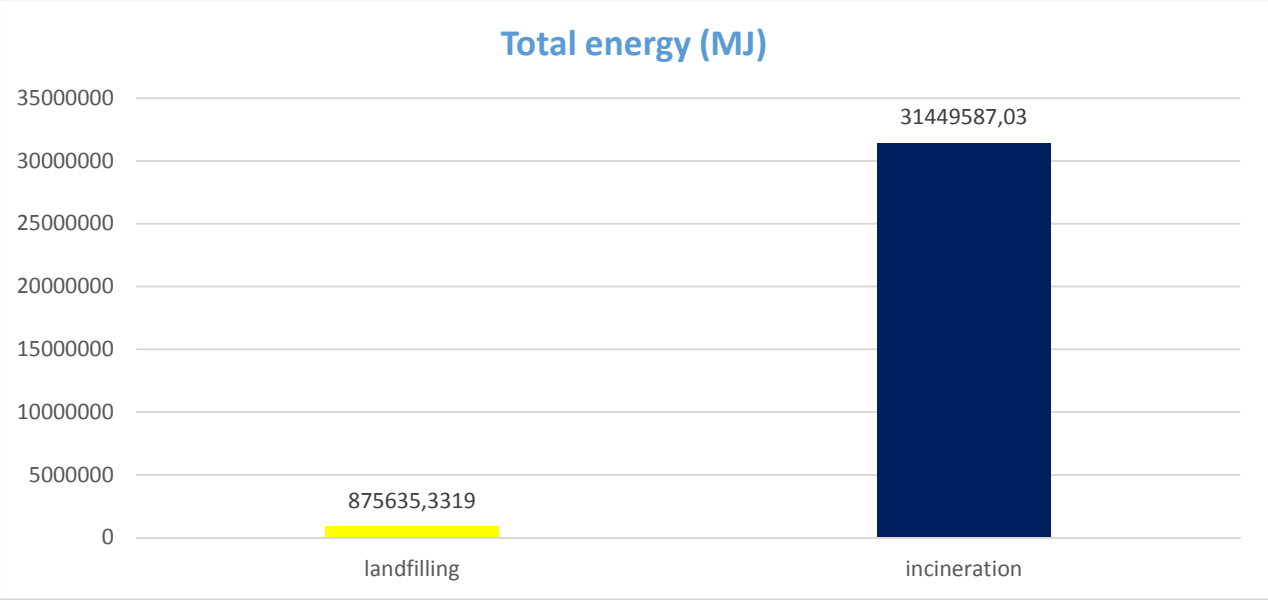


Figure 35 Energy production

This is ideal for the Avezzano inhabitants, as the city, like the whole Italy, depend strongly on external Countries for the e energy production. However building an incineration plant need a deeper analysis, with this study is clear that the waste to energy has mayor effect on Acidification Potential and Human toxicity potential. Acidification potential is dangerous for the flora and fauna of Marsica area (The area around Avezzano). Human toxicity potential, confirm the protest of greens and local inhabitants, as

incineration has great impact on human safety. Another helpful practice would be to move the landfilling from Aielli to Avezzano in order to avoid the transportation, that is as shown one of the biggest emitter of CO_2, consequently, reducing the distance, the process would produce less greenhouse gases and it would be more sustainable. It is necessary to evaluate the economic impact of an eventually incineration plant introduction. In order to reach an overall view.

8.10 Economic Assessment

It is not easy having a detailed economic analysis of the incineration practice. Many factors influence the cost of incineration: the cost of the land where the incineration is built up, the environmental and economic fees, dimensions and size of the technologies, final disposal treatment, price of energy, metal recover and cost of the personal. Energy price of production and distribution (Andretta, 2009).

Many information are indicated in BAT document: where it is guarantee an optimal energy production and utilization, which allows reaching the maximum value of energy obtained. A classification is presented by the Best Available technology published by BREF, under the IPPC Directive and the Industrial Emissions Directive with last references from 2006. The classification depends on the size of the plant. For plant that process less of 50000 ton of garbage the average cost value is 111.76 euros/ton.

According with CEWEP still there are not grants for the production of energy, and in relation to CEE/CEEA/CE n° 77 directive of September 2001, just the organic part of municipal waste is considered as renewable energy. Fees on incineration vary according to the Country. The same happens with landfilling. All results are showing in table 14:

Table 14 Incineration total cost

incineration cost	111,76 €/ton
total cost	644611,563 €/year
investment	88,66 €/MWh
waste energy	1,9 MWh/ton
total energy	10958,858 MWh/year
energy demand	1026,3 kWh/ab
total energy demand	434771,469 MWh/year

Total cost is based on 5767.82 ton of waste produced in the city of Avezzano, and the average italian household energy demand is 1026.3 kWh/ab (Italian Statistic Institute,2014)- This value has been multiply for 42 434 number of inhabitants.

According with this calculation waste to energy produces approximately 10958.858 MWh/year, that cover 2,52% of the total energy demand of the Avezzano municipal. Therefore, it would be helpful to improve the ratio of fossil energy towards more renewables resources, In the Abruzzo zone solar or wind, power could be improved to cover the energy supply.

Regarding landfilling price, according the Italian the average price of landfilling is 471807.676€ (Andretta, Bologna 2009) for landfill that contains less than 50000 ton.

Table 15 Landfilling cost

average price	**81,8 €/ton**
total price	471.807,68 €

Approximately incineration is 30% more expensive than landfilling, although, as showed in the previous chapter it is an advantageous source of energy.

8.11 Sensitivity analysis

The database used by GaBi are average of European condition. In the case of incineration and landfilling, they include the state-of-art of the technologies for the waste treatment, but they don't perform the real Italian condition. The incineration technology includes: for landfill a site based leachate treatment plant, a modern flue gas cleaning system and slag treatment including metal recovery after combustion; for the combustion modern grate combustion and a modern end of pipe system. A more detailed model should be developed with a deeper study of the local Italian framework and other technologies, which have proved practicability should be included (Büning, 2004).

In the studied model for landfilling, the pretreatment of waste is not considered, while Abruzzo is the unique Italian region where all waste is pre-treated, (Lega Ambiente, 2012) before landfilling. If this method would be applied also for incineration, the calorific value would increase (Büning, 2004) due to this fact more energy would be produced. Another important point to be studied is the Italian energy mix. GaBi4 debases use a European energy mix supply, the consequence is that the results for this study dependent mainly on European condition and they are not calibrated the specific situation in Abruzzo.

8.12 Recommendations

Based on these considerations, recommendations for further activities could be given. This analysis could be a starting point for ongoing research. To improve the results of this investigation, it would be worthwhile to develop an "Abruzzo specific" database, those would mean a big support, even though, as specified before, it is rare having reliable data. This database should contain statistics about waste composition, about more appropriate technology that could be adopted, coherently with Italian scenario and according with Italian average.

Furthermore, an algorithm for a more detailed calculation of the distances between the main city and the workspace need to be performed.

A deeper analysis of the energy mix and an accurate calculation of leachate and slag, considering also a pretreatment process before landfilling, is also necessary. Another useful study is to extend the LCA / to analyze the recycling practice in Abruzzo, even if Abruzzo is one of the six region with a better waste organization, (Lega Ambiente 2012). A new combination between recycling and waste to energy could be find in order to have an optimal and sustainable energy production with less impact on the environment and on human health.

In order to have a sustainable perspective also would be necessary to introduce a Social Life Cycle Assessment and a Life Cycle Cost Assessment that would consider also the social and economic feasibility of the introduction of the incineration .

9. Conclusions

Based on previous discussion and analysis, it is possible to draw conclusions

- According to Life Cycle Assessment, Incineration practice has more effect on air quality and consequently on human health; however landfilling could lead to a degradation of soil, fresh and marine water quality that could have effect especially on agriculture, influencing also the income of Avezzano inhabitants.

- Incineration more risky impact in comparison to landfilling is the Acidification Potential that is dangerous for the ecological environment and for Human health but also for historic monument and architectures. However according with LCA performed by GaBi4, Incineration saves more CO_2 than landfilling during the transportation phase.

- Incineration produces almost 35% more energy than Landfilling and it could be an optimal energy source for the Avezzano inhabitants as it covers the 2,52% of the municipal energy demand, that would be local produced, instead to be imported. This scenario allows to save money and to avoid CO_2 during the energy transportation.

- Incineration results to be 30% more expensive than landfilling, however deeper assessment should be made as it is not easy to evaluate the overall cost of waste to energy plant, many actors, polices and situations need to be analyzed and for this reason further study about economic but also social assessment should be done.

References

Abeliotis K.,"Life Cycle Assessment in Municipal Solid Wate Management" Harokopio, University Greece 2011.

Aitor P. Acero, Cristina Rodríguez, Andreas Ciroth, "Impact assessment methods in Life Cycle Assessment and their impact categories", January 2014.

Aciam Agency website http://www.aciam.it/articoli/257/il-trattamento-dei-rifiuti-urbani-tal-quali.html.

Andretta, "Analisi prezzi medi impianti; Anno 2009 Le Tariffe per il recupero e lo smaltimento dei rifiuti urbani per tipologia e caratteristiche degli impianti", Bologna 2009

"Avfall Sverige", Swedish Waste Management 2014

Baumgartner, A., Liebscher, H.-J. mit Beiträgen von Benecke, P., Brechtel, H. u.a.: Allgemeine Hydrologie — Quantitative Hydrologie, 2. Auflage, Band 1, in Lehrbuch der Hydrologie, Gebrüder Bornträger, Berlin, Stuttgart 1996

Büning G., "Development of an LCA-based Waste Management Model and its Application to optimize Sydney's domestic Waste Management", Diploma Thesis, Höxter, October 2004.

Capellia L., Sironia S., Del Rosso R., Magnano. E. "Evaluation of Landfill Surface Emissions. Milano, VOL. 40, 2014"

CEWEP, confederation of Europen waste to energy plants, Energy recovery http://www.cewep.eu/information/whatiswastetoenergy/subdir6/index.html

Cherubini F., Bargigli S., Ulgiati S., "Life cycle assessment of urban waste management: Energy performances and environmental impacts. The case of Rome, Italy ".Febrary 2008; 28(12):2552-64.

CNR Area Bologna "Analisi Ambientale della gestione dei rifiuti con il metodo Lca".

Consonni S., Giugliano M., Grosso M., 2005. "Alternative strategies for energy recovery from municipal solid waste. Part B: emission and cost estimates. Waste Management" 25, 137–148.

Krümpelbeck, I.: Untersuchung zum langfristigen Verhalten von Siedlungsabfalldeponien, Fachgebiet Abfall- und Siedlungswasserwirtschaft Bergische Universität - Gesamthochschule Wuppertal, Dissertation, Wuppertal / Germany, 2000

Damgaard A. "Implementation of life cycle assessment models in solid waste management" PhD Thesis, June 2010, Department of Environmental Engineering Technical University of Denmark.

Environmetal Protection Agency, Final Draft BAT Guidance Note on "Best Available Techniques for the Waste Sector: Landfill Activities", December 2011

EPA, Environmentl Protection Agency http://www.epa.ie/licensing/info/bref/#.VXjYYM_keko

European Commission; Directrate-General Enviroment"Guidelines on the interpretation of the energy efficiency formula for incineration facilities dedicater to the processing of municipal solid waste according to annex II of directive 2008/98/Ec "

European Commission Communication of 21 December 2005: "Taking sustainable use of resources forward: A Thematic Strategy on the prevention and recycling of waste"

European Union Integrated Pollution Prevention and Control "Reference Document on the Best Available Techniques for Waste Incineration", August 2006

European Waste Framework Hierarchy http://ec.europa.eu/environment/waste/framework/

Eurostat, total greenhouse gas emission by countries

Ferreira S., Cabral M., Simoes N., Marques R.S. "Life Cycle Assessment of waste Management operation". Lisbon, 29 November 2012.

Finnveden, G.; Johannsson, J.; Lind, P.; Moberg, A. (2000); Life Cycle Assessmenst of Energy from Solid Waste. (fms Forskningsgruppen förMiljöstrategiska Studier, Stockholm) → www.infra.kth.se/fms/.

Fraunhofer Institute, http://www.ibp.fraunhofer.de/en/Expertise/Life_Cycle_Engineering/Material_and_SubstanceFlowAnalysis.html

GaBi Paper Clip Tutorial, Introduction to LCA and modelling using GaBi, part 1. PE International.

GaBi 4 Manual (2003): GaBi 4 - Get ready for tomorrow. (IKP Institut für Kunststoffprüfung, Stuttgart / PE Europe GmbH, Leinfelden- Echterdingen).

GaBi Modelling Principles, PE International. Universitat of Stuttgard.

Gabi process dataset, Waste Incineration of municipal solid waste http://gabi-documentation-2014.gabi-software.com/xml-data/processes/4f035020-4599-424d-8f48-627b35dd1a7f.xml

Grosso M., Motta A., Rigamonti L. "Efficiency of energy recovery from waste incineration, in the light of the new Waste Framework Directive", July 2010, Milan 1238-43.

GUINEE, J. (final editor) (2001): Life Cycle Assessment - An operational guide to the ISO standards. (CML Centre of Environmental Science, Leiden University – Final Report).

Intergovernmental panel on climatic change, ipcc, Climate Change 2007: Working Group I: The Physical Science Basis.

ISPRA, Italian Institute for Environmental Protection and Research, Rapporto Rifiuti Urbani 2013.

ISPRA, Italian Institute for Environmental Protection and Research Rapporto Rifiuti Urbani 2014.

ISO - International Organization for Standardization, 14040:2006 Environmental management -- Life cycle assessment -- Principles and framework

ISO - International Organization for Standardization, 14044:2006 Environmental management -- Life cycle assessment -- Requirements and guidelines

I.stat,Italian statistic institute, "energy household supply" http://dati.istat.it/Index.aspx?DataSetCode=DCCV_CNSENRG

i.stat, italian statistic institute, demographi index http://demo.istat.it/bilmens2014gen/index.html

International Energy Agency

Lega Ambiente ,"ridurre e riciclare prima di tutto", rappporto ecotassa reionale. 19 Novembre, Roma

MUD, definition http://mud.ecocerved.it/

Process data set Gabi: http://gabi-documentation-2014.gabi-software.com/xml-data/processes/89863fcb-3306-11dd-bd11-0800200c9a66.xml.

Sel İ., Çetindemir M., Arıkan O., Demiri. and Özkaya B." Landfill Gas to Electricity Production at Sanitary Landfills in Kocaeli". Nevsehir, Turkey, June 18 – 21, 2013.

Sundqvist IVL Jan-Olov, “Life cycles assessments and solid waste, Guidelines for solid waste treatment and disposal in LCA, Final Report”, Swedish Environmental Research Institute December 1999.

United Nations Environment Program, Division of Technology. Industry and Economics. http://www.unep.or.jp/ietc/ESTdir/Pub/MSW/SP/SP5/SP5_2.asp.

United Nations framework convention on climatic change

Tekneko web site http://www.tekneko.com/azienda.php.

Thomé-Kozmiensky, K. J. (Ed.): Deponie 3 - Ablagerung von Abfällen, Thomé-Kozmiensky, K. J. (Ed.), EF-Verlag für Energie- und Umwelttechnik, Berlin / Germany, 1989

Weber, B., 1990. Minimierung von Emissionen der Deponie, Veröffentlichungen des ISAH der Uni Hannover, Heft 74. (Dissertation, Hannover).

World Bank,”What a Waste A Global Review of Solid Waste Management, Urban Development Series”, 2012.

Zaman A.U., “Comparative study of municipal solid waste treatment technologies using life cycle assessment method”, Stockholm, 2010, 1735-1472

ANNEX I
Landfilling Emissions

CML2001, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]		kg CO2-Equiv.
Emissions to air		**3840841,55**
Inorganic emissions to air		1509622,29
	Carbon dioxide	1502984,61
	Carbon dioxide (biotic)	1491,99589
	Nitrous oxide (laughing gas)	5145,67937
	Sulphur hexafluoride	0,01139794
Organic emissions to air (group VOC)		2331219,26
	Group NMVOC to air (Halogenated organic emissions to air)	60,7571867
	Methane	2331157,25
	VOC (unspecified)	1,25292743

CML2001 - Nov. 09, Marine Aquatic Ecotoxicity Pot. (MAETP inf.)		kg DCB-Equiv.
Emissions to air (tot)		8497352,799
Heavy metals to air		489485,0773
	Antimony	7,488582496
	Arsenic (+V)	729,3233169
	Arsenic trioxide	0,001748919
	Cadmium (+II)	1135,820126
	Chromium (+III)	0,014615343
	Chromium (unspecified)	13,51701739
	Cobalt	2492,505135
	Copper (+II)	1084,018033

	Hydrogen arsenic (arsine)	0,169388341
	Lead (+II)	48,39077016
	Mercury (+II)	981,8866298
	Molybdenum	267,3221663
	Nickel (+II)	26080,718
	Selenium	108593,2525
	Thallium	98,69882022
	Tin (+IV)	11,07563483
	Vanadium (+III)	347164,4068
	Zinc (+II)	776,4679726
	Inorganic emissions to air	8007853,266
Inorganic emissions to air		131535,1412
	Beryllium	15411,54203
	Carbon disulphide	5,16E-07
	Hydrogen fluoride	7860906,071
	Tin oxide	4,29E-06
	Zinc oxide	7,00E-05
	Zinc sulphate	0,511117845
Organic emissions to air (group VOC)		14,45588483
	VOC (unspecified)	0,000535445

CML2001 - Nov. 09, Marine Aquatic Ecotoxicity Pot. (MAETP inf.)		**kg DCB-Equiv.**
Emissions to fresh water		21060899,93
Heavy metals to fresh water		177825,6951
	Antimony	3,34E-05
	Arsenic (+V)	761,120765
	Cadmium (+II)	5046,770445
	Chromium (+III)	0,776096728
	Chromium (+VI)	5,38E-09
	Chromium (unspecified)	101,1832722
	Cobalt	23,20363524

	Copper (+II)	3559,740574
	Lead (+II)	13,76314358
	Mercury (+II)	25,52259016
	Molybdenum	18528,639
	Nickel (+II)	82892,64428
	Selenium	41067,88996
	Thallium	8,98233508
	Tin (+IV)	0,000432226
	Vanadium (+III)	24812,92775
	Zinc (+II)	982,5307479
Inorganic emissions to fresh water		20883074,17
	Barium	11590,86896
	Beryllium	5994,176329
	Hydrogen fluoride (hydrofluoric acid)	20865489,12
Organic emissions to fresh water		0,069736107
	Halogenated organic emissions to fresh water	4,38E-09
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	4,38E-09
	Vinyl chloride (VCM; chloroethene)	1,73E-12
	Hydrocarbons to fresh water	0,069588876
	Acrylonitrile	1,02E-06
	Anthracene	0,012063016
	Aromatic hydrocarbons (unspecified)	0
	Benzene	0,000192018
	Benzo{a}anthracene	0,002348858
	Benzofluoranthene	0,046062247
	Chrysene	0,003477801
	Ethyl benzene	1,72E-05
	Fluoranthene	0,000433668
	Phenol (hydroxy benzene)	0,00380675
	Toluene (methyl benzene)	7,46E-05

	Xylene (isomers; dimethyl benzene)	0,001111678
	Naphthalene	0,000147227

CML2001 - Nov. 09, Marine Aquatic Ecotoxicity Pot. (MAETP inf.)		**kg DCB-Equiv.**
Emissions to sea water		313950,4805
Heavy metals to sea water		90792,00159
	Arsenic (+V)	674,3647587
	Cadmium (+II)	6438,528474
	Chromium (unspecified)	31,74334976
	Cobalt	22568,8402
	Copper (+II)	5582,939949
	Lead (+II)	8,752674907
	Mercury (+II)	46,05062526
	Molybdenum	0,028688517
	Nickel (+II)	13891,49365
	Tin (+IV)	0,000467963
	Vanadium (+III)	35249,9272
	Zinc (+II)	6299,331557
Inorganic emissions to sea water	Inorganic emissions to sea water	223111,1048
	Barium	120027,3199
	Beryllium	103083,7848
Organic emissions to sea water	Organic emissions to sea water	47,37413097
	Hydrocarbons to sea water	47,24872201
	Naphthalene	0,125408959

CML2001 - Nov. 09, Marine Aquatic Ecotoxicity Pot. (MAETP inf.)		**kg DCB-Equiv.**
Heavy metals to industrial soil		211759,463

	Arsenic (+V)	965,407108
	Cadmium (+II)	5587,4757
	Chromium (+III)	1,78E-05
	Chromium (unspecified)	462,99955
	Cobalt	192,808124
	Copper (+II)	2686,22606
	Lead (+II)	29,8765329
	Mercury (+II)	0,84714659
	Nickel (+II)	196685,75
	Zinc (+II)	5148,07312

CML2001, Terrestric Ecotoxicity Potential (TETP inf.)		**kg DCB-Equiv.**
Emissions to air		59,00450844
Heavy metals to air		56,48003326
	Antimony	0,000138365
	Arsenic (+V)	5,071307315
	Arsenic trioxide	1,22E-05
	Cadmium (+II)	0,083498331
	Chromium (+III)	0,008450613
	Chromium (unspecified)	7,815560073
	Cobalt	0,049853814
	Copper (+II)	0,008482665
	Hydrogen arsenic (arsine)	0,001177832
	Lead (+II)	0,107574597
	Mercury (+II)	23,17295474
	Molybdenum	0,002410136
	Nickel (+II)	0,805392541
	Selenium	0,273956757
	Thallium	0,00130855
	Tin (+IV)	0,021196673
	Vanadium (+III)	18,91864245
	Zinc (+II)	0,138115642

Inorganic emissions to air		0,878602299
	Barium	0,819981646
	Beryllium	0,057960617
	Carbon disulphide	1,74E-09
	Hydrogen fluoride	0,000569098
	Tin oxide	8,20E-09
	Zinc oxide	1,25E-08
	Zinc sulphate	9,09E-05
Organic emissions to air (group VOC)		1,645872881
	Group NMVOC to air	1,645741228
	VOC (unspecified)	0,000131653

CML2001, Terrestric Ecotoxicity Potential (TETP inf.)		**kg DCB-Equiv.**
Emissions to fresh water		0,110806082
Heavy metals to fresh water		0,110785855
	Antimony	2,04E-29
	Arsenic (+V)	6,67E-20
	Cadmium (+II)	3,24E-22
	Chromium (+III)	2,05E-22
	Chromium (+VI)	3,55E-31
	Chromium (unspecified)	2,67E-20
	Cobalt	1,43E-23
	Copper (+II)	6,21E-23
	Lead (+II)	5,92E-24
	Mercury (+II)	0,110785855
	Molybdenum	2,05E-20
	Nickel (+II)	3,79E-20
	Selenium	2,52E-20
	Thallium	1,06E-23
	Tin (+IV)	2,77E-28
	Vanadium (+III)	2,95E-20
	Zinc (+II)	1,80E-22

Inorganic emissions to fresh water	I	1,76E-05
	Barium	7,07E-21
	Beryllium	3,66E-21
	Hydrogen fluoride (hydrofluoric acid)	1,76E-05
Organic emissions to fresh water		2,59E-06
	Halogenated organic emissions to fresh water	5,87E-14
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	5,75E-14
	Vinyl chloride (VCM; chloroethene)	1,18E-15
	Hydrocarbons to fresh water	2,52E-06
	Acrylonitrile	7,29E-09
	Anthracene	7,87E-08
	Benzene	9,94E-07
	Benzo{a}anthracene	3,95E-09
	Benzofluoranthene	2,18E-08
	Chrysene	9,77E-09
	Ethyl benzene	1,50E-08
	Fluoranthene	2,47E-09
	Phenol (hydroxy benzene)	1,68E-07
	Toluene (methyl benzene)	8,54E-07
	Xylene (isomers; dimethyl benzene)	3,68E-07
	Naphthalene	6,82E-08

CML2001, Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]		**kg DCB-Equiv.**
Emissions to sea water		0,18767742
Heavy metals to sea water		0,18767417
	Arsenic (+V)	5,83E-20
	Cadmium (+II)	3,92E-22
	Chromium (unspecified)	7,91E-21

	Cobalt	1,38E-20
	Copper (+II)	9,37E-23
	Lead (+II)	3,54E-24
	Mercury (+II)	0,18767417
	Molybdenum	3,17E-26
	Nickel (+II)	6,28E-21
	Tin (+IV)	2,82E-28
	Vanadium (+III)	4,16E-20
	Zinc (+II)	1,09E-21
Inorganic emissions to sea water		1,36E-19
	Barium	7,31E-20
	Beryllium	6,29E-20
Organic emissions to sea water		3,25E-06
	Hydrocarbons to sea water	3,18E-06
	Naphthalene	7,21E-08

CML2001, Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]		**kg DCB-Equiv.**
Emissions to industrial soil		4569,39059
Heavy metals to industrial soil		4569,39059
	Arsenic (+V)	41,7793965
	Cadmium (+II)	8,3035218
	Chromium (+III)	0,00017164
	Chromium (unspecified)	4459,88469
	Cobalt	0,01951556
	Copper (+II)	0,32255641
	Lead (+II)	1,28959674
	Mercury (+II)	0,28658787
	Nickel (+II)	39,9440726
	Zinc (+II)	17,5604802

CML2001, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]		kg DCB-Equiv.
Emissions to air	Emissions to air	6549,831012
Heavy metals to air	Heavy metals to air	1938,214857
	Antimony	1,519702681
	Arsenic (+V)	1095,824242
	Arsenic trioxide	0,002628351
	Cadmium (+II)	149,0554282
	Chromium (+III)	0,001803358
	Chromium (unspecified)	1,667837509
	Cobalt	8,011768498
	Copper (+II)	5,211251682
	Hydrogen arsenic (arsine)	0,254509688
	Lead (+II)	3,202675973
	Mercury (+II)	4,9174782
	Molybdenum	0,745694414
	Nickel (+II)	243,1432376
	Selenium	244,3144142
	Thallium	1,664180677
	Tin (+IV)	0,002558954
	Vanadium (+III)	177,4696437
	Zinc (+II)	1,205801042
Inorganic emissions to air		3047,091943
	Ammonia	0,056011852
	Barium	127,6372233
	Beryllium	7,434040121
	Carbon disulphide	8,15E-07
	Hydrogen chloride	1,999698375
	Hydrogen fluoride	549,9519012
	Hydrogen sulphide	2,359014242
	Nitrogen dioxide	9,55E-09

	Nitrogen oxides	2312,100942
	Sulphur dioxide	45,55231758
	Tin oxide	9,90E-10
	Zinc oxide	1,09E-07
	Zinc sulphate	0,000793731
Organic emissions to air (group VOC)		1306,994502
	Group NMVOC to air	1306,993136
	VOC (unspecified)	0,001365431
Particles to air		257,5297102

CML2001, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]		**kg DCB-Equiv.**
Emissions to fresh water		1721,617237
Heavy metals to fresh water		168,3133735
	Antimony	6,33E-06
	Arsenic (+V)	6,102677789
	Cadmium (+II)	0,524477642
	Chromium (+III)	0,001850029
	Chromium (+VI)	5,34E-12
	Chromium (unspecified)	0,241196769
	Cobalt	0,000511809
	Copper (+II)	0,020483654
	Lead (+II)	0,152045078
	Mercury (+II)	0,169806866
	Molybdenum	48,891489
	Nickel (+II)	12,19756154
	Selenium	90,74574058
	Thallium	0,076075969
	Tin (+IV)	6,10E-09
	Vanadium (+III)	9,148015079
	Zinc (+II)	0,04143538
Inorganic emissions to fresh water		1420,680209
	Barium	8,769469347

	Beryllium	0,155272198
	Hydrogen fluoride (hydrofluoric acid)	1411,755467
Organic emissions to fresh water		132,6236549
	Halogenated organic emissions to fresh water	7,49E-07
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	8,40E-08
	Vinyl chloride (VCM; chloroethene)	6,65E-07
	Hydrocarbons to fresh water	132,6228834
	Acrylonitrile	0,013372692
	Anthracene	8,21E-06
	Benzene	132,3961391
	Ethyl benzene	0,010471827
	Phenol (hydroxy benzene)	0,003324624
	Toluene (methyl benzene)	0,018265596
	Xylene (isomers; dimethyl benzene)	0,181301432
	Naphthalene	0,000770673

CML2001, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]		**kg DCB-Equiv.**
Emissions to sea water		116,1524799
Heavy metals to sea water		19,53714569
	Arsenic (+V)	4,717480658
	Cadmium (+II)	0,362027138
	Chromium (unspecified)	0,038779089
	Cobalt	0,169499987
	Copper (+II)	0,022342365
	Lead (+II)	0,06098174
	Mercury (+II)	0,201241462
	Molybdenum	7,43E-05
	Nickel (+II)	1,798680998
	Tin (+IV)	4,09E-09
	Vanadium (+III)	11,98598454
	Zinc (+II)	0,180053375

Inorganic emissions to sea water		91,45811176
	Barium	88,86709844
	Beryllium	2,591013326
Organic emissions to sea water		5,157222463
	Hydrocarbons to sea water	5,156483389
	Anthracene	4,72E-06
	Benzene	5,155392076
	Ethyl benzene	0,000275885
	Phenol (hydroxy benzene)	3,97E-06
	Toluene (methyl benzene)	0,000563754
	Xylene (isomers; dimethyl benzene)	0,00024298
	Naphthalene	0,000739074

CML2001, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]		**kg DCB-Equiv**
Emissions to industrial soil	Emissions to industrial soil	273,418236
Heavy metals to industrial soil	Heavy metals to industrial soil	273,418236
	Arsenic (+V)	12,78021
	Cadmium (+II)	3,31948015
	Chromium (+III)	8,17E-06
	Chromium (unspecified)	212,165364
	Cobalt	0,00516875
	Copper (+II)	0,02817791
	Lead (+II)	11,6318101
	Mercury (+II)	0,00553037
	Nickel (+II)	33,1810185
	Zinc (+II)	0,30146823

CML2001, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]
kg DCB-Equiv.

Emissions to air		81,9955909
Heavy metals to air		58,001668
	Antimony	0,00084368
	Arsenic (+V)	0,1560201
	Arsenic trioxide	3,74E-07
	Cadmium (+II)	0,2974421
	Chromium (+III)	5,36E-06
	Chromium (unspecified)	0,00495743
	Cobalt	0,29312798
	Copper (+II)	0,26893745
	Hydrogen arsenic (arsine)	3,62E-05
	Lead (+II)	0,01647362
	Mercury (+II)	0,25928006
	Molybdenum	0,01337388
	Nickel (+II)	4,36880205
	Selenium	2,79853409
	Thallium	0,00598124
	Tin (+IV)	0,00374382
	Vanadium (+III)	49,3087931
	Zinc (+II)	0,20531544
Inorganic emissions to air		8,68229968
	Barium	7,22538385
	Beryllium	0,56191004
	Carbon disulphide	1,11E-08
	Hydrogen fluoride	0,89487061
	Tin oxide	1,45E-09
	Zinc oxide	1,85E-08
	Zinc sulphate	0,00013515
Organic emissions to air (group VOC)		15,3116232
	Group NMVOC to air	15,3104667
	VOC (unspecified)	0,00115654

CML2001, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)		kg DCB-Equiv.
Emissions to fresh water	Emissions to fresh water	244,063803
Heavy metals to fresh water	Heavy metals to fresh water	215,755759
	Antimony	2,43E-08
	Arsenic (+V)	1,32724944
	Cadmium (+II)	34,8955101
	Chromium (+III)	0,00623259
	Chromium (+VI)	4,32E-11
	Chromium (unspecified)	0,81257134
	Cobalt	0,01803643
	Copper (+II)	17,7007714
	Lead (+II)	0,11925629
	Mercury (+II)	0,20448191
	Molybdenum	4,22251394
	Nickel (+II)	119,279073
	Selenium	4,72954732
	Thallium	0,00270707
	Tin (+IV)	3,58E-06
	Vanadium (+III)	25,9301299
	Zinc (+II)	6,50767505
Inorganic emissions to fresh water		11,4636064
	Barium	3,1678664
	Beryllium	1,01497353
	Hydrogen fluoride (hydrofluoric acid)	7,28076652
Organic emissions to fresh water		16,844437
	Halogenated organic emissions to fresh water	1,70E-08
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	1,69E-08
	Vinyl chloride (VCM; chloroethene)	1,28E-10
	Hydrocarbons to fresh water	16,7529939

	Acrylonitrile	0,00014998
	Anthracene	0,22855541
	Benzene	0,00661243
	Benzo{a}anthracene	0,03247018
	Benzofluoranthene	0,12373889
	Chrysene	0,02160137
	Ethyl benzene	0,00691094
	Fluoranthene	0,0065719
	Phenol (hydroxy benzene)	16,0290181
	Toluene (methyl benzene)	0,01776811
	Xylene (isomers; dimethyl benzene)	0,2795966
	Naphthalene	0,09144311

CML2001, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]		**kg DCB-Equiv.**
Emissions to sea water		0,00107352
Heavy metals to sea water		0,00016633
	Arsenic (+V)	7,57E-23
	Cadmium (+II)	8,80E-23
	Chromium (unspecified)	3,41E-25
	Cobalt	3,41E-21
	Copper (+II)	1,55E-22
	Lead (+II)	4,31E-26
	Mercury (+II)	0,00016633
	Molybdenum	7,21E-27
	Nickel (+II)	1,47E-21
	Tin (+IV)	3,68E-30
	Vanadium (+III)	4,60E-21
	Zinc (+II)	9,91E-23
Inorganic emissions to sea water		5,17E-20
	Barium	2,66E-20
	Beryllium	2,51E-20
Organic emissions to sea water		0,00090719

	Hydrocarbons to sea water	0,00086359
	Anthracene	0,00050353
	Benzene	2,26E-07
	Benzo{a}anthracene	2,80E-05
	Benzofluoranthene	0,00026544
	Chrysene	3,85E-05
	Ethyl benzene	3,71E-08
	Fluoranthene	2,67E-05
	Phenol (hydroxy benzene)	8,63E-07
	Toluene (methyl benzene)	1,21E-07
	Xylene (isomers; dimethyl benzene)	1,61E-07
	Naphthalene	4,36E-05

CML2001, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.] Emissions to industrial soil		**kg DCB-Equiv.**
Heavy metals to industrial soil		374,926459
	Arsenic (+V)	1,68348586
	Cadmium (+II)	38,6341755
	Chromium (+III)	1,43E-07
	Chromium (unspecified)	3,71820515
	Cobalt	0,14987179
	Copper (+II)	13,35723
	Lead (+II)	0,25887723
	Mercury (+II)	0,00434087
	Nickel (+II)	283,022625
	Zinc (+II)	34,0976474

CML2001, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**kg Phosphate-Equiv.**

Emissions to air		250,6744941
Inorganic emissions to air		250,6744941
	Ammonia	0,196041483
	Ammonium	1,30E-05
	Ammonium nitrate	7,91E-07
	Nitrogen dioxide	1,03E-09
	Nitrogen monoxide	0,000836851
	Nitrogen oxides	250,477602

CML2001, Eutrophication Potential (EP) [kg Phosphate-Equiv.]		**kg Phosphate-Equiv.**
Emissions to fresh water		997,041128
Analytical measures to fresh water		2,34705422
	Biological oxygen demand (BOD)	0,01547564
	Chemical oxygen demand (COD)	2,03611352
	Total dissolved organic bounded carbon	3,70E-07
	Total organic bounded carbon	0,2954647
Inorganic emissions to fresh water		994,619223
	Ammonia	0,06590933
	Ammonium / ammonia	451,597796
	Nitrate	0,23108884
	Nitrogen	2,27E-05
	Nitrogen organic bounded	0,07533563
	Phosphate	0,084405
	Phosphorus	542,564666
Organic emissions to fresh water		0,07485105
	Hydrocarbons to fresh water	0,07485105
	Acetic acid	0,00016708
	Hexane (isomers)	3,53E-10
	Hydrocarbons (unspecified)	0,00332279

	Methanol	0,00178472
	Oil (unspecified)	0,03548896
	Xylene (isomers; dimethyl benzene)	0,0340875
	Organic compounds (dissolved)	5,99E-10
	Organic compounds (unspecified)	1,59E-21

CML2001, Eutrophication Potential (EP) [kg Phosphate-Equiv.]		**kg Phosphate-Equiv.**
Emissions to sea water		0,03529596
Analytical measures to sea water		0,01707862
	Biological oxygen demand (BOD)	0,000391
	Chemical oxygen demand (COD)	0,0156449
	Total organic bounded carbon	0,00104273
Inorganic emissions to sea water		0,00090212
	Ammonia	1,33E-06
	Nitrate	0,00090079
Organic emissions to sea water		0,01731522
	Hydrocarbons to sea water	0,01731522
	Acetic acid	8,56E-06
	Hexane (isomers)	2,43E-10
	Oil (unspecified)	0,01627191
	Xylene (isomers; dimethyl benzene)	0,00103475

CML2001, Eutrophication Potential (EP) [kg Phosphate-Equiv.]		**kg Phosphate-Equiv.**
Emissions to industrial soil(total)		8678,97664
	Inorganic emissions to industrial soil	8678,97664

CML2001, Ozone Layer Depletion Potential (ODP, steady state)	**kg R11-Equiv.**

Organic emissions to air (group VOC)		0,006493881
	Group NMVOC to air	0,006493881

CML2001 - Nov. 09, Acidification Potential (AP) [kg SO2-Equiv.] Emissions to air		**kg SO2-Equiv.**
Inorganic emissions to air (total)		1554,09339
	Ammonia	0,89618964
	Ammonium	0,00012579
	Ammonium nitrate	3,75E-06
	Hydrogen bromine (hydrobromic acid)	3,22E-05
	Hydrogen chloride	2,99529288
	Hydrogen fluoride	0,26270486
	Hydrogen sulphide	17,1564672
	Nitrogen dioxide	3,98E-09
	Nitrogen monoxide	0,00318004
	Nitrogen oxides	963,375392
	Sulphur dioxide	569,40397
	Sulphuric acid	3,38E-05

CML2001 - Nov. 09, Acidification Potential (AP) [kg SO2-Equiv.] Emissions to fresh water		kg SO2-Equiv.
Inorganic emissions to fresh water(tot)		0,52839511
	Hydrogen chloride	2,26E-06
	Hydrogen fluoride (hydrofluoric acid)	0,528177622
	Sulphuric acid	0,000215228

Incineration Emission:

CML2001 - Nov. 09, Global Warming Potential (GWP 100 years)		kg CO2-Equiv.
Emissions to air		7462113,037
Inorganic emissions to air		7405028,348
	Carbon dioxide	7291207,774
	Carbon dioxide (biotic)	235,5054545
	Nitrous oxide (laughing gas)	113585,0464
	Sulphur hexafluoride	0,022419382
Organic emissions to air (group VOC)		57084,68917
	Group NMVOC to air	106,1378027
	Methane	56978,16269
	VOC (unspecified)	0,388684923

CML2001 - Nov. 09, Ozone Layer Depletion Potential (ODP, steady state)		[kg R11-Equiv.]
Emissions to air		0,011773818
Organic emissions to air (group VOC)		0,011773818
	NMVOC (Halogenated organic emissions to air)	0,011773818

CML2001 - Nov. 09, Acidification Potential (AP)		kg SO2-Equiv.
Emissions to air		6830,546858
Inorganic emissions to air		6830,546858
	Ammonia	259,5116578
	Ammonium	4,63E-06
	Ammonium nitrate	1,51E-06

	Hydrogen bromine (hydrobromic acid)	8,15E-05
	Hydrogen chloride	68,88425231
	Hydrogen fluoride	0,234475202
	Hydrogen sulphide	4,156403087
	Nitrogen dioxide	6,59E-09
	Nitrogen monoxide	1,07E-06
	Nitrogen oxides	4617,14471
	Sulphur dioxide	1880,612781
	Sulphuric acid	0,002489801

CML2001 - Nov. 09, Acidification Potential (AP)		**kg SO2-Equiv.**
Emissions to fresh water		0,00054195
Inorganic emissions to fresh water		0,00054195
	Hydrogen chloride	5,28E-06
	Hydrogen fluoride (hydrofluoric acid)	3,38E-05
	Sulphuric acid	0,00050289

CML2001 - Nov. 09, Eutrophication Potential (EP)		**[kg Phosphate-Equiv.]**
Emissions to air		1360,138427
Inorganic emissions to air		1360,138427
	Ammonia	56,76817515
	Ammonium	4,78E-07
	Ammonium nitrate	3,19E-07
	Nitrogen dioxide	1,71E-09
	Nitrogen monoxide	2,81E-07
	Nitrogen oxides	1200,457625
	Nitrous oxide (laughing gas)	102,9126259

CML2001 - Nov. 09, Eutrophication Potential (EP)		**[kg Phosphate-Equiv.]**
Emissions to fresh water		23,38650282
Analytical measures to fresh water		0,960682206

	Biological oxygen demand (BOD)	0,012341164
	Chemical oxygen demand (COD)	0,794051089
	Total dissolved organic bounded carbon	2,12E-07
	Total organic bounded carbon	0,154289742
Inorganic emissions to fresh water		20,33097949
	Ammonia	0,010097389
	Ammonium / ammonia	19,38786841
	Nitrate	0,308784939
	Nitrogen	1,34E-07
	Nitrogen organic bounded	0,434486906
	Phosphate	0,105048034
	Phosphorus	0,084693675
Organic emissions to fresh water	Organic emissions to fresh water	2,094841128
	Hydrocarbons to fresh water	2,094841127
	Organic compounds (dissolved)	9,92E-10
	Organic compounds (unspecified)	3,72E-21

CML2001 - Nov. 09, Eutrophication Potential (EP)		**[kg Phosphate-Equiv.]**
Emissions to sea water		0,247448282
Analytical measures to sea water		0,105897343
	Biological oxygen demand (BOD)	0,001279587
	Chemical oxygen demand (COD)	0,101205329
	Total organic bounded carbon	0,003412427
Inorganic emissions to sea water		0,006792211
	Ammonia	6,65E-06
	Nitrate	0,006785562
Organic emissions to sea water		0,134758728
	Hydrocarbons to sea water	0,134758728
	Acetic acid	6,19E-05
	Hexane (isomers)	1,22E-09
	Oil (unspecified)	0,126798325
	Xylene (isomers; dimethyl benzene)	0,00789846

CML2001 - Nov. 09, Eutrophication Potential (EP)		[kg Phosphate-Equiv.]
Emissions to industrial soil		3,684707801
Inorganic emissions to industrial soil		3,684707801
	Ammonia	1,940612688
	Phosphorus	1,744095113

CML2001 - Nov. 09, Human Toxicity Potential (HTP inf.)		kg DCB-Equiv.
Emissions to air		30906,10546
Heavy metals to air		17216,99236
	Antimony	2,554485732
	Arsenic (+V)	1075,785037
	Arsenic trioxide	0,00502299
	Cadmium (+II)	13194,62753
	Chromium (+III)	0,003958715
	Chromium (unspecified)	23,87033198
	Cobalt	27,8015026
	Copper (+II)	206,5677701
	Hydrogen arsenic (arsine)	0,486388593
	Lead (+II)	798,4239952
	Mercury (+II)	9,741696971
	Molybdenum	3,595534333
	Nickel (+II)	814,109244
	Selenium	383,7848936
	Thallium	5,254984043
	Tin (+IV)	0,004233236
	Vanadium (+III)	667,8383603
	Zinc (+II)	2,537388883
Inorganic emissions to air		11967,42921
	Ammonia	16,21947861
	Barium	169,7927925

	Beryllium	12,40415474
	Carbon disulphide	1,85E-06
	Hydrogen chloride	45,98806618
	Hydrogen fluoride	490,8553375
	Hydrogen sulphide	0,571505424
	Nitrogen dioxide	1,58E-08
	Nitrogen oxides	11081,1473
	Sulphur dioxide	150,4490225
	Tin oxide	1,90E-09
	Zinc oxide	2,09E-07
	Zinc sulphate	0,001547887
Organic emissions to air (group VOC)		1625,259689
Group NMVOC to air		1625,257567
	Group PAH to air	0,002205775
	Anthracene	1,35E-06
	Naphthalene	0,002204428
	Halogenated organic emissions to air	806,4680334
	Acrolein	0,00103923
	Benzene	804,0746538
	Butadiene	0,003029649
	Ethene (ethylene)	0,003139119
	Ethyl benzene	0,122787958
	Formaldehyde (methanal)	1,522840412
	NMVOC (unspecified)	13,00475883
	Phenol (hydroxy benzene)	3,00E-07
	Styrene	9,24E-10
	Toluene (methyl benzene)	0,020467384
	Xylene (dimethyl benzene)	0,034611609
	VOC (unspecified)	0,002121695
Particles to air		96,42419641

CML2001 - Nov. 09, Human Toxicity Potential (HTP inf.)	**kg DCB-Equiv.**

Emissions to fresh water		452,4394543
Heavy metals to fresh water		334,940978
	Antimony	1,21E-05
	Arsenic (+V)	14,37646545
	Cadmium (+II)	0,200892393
	Chromium (+III)	0,003146955
	Chromium (+VI)	5,00E-05
	Chromium (unspecified)	0,057537117
	Cobalt	0,001126733
	Copper (+II)	0,045639745
	Lead (+II)	0,262894256
	Mercury (+II)	0,470767567
	Molybdenum	92,21940217
	Nickel (+II)	4,604226857
	Selenium	204,5944213
	Thallium	0,138720709
	Tin (+IV)	1,33E-08
	Vanadium (+III)	17,95858656
	Zinc (+II)	0,007088098
Inorganic emissions to fresh water		47,36840403
	Barium	47,01340438
	Beryllium	0,264728653
	Hydrogen fluoride (hydrofluoric acid)	0,090270999
Organic emissions to fresh water		70,13007229
	Halogenated organic emissions to fresh water	1,23E-06
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	1,34E-07
	Vinyl chloride (VCM; chloroethene)	1,10E-06
	Hydrocarbons to fresh water	70,12547812
	Naphthalene	0,004592936

CML2001 - Nov. 09, Human Toxicity Potential (HTP inf.)		kg DCB-Equiv.
Emissions to sea water	Emissions to sea water	866,0094346
Heavy metals to sea water	Heavy metals to sea water	140,4802417
	Arsenic (+V)	30,58826102
	Cadmium (+II)	0,624252759
	Chromium (unspecified)	0,231802373
	Cobalt	1,306947509
	Copper (+II)	0,127784463
	Lead (+II)	0,342223326
	Mercury (+II)	1,321444844
	Molybdenum	0,00037244
	Nickel (+II)	12,13240758
	Tin (+IV)	2,05E-08
	Vanadium (+III)	92,41911307
	Zinc (+II)	1,385632305
Inorganic emissions to sea water	Inorganic emissions to sea water	689,493703
	Barium	669,5153954
	Beryllium	19,97830762
Organic emissions to sea water	Organic emissions to sea water	36,03548992
	Hydrocarbons to sea water	36,02938181
	Anthracene	3,83E-05
	Benzene	36,02227294
	Ethyl benzene	0,0015188
	Phenol (hydroxy benzene)	3,01E-05
	Toluene (methyl benzene)	0,00366691
	Xylene (isomers; dimethyl benzene)	0,00185471
	Naphthalene	0,006108112

CML2001 - Nov. 09, Human Toxicity Potential (HTP inf.)		kg DCB-Equiv.
Emissions to industrial soil		3,861074378
Heavy metals to industrial soil		3,861074378
	Arsenic (+V)	0,004380588
	Cadmium (+II)	0,0026
	Chromium (+III)	1,86E-05

	Chromium (unspecified)	3,211415355
	Cobalt	0,01126814
	Copper (+II)	0,000136934
	Lead (+II)	0,00085818
	Mercury (+II)	0,000233491
	Nickel (+II)	0,62966096
	Zinc (+II)	0,000502142

CML2001, Marine Aquatic Ecotoxicity Pot. (MAETP inf.)		**[kg DCB-Equiv.]**
Emissions to air		8952028,448
Heavy metals to air		1734676,76
	Antimony	12,58764453
	Arsenic (+V)	715,9862697
	Arsenic trioxide	0,003342326
	Cadmium (+II)	100544,6342
	Chromium (+III)	0,032083472
	Chromium (unspecified)	193,4575105
	Cobalt	8649,199987
	Copper (+II)	42969,17547
	Hydrogen arsenic (arsine)	0,323714815
	Lead (+II)	12063,77179
	Mercury (+II)	1945,151888
	Molybdenum	1288,954307
	Nickel (+II)	87325,2895
	Selenium	170585,3092
	Thallium	311,6613072
	Tin (+IV)	18,32224608
	Vanadium (+III)	1306418,964
	Zinc (+II)	1633,935561
Inorganic emissions to air		7216885,431
	Barium	174978,1009

	Beryllium	25715,10902
	Carbon disulphide	1,18E-06
	Hydrogen fluoride	7016191,224
	Tin oxide	8,22E-06
	Zinc oxide	0,000134348
	Zinc sulphate	0,996752118
Organic emissions to air (group VOC)		466,2564013
	Group NMVOC to air	466,2562485
	Group PAH to air	337,4670698
	Anthracene	0,004397212
	Benzo{a}anthracene	0,001326548
	Benzo{a}pyrene	0,142765768
	Benzo{ghi}perylene	0,001924784
	Benzofluoranthene	0,275358664
	Chrysene	0,001322703
	Indeno[1,2,3-cd]pyrene	0,006290423
	Naphthalene	0,00024799
	Phenanthrene	0,000620939
	Polycyclic aromatic hydrocarbons (PAH)	337,0328147
	Halogenated organic emissions to air	123,5949583
	Dichloromethane (methylene chloride)	2,51E-13
	Dioxins (unspec.)	0,041903545
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	123,5530547
	Vinyl chloride (VCM; chloroethene)	7,90E-08
	Acrolein	0,010337087
	Alkene (unspecified)	1,82E-11
	Benzene	0,001185341
	Butadiene	3,74E-12
	Ethene (ethylene)	3,91E-13
	Ethyl benzene	0,000100394
	Fluoranthene	0,001685364
	Formaldehyde (methanal)	2,994926065

	NMVOC (unspecified)	2,185601228
	Phenol (hydroxy benzene)	3,20E-07
	Styrene	9,93E-12
	Toluene (methyl benzene)	4,38E-05
	Xylene (dimethyl benzene)	0,000340791
	VOC (unspecified)	0,000152818

CML2001, Marine Aquatic Ecotoxicity Pot. (MAETP inf.)		**kg DCB-Equiv.**
Emissions to fresh water		293246,711
Heavy metals to fresh water		219553,405
	Antimony	6,40E-05
	Arsenic (+V)	1793,0205
	Cadmium (+II)	1933,08105
	Chromium (+III)	1,32016355
	Chromium (+VI)	0,05029435
	Chromium (unspecified)	24,1371134
	Cobalt	51,0821239
	Copper (+II)	7931,47802
	Lead (+II)	23,797228
	Mercury (+II)	70,7580792
	Molybdenum	34948,8233
	Nickel (+II)	31289,5768
	Selenium	92591,2459
	Thallium	16,3788371
	Tin (+IV)	0,00094186
	Vanadium (+III)	48710,579
	Zinc (+II)	168,075553
Inorganic emissions to fresh water		73692,8739
	Barium	62139,0175
	Beryllium	10219,6674
	Hydrogen fluoride (hydrofluoric acid)	1334,18896

Organic emissions to fresh water		0,43254328
	Halogenated organic emissions to fresh water	7,00E-09
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	7,00E-09
	Vinyl chloride (VCM; chloroethene)	2,87E-12
	Hydrocarbons to fresh water	0,43166585
	Acrylonitrile	2,55E-06
	Anthracene	0,06900942
	Benzene	0,00010159
	Benzo{a}anthracene	0,01481279
	Benzofluoranthene	0,31969637
	Chrysene	0,02243844
	Ethyl benzene	4,80E-06
	Fluoranthene	0,00231286
	Phenol (hydroxy benzene)	0,00305388
	Toluene (methyl benzene)	3,29E-05
	Xylene (isomers; dimethyl benzene)	0,00020026
	Naphthalene	0,00087742

CML2001, Marine Aquatic Ecotoxicity Pot. (MAETP inf.)		**kg DCB-Equiv.**
Emissions to sea water		2335456,34
Heavy metals to sea water		635942,6079
	Arsenic (+V)	4372,597739
	Cadmium (+II)	11102,12119

	Chromium (unspecified)	189,7461735
	Cobalt	174019,4199
	Copper (+II)	31930,95161
	Lead (+II)	49,11912185
	Mercury (+II)	302,389779
	Molybdenum	0,143744608
	Nickel (+II)	93700,4745
	Tin (+IV)	0,002344743
	Vanadium (+III)	271798,0318
	Zinc (+II)	48477,61003
Inorganic emissions to sea water		1699112,668
	Barium	904273,2347
	Beryllium	794839,4336
Organic emissions to sea water		401,0638772
	Hydrocarbons to sea water	400,0274291
	Anthracene	4,330496061
	Benzene	0,002604246
	Benzo{a}anthracene	18,86635861
	Benzofluoranthene	364,3834857
	Chrysene	9,58593386
	Ethyl benzene	0,001333213
	Fluoranthene	1,07518425
	Phenol (hydroxy benzene)	1,761933951
	Toluene (methyl benzene)	0,004845925
	Xylene (isomers; dimethyl benzene)	0,015253351
	Naphthalene	1,036448088

CML2001, Marine Aquatic Ecotoxicity Pot. (MAETP inf.)		**[kg DCB-Equiv.]**
Emissions to industrial soil		4186,12901
Heavy metals to industrial soil		4186,12901
	Arsenic (+V)	0,33090624
	Cadmium (+II)	4,37641878
	Chromium (+III)	4,06E-05
	Chromium (unspecified)	7,00813665
	Cobalt	420,331367

	Copper (+II)	13,0540448
	Lead (+II)	0,00220425
	Mercury (+II)	0,03576628
	Nickel (+II)	3732,4152
	Zinc (+II)	8,57492016

CML2001 - Nov. 09, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)		**kg DCB-Equiv.**
Emissions to air		286,3703824
Heavy metals to air		247,9539428
	Antimony	0,001418146
	Arsenic (+V)	0,153166979
	Arsenic trioxide	7,15E-07
	Cadmium (+II)	26,33005565
	Chromium (+III)	1,18E-05
	Chromium (unspecified)	0,070951417
	Cobalt	1,017178442
	Copper (+II)	10,66035804
	Hydrogen arsenic (arsine)	6,93E-05
	Lead (+II)	4,106856671
	Mercury (+II)	0,513642899
	Molybdenum	0,064485193
	Nickel (+II)	14,62792949
	Selenium	4,396118469
	Thallium	0,018886967
	Tin (+IV)	0,006193346
	Vanadium (+III)	
	Zinc (+II)	185,5545704
Inorganic emissions to air		0,432048978
	Barium	11,34831307
	Beryllium	9,611757982
	Boron compounds (unspecified)	0,937581585
	Carbon disulphide	0

	Hydrogen fluoride	2,53E-08
	Tin oxide	0,798709875
	Zinc oxide	2,78E-09
	Zinc sulphate	3,55E-08
Organic emissions to air (group VOC)		0,000263563
	Group NMVOC to air	27,06812654
	VOC (unspecified)	27,06632942

CML2001 - Nov. 09, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)		**kg DCB-Equiv.**
Emissions to fresh water		207,351095
Heavy metals to fresh water		172,623732
	Antimony	4,66E-08
	Arsenic (+V)	3,12668576
	Cadmium (+II)	13,3661418
	Chromium (+III)	0,01060182
	Chromium (+VI)	0,0004039
	Chromium (unspecified)	0,19383764
	Cobalt	0,03970667
	Copper (+II)	39,4391885
	Lead (+II)	0,20620065
	Mercury (+II)	0,56689965
	Molybdenum	7,9645296
	Nickel (+II)	45,0244016
	Selenium	10,6631892
	Thallium	0,0049362
	Tin (+IV)	7,80E-06
	Vanadium (+III)	50,9037729
	Zinc (+II)	1,11322835
Inorganic emissions to fresh water		18,7139598
	Barium	16,9830327
	Beryllium	1,73046159

Hydrogen fluoride (hydrofluoric acid)		0,00046555
Organic emissions to fresh water		16,0134036
	Halogenated organic emissions to fresh water	2,73E-08
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	2,71E-08
	Vinyl chloride (VCM; chloroethene)	2,12E-10
Hydrocarbons to fresh water		15,4684353
	Acrylonitrile	0,00037265
	Anthracene	1,30750697
	Benzene	0,00349839
	Benzo{a}anthracene	0,20476933
	Benzofluoranthene	0,85881337
	Chrysene	0,13937001
	Cresol (methyl phenol)	0
	Ethyl benzene	0,00192588
	Fluoranthene	0,03504951
	Phenol (hydroxy benzene)	12,858925
	Toluene (methyl benzene)	0,0078369
	Xylene (isomers; dimethyl benzene)	0,05036728
Naphthalene		0,54496832

CML2001 - Nov. 09, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)		**kg DCB-Equiv.**
Emissions to sea water		0,00858925
Heavy metals to sea water		0,00109217
	Arsenic (+V)	4,91E-22
	Cadmium (+II)	1,52E-22
	Chromium (unspecified)	2,04E-24
	Cobalt	2,63E-20
	Copper (+II)	8,89E-22

	Lead (+II)	2,42E-25
	Mercury (+II)	0,00109217
	Molybdenum	3,61E-26
	Nickel (+II)	9,90E-21
	Tin (+IV)	1,84E-29
	Vanadium (+III)	3,55E-20
	Zinc (+II)	7,63E-22
Inorganic emissions to sea water		3,94E-19
	Barium	2,00E-19
	Beryllium	1,94E-19
Organic emissions to sea water		0,00749707
	Hydrocarbons to sea water	0,0071367
	Anthracene	0,00408821
	Benzene	1,58E-06
	Benzo{a}anthracene	0,00023692
	Benzofluoranthene	0,00225
	Chrysene	0,00032575
	Ethyl benzene	2,04E-07
	Fluoranthene	0,00022549
	Phenol (hydroxy benzene)	6,54E-06
	Toluene (methyl benzene)	7,87E-07
	Xylene (isomers; dimethyl benzene)	1,23E-06
	Naphthalene	0,00036037

CML2001 - Nov. 09, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)		**kg DCB-Equiv.**
Emissions to industrial soil		5,90654483
Heavy metals to industrial soil		5,90654483
	Arsenic (+V)	0,00057704
	Cadmium (+II)	0,03026041
	Chromium (+III)	3,26E-07

	Chromium (unspecified)	0,05628016
	Cobalt	0,326728
	Copper (+II)	0,0649111
	Lead (+II)	1,91E-05
	Mercury (+II)	0,00018327
	Nickel (+II)	5,37079047
	Zinc (+II)	0,05679496

CML2001, Terrestric Ecotoxicity Potential (TETP inf.)		**kg DCB-Equiv.**
Emissions to air		276,3514358
Heavy metals to air		272,1438517
	Antimony	0,00023258
	Arsenic (+V)	4,978568932
	Arsenic trioxide	2,32E-05
	Cadmium (+II)	7,39140731
	Chromium (+III)	0,018550712
	Chromium (unspecified)	111,8574277
	Cobalt	0,17299688
	Copper (+II)	0,336242673
	Hydrogen arsenic (arsine)	0,002250932
	Lead (+II)	26,81824219
	Mercury (+II)	45,90643697
	Molybdenum	0,011621018
	Nickel (+II)	2,696671801
	Selenium	0,430349004
	Thallium	0,004132009
	Tin (+IV)	0,035065318
	Vanadium (+III)	71,19299327
	Zinc (+II)	0,290639236
Inorganic emissions to air		1,188198427
Organic emissions to air (group VOC)		3,019385676

	Group NMVOC to air	3,019298003
	Group PAH to air	0,037280577
	Anthracene	8,19E-08
	Benzo{a}anthracene	3,00E-07
	Benzo{a}pyrene	2,52E-05
	Benzo{ghi}perylene	2,37E-07
	Benzofluoranthene	6,91E-05
	Chrysene	6,88E-07
	Indeno[1,2,3-cd]pyrene	6,94E-07
	Naphthalene	2,23E-07
	Phenanthrene	1,16E-08
	Polycyclic aromatic hydrocarbons (PAH)	0,037184078
	Halogenated organic emissions to air	0,005000158
	Dichloromethane (methylene chloride)	2,79E-16
	Dioxins (unspec.)	1,70E-06
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	0,004998462
	Vinyl chloride (VCM; chloroethene)	1,59E-10
	Acrolein	0,000298206
	Alkene (unspecified)	3,09E-13
	Benzene	6,59E-06
	Butadiene	3,17E-14
	Ethene (ethylene)	6,65E-15
	Ethyl benzene	1,81E-07
	Fluoranthene	1,53E-07
	Formaldehyde (methanal)	1,722810053
	NMVOC (unspecified)	1,253900649
	Phenol (hydroxy benzene)	1,92E-09
	Styrene	2,65E-15
	Toluene (methyl benzene)	9,97E-07
	Xylene (dimethyl benzene)	4,36E-07
	VOC (unspecified)	8,77E-05

CML2001, Terrestric Ecotoxicity Potential (TETP inf.)		[kg DCB-Equiv.]
Emissions to fresh water		0,307141687
Heavy metals to fresh water		0,30713945
	Antimony	3,91E-29
	Arsenic (+V)	1,57E-19
	Cadmium (+II)	1,24E-22
	Chromium (+III)	3,48E-22
	Chromium (+VI)	3,32E-24
	Chromium (unspecified)	6,37E-21
	Cobalt	3,14E-23
	Copper (+II)	1,38E-22
	Lead (+II)	1,02E-23
	Mercury (+II)	0,30713945
	Molybdenum	3,86E-20
	Nickel (+II)	1,43E-20
	Selenium	5,67E-20
	Thallium	1,93E-23
	Tin (+IV)	6,03E-28
	Vanadium (+III)	5,80E-20
	Zinc (+II)	3,08E-23
Inorganic emissions to fresh water		1,13E-09
	Barium	3,79E-20
	Beryllium	6,25E-21
	Hydrogen fluoride (hydrofluoric acid)	1,13E-09
Organic emissions to fresh water		2,24E-06
	Halogenated organic emissions to fresh water	9,40E-14
	Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	9,20E-14
	Vinyl chloride (VCM; chloroethene)	1,95E-15
	Hydrocarbons to fresh water	1,83E-06
	Acrylonitrile	1,81E-08

	Anthracene	4,50E-07
	Benzene	5,26E-07
	Benzo{a}anthracene	2,49E-08
	Benzofluoranthene	1,52E-07
	Chrysene	6,30E-08
	Ethyl benzene	4,19E-09
	Fluoranthene	1,32E-08
	Phenol (hydroxy benzene)	1,35E-07
	Toluene (methyl benzene)	3,77E-07
	Xylene (isomers; dimethyl benzene)	6,63E-08
	Naphthalene	4,06E-07

CML2001, Terrestric Ecotoxicity Potential (TETP inf.)		**[kg DCB-Equiv.]**
Emissions to sea water		1,23238309
Heavy metals to sea water		1,232355695
Inorganic emissions to sea water	Inorganic emissions to sea water	1,04E-18
	Barium	5,50E-19
	Beryllium	4,85E-19
Organic emissions to sea water		2,74E-05
	Hydrocarbons to sea water	2,68E-05
	Naphthalene	5,96E-07

CML2001, Terrestric Ecotoxicity Potential (TETP inf.)		**[kg DCB-Equiv.]**
Emissions to industrial soil		68,37127695

Heavy metals to industrial soil		68,37127695
	Arsenic (+V)	0,014320449
	Cadmium (+II)	0,006503776
	Chromium (+III)	0,000390733
	Chromium (unspecified)	67,50650474
	Cobalt	0,042544893
	Copper (+II)	0,001567502
	Lead (+II)	9,51E-05
	Mercury (+II)	0,012099657
	Nickel (+II)	0,758000335
	Zinc (+II)	0,029249724

ANNEX II

1. Incineration of MSW

Incineration is a thermal treatment in which the waste is combusted with excess of air. Incineration itself is one part of the overall complex waste treatment system, it is one of the solution adopted in line with other treatments like landfilling and gas treatment.

The incineration sector has found a rapid technological development during the last 10 to 15 years, thanks also to the legislation that drive also the industrial production, like the reduce of emissions to air.

Continual process of development are still ongoing, that aim to limit costs, improving environment performance and previously reduce the volume of hazard, capturing or destroying potentially harmful substances that could be released during the incineration process.

Waste incineration is the oxidation of combustible materials contained in the waste. Waste is generally a highly heterogeneous material, consisting essentially of organic substances, minerals, metals and water [9]. During incineration, flue-gases are created that will contain the majority of the available fuel energy as heat.

The organic fuel substances in the waste will burn when they have reached the necessary ignition temperature and been exposed to oxygen.

The organic part oxidized with production of CO_2 and H_2O, while the inorganic noncombustible is discharged as slag or ash. The energy generated during the process is produced for stream production, district heating production and electric power production. Since is a combustion process it also gives dangerous emissions to the environment, as

- Nitrogen oxides,
- Sulphur oxides,
- Hydrochloric acid,
- Heavy metals,
- polyromantic hydrocarbons (PAH),
- chlorinated organic compounds (for example TCDD and other “dioxins”)

Before 2008, according to the waste hierarchy defined in Directive 2006/12/EC,1, waste incineration were considered as disposal operations, instead of an alternative way of energy production, in the form of power and heat production (Grosso 2010)

Nowadays Incineration is one of the most argued issue, because for one side energy recovery from waste is an undeniable interesting option of treating waste, but in opposition to that, the environmentalist associations asserted that promoting incineration would affect negatively waste recycling for material recovery and recycling (Grosso 2010) . Moreover, the impact of an incinerator on the environment can be effectively reduced with state-of-the-art technologies for flue gas treatment (Grosso 2005) and with the introduction of the Best Available Technology. Waste-to-energy lobby also tried to underline the positive contribute that these plants might give by reducing the dependence on landfills and fossil fuels. (EPA ,Environmental protection Agency) .

1.2 R1 Formula

With the R1 formula The Dircetive allows The Directive allows municipal waste incinerators to be classified as recovery operations provided they contribute to the generation of energy with high efficiency to promote the use of waste to produce energy in energy efficient municipal waste incinerators and encourage innovation in waste incineration. (Grosso, 2010).

Energy efficiency – $\frac{Ep-(Es+Ei)}{o.97*(Ew+Ef)}$ (3)

E_p : annual energy produced as heat or electricity,calculated with energy in the form of electricity being multiplied by 2.6 and heat produced for commercial use multiplied by 1.1 (GJ/year)

E_f: annual energy input to the system from fuels contributing to the production of steam(GJ/year)

E_w: annual energy contained in the treated waste calculated using the net calorific value of thewaste (GJ/year)

E_i: annual energy imported excluding E_w and E_f (GJ/year)

0.97 is a factor accounting for energy losses due to bottom ash and radiation (Grosso 2010).

1.2 Best Available Techniques

The R1 formula shall be applied in accordance with BREF, Reference formula shall be applied in accordance with the

Reference Document on Best Available Techniques for Waste Incineration (BREF WI).

“the most effective and advanced stage in the development of an activity and its methods of operation, which indicate the practical suitability of particular techniques for providing, in principle, the basis for emission limit values, and in the case of an industrial emissions directive activity other additional licence conditions, designed to prevent or eliminate or, where that is not practicable, generally to reduce an emission and its impact on the environment as a whole”

B ‘best’ in relation to techniques, means the most effective in achieving a high general level of protection of the environment as a whole

A ‘available techniques’ means those techniques developed on a scale which allows implementation in the relevant class of activity under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced within the State, as long as they are reasonably accessible to the person carrying on the activity

T ‘techniques’ includes both the technology used and the way in which the installation is designed, built, managed, maintained, operated and decommissioned

1.3 Incineration techniques

The state of art of incineration techniques are described above according with Division of Technology, Industry and Economics of United Nations Environment Program.

A modern incinerator is a complex industrial process plant involving several process steps in order to optimise the energy production and to minimise the unwanted emissions. The process plant can be divided in several sub-plants of which the most important are.

· Combustion chamber, where the solid material is combusted.

· After-combustion chamber, where the gases from the combustion chamber are hold at high temperature and oxygen excess in order to oxidize unburned gases.

· Boiler, which recovers the energy from the flue gases.

· Flue gas cleaning system (there are several systems available)

· In cases of wet flue gas cleaning there is also a water treatment system.

· Ash handling system.

· Landfilling of slags and ashes.

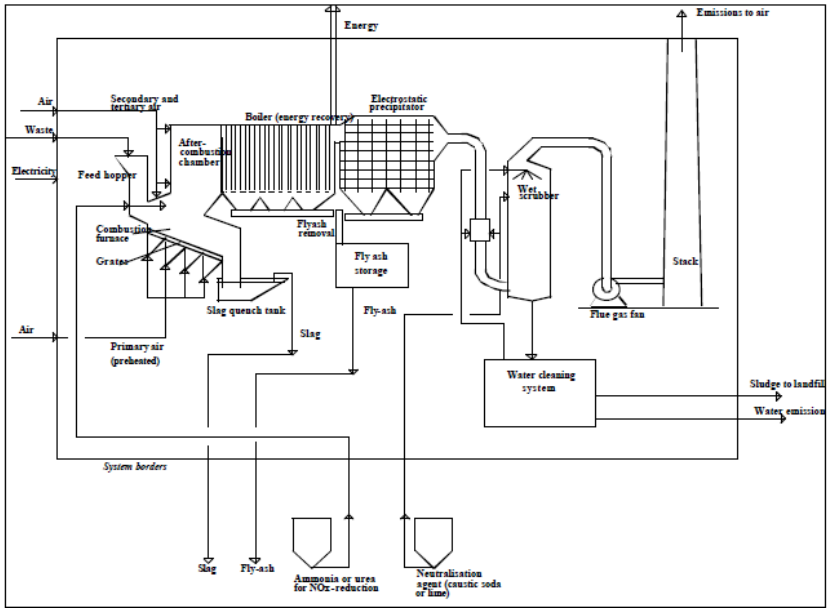


Figure 1.2 Illustration of an incinerator plan and the system boundaries used in this (Sundqvist, 1999)

Mass-burn systems

Mass-burn systems are the predominant form of MSW incineration. Mass-burn systems, Generally formed by two or three incineration units (each one with a capacity from 50 to 1,000 tons per day) with a general facility capacity that ranges from about 100 to 3,000 tons per day. The success of these facilities is that they are able to accept refuse that has undergone little preprocessing other than the removal of oversized items, such as refrigerators and sofas. Although this versatility makes mass-burn facilities convenient and flexible, local programs to separate household hazardous wastes (eg, cleaners and pesticides) and recover certain materials (eg, iron scrap) are Necessary to Help Ensure environmentally responsible incineration and resource conservation.

Modular incinerators

Modular incinerator units are usually prefabricated units with relatively small capacities of between 5 and 120 tons of solid waste per day. Typical facilities have between one and four units for a total plant capacity of about 15 to 400 tons per day. The majority of modular units produce steam as the sole energy product. Due to their small capacity, modular incinerators are generally used in smaller communities or for commercial and industrial operations. Their prefabricated design gives modular facilities the advantage of shorter CONSTRUCTION times. On average, capital costs per ton of capacity are lower for modular units than for other MSW incineration options.

Fluidized-bed incinerators

In a fluidized-bed incinerator, the stoker grate is replaced by a bed of limestone or sand that can withstand high temperatures, fed by an air distribution system. The heating of the bed and the increasing of the air velocities cause the bed to bubble, which gives rise to the term fluidized. There are two types of fluidized-bed technologies, a bubbling bed and a circulating bed. The differences are reflected in the relationship between air flow and bed material, and have implications for the type of wastes that can be burned, as well as the heat transfer to the energy recovery system.

Unlike mass-burn incinerators, fluidized-bed incinerators require front-end pre-processing, also called fuel preparation. They are generally also associated with source separation because glass and metals do not fare well in these systems. Also, fluidized-bed systems can successfully burn wastes of widely varying moisture and heat content, so that the inclusion of paper and wood, which are both recyclable and burnable, is not a crucial factor in their operation (and thus paper can be extracted for higher-value recycling). These factors would appear to indicate that fluidized-bed technologies are more compatible with high-recovery recycling systems, since there might be less competition for waste streams that are both burnable and recyclable. For this reason, fluidized-bed technology may be a sound choice for high-recycling cities in developing countries when they first move to incineration.

Fluidized-bed systems are more consis-tent in their operation than mass burn and can be controlled more effectively to achieve higher energy conversion efficiency, less residual ash, and lower air emissions. Cost comparisons with mass-burn are inconclusive. In general, however, fluidized-bed

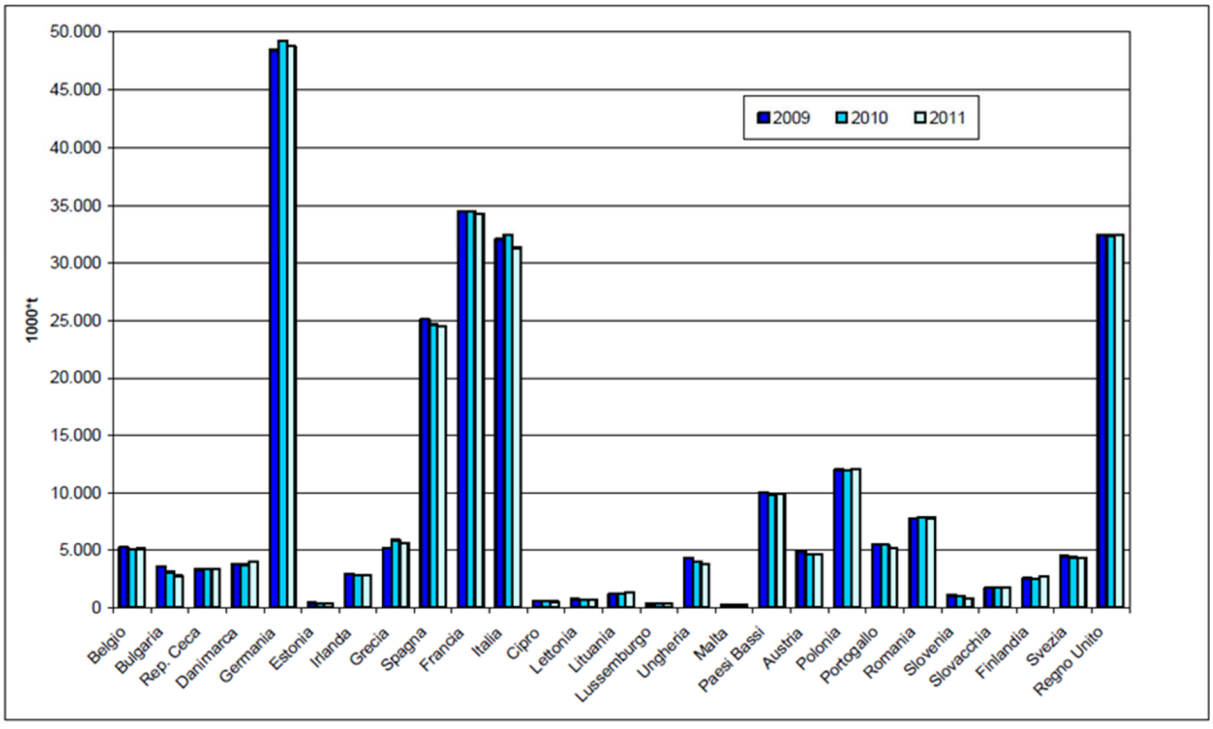
incinerators appear to operate efficiently on smaller scales than do mass-burn incinerators, which may make them attractive in some situations.

1.4 Waste Management Europa

The European Statistic Office, Eurostat holds the leadership of the Environmental Data Centre on Waste.

According with Eurostat, the amount of municipal waste in EU28 during 2012 (data obtained on 2014) is decreased of about 2.4% compared to 2011 (from almost 253 million tons in approximately 246.8 million tons).

2012 has been a consequence of the previous downward trend of municipal waste production that started in the previous years (between 2010 and 2011 the decline registered was 0.9%). Considering the group EU 15 , the reduction recorded between 2011 and 2012 amounted to 2.6 % (from about 214.6 to almost 209 million tons) , while in reference to the new Member States , it is noted in the same period fell by 1.4 % (from about 38.4 to about 37.8 million tons) .



Fonte: elaborazioni ISPRA su dati Eurostat

*Fig. 1.2 Urban Solid Production UE (1000*t), 2009-2011, ISPRA (2013)*

The strongest reduction has been calculated in Italy and Spain (-4,4%); followed by Great Britain and Germany, respect, -3,3% and -2,2% while France presents a small reduction (-0,2%). The quantity of waste in these 5 Countries (Italy, Spain, Germany, Great Britain, France) on 2012 amounts of 165,8 million of tons (almost 4,6 million of tons less than the privies year), and is as the 67,2% of the UE production. However analyzing the data of the per capita production, reporting also with the population, the situation results characterized by different variability. Estonia and Denmark are in the opposite extreme, the first one with the amount 668 kg habitant, and the second 279. However, a great difference come out between the "older" and the " new" member states.

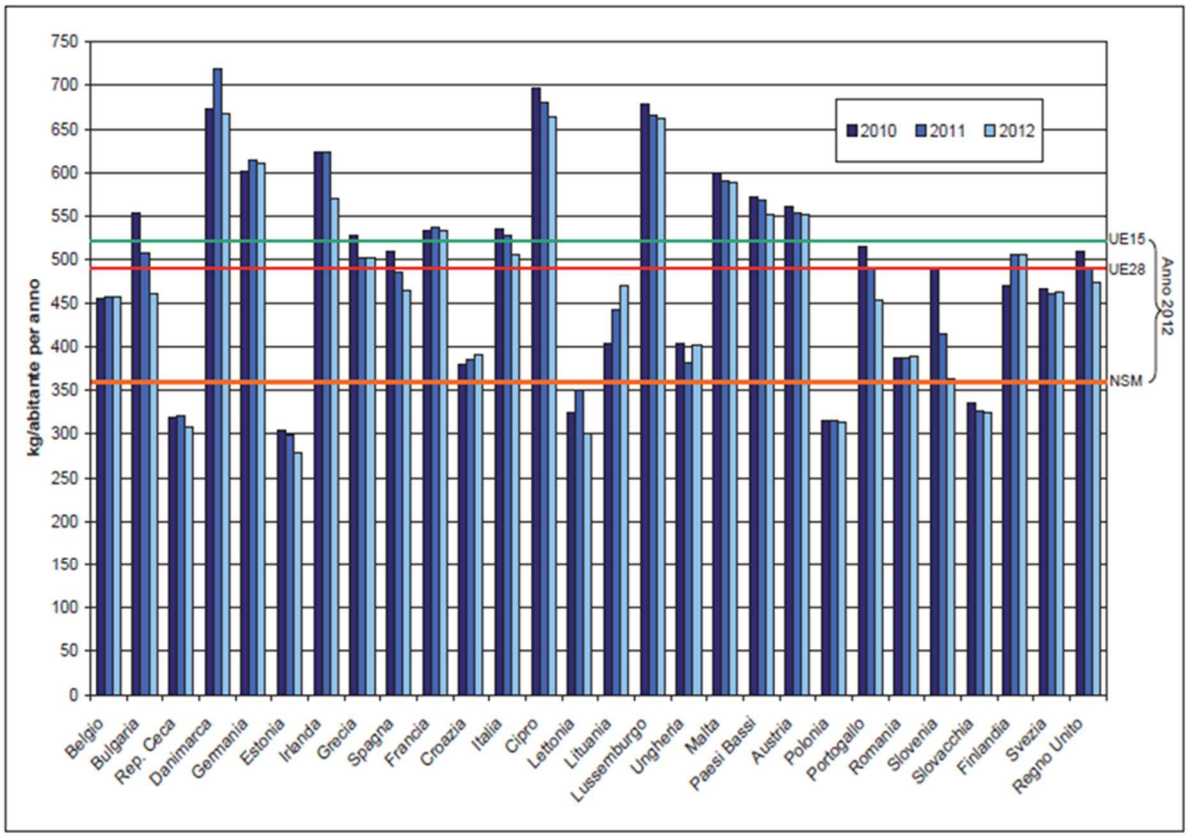


Fig. 1.3 per capita municipale Waste production (kg/ab), 2009-2011, ISPRA, Eurostat (2013)

Figure 1.3 shows the present situation in European Union relating to the amount of per capita municipal waste disposed of in landfills in 2011. The value per capita for the disposal in landfill in EU27 countries amounted on average to 176 kg / inhabitant per year, 5.9% less over the previous year. The data is diversified in the Community, with lower values in EU 15 (average 159 kg / inhabitant per year), in which the measures undertaken for the removal of waste from the landfill are now consolidated, and values much higher in the NMS (on average 240 kg / inhabitant per year), in which the implementation of EU

legislation was started more recently. In both groups there was a reduction compared to 2010 (-5.9% in the old Member and-5.5% In the NMS).(ISPRA)

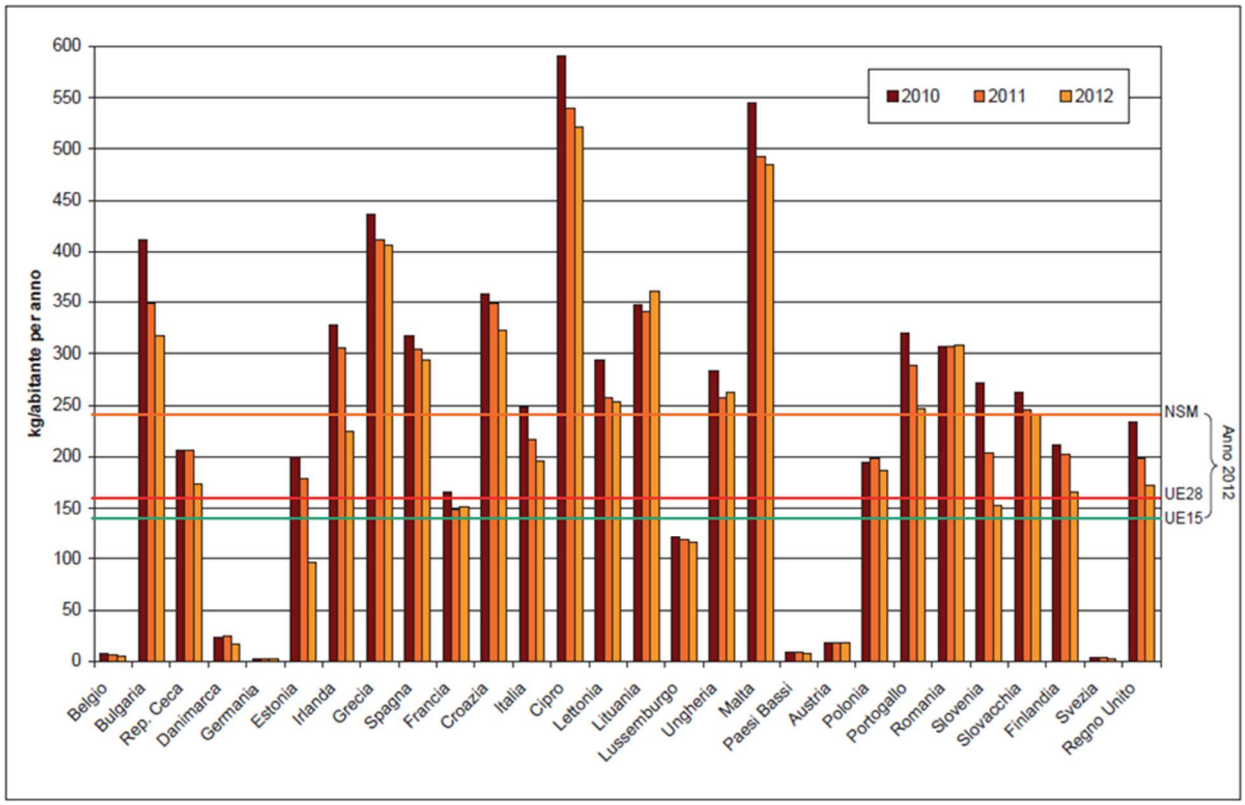


Fig.1.4 Landfilling Waste disposal UE (kg/ab) 2010-2012, ISPRA, (2014)

As for landfilling, also data concerning the incineration highlight are highly heterogeneous among members: about 30 million tonnes (53.1% of the total EU-27) are incinerated in only Germany and France, while 6 states States (Bulgaria, Estonia, Greece, Cyprus,Latvia and Romania) are not satisfied at all.

The situation with regard to the quantities per capita municipal waste incineration started in 2011 in Europe it is illustrated in thematic map of Figure 1.4. It can be observed that in ten Member States (Bulgaria,Estonia, Greece, Cyprus, Latvia, Romania, Lithuania, Poland, Malta and Slovenia) the quantity initiated incineration do not exceed 6 kg per capita. The average amount per capita municipal waste incinerated in the countries of EU 27 during 2011 is equal to 113 kg / inhabitant per year. Incineration is particularly widespread in the central Europe, in particular Denmark (387 kg / inhabitant per year), Luxembourg (264), Sweden (237), Germany (220), countries Netherlands and Belgium (193), France (184) and Austria(183). When considering the two territorial groupings EU 15 and the NMS, we note the emergence of a situation opposite to that registered with reference to disposal in landfill.

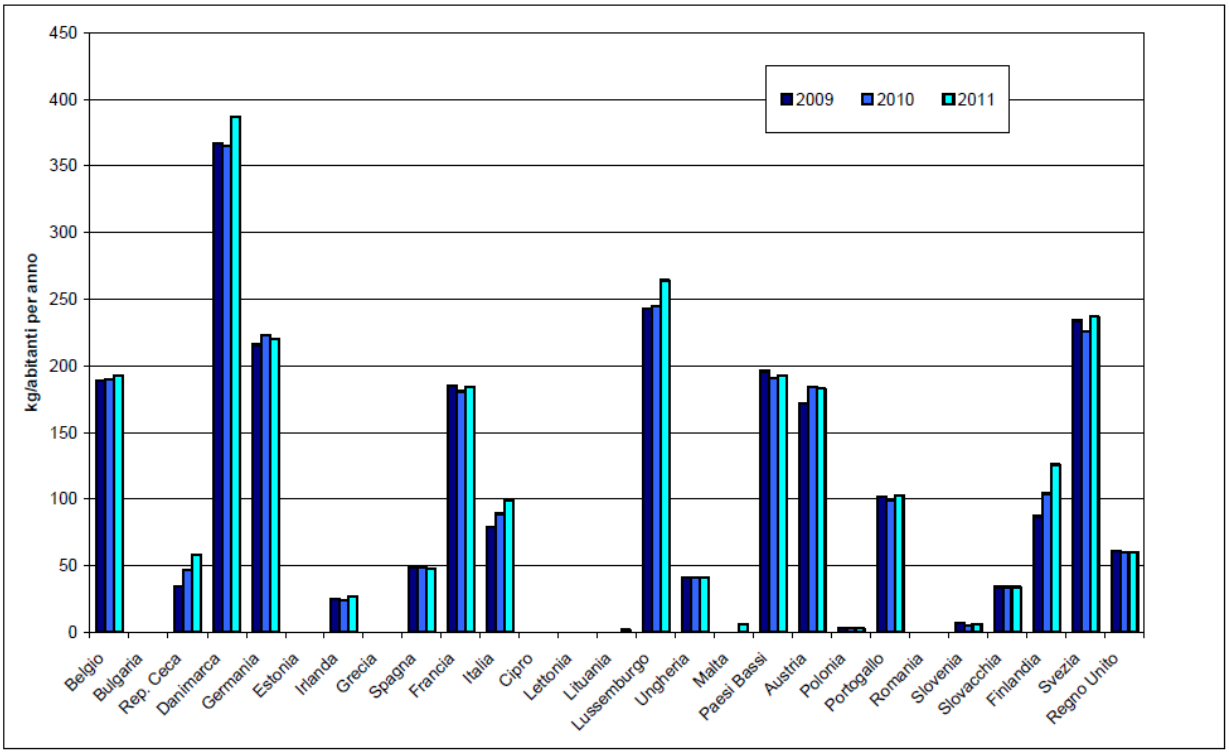


Fig 1.5. Incineration waste UE (kg/ab), 2009-2011, ISPRA, (2013)

2.5 Waste Management Italy

On July 2012, the European Commission published the document "Screening of waste management performance of EU Member" [10], with the aim to figure the present situation in Europe regarding municipal waste management. Major discrepancies have been found in the implementation and application of the European Waste Framework Directive into national legislation.

The study analyses the practical implementation of the waste management hierarchy taking in consideration the application of economic and legal instruments to move up the waste hierarchy, sufficiency of treatment infrastructure and quality of waste management planning. The screening results confirm the assumption of large differences within the 27 EU Countries, with deep gap especially regarding the application of legal or economic instruments and planning quality in municipal waste management framework, which the most critical adoption of landfilling in the Urban area .

The evaluation allowed the classification for the members States into three different group according with Urban Waste Management.

Italy has been placed in the Group of States those present the largest deficit with deficiencies such as weak or non-existent policies of waste prevention, lack of incentives to promote alternative management options to landfill and inadequacy infrastructure for the treatment of waste.

The policies of waste management must necessarily take into account the priorities identified at European level. First the abandonment of the landfilling use and second the activation of useful actions to realize the decoupling between economic indicators and the production of waste.

Nowadays in Italy waste production has decreased as a consequence of the crisis, that counts less disposal in the landfilling. However It is necessary asking if the trend fit exclusively to an international economic crisis, that affects primarily the consumptions or if it linked with a more “virtuous” lifestyle, with particular attention to consumption and disposal, and also if it is a consequence of an improving of local rules, and environmental attention.

Figure 1.6 shows the tendency of economic factors BIP, consumption, and waste production, during the period (2001-2011) they follow the same trend.

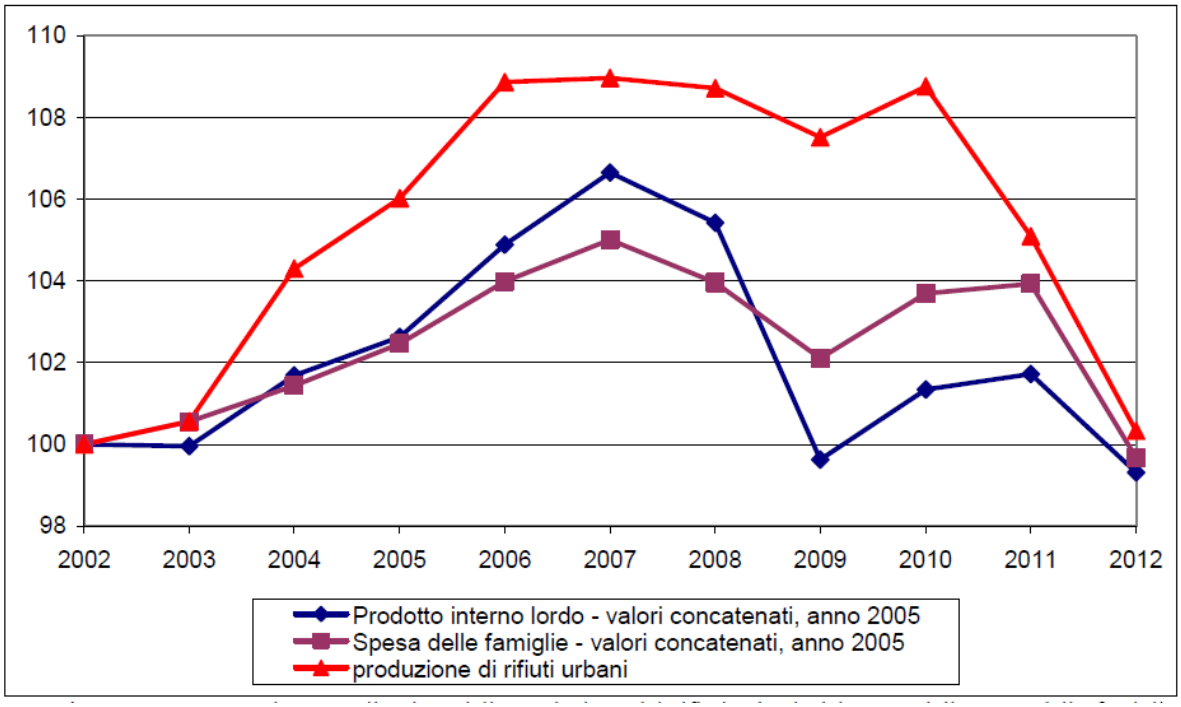


Fig. 1.6 comparation between BIP, consumption and solid waste production. (ISPRA, 2014)

Figure 1.7 shows the division of waste management in Italy, landfilling in Italy is still the most common practice, while incineration and energy production are just (incinerator, gas production, composting) a little percentage, the 1,8% of waste is exported.

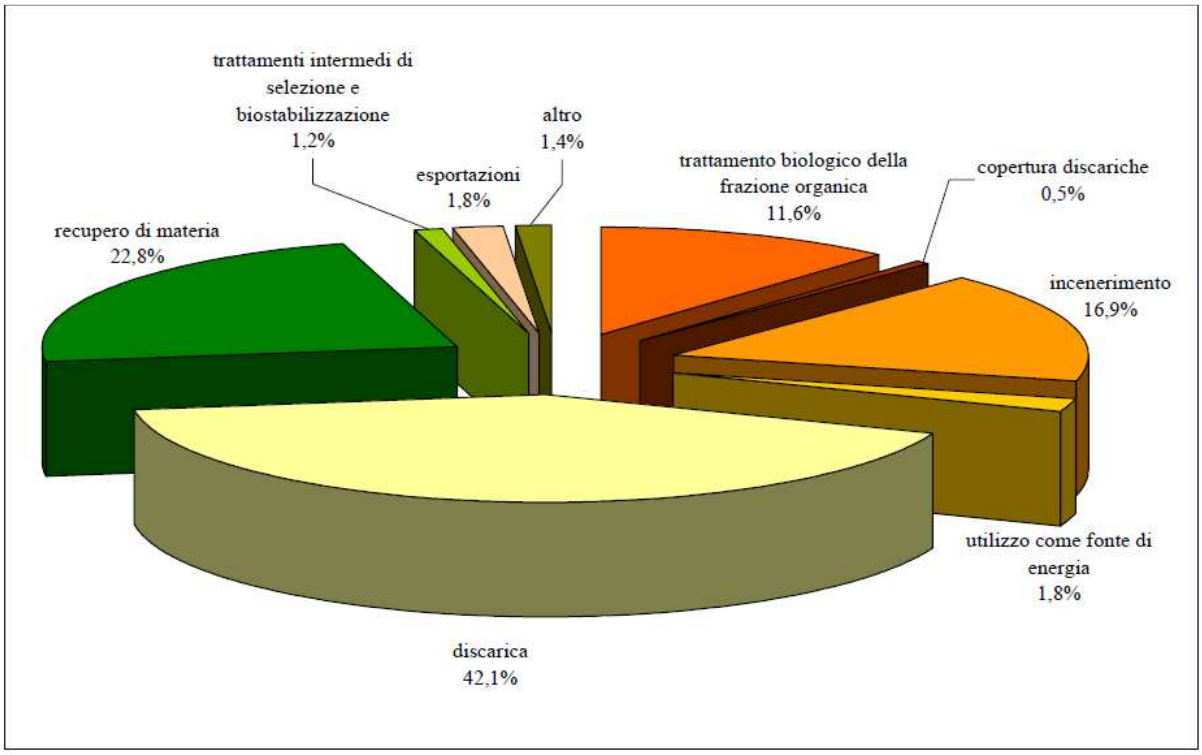


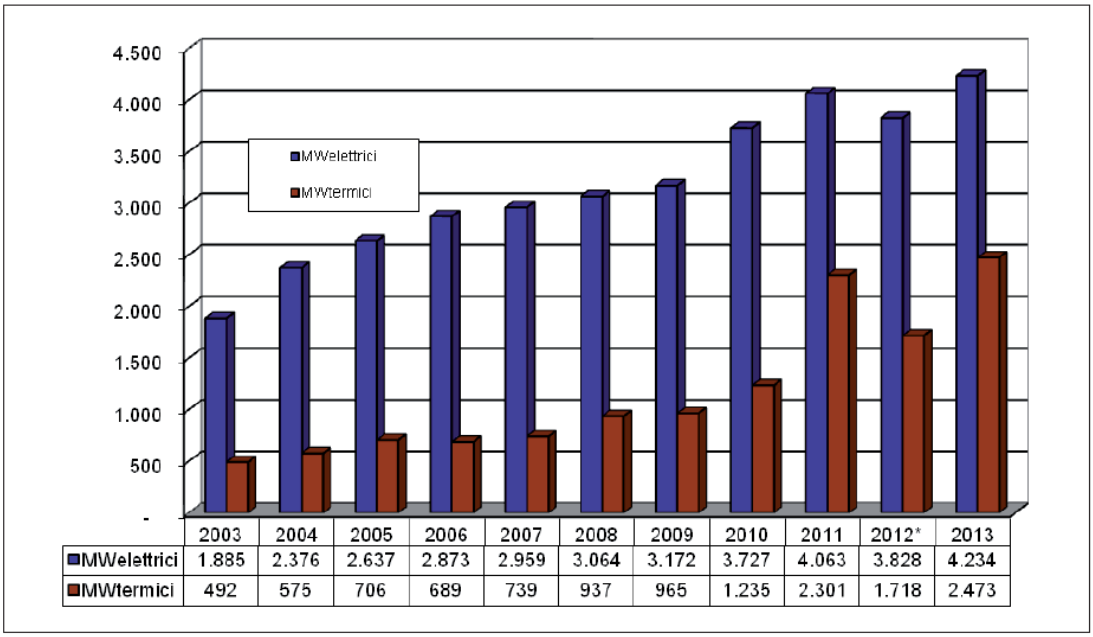
Fig. 1.7 Italian Waste Managment Tratment (ISPRA, 2014)

Fig.1.8 shows the list of approved facilities for the production of secondary solid fuel (CSS); the amount of authorized treatment amounted to 6.6 million tons, an increase over to 2010, by 6.3%. This value, in some installations, also includes the line biological treatment of recyclables.

Of a total of 57 plants surveyed, 55 those Operating. 24 plants are located in the North , accounting for 42.1% of national envelope; 20 plants in the center and 13 plants in the South, respectively, 35.1% and 22.8% of the national total.

The production of CSS, in 2011 (1.094.908 tons), points out, compared to 2010, an increase of 2.1%.

The incineration with recovery systems for the production of Electric energy uses about 3.5 million tons of waste treated and recover 2.4 million MWh of energy electricity. The plants, with cogeneration, incinerated about 2.3 million tonnes of waste with a recovery about 1.7 million MWh of electric energy and 2.3 million MWh of Thermal energy. Figure 9 shows that the production of electric energy has a rising trend in the period 2001-2011, from 1.2 million MWh of electricity produced in 2001, to 4,000,000 MWh in 2011. The thermal energy recovery starts to have more widespread and has increased from 505 thousand MWh in 2001 to 2.3 million MWh in 2011.



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012*	2013
MWelettrici	1.885	2.376	2.637	2.873	2.959	3.064	3.172	3.727	4.063	3.828	4.234
MWtermici	492	575	706	689	739	937	965	1.235	2.301	1.718	2.473

*Fig 1.8 Energy production by Incineration (1000*MWh),2003-2013 (ISPRA 2014)*

Table 1. Energy production according with the plants and treated waste

	n. impianti	totale rifiuti trattati	ReEnergetico		kWh/t Eletterico	
			REElettrico (MWhe)	RETermico (MWht)	kg*kWhe	kg*kWht
Impianti con RET&E	*15*	*2.435.597*	*1.738.163*	*2.472.559*	*0,71*	*1,02*
Impianti con REE	*32*	*3.379.619*	*2.495.654*	*-*	*0,74*	*-*
Totale	**47**	**5.815.216**	**4.233.817**	**2.472.559**	***1,374***	***0,985***
Legenda - ***RET&E****=impianti con ciclo di cogenerazione;* ***REE****=impianti con solo recupero energetico elettrico.*						

ANNEX III

Equivalence factors taken from GaBi4

Equivalence factors for climate change [kg CO2-eq.]	
Carbon dioxide [Inorganic emissions to air]	1
Carbon tetrachloride (tetrachloromethane) [HOE to air]	1400
CFC 11 (trichlorfluormethane) [HOE to air]	4000
CFC 11 (trichlorofluoromethane) [HOE to air] 4000	4000
CFC 113 (trichlorofluoroethane) [HOE to air] 5000	5000
CFC 114 (dichlorotetrafluoroethane) [HOE to air] 9300	9300
CFC 115 (chloropentafluoroethane) [HOE to air] 9300	9300
CFC 116 (hexafluoroethane) [HOE to air] 12500	12500
CFC 12 (dichlorodifluoromethane) [HOE to air] 8500	8500
CFC 123 (dichlorotrifluoroethane) [HOE to air] 93	93
CFC 124 (chlorotetrafluoroethane) [HOE to air] 480	480
CFC 125 (pentafluoroethane) [HOE to air] 3200	3200
CFC 13 (chlorotrifluoromethane) [HOE to air] 11700	11700
CFC 134a (tetrafluoroethane) [HOE to air] 1300	1300
CFC 141b (dichloro-1-fluoroethane) [HOE to air] 630	630
CFC 142b (chlorodifluoroethane) [HOE to air]	2000
CFC 143 (trifluoroethane) [HOE to air]	290
CFC 143a (trifluoroethane) [HOE to air]	4400
CFC 152a (difluoroethane) [HOE to air]	140
CFC 22 (chlorodifluoromethane) [HOE to air]	1700
CFC 225ca (dichloropentafluoropropane) [HOE to air]	170
CFC 225cb (dichloropentafluoropentane) [HOE to air]	530
CFC 227ea (septifluoropropane) [HOE to air]	3300
CFC 23 (trifluoromethane) [HOE to air]	12100
CFC 236fa (hexafluoropropane) [HOE to air]	8000
CFC 245ca (pentafluoropropane) [HOE to air]	610
CFC 32 (trifluoroethane) [HOE to air]	580
CFC 43-10 (decafluoropentane) [HOE to air]	1600
Dichloromethane (methylene chloride) [HOE to air]	9
Halon (1301) [HOE to air]	5600

Laughing gas (dinitrogen monoxide) [Inorganic emissions to air]	310
Methane [Organic emissions to air (group VOC)]	21
Nitrous oxide (laughing gas) [Inorganic emissions to air] 310	310
Sulphur hexafluoride [Inorganic emissions to air]	23900
Tetrafluoromethane [HOE to air]	6300
Trichloroethane [HOE to air]	110
Trichloromethane (chloroform) [HOE to air]	5

Equivalence factors for eutrophication potential [kg PO43--eq.]	
Ammonia [aust inorganic emissions to air]	0,33
Ammonium / ammonia [Inorganic emissions to water]	0,33
Ammonium nitrate [Inorganic emissions to air]	0,8
Chemical oxygen demand (COD) [Analytical measures to water]	0,022
Kjeldahl N [Analytical measures to water]	0,42
Nitrate [Inorganic emissions to water]	0,1
Nitrogen oxides [Inorganic emissions to air]	0,13
Phosphate [Inorganic emissions to water]	1
Total P (Total-P) [Analytical measures to water]	3,06

Equivalence factors for POCP [kg C2H4-eq.]	
Acetone (dimethylcetone) [Group NMVOC to air]	0,178
aliphatic hydrocarbons [Group NMVOC to air]	0,396
Aromatic hydrocarbons (unspecified) (Copy) [Group NMVOC to air]	0,7609
Benzene [Group NMVOC to air]	0,189
Benzo{a}pyrene [Group PAH to air]	0,761
Butadiene [Group NMVOC to air]	0,906
Butane (n-butane) [Group NMVOC to air]	0,41
Butene (vinyl acetylene) [Group NMVOC to air]	0,959
Butylacetate [Group NMVOC to air]	0,323
Butylene glycol (butane diol) [Group NMVOC to air]	0,196
Butyraldehyde (n-; iso-butanal) [Group NMVOC to air]	0,568
Carbon monoxide [Inorganic emissions to air]	0,036
Carbon tetrachloride (tetrachloromethane) [HOE to air]	0,005

CFC 11 (trichlorfluormethane) [HOE to air]	0,021
CFC 11 (trichlorofluoromethane) [HOE to air]	0,021
CFC 113 (trichlorofluoroethane) [HOE to air]	0,021
CFC 114 (dichlorotetrafluoroethane) [HOE to air]	0,021
CFC 115 (chloropentafluoroethane) [HOE to air]	0,021
CFC 116 (hexafluoroethane) [HOE to air]	0,021
CFC 12 (dichlorodifluoromethane) [HOE to air]	0,021
CFC 125 (pentafluoroethane) [HOE to air]	0,021
CFC 13 (chlorotrifluoromethane) [HOE to air]	0,021
CFC 134a (tetrafluoroethane) [HOE to air]	0,021
CFC 141b (dichloro-1-fluoroethane) [HOE to air]	0,021
CFC 142b (chlorodifluoroethane) [HOE to air]	0,021
CFC 22 (chlorodifluoromethane) [HOE to air]	0,021
Chlorobenzene [HOE to air]	0,021
Chloromethane (methyl chloride) [HOE to air]	0,021
Cyclohexane (hexahydro benzene) [Group NMVOC to air]	0,761
Cyclohexanol [Group NMVOC to air]	0,196
Cyclohexanone [Group NMVOC to air]	0,761
Cyclopentanone [Group NMVOC to air]	0,761
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene) [HOE to air]	0,021
Dichlorobenzene (p-DCB; 1,4-dichlorobenzene) [HOE to air]	0,021
Dichloroethane [HOE to air]	0,021
Dichloroethane (ethylene dichloride) [HOE to air]	0,021
Dichloroethane (isomers) [Group NMVOC to air]	0,021
Dichloromethane (methylene chloride) [HOE to air]	0,01
Ethanal (Acetaldehyde) [Group NMVOC to air]	0,52701
Ethane [Group NMVOC to air]	0,082
Ethanol (ethyl alcohol) [Group NMVOC to air]	0,268
Ethene (ethylene) [Group NMVOC to air]	1
Ethine (acetylene) [Group NMVOC to air]	0,168
Ethyl benzene [Group NMVOC to air]	0,593
Ethyl benzene [Group NMVOC into air]	0,593
Ethylene acetate (ethyl acetate) [Group NMVOC to air]	0,218
Formaldehyde (methanal) [Group NMVOC to air]	0,421

Furfuryl alcohol [Group NMVOC to air]	0,196
Heptane (isomers) [Group NMVOC to air]	0,529
Hexane (isomers) [Group NMVOC to air]	0,421
Hydrocarbons [Group NMVOC to air]	0,39799
Methane [Organic emissions into air (group VOC)]	0,007
Methane [Organic emissions to air (group VOC)]	0,007
Methanol [Group NMVOC to air]	0,123
Methyl acetate [Group NMVOC to air]	0,025
NMVOC (unspecified) [Group NMVOC to air]	0,416
Octane [Group NMVOC to air]	0,493
Pentane (n-pentane) [Group NMVOC to air]	0,408
Phenol (hydroxy benzene) [Group NMVOC to air]	0,761
Polychlorinated biphenyls (PCB unspecified) [HOE to air]	0,021
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [HOE to air]	0,021
Polychlorinated dibenzo-p-furans (2,3,7,8 - TCDD) [HOE to air]	0,021
Polycyclic aromatic hydrocarbons (PAH) [Group PAH to air]	0,76098
Propane [Group NMVOC to air]	0,42
Propanol (iso-propanol; isopropanol) [Group NMVOC to air]	0,196
Propene (propylene) [Group NMVOC to air]	1,03
Propyl acetate [Group NMVOC to air]	0,215
Propylene glycol [Group NMVOC to air]	0,196
Styrene [Group NMVOC to air]	0,761
Tetrachloroethene (perchloroethylene) [HOE to air]	0,021
Tetrafluoromethane [HOE to air]	0,021
Toluene (methyl benzene) [Group NMVOC to air]	0,563
Trichloroethane [HOE to air]	0,001
Trichloroethene (isomers) [HOE to air]	0,066
Trichloromethane (chloroform) [HOE to air]	0,021
Vinyl chloride (VCM; chloroethene) [HOE to air]	0,021
VOC (unspecified) [Organic emissions to air (group VOC)]	0,337
Xylene (dimethyl benzene) [Group NMVOC to air]	0,777

Equivalence factors for HTPAU [kg DCB-eq.]	
Acrylonitrile [Hydrocarbons to water]	1800
Acrylonitrile [Group NMVOC to air]	200
Ammonia [Inorganic emissions to air]	0,016
Ammonium / ammonia [Inorganic emissions to water	1
Antimony [Heavy metals to water]	74
Arsenic [Heavy metals to water]	9
Barium [Inorganic emissions to water]	17
Barium [Inorganic emissions to air]	110
Benzene [Hydrocarbons to water]	190
Benzene [Group NMVOC to air]	160
Beryllium [Inorganic emissions to air]	20000
Beryllium [Inorganic emissions to water]	520
Cadmium [Heavy metals to soil]	560
Cadmium [Heavy metals to water]	0,14
Carbon disulphide [Inorganic emissions to air]	0,18
Chlorobenzene [HOE to air]	0,86
Chromium (unspecified) [Heavy metals to air]	1
Chromium (unspecified) [Heavy metals to water]	1
Chromium +VI [Heavy metals to water]	0,02
Copper [Heavy metals to water]	0,0085
Copper [Heavy metals to air]	370
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene) [HOE to air]	0,98
Dichloroethane [HOE to air]	0,51
Ethyl benzene [Group NMVOC to air	0,047
Ethyl benzene [Hydrocarbons to water]	0,046
Formaldehyde (methanal) [Group NMVOC to air]	0,047
Formaldehyde (methanal) [Hydrocarbons to water]	0,019
Hydrogen chloride [Inorganic emissions to air]	0,073
Hydrogen sulfide [Inorganic emissions to air]	0,018
Lead [Heavy metals to soil]	11
Lead [Heavy metals to water]	0,06
Mercury [Heavy metals to water]	7,4

Mercury [Heavy metals to air]	1200
Mercury [Heavy metals to soil]	220
Molybdenum [Heavy metals to air]	890
Nickel [Heavy metals to water]	3,4
Nitrogen oxides [Inorganic emissions to air]	0,055
Phenol (hydroxy benzene) [Hydrocarbons to water]	0,02
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - PCDD) [HOE to water]	1
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [HOE to air]	1
Polycyclic aromatic hydrocarbons (PAH) [Group PAH to air]	1
Polycyclic aromatic hydrocarbons (PAH, unspec.) [Hydrocarbons to water]	1
Selenium [Heavy metals to water]	2700
Selenium [Heavy metals to air]	8100
Sulphur dioxide [Inorganic emissions to air]	0,008
Tetrachloroethene (perchloroethylene) [HOE to water]	1
Tetrachloroethene (perchloroethylene) [HOE to air]	1
Tin [Heavy metals to soil]	0,054
Tin [Heavy metals to water]	8,90E-05
Toluene (methyl benzene) [Group NMVOC to air]	0,017
Toluene (methyl benzene) [Hydrocarbons to water]	0,018
Trichloroethane [HOE to air]	1,8
Trichloroethene (isomers) [HOE to air	1,8
Trichloromethane (chloroform) [HOE to air]	1,5
Trichloromethane (chloroform) [HOE to water]	1,5
Vanadium [Heavy metals to air]	940
Vinyl chloride (VCM; chloroethene) [HOE to water]	19
Zinc [Heavy metals to air]	9,1
Zinc [Heavy metals to water]	0,0032
Zinc [Heavy metals to soil]	1,2

Equivalence factors for FAEP [kg DCB-eq.]	
Acrylonitrile [Group NMVOC to air]	0,4
Acrylonitrile [Hydrocarbons to water]	150
Antimony [Heavy metals to water]	2,3
Arsenic [Heavy metals to water]	17
Barium [Inorganic emissions to air]	14
Barium [Inorganic emissions to water] 48	48
Benzene [Group NMVOC to air]	5,70E-05
Benzene [Hydrocarbons to water]	0,15
Beryllium [Inorganic emissions to air]	7500
Beryllium [Inorganic emissions to water]	26000
Cadmium [Heavy metals to water]	93
Cadmium [Heavy metals to soil]	64
Carbon disulphide [Inorganic emissions to air]	0,021
Chlorobenzene [HOE to air]	0,00031
Chromium +VI [Heavy metals to water]	1,7
Chrysene [Hydrocarbons to water]	3200
Copper [Heavy metals to water]	73
Copper [Heavy metals to air]	27
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene) [HOE to air]	0,002
Dichloroethane [HOE to air]	8,40E-05
Ethyl benzene [Hydrocarbons to water]	0,94
Ethyl benzene [Group NMVOC to air]	8,20E-05
Formaldehyde (methanal) [Hydrocarbons to water]	980
Formaldehyde (methanal) [Group NMVOC to air]	3,6
Lead [Heavy metals to soil	0,56
Lead [Heavy metals to water]	0,57
Mercury [Heavy metals to air]	28
Mercury [Heavy metals to soil]	68
Mercury [Heavy metals to water]	100

Molybdenum [Heavy metals to air]	50
Nickel [Heavy metals to water]	280
Phenanthrene [Hydrocarbons to water]	390
Phenol (hydroxy benzene) [Hydrocarbons to water]	840
Selenium [Heavy metals to water]	1100
Selenium [Heavy metals to air]	300
Tin [Heavy metals to soil]	0,59
Tin [Heavy metals to water]	0,61
Toluene (methyl benzene) [Group NMVOC to air]	4,30E-05
Toluene (methyl benzene) [Hydrocarbons to water]	0,49
Trichloroethane [HOE to air]	8,20E-05
Trichloromethane (chloroform) [HOE to air]	6,90E-05
Trichloromethane (chloroform) [HOE to water]	0,067
Vanadium [Heavy metals to air]	340
Vinyl chloride (VCM; chloroethene) [HOE to water]	0,045
Zinc [Heavy metals to soil]	4,4
Zinc [Heavy metals to air]	2,2
Zinc [Heavy metals to water]	5,6

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