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Laura Sokka, Sirkka Koskela and Jyri Seppälä

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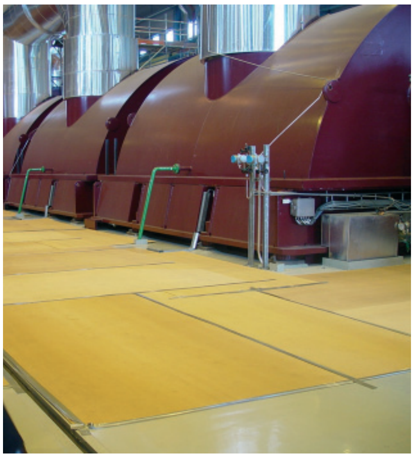

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Preface

The inventory was conducted by Laura Sokka, Sirkka Koskela and Jyri Seppälä from the Finnish Environment Institute. Data on hard coal mining in Poland was collected by Joanna Kulczycka, Malgorzata Goralczyk, Karel Koneczny and Anna Henclik from the Mineral and Energy Economy Research Institute of Cracow, Poland. The authors wish to thank Arja Valli from Fortum Power and Heat Oy, Toni Hemminki from Rautaruukki Finland, and International Iron and Steel Institute for providing information for this study. The financial support given by the EU LIFE instrument for the OSELCA project is gratefully acknowledged.

The publication of this report has been approved by the steering group of the OSELCA project. The members of the steering group were Mr. Tõnis Meriste, Eesti Energia Ltd; Mr. Reigo Lehtla, Eesti Energia Ltd.; Dr. Siret Talve, CyclePlan Ltd.; Professor Jyri Seppälä, Finnish Environment Institute; Mr. Alec Estlander, Finnish Environment Institute; Dr. Antero Honkasalo, Finnish Ministry of Environment; Mr. Jüri Truusa, Estonian Ministry of Environment (Chairman of the Steering Committee) and substitute members Mr. Viktor Grigorjev, Estonian Ministry of Environment; Ms. Madis Laaniste, Estonian Ministry of Economic Affairs and Communications and Ms. Viive Savel, Estonian Ministry of Economic Affairs and Communications.

Contents

Introduction

Dissemination and promotion of Life Cycle Thinking and the IPP (Integrated Product Policy) approach are central aims of the EU Life-Environment project OSELCA *'Introduction and Implementation of Life Cycle Assessment Methodology in Estonia: Effects of Oil Shale Electricity on the Environmental Performance of Products'* (website: www.energia.ee/OSELCA). The project was launched in October 2003 by Estonian state-owned energy company (Eesti Energia AS), Estonian consultancy CyclePlan Ltd. and the Finnish Environment Institute SYKE, and it will last until the end of 2005.

The project comprises eight tasks altogether. The present Life Cycle Inventory (LCI) report of the hard coal based electricity generation is one outcome of the Task 2 *'Identification of the differences between the environmental impacts caused by oil shale electricity and coal electricity through their whole life cycles'*.

Estonia is the only country in Europe with a considerable oil shale mining industry. Over 95% of the Estonian electricity generation is based on oil shale. One of the main aims of the OSELCA project was to investigate the environmental impacts of oil shale electricity in relation to other fossil fuels. The only fuel comparable to oil shale is hard coal as both are solid fossil fuels, extracted by underground or open pit mining. Thus, the oil shale electricity was compared to the hard coal electricity. In order to make a reliable comparison between them, the LCA methodology was applied according to the standards EN ISO 14040-14043. The purpose of the current report is to document the Life Cycle Inventory (LCI) of the hard coal electricity. The inventory was conducted according to the EN ISO Standard 14041 on Life Cycle Assessment and Inventory Analysis. The Life Cycle Assessment (LCA) will be conducted on the basis of the inventory results, presented here.

2 Goal and scope of the study

In the present LCI, a product system of the hard coal electricity is presented which covers all the life cycle stages - starting from the extraction of resources up to the delivery of electric power to the grid. Since the OSELCA project is focused on the future, not on the average Finnish situation, the Finnish Meri-Pori power plant, representing the best available power plant technology, was chosen as a case study power plant. Although the Meri-Pori obtains its fuel from many different countries, inventory data on the coal mining was collected using the average interventions of coal mining in Poland, as Poland is one of the largest suppliers of hard coal to Finland.

In this report LCI results are analysed briefly. The results will be examined in more detail during the Environmental Impact Assessment stage that will be carried out later. The impact assessment and comparison with oil shale electricity will be described in a separate report, which will be published later in the frames of the OSELCA project. The current inventory analysis concentrates on the quantitatively measured emissions. The impact assessment will also include qualitative assessment of those environmental impacts for which quantitative data is difficult to obtain.

2.1 Functional unit

Before this Life Cycle Inventory was conducted, a functional unit was defined which served as a reference unit for the whole inventory. All inputs and outputs were calculated per the functional unit thereby making it possible to compare different products or services. As the purpose of this study was to conduct a life-cycle inventory of electricity generated from hard coal, ***1 MWh electricity at consumer*** was defined as the functional unit of this product system.

Calculation of inventory results per 1 MWh electricity makes comparison of electricity generation across different fuels possible. It should, however, be kept in mind that different production systems are only then comparable if data on their inputs and outputs have been collected in the same level of detail and by using the same methods and boundaries.

2.2 System boundaries

The study covered all the processes in the life cycle of the product, starting from the extraction of raw materials from nature and finishing with the delivery of electricity to the electric grid (Figure 1).

Following processes were included in the inventory:

1. The mining and processing of the hard coal in Poland
2. The manufacturing of the raw materials
3. All transportation processes for which emission data were obtainable
4. The conversion of the hard coal into the electricity in the Finnish power plant

5. The electricity and heat generation related to the hard coal mining, and to the production of the raw materials
6. The transmission of the electric power through the grid to customers, accounting for the average Finnish transmission losses (approximately 3.5%, Statistics Finland 2003).
7. The savings in the external processes through the waste recovery (utilisation of the by-products)

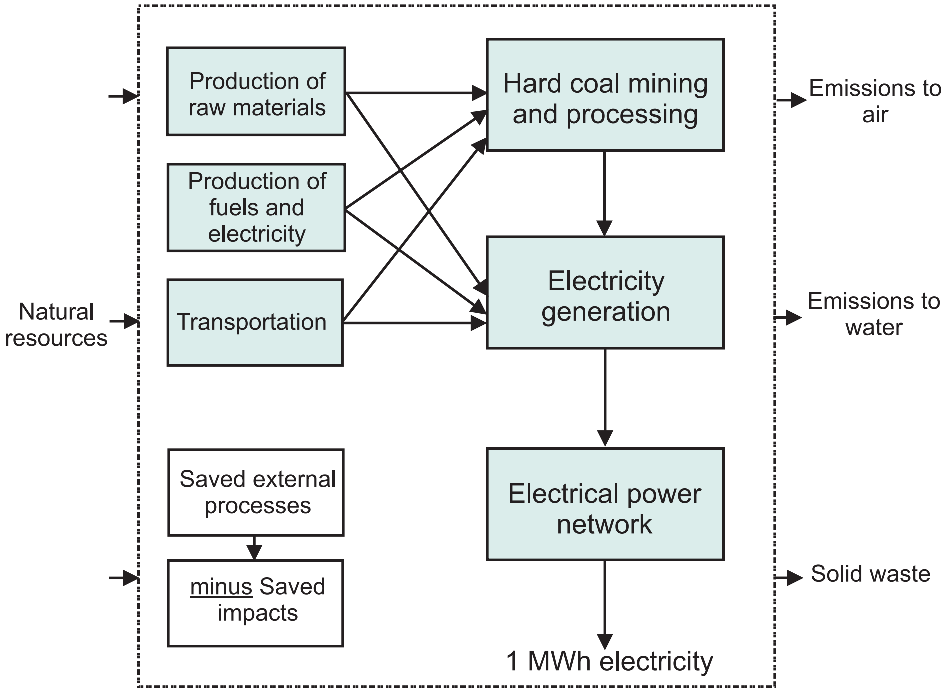

Figure 1. System boundaries of the hard coal electricity generation

Following activities were excluded from the inventory:
1. End use of the electricity
2. Construction and dismantling of the extraction facilities[1]
3. Maintenance processes of the distribution network
4. Building of the infrastructure
5. Production of the manufacturing equipment
6. The packaging materials of products or raw materials
7. Return trip except for transportation of hard coal within Poland. For all the other inputs, the vehicles were assumed to return with other commodities.

2.3 Description of data categories

A flow chart of the system was constructed to describe the material and energy flows of the system. In the flowchart a module was used as the basic unit of the system and modules were connected to each other by flows. One module could contain one or several unit processes, which were the smallest unit for which information was collected (Figure 2). For each unit process, data on its inputs and outputs were gathered. Inputs were divided into three main categories: resources

[1] *Some raw material and by-product modules, which were taken from the Ecoinvent database, include the infrastructure (i.e. points 2-5) but its impact for the study as a whole was considered very small.*

(or materials), fuels and energy inputs. Outputs were divided into six main categories: products, by-products, waste heat, solid waste, emissions to air, and emissions to water (Figure 2). Inventory results were presented as a list of total inputs and outputs.

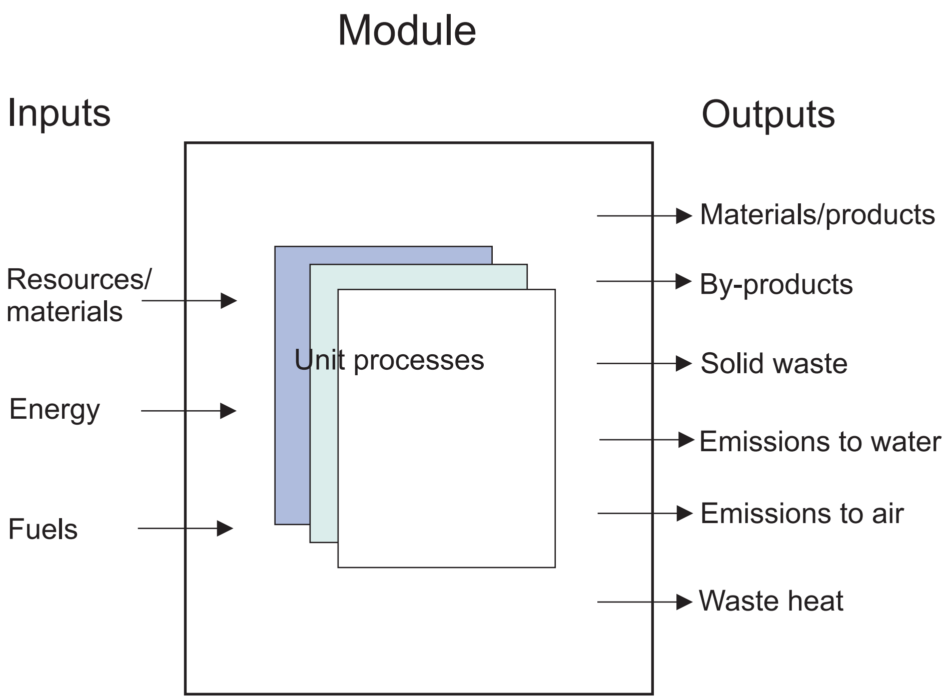

Figure 2. Principal scheme, explaining relationships between module and unit processes, and shows the main categories of inputs and outputs

Emissions to water and air

Life Cycle Inventory results usually contain a huge number of emissions. However, not all of these data are usable due to limited data quality or data coverage. The emissions to water and air that will be included in the impact assessment are presented in Table 1. Emissions to soil were excluded from the inventory. Noise, odour and vibrations were also ignored because there was no reliable quantitative data available on these issues.

Table 1. Emissions to air and water for which more detailed data were collected

Emissions to air	Emissions to water
Carbon Dioxide, CO_2	Biological Oxygen Demand, BOD
Carbon Monoxide, CO	Chemical Oxygen Demand, COD
Methane, CH_4	Ammonium, NH_4^+
Sulphur Dioxide, SO_2	Nitrate, NO_3^-
Nitrogen Dioxide, NO_2	Total Nitrogen, N
Nitrous Oxide, N_2O	Phosphate, PO_4^{2-}
Ammonia, NH_3	Total Phosphorus, P
Hydrogen chloride, HCl	Cyanides
Hydrogen Fluoride, HF	Fluorine, F^-
Hydrogen Sulphide, H_2S	Metals (Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Mg, Ni, Pb, V, Zn)
Metals (As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Zn)	Oil
Primary particulate matter (Total & PM2.5)	Phenols
Volatile Organic Compounds (VOC, NMVOC)	
Persistent Organic Pollutants (PAH, PCB, PCDD/F)	
Cyanides	
Benzene	
Formaldehyde	
Toluene	

Solid waste

Formation of the solid wastes in the system was given according to the waste classification of the European Commission Decision 2001/118/EC (see Table 2). Due to limited data availability, only the largest fractions of the mining waste have been taken into account. For the power plant, more detailed data was available. Waste paper and metal scrap from the power plant were included into the municipal solid waste stream because of their small quantity. Batteries, waste oils, fluorescent tubes and pickling sludge were altogether classified as hazardous waste.

Table 2. Classification and disposal methods of wastes from the mines and the power plants

Type of waste	EWC Code	Utilisation / disposal
Mining		
Waste from processing	010412	Use for engineering works, backfilling or other use at the mining site
Waste from excavation	010102	“
Flotation waste	-	“
Waste from clearing mine headings	-	“
Power plant		
Bottom ash	100101	Earth construction
Fly ash	100102	Earth construction and cement manufacturing
Gypsum	100105	Gypsum board manufacturing
Mixed municipal waste	200301	Landfilling
Paper and cardboard	200101	Recycling
Metal scrap	170407	Recycling
Pickling sludge	100122	Hazardous waste treatment plant
Lead batteries	160601	“
Mineral based non-chlorinated engine, gear and lubricating oils	130205	“
Fluorescent tubes	200121	“
Oil wastes not otherwise specified	130899	“
Sludge resulting from desulphurisation	100121	Energy recovery at the power plant
Municipal sewage sludge	190805	Landfilling or recycling in agriculture and earth construction.
Waste from cooling water treatment	100126	Recycling or landfilling

Land use

Land usage, directly related to the operation of the hard coal mining, preparation and electricity generation facilities, was assessed. Additionally, the required land area for the management of waste, directly related to hard coal, was taken into account. The land usage for other production processes or for raw material extraction and deposition was excluded from the study due to the lack of data.

2.4 Criterions of the inclusion for inputs and outputs

In this inventory all the inputs and outputs for which appropriate data was available, were included in the inventory. However, for some raw materials or transportation processes no inventory data was obtainable. The mining raw materials tar board, fibreboard and glass were only listed as inputs but their production was not taken into account because no inventory data was available on them. Inclusion of transport profiles is described in section 3.2.3.

2.5 Data quality requirements

For the hard coal mining and electricity generation in the coal-fired power plant, primary (site-specific) inventory data was used. Data on the hard coal mining and processing in Poland were collected by the Mineral and Energy Economy Research Institute of Cracow. Most data was calculated as an average of 38 hard coal mines. Data on the Meri-Pori power plant were received directly from the plant[2] or from data submitted to the *Vahti* database of the Finnish Environmental Administration[3] by the power plant. Data on the power plant are primarily based on measurements or calculations conducted on site.

Secondary LCI data on the raw materials, fuels, electricity, transportation and by-products were obtained from different databases[4]. The following databases were used as reference sources: KCL EcoData (*Keskuslaboratorio Oy*), IISI database (*International Iron and Steel Institute*), LIPASTO (*Technical Research Centre of Finland, VTT*) and Ecoinvent (*Swiss Centre for Life Cycle Inventories*).

Information on the power plant originates mainly from year 2003. Data on mining originates from year 2002. For raw materials and by-products, the latest available year was used. Most of the data originates from early 2000s.

[2] Contact person at the Meri-Pori power plant was Arja Valli, environmental, health and safety manager of the plant.
[3] Vahti database is a database containing Finnish nationwide basic information on environmental permissions, waste generation and emissions to water and air. Vahti is maintained by the Finnish Environment Institute and Regional Environment Centres.
[4] More information on many of these databases can be found in a separate report published within the OSELCA project (see Koskela & Hiltunen 2004).

3 Inventory analysis

3.1 Life cycle stages of the product system

According to the defined boundaries, the study covered all the processes in the life cycle of the product from the mining of hard coal to the delivery of electricity to the electric grid. The flow chart of the system was constructed using an LCA software tool. Many such LCA software tools have been designed for storing, viewing and printing LCA data. In this inventory, the KCL-ECO 3.02 software (KCL 2003) has been used to model the studied product system with all its life cycle stages (see Figure 3).

Division of the product system into different life cycle stages facilitates the interpretation of the LCI results. It enables one to evaluate and compare the relative contributions of the interventions between the stages. How the life cycle stages are defined depends on the purpose of the study. In this inventory, the LCI data was compiled according to the following six life cycle stages:

1. Hard coal mining and processing
2. Raw materials to coal mines and the power plant
3. External electricity and heat generation in Poland (coal mining and its raw materials) and in Finland (power plant and its raw materials)
4. Hard coal power plant
5. Transportation
6. Recovered wastes, treated as by-products (treated as savings in external processes – more thoroughly described in Section 3.2.5)

All these life cycle stages are shown on the flowchart with different colours. The software calculates the inventory results per the functional unit (1 MWh electricity) by the modules, the life cycle stages or for the system as a whole.

In the flowchart the mining modules are marked with grey colour. They include mining and processing of the hard coal, also manufacturing and burning of fuels used in the mine. The raw material modules are marked with light green. They cover the production of raw materials for both mining and power plant. The external electricity and heat generation in Poland is marked with dark green and in Finland with turquoise. The power plant module is coloured with purple. This module includes also the final product - i.e. 1 MWh of electricity at grid - including average transmission losses in Finland. The transportation modules are painted blue and shown as short diagonal lines, which cross the arrows. Transportation was not taken into account for all the raw materials or by-products. Indirect (from the production of fuels) and direct emissions together constitute summarised input and output factors, used in the transportation modules. Credited by-product modules (i.e. avoided emissions) are marked with dark lilac colour. These contain waste materials from the mine or the power plant that were utilised in other production processes to replace virgin raw materials.

In the following section the modules of the product system and their data sources are described in detail from the viewpoint of the two main processes – hard coal mining in Poland and electricity generation from hard coal in Finland - with all their material and energy inputs. The Polish and Finnish electricity generation models, used for manufacturing of raw materials, are discussed in Section 3.2.4. Credits, given to recovered wastes or by-products, are explained in Section 3.2.5. The LCI results are, however, presented according to the life cycle stages (Section 4).

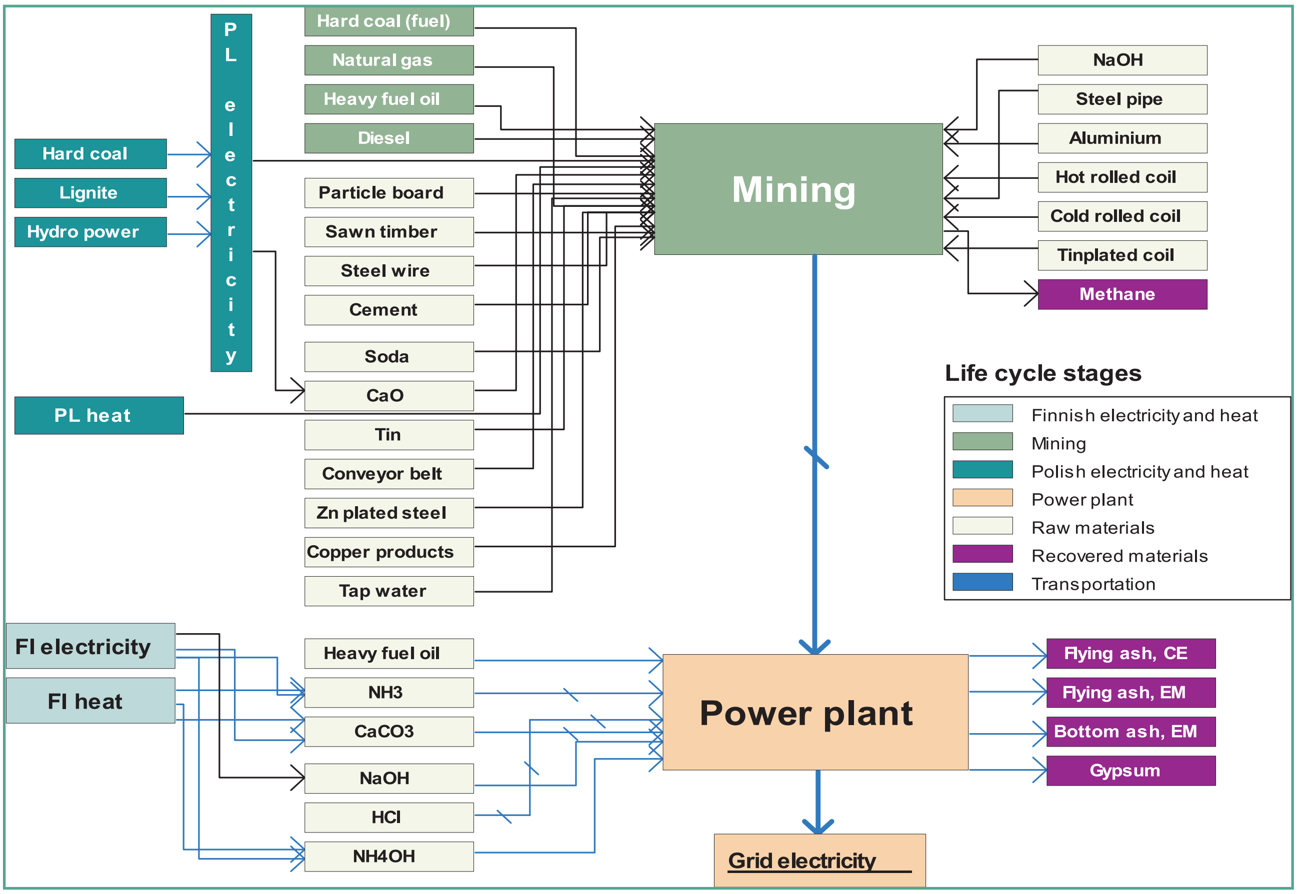

Figure 3. The flowchart of the hard coal electricity product system

3.2 Description of unit processes and data sources

3.2.1 Hard coal mining and processing

Poland is the second largest hard coal producer in Europe (Blaschke and Nycz 2003). Approximately 20-25% of its hard coal is exported. Hard coal is mined from underground, using mainly the underground mining system '*longwall*' - with caving, hydraulic filling or dry filling. Other mining systems - such as room and pillar – are practically not used at all. The advantages of the longwall method include the possibility of concentrating the output on a limited space and low losses of deposit resources. The efficiency of the system depends on the thickness of the deposit layer, the capacity of the swath, the speed of layer mining, the length of the wall and the type of the mechanical miner used (Goralczyk 2004).

Although the production system of underground hard coal mining consists of several different process steps (Figure 4), in this study they were all treated within one module at the flow chart. The main process steps of hard coal extraction are mining and processing of the coal. Since in the mined coal the heat content varies between 14.9 and 24.2 MJ kg^{-1} and the ash content between 17% and 42%, processing is needed in order to improve the quality of the hard coal (Gawlik 2004). Through processing the quality of the hard coal is increased[5].

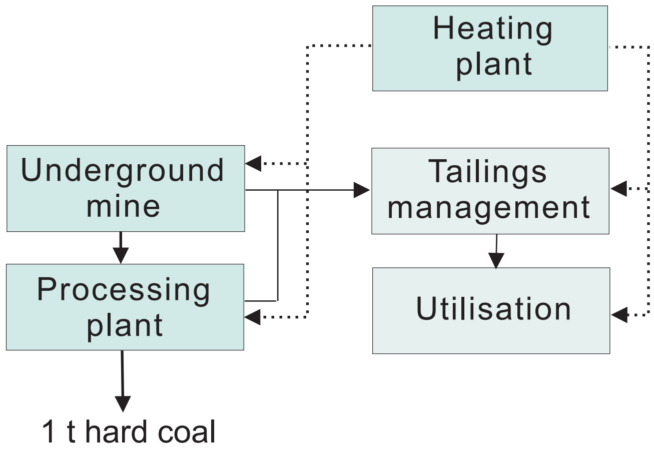

Figure 4. The processes included in the hard coal mining module

Mining data used in this inventory represents average hard coal mining in Poland. Data were received from the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (Kulczycka et al. 2004). Most of the data has been calculated as an average of all hard coal mines (38) in Poland. Data on all inputs and land use originates from the Central Statistical Office of Poland. Amount of water released from the mines was received from the Polish State Geological Institute. Data on emissions to water and air are from the Marshal Office in Katowice. This data includes only 17 mines. Particles and methane are the only emissions to air that are measured from the mines or processing plants, and therefore secondary data from the Ecoinvent database was used to estimate the emissions from burning of the fuels. Solid waste generation data stems from the Higher Mining Office in Katowice.

Some of the raw materials were not presented as their own modules but only listed as inputs to the mines or the power plant (Appendix 1 and 2). Table 3 presents the mining raw material modules. Lime (CaO) is used to prevent explosions at the mines, and soda ($NaHCO_3$) and sodium chloride (NaOH) are used as cleaning reagents for both mining and processing. Steel, copper, timber and particleboard are utilised as construction materials.

Almost 90% of the mining waste was recovered, mainly for engineering works (Kulczycka et al. 2004). However, waste management and recycling were ignored in the inventory, as it was not possible to receive detailed data over them.

[5] *The standard quality requirements for hard coal on the international mining-markets are heat content >25 MJ kg^{-1} and ash content <15% (Blaschke & Nycz 2003).*

Table 3. Coal and raw material mining modules (all modules include electricity generation except for CaO)

Module	Unit processes	Year	Reference
Coal mining			
Hard coal mining and processing	Includes inputs and outputs of mining and processing of hard coal. Most data has been calculated as an average of all mines in Poland except for emissions to water. For emissions to air from fuel combustion, no data was available so secondary data was used (see fuel modules below).	2002	Kulczycka et al. 2004
Fuels			
Hard coal (fuel)	Energy conversion of hard coal for electricity generation. The module represents average Polish technology. Some data has been derived from European data.	1993-2000	Ecoinvent Database, v.1.1, 2004
Natural gas	Includes burning of natural gas for energy generation. Module only covers the energy conversion stage. Natural gas originates from the methane released in the mines so emissions and resource usage from its production are not taken into account. Data is average for CENTREL[6] countries.	1990-2000	Ecoinvent Database, v.1.1, 2004
Heavy fuel oil	Data includes the whole energy generation cycle from heavy fuel oil with European average technology. Heavy fuel oil is burned in a non-modulating, non-condensing 1 MW industrial furnace. European average technology.	1991-2000	Ecoinvent Database, v.1.1, 2004
Diesel oil	Burning of diesel in a building machine. The module includes the input 'building machine' for infrastructure, lubricating oil and fuel consumption and some measured emissions to air as output. Data represents global average production but some data is extrapolated from European or Swiss conditions. Average current technology from one type of machine.	1996-2001	Ecoinvent Database, v.1.1, 2004
Chemicals			
$NaHCO_3$	Manufacturing of soda powder by Solvay technique. Includes the consumption of raw materials, auxiliaries, energy, and infrastructure, as well as transport of the raw materials, auxiliaries and wastes. European technology.	1999	Ecoinvent Database v.1.1, 2004
NaOH, 50%	Production of NaOH through electrolysis of an aqueous solution of sodium chloride. Calculated from the production of 100% NaOH. European technology for 1989.	1994	IISI 1998
CaO	Manufacturing of CaO through calcination. European average technology for 1995.	1996	KCL EcoData 1998
Metals and other materials			
Steel pipe	Production of steel pipe. Worldwide average production technology.	1999-2000	IISI 2002
Steel wire	Production of steel wire. Worldwide average production technology.	1999-2000	IISI 2002
Mixed cold rolled steel	Production of finished cold rolled coil. Data is European average.	1999-2000	IISI 2002
Mixed hot rolled steel	Production of hot rolled coil. Data is European average.	1999-2000	IISI 2002
Mixed aluminium products	Calculated from a mix of primary and secondary aluminium on the basis of their share of the world production.	2002	Ecoinvent Database v.1.1, 2004

[6] CENTREL is a regional group of four Eastern European electricity transmission operator companies from Czech Republic, Hungary, Poland and Slovak Republic.

Tin	Worldwide primary tin production including mining, beneficiation, smelting and refining of tin ore and tin. Transports from major European producers are also included.	1996-2003	Ecoinvent Database v.1.1, 2004
Zn coated steel plate and belt	Production of hot-dip galvanised coil. Data is European average.	1999-2000	IISI 2002
Tin coated steel plate and belt	Production of tinplated coil. Data is European average.	1999-2000	IISI 2002
Copper wire	Includes both insulated and uncovered copper wire. Data represents production of mixed copper products. Production data is based on production at the Outokumpu Harjavalta Metals Oy and Outokumpu Poricopper Oy factories.	1997-1998	Seppälä et al. 2000
Conveyor belt	Production of conveyor belt including raw materials and infrastructure. Most of the data is taken from production of one type of conveyor belt and completed with assumed transportation distances of components.	2000-2001	Ecoinvent Database, v.1.1, 2004
Timber	Production of sawn timber with Finnish average technology. The average density of wood is assumed to be 400 kg/m^3.	1998	KCL EcoData 2000.
Particle board	Includes the production of particleboard for outdoor use. Contains the inputs to the production processes, their transportation and the process emissions as far as available. German data is used to represent the whole Europe.	1986-2000 (technology is for 1996)	Ecoinvent Database, v.1.1, 2004
Cement	Manufacturing of cement.	1994	IISI 1998
Tap water	Contains infrastructure and energy use for water treatment and transportation to the end-user. Emissions from water treatment are not included in the module	2000	Ecoinvent Database v.1.1, 2004

3.2.2 Electricity generation in the hard coal power plant

The Meri-Pori coal-fired power plant is located in Pori, at the western coastline of Finland. The plant was constructed in 1993 and opened for commercial use in the beginning of 1994. It is the newest hard coal power plant in Finland and it is the only one with a selective catalytic reduction (SCR) to remove NO_x from the flue gas. In a condensing power plant, such as Meri-Pori, the exhaust steam is condensed to the lowest available temperature (15-45°C) for the highest possible power generation efficiency. Marine water serves as an ultimate sink for the steam of a condensing plant. The plant produces only electricity. The efficiency of the Meri-Pori power plant is 43.5%. (Finnish Environment Institute 2001.)

The total area of the power plant territory is 52.5 ha. In addition to the power plant site, the power plant has 11 ha of coal storage field and 82 ha joint banking area together with the Tahkoluoto power plant of the Pohjolan Voima Group. The estimated total banking capacity of the area is 9,000,000 m^3 of which 6,800,000 m^3 belongs to Meri-Pori plant. The banking area is located 15 km away from the power plant and is reserved for waste disposal. However, so far hardly any waste has been delivered there.

Meri-Pori power plant uses the entrance channel of the Port of Pori, which is over 15 m deep, thus making the port navigable for vessels with coal cargos as large as 120,000 t. It makes importing of coal even from such distant countries as Colombia or Indonesia economical. However, since this study does not concentrate on the Meri-Pori power plant as such, it was assumed that all the coal is imported from Poland. Poland serves as the second largest supplier of the hard coal for Finland (Viheriävaara 2003).

The power plant module of this inventory includes the generation of electricity with hard coal. This module covers material use, waste generation and emissions to air and water from all the operations within the power plant site (Table 4). Data on the raw material consumption, land use and waste formation at the power plant were obtained from the company (Valli 2004) and Vahti Database. Data on the emissions to air and water were received from Vahti Database.

Heavy fuel oil is used as start-up fuel of the power plant. In addition, the plant burns very small amounts (2.37 t in 2003) of its own desulphurisation sludge and waste oils.

Limestone is used for cleaning up of exhaust gases; Nordkalk Oy, which imports it from Estonia, supplies it. The flue gases are passed through a scrubber with circulating limestone slurry. Sulphur dioxide reacts with the limestone slurry and the end product is gypsum. Ammonia is used for reducing NO_x emissions. The ammonia used at the power plant originates from Russia and it is provided to the power plant by Kemira Oy's Uusikaupunki factory.

The power plant uses mainly seawater but it also receives water from the Porin Vesi water plant. The seawater is used as cooling water. It flows through the condenser and is released back to the Gulf of Bothnia - ca 10 degrees warmer, but its quality remains unaffected (Valli 2004). Seawater is only cleaned mechanically. Tap water is used as process water. Sodium hydroxide (50%) and hydrochloric acid (35%) are used in its purification for the process. Ammonia water (25%) is used to increase the pH of the water vapour circle in order to keep corrosion as low as possible. Säteri Oy provides sodium hydroxide from Valkeakoski, Southern Finland, and its country of origin varies. Hydrochloric acid is supplied by Finnish Chemicals Oy who manufactures it itself. Algol Oy supplies ammonia water to the plant.

Table 4. Modules of the power plant and its raw materials

Module	Unit processes	Data from year	Reference
Electricity generation at coal-fired power plant	Generation of electricity using hard coal at the Meri-Pori power plant. Covers all the operations at the power plant site. Plant represents Finnish best available technology.	2003	Valli 2004 Vahti Database 2004
Fuels			
Heavy fuel oil	Extraction, transportation and refining of crude oil. Includes transportation of heavy fuel oil to the end-user. Data represents Finnish average technology.	2002	Fortum Oil and Gas Oy 2002, Laukka 2003
Chemicals			
NH3	Mining, refining and transportation processes relevant for the manufacture. Finnish average technology.	1992	KCL EcoData 1997
CaCO3	Mining, refining and transportation of CaCO3	1992	KCL EcoData 1997
NaOH	Includes mining, refining and transports concerning the manufacture. Finnish average technology for 1996	1996	KCL EcoData 1997
HCl, 35%	Production of HCl from the combustion of chlorine with hydrogen. Includes precursor compounds, auxiliary materials, transports and infrastructure. Data is based on plant and literature data from Europe and North America. Calculated from the production of 30% HCl.	1997-2000	Ecoinvent Data v1.01, 2003
NH4OH, 25%	Calculated from the production of 100% NH3.	see NH3	see NH3

3.2.3 Transportation

Only the transportation of hard coal from Poland to the power plant, and transportation of ammonia (NH_3), hydrogen chloride (HCl), sodium hydroxide (NaOH) and calcium carbonate ($CaCO_3$) within Finland to the Finnish power plant were assessed in the inventory. Transportation of mining raw materials from the producer to the mines was excluded from the inventory due to lack of data. Internal transportation on power plant area was not assessed in this study. In the KCL-ECO flow chart transportation modules are shown as short diagonal lines, crossing the flow arrows, not as separate modules (see Figure 3).

Assumedly all the hard coal was transported by using electric trains in Poland. The average electricity consumption of trains with full coal cargo is 0.02 kWh per ton/km and that of empty trains 0.014 kWh. 70% of the trains were assumed to return empty and for them the return trip was taken into account. (Kulczycka et al. 2004) The other transportation modules were calculated by combining emission factors for vehicles with data on fuel production (Table 5).

Table 5. Transportation modules

Modules	Unit processes	Data from (year)	Reference
Electric train (Poland)	Train is operated with electricity generated in Poland	See section 3.2.4	See section 3.2.4
Ship dwt. 2000-8000	Emissions of a typical Baltic Sea ferry. Includes fuel production.	1997	Koskela 2002
Truck (Finnish average) 14.2 t	Includes production of diesel oil and emissions from transportation. Represents Finnish average technology	1997	Koskela 2002

Transportation distances in Finland were estimated from Tiehallinto (2004). Transportation distance from Gdansk to Meri-Pori was estimated using a common school atlas (Palosaari ym. 1986). Average transportation distance from the mines to the harbour was received from Kulczycka et al. (2004). Return transport was only assessed for transportation of hard coal from mines to the harbour. There it was estimated that 70% of the trains return empty (Kulczycka et al. 2004). For other commodities, return trip was neglected under the assumption that other goods were transported on the return way.

Table 6. Transportation of materials to the power plant

Transported material	Mode of transportation and distance (km)			Reference
	Cargo ferry	Train (electric, Polish)	Truck (Finnish average)	
Hard coal	810	410		Kulczycka 2004, Palosaari et al. 1986
NH_3			108	Tiehallinto 2004
$CaCO_3$			174	“
NaOH			157	“
HCl			418	“
Gypsum			62	“

3.2.4 Country-specific electricity and heat generation models

In most of the raw material modules the environmental burden of electricity and/or heat generation was included in the module. In these cases it was not necessary to take into account the indirect emissions of electricity or heat generation. However, if the electricity generation was not included in the raw material module then external electricity or heat generation had to be taken into account (see flow chart in Section 3.1). Also the Polish mines use externally produced electricity. Two different electricity generation models were used in this inventory; the Polish electricity and heat generation model, which was used for modelling the production of mining raw materials, and the Finnish electricity and heat generation models, which was used for modelling the production of the power plant raw materials.

Polish electricity generation model

The Polish electricity generation model was constructed on the basis of the electricity generation data of the Ecoinvent database (v.1.01, 2003). Data for hard coal and lignite stem from the years 1993-2000, and data for hydropower originate from the year 2000. Production of the fuel is included in the electricity generation data.

The Polish electricity generation profile was calculated from the Polish Power Grid Company, PSE (2004). An average of the years 2000-2002 was used. As Poland is a net exporter of electricity, imports of electricity were not included in the model.

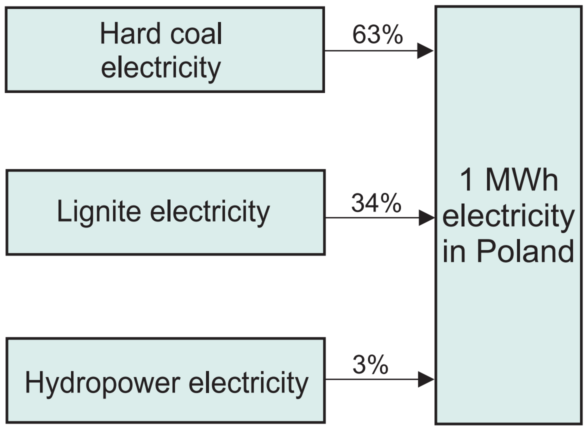

Figure 5. Polish electricity generation model (shares of different fuels calculated as an average of years 2000-2002) (PSE 2004)

Table 7. Polish electricity generation modules

Module	Unit processes	Year	Reference
Hard coal electricity	Average hard coal electricity generation in Poland with 31.2% efficiency (assumed average net efficiency of Polish hard coal power plants). Part of the data is for Europe or Germany as no country-specific data was available.	1993-2000	Ecoinvent Database, v.1.01 (2003)
Lignite electricity	Average lignite electricity generation in Poland with 35% efficiency (assumed average net efficiency of Polish lignite power plants). Part of the data is for Europe or Germany as no country-specific data was available.	1993-2000	Ecoinvent Database, v.1.01 (2003)
Hydropower electricity	Hydropower electricity generation in Poland. Data includes shares of electricity produced with run-of-river and reservoir hydropower plants. The shares have been calculated as annual averages from net generation levels.	2000	Ecoinvent Database, v.1.01 (2003)

Table 8. Some air emissions from the Polish electricity generation profile

Emissions to air	Unit	Amount/MWh
CO_2	kg	1029
NO_x	g	1943
N_2O	g	6.198
SO_2	g	7506
NMVOC	g	23.97
CH_4	g	2679
Particles	g	1524
As	mg	89.2
Cd	mg	11.41
Cr	mg	67.16
Cu	mg	160.8
Hg	mg	351.1
Ni	mg	195.1
Pb	mg	131.1
Zn	mg	441.4

Polish heat generation model

For heat used for mining in Poland, inputs and outputs for heat generation were taken from the Ecoinvent database (v.1.01, 2003). Data is for European heat generation derived from hard coal burned in 1-10 MW industrial furnace. Data is for 1988-1992. Combustion process, softened water treatment, coal transport, ash disposal and electricity requirement are included in the data. Most data represent German conditions. The heating value and emission data are average values taken from the literature. Technology level of the module represents stoker boiler technology used in the early 1990s. The use of this module for mining may lead to an underestimation of emissions because hard coal burned at the mines is usually of lower quality than hard coal burned elsewhere. However, the module was used due to lack of better data.

Table 9. Fuel use of the heating generation model used for mining (Ecoinvent v.1.01, 2003)

Fuel input	Kg /MJ
Hard coal, in ground	0.06
Lignite, in ground	0.002
Crude oil, in ground	0.0009

Table 10. Emissions to air from heat generation (Ecoinvent v.1.01, 2003)

Emissions to air	Unit	Value /MJ
CO_2	kg	0.12
NO_x	g	0.31
SO_2	g	0.67
NMVOC	g	0.009
CH_4	g	0.35
Particles	g	0.19
As	mg	0.03
Cd	mg	0.0022
Cr	mg	0.03
Cu	mg	0.02
Hg	mg	0.004
Ni	mg	0.04
Pb	mg	0.098
Zn	mg	0.009

Finnish electricity generation model

The Finnish electricity generation model was designed by Laukka (2003). The Finnish electricity generation profile may annually vary a lot depending above all on the availability of hydropower and on the situation at the international electric market. Therefore the Finnish electricity generation model was based on the average electricity generation profile in Finland between 2000-2002 (Adato Energia Oy 2003). The main sources of energy for electricity generation in Finland during those years were nuclear power, hydropower and hard coal (Figure 6). Also domestic biofuels (mainly wood and peat) had a significant role in the electricity generation profile. The model takes into account average net imports from Russia and Sweden. The imports vary depending on the price of the electricity but in this inventory it was assumed that half of the import electricity from Sweden was generated with hydropower and another half with nuclear power. 50% of the electricity from Russia was assumed to be produced with nuclear power, 30% with natural gas and 20% with hydropower (IVO 1998).

The specific emissions of the electricity produced in Finland were calculated from annual emissions of power plants during 2000-2002 (Heikkinen 2003). The metal emissions were estimated on the basis of the Finnish power plant technology and fuels used (Petäjä 2003). The model includes also emissions from the production of the fuels.

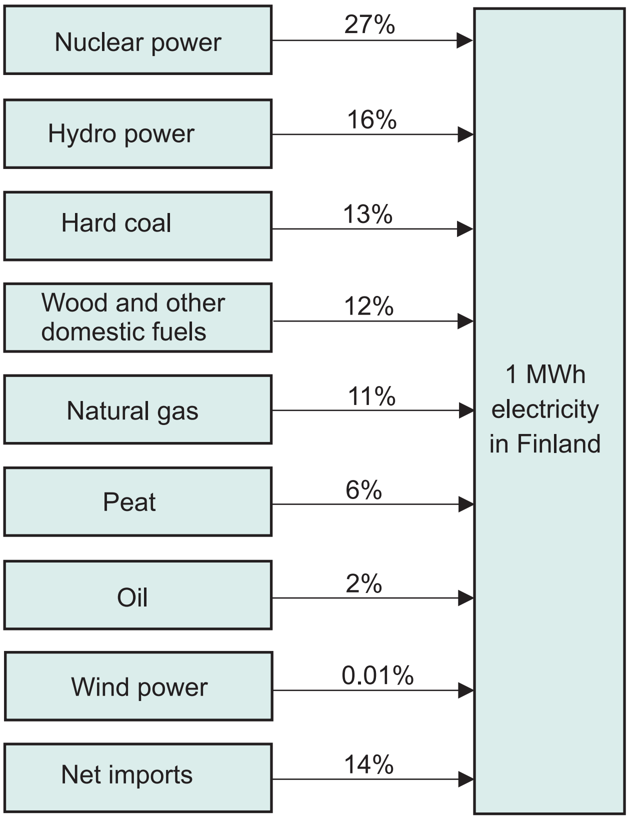

Figure 6. Finnish electricity generation model (shares of different fuels calculated as an average of 2000-2002) (Adato Energia Oy 2003)

Table 11. Some emissions to air from the Finnish electricity generation (Heikkinen 2003, Petäjä 2003).

Emissions to air	Unit	Amount/MWh
CO_2	kg	201
CO	g	130
NO_X	g	379
N_2O	g	6
SO_2	g	316
NMVOC	g	1152
CH_4	g	183
Particles	g	49
As	mg	1.25
Cd	mg	0.88
Cr	mg	5.73
Cu	mg	3.57
Hg	mg	4.35
Ni	mg	18.36
Pb	mg	17.52
Zn	mg	7.84

Finnish heat generation model

Also heat generation was not included in all of the power plant raw material modules. Use of externally generated heat was therefore taken into account for these raw materials. In case of the power plant raw materials the average district heat generation in Finland in 2000 was used (Tattari 2003, ref. Laukka 2003). The Finnish district heat generation model is an average for the whole country including generation of fuels and transmission losses (Tattari 2003). This is somewhat misleading as heat generation is very local. However, data for the whole country had to be used because local data was not available.

Table 12. Emissions to air from the average Finnish district heat generation (Tattari 2003).

Emissions to air	Unit	Amount/MWh
CO_2	kg	234
CO	g	390
NO_x	g	503
N_2O	g	21
SO_2	g	453
CH/VOC[1)]	g	775
CH_4	g	740
Particles	g	517
Heavy metals[2)]	g	0.093

[1)] Includes CH4 emissions
[2)] As, Hg, Cd, Cr and Pb

3.2.5 Savings in external processes

Some by-products were created during hard coal mining and conversion to electricity, namely *methane* at the mines, and *fly ash, bottom ash* and *gypsum* at the power plant. Also most of the mining waste was re-used for industrial purposes but as it was not possible to obtain accurate information over its utilisation, it was ignored in this study. Credits were given for the by-products of the generation system, i.e. the so-called '*avoided burden approach*' was used in the treatment of the by-products. This was done by deducting the production data of the material the by-product replaces, from the total life cycle emissions of hard coal electricity. The idea is that emissions from the production of the material the by-product replaces elsewhere are avoided.

It was estimated that 22% of the methane produced in the Polish mines is recovered (Bibler et al. 1998). 2% of this methane is used for own purposes and the rest is sold for external use. This methane was assumed to replace natural gas produced in Russia. The hard coal electricity generation system of was therefore credited for the emissions that are generated during the production of natural gas (Table 13).

The ratio of bottom ash to fly ash produced at the Meri-Pori power plant is typically 1:10 (Valli 2004). Bottom ash is left behind in the burning process and it originates from the coarser and less volatile mineral matter of the fuel. Fly ash originates from the lighter and more volatile mineral matter of the coal, which is collected by the electrostatic precipitators. (Mroueh et al. 2000) The fly ash produced in Meri-Pori is utilised in concrete or asphalt production (5%) or for earth construction (95%) (Valli 2004). In this inventory it was assumed that flying ash is only utilised in earth construction and concrete production, and the use for asphalt production was ignored. Practically all the bottom ash is used in earth construction where it replaces natural stone materials. In concrete production, fly ash replaces cement and it is used to improve the structure of the concrete. (Finn-Ash Power Oy)

Gypsum is formed during the removal of sulphuric acid from the flue gases. It is sold to a gypsum board manufacturer Knauf Oy, which operates in Kankaanpää (Western Finland) and uses it to replace mineral gypsum.

Table 13. The by-product modules

Module	Unit processes	Data from (year)	Reference
Methane production	Exploration and production of gas onshore in combined oil gas production. Data is for Russia but it is mainly based on extrapolated European data because there is not much information available on Russian production.	1989-2000	Ecoinvent v.1.1, 2004
Utilisation of bottom and fly ash in embankment production	Production of embankment (massive rock). Data is based on several French sites. Electricity is included in the module.	1998	IISI 1998
Fly ash utilisation in cement manufacturing	Use of flying ash in cement manufacturing. Electricity is included in the module.	1994	IISI 1998
Use of gypsum to replace mineral gypsum	Includes mining and crushing of gypsum.		
Data for Switzerland.	1997-2003	Ecoinvent 1.01, 2003	

Recycling of steel

Recycling of steel was taken into account according to a methodology recommended by World Iron and Steel Industry (IISI 2002). As LCI data in IISI represents *'cradle to gate'* data, it does not allocate for steel recycling. Therefore the scrap material inputs to the system do not carry any allocation from the primary production route. However, secondary steel cannot exist without a primary source. Moreover, the quality of secondary steel does not differ from that of primary steel. Also the steel recycling markets function efficiently. Thus, IISI considers primary steel only the first life cycle stage in steel production and finds that full scope LCA studies should allocate to scrap inputs and outputs identically (IISI 2002). This approach was taken in this inventory as well. The allocation to scrap inputs and outputs was conducted according to the calculation presented below (adopted from IISI 2002).

In the example calculation, CO_2 emissions are calculated for two similar hot-rolled steel products. The other one stems from BF (blast furnace) route (based on primary steel) and the other from EAF (electric arc furnace) route (based on scrap). Summarised CO_2 emissions from the BF route are 1900 kg per ton of steel and respectively 550 kg per tom of steel from EAF route. The EAF route is assumed to need 1.07 kg recycled steel to produce 1 kg steel (which is equivalent in quality to 1 kg primary steel). The recycling rate of end products is assumed to be 80%.

Under these assumptions the recycling of steel saves:

(1900-550) kg CO_2/ 1.07 kg recycled steel = **1262 kg CO_2/t recycled steel**

Net consumption of recycled steel throughout the product life cycle in the EAF route is

-1.07 t + 0.8 t = -0.27 t

Net production of recycled steel throughout the product life cycle in the BF route is

0t + 0.8t = 0.8t

The environmental burden for both production routes are calculated by taking into the account CO_2 emissions of recycled steel at the both ends of the steel product life cycle:

- EAF route:

550 kg CO_2/ t steel + 0.27 t recycled steel * 1262 kg CO_2 / t recycled steel = **891 kg CO_2/ t steel**

- BF route:

1900 kg CO_2/ t steel – 0.8 t recycled steel * 1262 kg CO_2 / t recycled steel = **891 kg CO_2/ t steel.**

The same calculation was repeated for each input and output of the steel product in question.

One can see from the above that the two production systems are identical when boundaries are expanded to take into account scrap inputs and outputs. This means that the environmental burden of steel production does not depend on the manufacturing process but on the recycling rate of the final product.

Results

4

In this inventory, electricity generation with hard coal was assessed. For this, environmental inputs and outputs throughout the product life cycle, i.e. from hard coal mining to the electrical power network, were gathered. Whereas the hard coal production took place in Poland and mining data was assumed to be average Polish mining technology, the electricity generation was assumed to take place in Finland, at the Meri-Pori power plant.

In the following sections, summary of the inventory results is presented. More detailed tables of results per life cycle stages, and total results can be found in Appendices 1 and 2. All results are based on the flow chart of hard coal electricity (shown on the Figure 3, Section 3.1) and all calculations are being conducted per one MWh of generated electricity. Section 4.1 presents some summary results for the whole system. In Section 4.2 the main emissions to air per life cycle stages are presented. Section 4.3 shows formation of the main waste materials, and land use of the key production processes.

4.1 Inputs and outputs per 1 MWh electricity produced

Summary results of the main emissions to air from the system are shown in Table 14. Emissions to water are not considered here as they are negligible. However, all the emissions are listed in the Appendix 2. In addition, emissions to water will be discussed in the forthcoming impact assessment.

Table 14. Some emissions to air from the product system

Life cycle stage	Abbr.	CO_2 (kg/MWh)	NO_x (g/MWh)	SO_2 (g/MWh)	CH_4 (g/MWh)	Particle (g/MWh)
Mining	MI	3.2	8.8	21.0	1679	7.7
Polish electricity and heat generation	PL	20.0	39.1	142.0	52.5	29.7
Raw materials	RM	1.0	10.2	1.9	3.9	139.3
Power plant	PP	831.7	602.4	822.1	0	31.6
Transportation	TP	11.1	164.3	137.7	11.8	10.4
Finnish electricity and heat generation	FI	0.34	0.71	0.62	0.86	0.56
Saved external processes	AE	-1.7	-5.9	-3.3	-3.8	-18.0
Total		**866**	**820**	**1122**	**1744**	**201**

The heavy metal emissions to the atmosphere occur mainly at the power plant (Figure 7). It produces 57-95% of total heavy metal emissions except for Hg, the share of which was 11%. Also Polish electricity generation (mainly used in the mining operations) is a large contributor to the heavy metal emissions. It produces most (~63%) of the Hg emissions and over 5-25% of the other metal emissions. Transportation of hard coal within Poland by electric trains also produces about 17% of the Hg emissions.

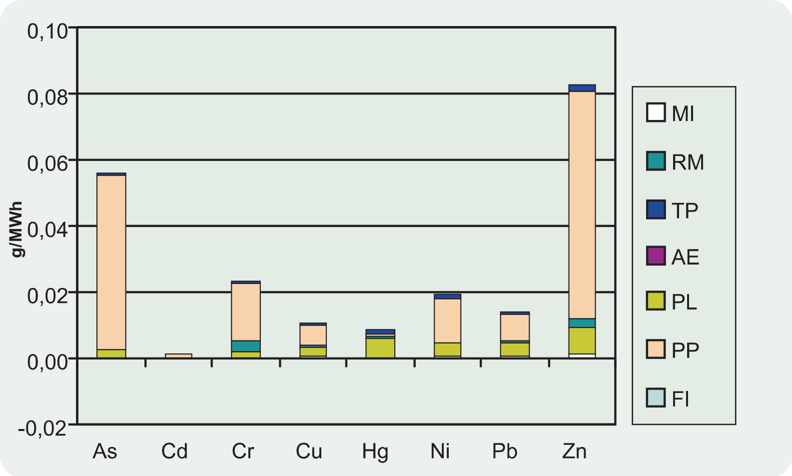

Figure 7. Atmospheric emissions of some heavy metals (g/MWh). The abbreviations of the life cycle stages are explained in Table 14.

4.2 Inputs and outputs according to the life cycle stages

The life cycle stages of the studied product system are following: mining, external electricity and heat generation in Poland, production of raw materials for both mining and power plant, power plant processes, transportation, external electricity and heat generation in Finland, and saved external processes.

Approximately 95% of all the CO_2 emissions of the whole system originate from the power plant (Figure 8). The power plant also causes most of the NO_X and SO_2 emissions (Figures 9 and 10). In addition, transportation of the hard coal from the mines to the power plant induces a great deal of NO_X emissions - 30% of the total emissions. It should be noted that CO_2, NO_X and SO_2 emissions are not measured at the mines. Therefore emissions from burning fuels at the mine area were included to the flow chart from the *Ecoinvent* database. Their contribution to the total emissions is minimal, however. As could be expected, CH_4 originates mainly from the mines (Figure 11). The contribution of the other life cycle stages to the CH_4 emissions is insignificant.

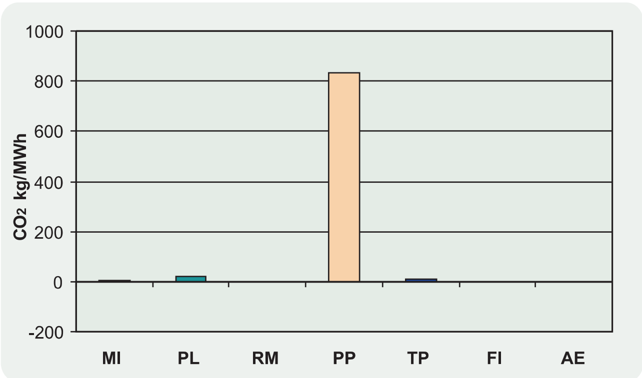

Fig. 8. CO_2 emissions according to the life cycle stages

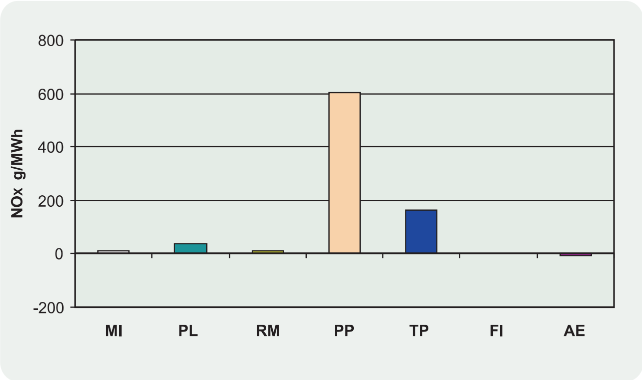

Fig. 9. NO_X emissions according to the life cycle stages

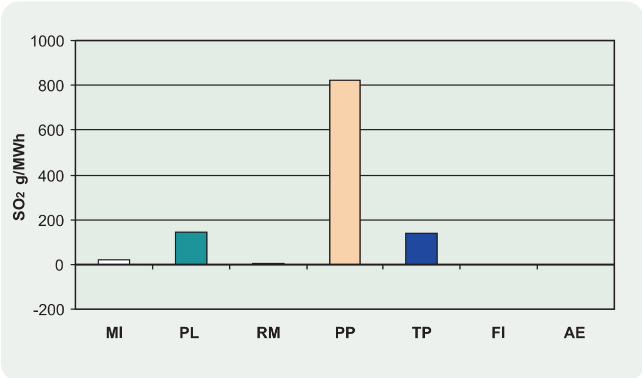

Fig. 10. SO_2 emissions according to the life cycle stages

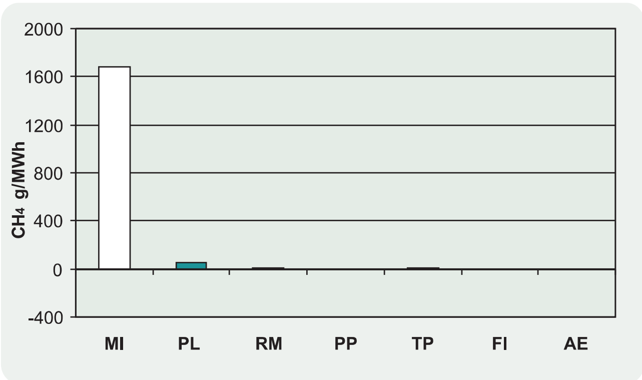

Fig. 11. CH_4 emissions according to the life cycle stages

Abbreviations: *MI = Mining, PL = Polish electricity and heat generation, RM = Raw materials, PP = Power plant, TP =Transportation, FI = Finnish electricity and heat generation and AE = Saved external processes.*

In this product system, most of the particle emissions originate from the production of limestone, which is used to reduce SO_2 emissions from the power plant (Figure 12). On the other hand, replacement of cement through fly ash recycling produces an approximately 4% reduction in particle emissions through saved limestone.

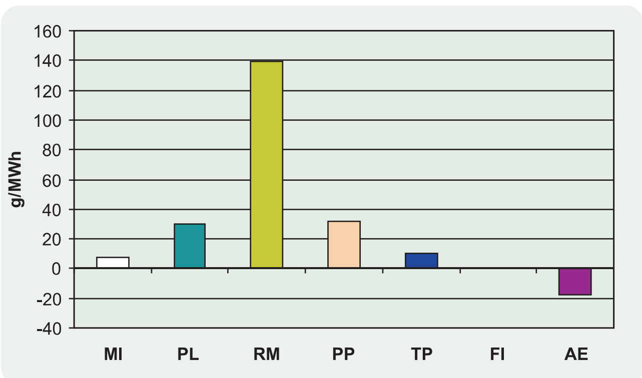

Figure 12. Particle emissions according to the life cycle stages (abbreviations are explained above)

4.3 Waste generation and land use

The largest waste fraction of the system, 109.1 kg/MWh, is created during processing of hard coal. Mining (excavation) generates about 7.5 kg waste/MWh. Also fly ash and gypsum produced at the power plant are large waste fractions. Waste generation during the raw material production is minimal compared to mining and power plant. Additionally, the amount of avoided waste from the saved external processes is larger than the amount of waste generated by raw material production.

Table 15. Waste generation according to the life cycle stages.

Waste fraction	Total amount (kg/MWh)	Recycled (kg/MWh)	Deposited (kg/MWh)
Mining *)			
Waste from processing	109.1	92.7	16.4
Waste from excavation	7.5	6.4	1.1
Flotation waste	7.3	6.2	1.1
Other waste	0.3	No information	No information
Power plant			
Fly ash	34.0	34.0	-
Bottom ash	5.1	5.1	-
Gypsum	8.9	8.9	-
Other waste	0.1	No information	No information
Raw material production			
Total waste	0.04	No information	No information
Manufacture of avoided products			
Mineral waste, inert	-0.05	No information	No information
Other processes			
Total hazardous waste from all life cycle phases	0.01	No information	No information

*) assumption was made that 85% of mining waste is recycled or reused

Land use directly related to hard coal mining and energy conversion is presented in Table 16. It will be dealt with more extensively in the impact assessment, especially land use of mining activities. According to the present data, land use for mining appears to be surprisingly small compared to the land use by the power plant. Possible differences in calculation procedures and boundaries will be checked at a later stage of the project. It should be noted that, as mentioned in Section 3.2.2, the power plant waste disposal area is an area that has been reserved for the power plant but so far it has not been necessary to dispose any waste there.

Table 16. Land usage for the mining and power plant operations

Operation area	Land use (m2/MWh)
Mine area	0.10
Processing plants	0.01
Tailings disposal areas	0.17
Power plant area	0.17
Coal field	0.04
Power plant waste disposal area	0.26

Sensitivity analysis 5

The sensitivity of the system to changes in four different factors, namely hard coal transportation distance (Case 1), power plant technology (Case 2), external electricity and heat generation (Case 3) and use of fly ash in concrete manufacturing (Case 4) was analysed (Figure 13). In each case, the variable in question was varied while everything else was held constant. In the following the four cases will be discussed.

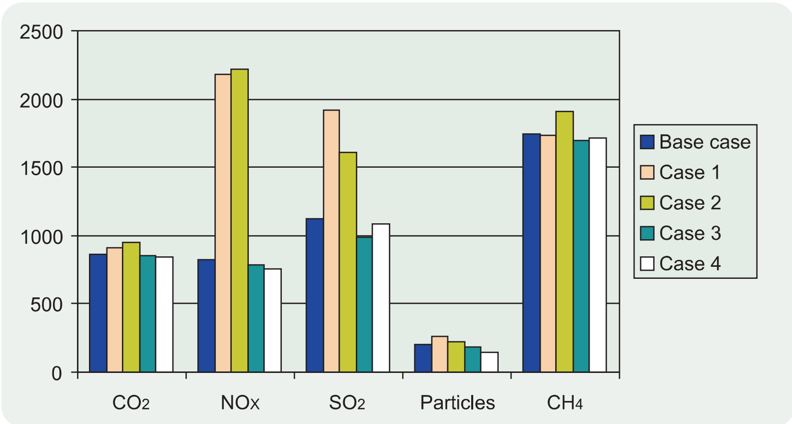

Figure 13. The sensitivity of the main emissions to air to the four different factors studied

Hard coal transportation distance

In this inventory, the hard coal is assumedly transported from Poland. However, the Meri-Pori power plant could also use hard coal transported from regions further away - such as from South America or South-East Asia. The impact of the much longer transportation distance on emissions to air was investigated (Figure 13, Case 1). Instead of transportation from Poland to Meri-Pori by electric train and ferry, hard coal was assumedly transported with ocean freight ferries from Colombia or Indonesia to Meri-Pori. Emissions are calculated by Koskela (2002). Transportation distance was estimated to be 10,000 km (average distance from Colombia or Indonesia to Finland). Train transportation was omitted.

Increasing transportation distance would lead to almost tripling of the NO_X emissions (see Figure 13). SO_2 emissions would rise by ca 70% and particle emissions by ca 30%. Thus, it can be concluded that hard coal transportation distance significantly influences NO_X, SO_2 and particle emissions of the whole system.

Power plant technology

Meri-Pori power plant represents the *Best Available Technology (BAT)* for the power plant and its emissions are therefore relatively low. In order to see how an older power plant would perform, inventory results were calculated for another power plant with less advanced emission reduction technology – for Tahkoluoto power plant, which is situated right next to Meri-Pori plant (Figure 13, Case 2). Data on Tahkoluoto power plant were taken from Vahti database. As no information was available over the raw material consumption of Tahkoluoto (except for the hard coal and heavy fuel oil), it was assumed to be the same as that of Meri-Pori. This assumption is probably not realistic but as the role of the power plant raw materials for the whole inventory was proved to be insignificant, this assumption was considered justified. Figure 13 shows the results of the comparison. For all substances, Tahkoluoto's emissions were higher than those of Meri-Pori. For NO_X and SO_2 the difference was 170% and 45%, respectively, which reflects Meri-Pori's advanced emission reduction systems. It is notable that if hard coal also was transported to Tahkoluoto from overseas (Case 1), the increase in NO_X, SO_2 and particle emissions would almost double.

External electricity and heat generation

Over 90% of the Polish electricity is generated from hard or brown coal. More than 50% of the Finnish electricity is generated from nuclear power, hydropower and natural gas, so it is therefore not so emission-intensive. In order to study the impact of Polish electricity and heat generation on the total emissions of the production system, the results were recalculated with the assumption that all external electricity and heat were generated in Finland. As seen from the Figure 13 (Case 3), the change in total emissions would be insignificant in this product system - CO_2, NO_X and CH_4 emissions would decrease by 2-4%. However, particle and SO_2 emissions would decrease by 10 and 11% respectively.

Use of fly ash in cement manufacturing

Cement production is energy intensive and highly polluting. The fly ash from hard coal power plants can be utilised in concrete manufacturing to replace cement. Current utilisation rate of the Meri-Pori plant's flying ash in cement manufacturing is 5% while the rest is used for earth construction works. Considerable emission reductions could be achieved by increasing the recycling rate. Figure 13 (Case 4) shows emission reductions, resulting from increasing the recycling rate up to 80% (the rest would still be utilised in earth construction). The increased recycling rate would have the greatest impact on total particle emissions, which would be reduced by approximately 30%. For the other emissions the reduction would range from 1.5 (CH_4) to 8% (NO_X).

Concluding remarks 6

The principal conclusion, to be drawn from this LCI of hard coal electricity, is that the main emissions to air mostly originate from conversing hard coal to electricity at the power plant. It is not an extraordinary finding since impacts of burning of fossil fuels are well known. In the studied product system for instance over 90% of the CO_2 emissions originated from the power plant. Electricity generation is also the main source for NO_X and SO_2 emissions, and for most heavy metal emissions to air. The final emissions of NO_X, SO_2, particulate matters and heavy metals depend on the quality of the hard coal in use and on the used air emission purification systems. The coal-fired power plant of this inventory represents high-end technological solution - including desulphurization and selective catalytic reduction of NOx emissions from the flue gas (*BAT-technology*). This alone lets one to conclude that particularly its NO_X, SO_2 and particle emissions are much lower compared to the older hard coal power plants.

Since this inventory dealt with only one power plant that generates solely electricity, no major allocation, i.e. dividing inputs and outputs between different forms of energy, was necessary. However, *'expanded system boundaries'* and *'avoided burden approach'* were adopted in this inventory, and the system was credited for the reuse of waste materials. Credits were given on the basis of saved external processes and the environmental burden as a whole was thereby reduced. Avoided emissions have minor relevance in this inventory except for particles, which were reduced by almost 10% through saved cement production.

Altogether the waste recycling rate of the investigated system is very high. Meri-Pori plant's SO_2 and particle emissions are being transformed into solid state with the help of additives or catalyst, i.e. to gypsum and fly ash. Practically all of these waste materials are recycled as construction materials. In addition, according to the Polish statistics over 85% of the mining waste was reused for engineering works or within the mining industry. In the long run a large proportion of the metals used at the mines are left behind after mine closing. Thus the recycling rate of metals is probably not as high as it is within other industries. Approximately 20% of the methane released in the Polish mines is recovered and used as a fuel and there are opportunities to further increase its use. Since methane released in the mining operations causes danger of explosion, its secure treatment is important for the safety of the workers as well.

Main data used in this inventory represents data of the real product system and its quality is high. Particularly data on the Meri-Pori power plant are very accurate. Also hard coal mining data represents well average underground hard coal mining practice in Poland. The rest of the data are secondary, i.e. average data from general databases. However, different data sources were studied in order to ensure that the best available data was chosen. For example, two kinds of electricity generation models were used for external electricity generation - one for the processes occurring in Poland and another for Finnish processes. Models were constructed on the basis of country-specific electricity generation profiles. Due to the fuels used, the emissions from the Finnish electricity generation are lower than those from the Polish generation. In this inventory the relevance of external electricity proved to be minor regarding emissions. However, in several other LCIs emissions from the generation of the input electricity have played a significant role, especially in the case of very energy-intensive products. Current inventory differs from those in that here the final product is electricity itself.

Each inventory is bound to a certain period in time. In this inventory data on mining were gathered for the year 2002 and data on the power plant for the year 2003. For secondary data the latest possible year was used.

In each Life Cycle Inventory number of generalisations are unavoidable and each study contains several uncertainties. In the current inventory these uncertainties were abated by the use of primary data on the power plant and mining operations. Sensitivity analysis proved the results to be fairly insensitive to the LCI data variation besides changes in the power plant technology and the distance of coal transport.

Inventory data produced in this study is applicable to systems, which are using modern power plant technology and Polish hard coal. Two main blocks of the investigated system - mining and power generation - can be used separately in different LCA studies, naturally.

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Appendix 1a. Selected inputs and outputs of the product system according to the life cycle stages (in kg/MWh)

	MI	EH_PL	RM_MI	AE_PL	TP	PP	EH_FI	RM_PP	AE_FI
Inputs									
Resources									
Bauxite			1.36E-05						-2.74E-04
Cr (ore)			1.35E-03						
Cu (ore)			2.36E-04						
Fe (ore)	9.41E-04		3.70E-2	-2.12E-03					-3.30E-03
Mn (ore)			1.25E-03						
Mo (ore)			1.33E-03						
Ni (ore)			4.59E-03						
Hard coal	4.49E+02	7.94E+00	8.61E-02	-1.05E-03	1.71E+00		1.87E-02	2.40E-03	-3.12E-01
Brown coal	2.27E-02	7.43E+00	4.56E-02	-7.36E-04	1.84E+00			4.13E-03	-6.15E-04
Crude oil	4.05E-02	6.69E-02	2.86E-02	-1.79E-03	1.27E-02		1.84E-03	8.35E-01	-6.66E-02
Natural gas	1.56E-02	7.84E-02	2.19E-02	-6.52E-01	1.82E-02		8.76E-03	1.27E-01	-1.45E-02
Heavy fuel oil			2.83E-05						
Chemicals									
CaCl2								6.97E-05	
CaCO3			1.23E-01					5.52	-2.62
HCl								3.17E-4	
NaCl			1.44E-03					1.88E-2	-2.50E-4
NaOH	1.36E-4							2.35E-06	
Outputs									
Emissions to air									
CO_2	3.16	2.00E+01	4.10E-01	-7.00E-02	3.57E+04	8.32E+02	3.40E-01	5.70E-01	-1.65E+00
N_2O	2.30E-05	1.35E-04	1.15E-05	-6.56E-07	2.92E-05		2.71E-06	4.86E-07	-2.87E-05
CH_4	1.68E+00	5.25E-02	7.07E-04	-2.00E-03	1.16E-02		8.62E-04	3.21E-03	-1.75E-03
SO_2	2.10E-02	1.42E-01	1.18E-03	-9.83E-04	1.37E-01	8.22E-01	6.25E-04	7.37E-04	-2.34E-03
NO_x	8.78E-03	3.91E-02	1.35E-03	-1.91E-04	1.64E-01	6.02E-01	7.07E-04	8.89E-03	-5.68E-03
NH_3			5.40E-08					2.09E-04	-1.43E-06
NMVOC	3.96E-04	5.69E-04	2.04E-4	-6.63E-04	5.33E-03		5.85E-04	1.70E-04	-1.16E-04
Particles	6.22E-3	1.95E-2	1.01E-3	-1.97E-5	1.04E-2	3.16E-2	5.65E-4	1.37E-1	-1.07E-2
As	3.02E-07	2.11E-06	5.79E-08	-7.01E-10	3.84E-07	5.29E-05	5.93E-10	2.91E-09	-6.31E-10
Cd	3.07E-08	2.36E-07	1.50E-08	-3.20E-10	4.92E-08	8.56E-07	4.17E-10	1.09E-09	-4.25E-10
Co			3.18E-13						
Cr	1.66E-07	1.69E-06	3.48E-06	-4.84E-09	2.89E-07	1.74E-05	2.72E-09	4.76E-08	-8.84E-10
Cu	3.36E-07	3.20E-06	3.64E-07	-5.55E-09	6.95E-07	6.34E-06	1.70E-09	1.35E-08	-9.48E-09
Hg	1.31E-07	6.17E-06	1.11E-07	-4.27E-09	1.51E-06	9.82E-07	2.07E-09	6.38E-09	-4.75E-10
Ni	6.23E-07	4.05E-06	2.85E-07	-5.51E-09	8.41E-07	1.33E-05	8.74E-09	1.73E-08	-6.05E-09
Pb	5.12E-07	3.96E-06	8.84E-07	-1.15E-08	5.65E-07	8.02E-06	8.33E-09	1.27E-08	-5.39E-09
Se			5.54E-11						
V			6.28E-12			1.96E-05	2.39E-08		
Zn	1.23E-06	7.82E-06	3.11E-06	-3.05E-08	1.90E-06	6.85E-05	3.73E-09	2.67E-08	-1.32E-08

	MI	EH_PL	RM_MI	AE_PL	TP	PP	EH_FI	RM_PP	AE_FI
Emissions to water									
As	1.04E-05	5.50E-05	1.31E-06	-2.68E-08	1.29E-05	1.20E-07		1.44E-08	-6.68E-09
Cd	7.87E-08	3.69E-06	1.01E-06	-1.82E-08	9.08E-07	1.90E-08		3.68E-09	-3.21E-09
Cr	4.42E-08	1.61E-07	1.21E-07	-3.02E-09	3.80E-08	1.00E-06		1.17E-09	-1.34E-09
Cu	2.48E-06	1.39E-04	8.17E-05	-1.23E-07	3.43E-05	8.71E-07		2.14E-07	-6.93E-08
Fe	1.29E-04	2.86E-02	1.51E-03	-3.95E-06	7.08E-03	9.51E-06	1.12E-09	1.48E-05	-2.07E-04
Hg	1.00E-08	8.01E-07	1.02E-07	-2.02E-09	1.98E-07	1.49E-07		1.22E-09	-3.32E-10
Mg			2.96E-15						
Mn			1.63E-14						
Ni	9.44E-06	1.53E-04	4.24E-05	-3.29E-07	3.73E-05	1.65E-07			
Pb	7.28E-07	1.46E-05	7.11E-06	-6.18E-08	3.62E-06	6.02E-07		2.91E-8	
V						2.20E-06			
Zn	3.35E-06	1.63E-02	2.10E-05	-5.02E-07	4.06E-03	1.77E-06		5.44E-06	-1.33E-06
Tot P	2.19E-08	6.49E-08	4.54E-07	-2.99E-10	1.34E-08	2.06E-06	1.77E-08	6.36E-10	-2.38E-09
PO_4 [1]			3.56E-07						-1.20E-05
Tot N	8.77E-07	4.06E-05	2.09E-06	-3.38E-08	1.36E-05	1.37E-03	4.91E-07	1.60E-06	-8.10E-08
NH_4, NH_3 [2]	2.15E-06	8.97E-06	4.55E-06	-4.45E-08	2.00E-06	1.32E-03	2.08E-07	1.34E-06	-3.26E-06
NO_2, NO_3 [2]	1.20E-05	4.60E-05	9.64E-07	-3.39E-08			3.08E-08	1.09E-06	-9.18E-07
Solid waste									
Hazardous			1.79E-05		1.32E-04	1.26E-02	4.36E-07	3.31E-04	-1.07E-04
Mineral. inert	2.50E-1		7.61E-03						-5.72E-02
Mun. and ind.			4.39E-07		2.08E-03	3.86E-02			
Cooling	4.88E-07					3.01E-02			
Excavation	7.45E+00								
Processing	1.09E+02								
Flotation	7.31E+00								
Sewage sludge			1.94E-08			2.31E-02			

Notes: [1] expressed as P
[2] expressed as N

Abbreviations used for the life cycle stages:
MI = Hard coal mining and processing. EH_PL = External electricity and heat production in Poland (coal mining and its raw materials). RM_MI =Raw materials to coal mining. AE_PL = Recovered wastes treated as by-products in Poland. TP = Transportation. PP = power plant. EH_FI = External electricity and heat production in Finland (for the power plant and its raw materials). RM_PP = Raw materials to the power plant. AE_FI = Recovered wastes treated as by-products in Finland.

Appendix 1b. Selected inputs and outputs of the system according to more detailed life cycle stages

Life cycle stages	MI	EH_PL	RM_PL	AE_PL	TP_ET	TP_S	TP_O	PP	EH_FI	RM_FI	AE_FI
Inputs											
Resources											
Bauxite			1.36E-5								-2.74E-4
Cr (ore)			1.35E-3								
Cu (ore)			2.36E-4								
Fe (ore)	9.41E-04		1.57E-4	-2.12E-3							-3.3E-3
Ni (ore)			4.59E-3								
Hard coal	4.5E+02	7.94E+0	8.61E-2	-1.05E-3	1.74				1.87E-2	2.4E-3	-3.12E-1
Brown coal	2.27E-02	7.43E+0	4.56E-2	-7.36E-4	1.87					4.13E-3	-6.15E-4
Crude oil	1.15E-02	6.69E-02	2.24E-2	-1.79E-3	1.29E-2				1.84E-3	8.35E-1	-6.66E-2
Natural gas (GJ)	4.88E-4										
Natural gas (kg)			5.4E-3						8.76E-3	1.26E-1	-1.41E-2
Natural gas (Nm^3)	8.13E-3	1.09E-1	2.31E-2	-6.52E-1	2.57E-2					1.58E-3	-5.70E-4
Heavy fuel oil			2.83E-5								
Chemicals											
CaCl2											-2.50E-4
CaCO3										5.52	-2.62
HCl										3.17E-4	
NaCl			1.45E-3							1.88E-2	
NaOH	1.36E-4		1.41E-8							2.35E-6	
Outputs											
Emissions to air											
CO2	3.16	2.00E+01	0.41	-0.07	4.53	6.53	5.56E-2	831.8	3.41E-1	5.7E-1	-1.65
N2O	2.3E-05	1.35E-04	1.15E-05	-6.6E-07	2.73E-5		2.47E-06		2.71E-06	4.86E-07	-2.87E-05
CH4	1.7E+00	5.25E-02	7.07E-04	-2.0E-03	1.18E-2		7.10E-06		8.62E-04	3.21E-03	-1.75E-03
SO2	2.1E-02	1.42E-01	1.18E-03	-9.8E-04	3.3E-2	1.05E-01	1.10E-05	8.22E-01	6.25E-04	7.37E-04	-2.34E-03
NOx	8.78E-03	3.91E-02	1.35E-03	-1.9E-04	8.55E-3	1.55E-01	6.50E-04	6.02E-01	7.07E-04	8.89E-03	-5.68E-03
NH3			5.40E-08							2.09E-04	-1.43E-06
NMVOC	3.96E-04	5.69E-04	1.84E-04	-6.6E-04	1.05E-4	5.14E-03	8.84E-5		5.85E-04	4.01E-6	-5.73E-04
Particles	7.69E-3	2.97E-2	1.95E-3	-4.8E-5	4.37E-3	5.97E-3	6.34E-5	3.16E-2	5.65E-4	1.37E-1	-1.79E-2
Dioxins			6.23E-10	-1.6E-11	3.93E-12					1.57E-12	-2.42E-12
As	3.02E-07	2.11E-06	5.79E-08	-7.0E-10	3.91E-7			5.29E-05	5.93E-10	2.91E-09	-6.31E-10
Cd	3.07E-08	2.36E-07	1.50E-08	-3.2E-10	5.01E-8			8.56E-07	4.17E-10	1.09E-09	-4.25E-10
Co			3.18E-13								
Cr	1.66E-07	1.69E-06	3.48E-06	-4.84E-9	2.94E-7			1.74E-05	2.72E-09	4.76E-08	-8.84E-10
Cu	3.36E-07	3.20E-06	3.64E-07	-5.55E-9	7.08E-7			6.34E-06	1.70E-09	1.35E-08	-9.48E-09
Hg	1.31E-07	6.17E-06	1.11E-07	-4.27E-9	1.54E-6			9.82E-07	2.07E-09	6.38E-09	-4.75E-10
Ni	6.23E-07	4.05E-06	2.85E-07	-5.5E-09	8.57E-7			1.33E-05	8.74E-09	1.73E-08	-6.05E-09
Pb	5.12E-07	3.96E-06	8.84E-07	-1.15E-8	5.76E-7			8.02E-06	8.33E-09	1.27E-08	-5.39E-09
Se			5.54E-11								
V			6.28E-12					1.96E-05	2.39E-08		
Zn	1.23E-06	7.82E-06	3.11E-06	-3.05E-8	1.94E-6			6.85E-05	3.73E-09	2.67E-08	-1.32E-08

Life cycle stages	MI	EH_PL	RM_PL	AE_PL	TP_ET	TP_S	TP_O	PP	EH_FI	RM_FI	AE_FI
Outputs											
Emissions to water											
As	1.04E-05	5.5E-5	1.31E-06	-2.7E-8	1.31E-05			1.20E-07		1.44E-08	-6.68E-09
Cd	7.87E-08	3.7E-6	1.01E-06	-1.8E-8	9.25E-07			1.90E-08		3.68E-09	-3.21E-09
Cr	4.42E-08	1.6E-7	1.21E-07	-3.0E-9	3.87E-08			1.00E-06		1.17E-09	-1.34E-09
Cu	2.48E-06	1.4E-4	8.17E-05	-1.2E-7	3.49E-05			8.71E-07		2.14E-07	-6.93E-08
Fe	1.29E-04	2.9E-2	1.51E-03	-4.0E-6	7.21E-03			9.51E-06	1.12E-09	1.48E-05	-2.07E-04
Hg	1.00E-08	8.0E-7	1.02E-07	-2.0E-9	2.02E-07			1.49E-07		1.22E-09	-3.32E-10
Mg			2.96E-15								
Mn			1.63E-14								
Ni	9.44E-06	1.5E-4	4.24E-05	-3.3E-7	3.80E-05			1.65E-7			
Pb	7.28E-07	1.5E-5	7.11E-06	-6.2E-8	3.69E-06			6.02E-7		2.91E-8	
V								2.20E-06			
Zn	3.35E-06	1.6E-2	2.10E-05	-5.0E-7	4.13E-03			1.77E-06		5.44E-06	-1.33E-06
Tot P	2.19E-08	6.5E-8	4.54E-07	-3.0E-10	1.37E-08			2.06E-06	1.77E-08	6.36E-10	-2.38E-09
PO4[1]			3.56E-7								-8.06E-6
Tot N	8.77E-07	4.1E-5	2.09E-06	-3.4E-8	1.00E-05	3.75E-06	3.29E-08	1.37E-03	4.91E-07	1.60E-06	-8.10E-08
NH4. NH3[2]	2.15E-06	9.0E-6	4.55E-06	-4.5E-8	2.04E-06			1.32E-03	2.08E-07	1.38E-06	-3.26E-06
NO2. NO3[2]	1.20E-05	4.6E-5	9.64E-07	-3.4E-8					3.07E-08	1.09E-06	-9.18E-07
Solid waste											
Hazardous			1.79E-5			1.31E-4	1.15E-6	1.26E-02	4.36E-07	3.31E-4	-1.07E-4
Mineral. inert	2.50E-1		7.61E-3								-5.72E-2
Mun. and ind.			4.38E-7			2.06E-3	1.81E-5	3.89E-02		2.37E-3	
Industrial sludge	4.88E-07							3.01E-02			
Excavation	7.45E+00										
Processing	1.09E+02										
Flotation	7.31E+00										
Sewage sludge			1.94E-8					2.31E-02			

Notes: [1]expressed as P
[2]expressed as N

Abbreviations used for the life cycle stages:
MI = Hard coal mining and processing, EH_PL = External electricity and heat generation in Poland (coal mining and its raw materials), RM_PL = Raw material production in Poland, AE_PL = Recovered wastes treated as by-products in Poland, TP_ET = Transportation with electric train, TP_S = Transportation with ship, TP_O = other transports, PP = power plant, EH_FI = External electricity and heat generation in Finland (power plant and its raw materials), RM_FI = Raw material production in Finland, AE_FI = Recovered wastes treated as by-products in Finland.

Appendix 2. Table XX. Inputs and outputs of the whole product system per 1 MWh electric power

Inputs

Variable	Unit	Value
Resources		
Ag, silver	kg	1.8E-08
Al	kg	5.1E-05
BaSO4. bariumsulphate	kg	1.7E-07
bauxite	kg	-2.6E-04
bentonite	kg	3.6E-09
calcite. in ground	kg	2.1E-02
Chromium	kg	1.4E-03
clay (in ground)	kg	8.6E-13
coal (in ground)	kg	-2.6E-01
copper ore	kg	2.4E-04
dolomite	kg	5.8E-04
gravel	kg	1.8E-08
ground water	m^3	1.2E-01
gypsum. in ground	kg	-9.0E+00
iron ore	kg	3.2E-02
land occupation	m2a	1.0E+00
land transformation	m^2	1.6E-03
limestone	kg	3.0E+00
manganese	kg	1.3E-03
Molybdenum. in ground	kg	1.3E-03
NaCl (in ground)	kg	1.4E-03
nickel. in ground	kg	4.6E-03
olivine (in ground)	kg	4.5E-08
rock (unspecified)	kg	-3.7E+01
salt rock	kg	1.2E-02
salt water	kg	3.4E-02
sand (in ground)	kg	3.7E-05
sea water	m^3	1.1E+02
sodium chloride	kg	1.9E-02
sulphur. in ground	kg	2.7E-08
water	m^3	5.9E-02
wood. hard. standing	m3	1.7E-07
wood. logs	kg	1.6E-01
wood. soft. standing	m^3	5.0E-07
wood. unspecified	m^3	6.8E-14
Energy and fuels		
wood based fuels	kg	2.4E-02
bark. SW	kg	4.9E-03
blast furnace gas	GJ	5.2E-05
brown coal	kg	9.4E+00
electric power	MWh	5.1E-02
feedstock	GJ	
Fuels. unspecified	MWh	2.0E-03
Fuels. unspecified	GJ	-8.1E-03
Natural gas. in ground	Nm3	-4.9E-01
hard coal	kg	4.6E+02
heat	MWh	
heat energy	GJ	6.2E-05
heavy fuel oil	kg	2.8E-05
natural gas	kg	1.3E-01
natural gas	GJ	4.9E-04
non renewable energy	MJ	3.5E+00
oil. crude	kg	9.1E-01
other fossil fuel	kg	8.4E-10
peat	kg	-5.5E-07
renewable energy	MJ	7.3E-01
uranium	kg	1.6E-05
wood	kg	9.9E-05
Materials/Products		
aluminium scrap	kg	3.0E-09
black liquor	kg	1.3E-07
Cu scrap	kg	7.1E-06
Cu sludges	kg	5.3E-06
explosives	kg	2.8E-08
Fennopol	kg	8.9E-08
ferromanganese (Fe. Mn)	kg	4.4E-09
FeSO4. ferrosulphate	kg	1.2E-08
fibreboard	m^2	1.3E-05
flue dust	kg	1.1E-08
fluorspar	kg	2.5E-08
gas/condensate	kg	3.8E-06
glass	m^2	1.7E-08
H2. hydrogen	kg	1.5E-09
hydraulic oil	kg	3.4E-08
industrial wastewood	MJ	2.1E-05
iron	kg	4.8E-06
metallurgical coal	kg	1.8E-06
mortar	kg	2.1E-08
N2. nitrogen	kg	2.9E-08
Na isobutylxantate	kg	1.6E-08
Na2B4O7 x 10 H2O. borax	kg	2.4E-08
Na2CO3. sodium carbonate	kg	1.3E-08

paper. unspecified	kg	8.7E-04
Pb. lead	kg	1.4E-10
raw materials (uncpecified)	kg	4.6E-08
S. sulphur	kg	1.8E-08
sinter magnesite	kg	3.3E-07
sodium ammonia vanadate	kg	8.6E-10
tarboard	m^2	1.4E-04
tin	kg	8.3E-05
wood (50% water)	kg	3.2E-06
wood in chips	MJ	2.4E-06
Chemicals		
CaCl2	kg	7.0E-05
CaCO3	kg	4.8E-03
CaSO4	kg	7.9E-08
H2O2. hydrogen peroxide	kg	4.8E-08
HCl. chem	kg	3.2E-04
Na dichromate	kg	1.9E-06
NaCl	kg	-2.4E-04
NaOH	kg	2.4E-06
trichlorine ethylene	kg	1.4E-08
trinitrotoluene (C7H5/NO2)3)	kg	1.1E-09

Outputs

Variable	Unit	Value
Products and by-products		
electric power	MWh	1.0E+00
recovered methane	Nm3	6.4E-01
massive rock	kg	3.7E+01
cement	kg	1.7E+00
chips	kg	6.1E-02
gypsum	kg	8.9E+00
Emissions to air		
Al. air	kg	3.3E-04
aldehydes. air	kg	-2.2E-07
As	kg	5.6E-05
benzene (C6H6). air	kg	4.6E-10
benzene. toluene. xylene (BTX). air	kg	3.0E-12
Benzo(a)pyrene	kg	2.6E-13
Butane	kg	4.5E-07
Cd	kg	1.2E-06
CH4	kg	1.7E+00
Cl2. air	kg	1.9E-05
CO	kg	9.3E-03
Co. cobalt. air	kg	3.2E-13
CO2. fossil	kg	8.7E+02
Cr	kg	2.3E-05
CS2. air	kg	1.6E-09
Cu. air	kg	1.1E-05
Dioxins	kg	6.4E-10
dust	kg	5.1E-07
ethane	kg	6.7E-07
F. air	kg	3.0E-09
formaldehyde	kg	1.6E-08
H2. air	kg	1.5E-03
H2S	kg	1.7E-06
HCl. air	kg	9.5E-04
HCN. hydrogen cyanide. air	kg	2.4E-13
heat. waste	GJ	2.5E+01
heavy metals. air	g	1.1E-04
hexane	kg	3.9E-07
HF	kg	-2.6E-06
Hg. air	kg	8.9E-06
hydrocarbons (except methane)	kg	-8.7E-05
hydrocarbons CH4 equiv.	kg	3.2E-09
metals (unspecified). air	kg	2.8E-10
N2O	kg	1.7E-04
NH3. air	kg	2.1E-04
Ni	kg	1.9E-05
NMVOC	kg	5.9E-03
NOx	kg	8.2E-01
organic matter (unspecified)	kg	-2.6E-07
PAH	kg	5.2E-07
particles	kg	2.0E-01
particles. PM 10. air	kg	9.9E-13
PM2.5	kg	9.9E-03
Pb	kg	1.4E-05
PCB	kg	1.9E-09
pentane	kg	5.6E-07
propane	kg	3.4E-07
propionic acid	kg	7.8E-09
Se. selenium. air	kg	5.5E-11
Si	kg	-6.1E-06
SO2	kg	1.1E+00
tars (unspecified) air	kg	1.5E-11
toluene	kg	7.3E-10
trichlorine ethylene. air	kg	1.4E-08
V. air	kg	2.0E-05
VOC	kg	7.4E-04
Zn	kg	8.3E-05

Emissions to water		
acids (H+). water	kg	1.9E-08
Al. water	kg	9.5E-07
As. water	kg	1.6E-10
BOD	kg	6.5E-03
BOD5	kg	3.2E-03
BOD7 ATU	kg	1.8E-05
Ca. water	kg	-3.5E-05
Cd. water	kg	5.7E-06
Cl. water	kg	1.5E+00
CN-, cyanides. water	kg	8.9E-13
CNS-, tiocyanates. water	kg	6.3E-13
COD	kg	1.9E-02
COD Mn. acid	kg	1.8E-05
COD. dichromate	kg	1.4E-02
Cr. water	kg	1.4E-06
Cu. water	kg	2.6E-04
dissolved matter (unspecified)	kg	9.3E-05
F. water	kg	-2.4E-07
Fe. water	kg	3.7E-02
Heat	GJ	4.4E+00
heavy metals. water	g	8.5E-02
Hg. water	kg	1.3E-06
hydrocarbons. water	kg	3.6E-10
inorganic dissolved matter (unspecified)	kg	3.4E-09
K+. potassium. water	kg	4.2E-15
metals (unspecified). water	kg	5.1E-09
Mg. water	kg	3.0E-15
Mn	kg	1.6E-14
N. tot	kg	1.4E-03
N. water as NH4	kg	4.9E-10
N-hexane (C6H14). water	kg	2.5E-14
Na+. sodium. water	kg	-1.2E-03
NaOH. water	kg	6.3E-06
NH3. water	kg	8.9E-07
NH4	kg	1.7E-03
NH4+. NH3. as N. water	kg	3.6E-06
Ni. water	kg	2.4E-04
nitrogenous matter (unspecified or N)	kg	6.9E-11
NO2. nitrogen dioxide. water	kg	1.0E-13
NO3	kg	2.6E-04
oil. water	kg	4.2E-03
organic dissolved matter (unspecified)	kg	7.6E-13
P. tot	kg	2.6E-06
Pb	kg	2.7E-05
phenol. water	kg	8.6E-07
phosphates	kg	-2.4E-05
phosphates. as P. water	kg	1.1E-12
phosphorus matter. water	kg	9.0E-13
S-. sulphides. water	kg	5.0E-13
SiO2. silicon dioxide. water	kg	6.1E-16
Sn 2+. Sn 4+. tin. water	kg	-2.2E-16
SO4. water	kg	5.9E-01
solids	kg	7.1E-04
solids. dissolved.w	kg	3.8E-05
Sr. strontium. water	kg	8.5E-17
sulphide	kg	2.8E-08
suspended matter (unspecified)	kg	1.1E-02
tars (unspecified) water	kg	2.1E-13
TSS	kg	2.1E-06
V. water	kg	2.2E-06
wastewater. unspecified	l	1.1E+05
Zn. water	kg	2.1E-02
Solid wastes		
enrichment sand	kg	1.6E-04
Cu production waste. unspecified	kg	1.1E-05
waste. ash	kg	5.5E-05
waste. bark	kg	1.1E-03
waste. industrial sludge	kg	3.0E-02
waste. processing	kg	1.1E+02
waste. flotation	kg	7.3E+00
waste. haz	kg	1.3E-02
waste. mineral. inert	kg	-5.0E-02
waste. municipal and industrial	kg	4.3E-02
waste. non mineral (inert)	kg	4.8E-07
waste. non toxic chemicals (unspecified)	kg	8.9E-11
waste. excavation	kg	7.5E+00
waste. sewage sludge	kg	2.3E-02
waste. slags and ash (unspecified)	kg	5.8E-06
waste. stone	kg	2.5E-01
waste. total	kg	3.5E-02
waste. unspecified	kg	1.7E-03
waste. wood	kg	3.2E-08

Documentation page

Publisher	Finnish Environment Institute (SYKE)	Date November 2005
Author(s)	Laura Sokka, Sirkka Koskela and Jyri Seppälä	
Title of publication	Life cycle inventory analysis of hard coal based electricity generation	
Parts of publication/ other project publications	This publication is only available on the internet www.environment.fi/publications	
Abstract	In this document, the Life Cycle Inventory (LCI) of hard coal electricity is described. The LCI presents the product system of hard coal electricity covering all the life cycle stages from the extraction of resources to the delivery of electric power to the grid. The Finnish Meri-Pori power plant, which represents best available power plant technology, was used as a case study power plant. Inventory data on coal mining was collected using the average interventions of underground coal mining in Poland. Main emissions to air from the system mostly originate from conversing hard coal to electricity at the power plant. Electricity generation is the main source for CO2, NOX, SO2 and most heavy metal emissions to air. The waste recycling rate of the investigated system is very high; almost 100% of the wastes produced at the power plant and over 85% of those produced during mining are recycled. In addition, approximately 20% of the methane released in the Polish mines is recovered and used as a fuel. LCI results were used in the life cycle impact assessment (LCIA) of hard coal electricity, and to identify the differences between the environmental impacts caused by oil shale electricity and coal electricity through their whole life cycle stages in the EU Life-Environment project (OSELCA). Inventory data produced in this study is applicable to systems using modern power plant technology and Eastern European hard coal. Two main blocks of the investigated system – mining and power generation – can also be used separately in different LCA studies.	
Keywords	life cycle, LCI, hard coal, electricity, mining, Finland	
Publication series and number	The Finnish Environment 797	
Theme of publication	Environmental protection	
Project name and number, if any	OSELCA-project, YA06022	
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Kuvailulehti

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Tekijä(t)	Laura Sokka, Sirkka Koskela ja Jyri Seppälä	
Julkaisun nimi	Kivihiilellä tuotetun sähkön inventaarioanalyysi	
Julkaisun osat/ muut saman projektin tuottamat julkaisut	Julkaisu on saatavilla vain internetissä www.environment.fi/publications	
Tiivistelmä	Julkaisussa tarkastellaan kivihiilellä tuotetun sähkön ympäristökuormitusta kivihiilen louhinnasta sähkön tuotantoon elinkaariarvioinnin inventaarioanalyysia (LCI) käyttäen. Inventaariota varten kerättiin tiedot tuotantoketjun prosessien ja kuljetusten päästöistä, jätteistä ja maankäytöstä. Kaksi pääelinkaarivaihetta olivat kivihiilen louhinta ja sähkön tuotanto. Kivihiilen ympäristökuormitus edustaa keskimääräistä puolalaista maanalaista kivihiilituotantoa ja sähkön tuotannon päästöt suomalaista parasta käyttökelpoista teknologiaa (BAT). Suurin osa tuotantojärjestelmän päästöistä ilmaan aiheutui voimalaitoksella. Yli puolet hiilidioksidi-, typen oksidi-, rikkidioksidi- ja metallipäästöistä syntyi sähkön tuotannossa polttolaitoksella. Metaanipäästöt aiheutuivat pääasiassa kaivoksilla ja hiukkaspäästöt raaka-aineiden tuotannossa (kalkkikivi). Voimalaitoksen jätteistä hyödynnettiin lähes 100 % ja kaivostoiminnan jätteistä yli 85 %. Lisäksi noin 20 % louhinnan aikana vapautuvasta metaanista otettiin talteen ja hyödynnettiin energian tuotannossa. Tämän inventaarion tuloksia käytettiin kivihiilellä tuotetun sähkön elinkaariarvioinnin ympäristövaikutusten arviointiin sekä palavalla kivellä ja kivihiilellä tuotetun sähkön ympäristövaikutusten vertailuun EU Life-projektissa (OSELCA). Kahden pääelinkaarivaiheen tuloksia (kaivostoiminta ja sähköntuotanto) voidaan käyttää myös erikseen muissa elinkaariarvioinneissa.	
Asiasanat	elinkaari, inventaario, LCI, kivihiili, sähkö, kaivostoiminta, Suomi	
Julkaisusarjan nimi ja numero	Suomen ympäristö 797	
Julkaisun teema	Ympäristönsuojelu	
Projektihankkeen nimi ja projektinumero	OSELCA-projekti, YA06022	
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Painopaikka ja -aika			

Presentationsblad

Utgivare	Finlands miljöcentral (SYKE)	Datum November 2005
Författare	Laura Sokka, Sirkka Koskela och Jyri Seppälä	
Publikationens titel	Livscykelinventering av elektricitet producerad med stenkol	
Publikationens delar/ andra publikationer inom samma projekt	Publication finns tillgånglig bara på internet www.environment.fi/publications	
Sammandrag	Publikationen behandlar den miljöbelastning stenkolsbaserad elektricitet orsakar från bryningen av kol till produktionen av el. Som metod har använts livscykelinventering (LCI). För inventeringen insamlades uppgifter om utsläpp från processer och transport samt om avfall och markanvändning i produktionskedjan. Två huvudskeden i livscykeln är brytningen av stenkol och produktionen av elektricitet. Stenkolets miljöbelastning motsvarar det som ett genomsnittlig polsk kolgruva producerar och elproduktionens utsläpp bästa användbara teknik (BAT) i Finland. Största delen av produktionssystemets utsläpp i luften producerades i kraftverket. Över hälften av koldioxid-, kväveoxid-, svaveloxid- och metallutsläppen uppkom vid produktionen av elektricitet i förbränningsanläggningen. Metanutsläpp uppkom i huvudsak i gruvorna och partikelutsläppen vid produktionen av råvaror (kalksten). Av kraftverkets avfall återvanns nästan 100 % och av gruvdriftens avfall över 80 %. Dessutom tillvaratogs cirka 20 % av det under brytningen uppkomna metanet och användes i energiproduktion. Resultaten av denna inventering användes för miljökonsekvensbedömning av el producerad med stenkol och för att jämföra miljökonsekvenserna mellan el producerad med oljerskiffer och stenkol i EU Life-projektet (OSELCA). Resultaten av de två viktigaste etapperna i livscykelin-venteringen (gruvdrift och elproduktion) kan användas skilt i andra livscykelanalyser.	
Nyckelord	livscykelinventering, LCI, stenkol, elproduktion, gruvdrift, utsläpp, återvinning	
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ENVIRONMENTAL PROTECTION

Life cycle inventory analysis of hard coal based electricity generation

In this document, the Life Cycle Inventory (LCI) of hard coal electricity is described. The LCI presents the product system of hard coal electricity covering all the life cycle stages from the extraction of resources to the delivery of electric power to the grid. The calculated environmental interventions of hard coal electricity represent the best available Finnish power plant technology and average interventions of underground coal mining in Poland. Two main blocks of the investigated system - mining and power generation – can be used separately in different LCA studies.

The study was conducted within the EU Life funded project OSELCA.

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