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ELECTRICITY SCENARIOS FOR THE BALTIC STATES AND MARGINAL ENERGY TECHNOLOGY IN LIFE CYCLE ASSESSMENTS – A CASE STUDY OF ENERGY PRODUCTION FROM MUNICIPAL WASTE INCINERATION

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In the present study two different sets of assumptions for future power production scenarios, one based on conventional technologies and another assuming a more sustainable energy oriented electricity production, for the Baltic States are analysed to identify the possible marginal electricity sources which could be used in consequential Life Cycle Assessment (LCA) studies in these countries. The environmental impacts of electricity production often account for a major portion of the total environmental burden in LCAs of many products and services. It is known that the environmental impacts of electricity production vary significantly between different energy sources, thus the choice of input data could significantly influence the final results of LCA studies. Therefore, it is important that the LCA practitioners and those who draw conclusions based on LCA studies have both an understanding about data sensitivity issues and the development of energy systems. In this article the implications of marginal data choices in LCA are discussed on the basis of a case study on energy production from municipal waste incineration in the Baltic States.

Introduction

Electricity production is presently very much in focus in the environmental debate, due to urgent needs to mitigate climate change and to reduce the dependency on diminishing fossil fuel resources. New political commitments to decrease fossil fuel based greenhouse gases (GHG) emissions are also emphasized in the Renewable Energy package proposed by the European

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Commission and endorsed by the heads of Member States of the European Union (EU) [1].

Energy also has been a major consideration in the Life Cycle Assessment (LCA), both since energy is part of any LCA study and since different ways to model energy systems in LCA have brought about a debate on LCA methodology [2–4]. Many LCA studies use average data (e.g. average electricity mix of a certain region or country) to model the background systems, the systems that indirectly are affected by the actual system under the study. The use of average data to model these systems may be relevant if the aim is to perform an attributional or retrospective LCA [3]. Attributional methodology for life cycle assessment aims at describing the environmentally relevant physical flows to and from a life cycle and its subsystems and usually shows the impacts of past activities. However, if the aim is to model the future consequences of a decision (consequential LCA study), the use of average data may be misleading, since these data are historical data and therefore cannot capture future consequences from changes in the system (e.g. changes in electric power production system). It should be noted that when applying average power production data, the results can be seriously affected by the delimitation of the market on which the action is taken. Consequential or change-oriented (prospective) LCA modelling is mainly characterised by including affected (marginal) technologies and processes instead of average technologies [5, 6].

The LCA methodology has been used only in a very few cases in the Baltic States. Recently, interest has been growing to conduct LCA studies for assessing the environmental performance of products and services [7–10]. Most of these studies have used a country specific electricity production profile, which is based on average electricity mix. Emission data for specific electricity sources (hydropower, nuclear, etc.) are usually obtained from international databases. Estonia is the only country in Europe where most of electricity is produced from oil shale. Therefore in Estonia, because of this unique electricity production profile, the oil shale based energy production system had to be examined first, before other LCA studies could be carried out. Oil shale based electricity production life cycle inventory (LCI) data is now available as an output of the OSELCA project [11] of Estonian Energy Company.

The electricity systems of the three Baltic States have been due to historical reasons a common system, which has the links to Russia and Belarus and operates in parallel with their power systems. The electricity production in the Baltic States includes a wide range of different types of plants – nuclear, hydro, fossil fuelled condensing and combined heat and power, as well as pumped storage and wind. In the years to come, the Baltic electricity sector is expected to go through major changes. Since the electricity market will be more liberal as well as open with links to the Central European and Nordic electricity systems, it will become less relevant to refer to separate national systems in the future. Phasing out of old nuclear, oil shale and coal based power production capacities in the new EU member states is laid down in the accession treaties.

In this paper the possible medium-term future electricity scenarios for the Baltic States are analysed to identify the marginal electricity sources which could be used in consequential LCA studies in these countries. It is important that complete and accurate LCA information and data on possible future marginal electricity sources are available for the LCA practitioners and commissioners of such studies in the Baltic region. To illustrate how the choice of the electricity input data could influence the results of the LCA, a case study on municipal solid waste (MSW) incineration with energy production was carried out. Waste management is an interesting aspect to discuss because waste incineration in combined heat and power (CHP) plants reduces the need for other energy resources causing a marginal effect on the electricity system.

The Baltic electricity system

The electricity systems of the three Baltic States are presently interconnected with each other and operate parallel (on a synchronous AC grid) with the United Power System of Russia and the Power System of Belarus via a power loop made up of high voltage transmission lines of 330 kV, 500 kV and 750 kV. The historically constructed grid of 330 kV dating from 1960 over the territory of the former USSR has been the reason for parallel operation of the Baltic power system with Belarus and Russia. The total installed capacity of the Baltic power system was 8.99 GW in January 2005. The peak demand in 2005 was just 4.12 GW [12], which means that the Baltic electricity system has currently high overcapacity. Until very recently, this system had no links to other European countries.

The electricity production in the three Baltic States differs considerably. The Estonian electricity production is based on a small number of large fossil-fuel power plants. The primary fuel for power production is oil shale, although natural gas, oil shale gas, shale oil, diesel oil, wood and peat are used as fuels; also, small hydropower plants and a growing number of wind turbines are in operation. The Latvian electricity system is based on hydropower and co-generation of fossil fuels (mainly natural gas and coal to some extent). The Lithuanian electricity system is dominated by nuclear power production. The total installed electricity production capacity in Lithuania amounts to nearly 5,000 MW and exceeds the present domestic need by more than two times, while the main source of electricity in the country is the Ignalina Nuclear Power Plant (NPP) which generates cheaper electricity than the existing thermal power plants using fossil fuel (mainly natural gas). The share of installed electricity production capacities in the three Baltic States [13] is presented in Fig. 1.

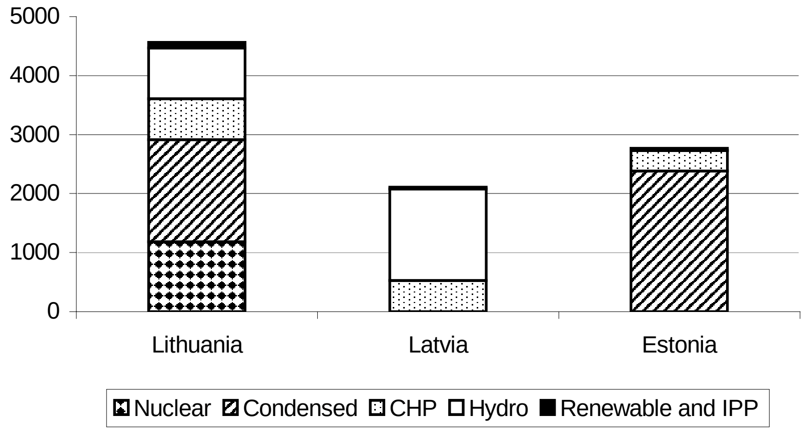

Fig. 1. Installed electricity production capacities 2005 (in MW).

Estonia and Lithuania are net electricity exporters. Both the Ignalina NPP in Lithuania and large oil shale fired thermal power plants in Estonia were built to supply electricity to the North-West regions of the former Soviet Union. Latvia is a net importer of electricity, buying from the other Baltic States as well as from Russia.

In the years to come, the Baltic electricity market is expected to undergo major changes. Up till recently, the electricity sector was characterised by vertically integrated monopolies, but at present the sector is undergoing reform processes to meet the requirements of the EU Directives regarding liberalisation of the electricity sectors. Decommissioning of the second unit of Lithuanian Ignalina NPP in 2009, closing down the worn-out oil shale power production capacities in Estonia by the end of 2015 and opening up the electricity market poses new challenges and forces to seek alternative electricity sources to cover the growing electricity demand of the Baltic States. While the other Baltic States have opened their electricity markets, Estonia has been granted the right to keep its market partly closed until 2013.

Aggressive Russian commercial activity in the natural gas and oil markets has forced the Baltic politicians to reconsider previous energy strategies, to make the security of energy supply the highest priority and take action to develop regional co-operation in the energy field. As a first step in regional co-operation, by the Governments of the three Baltic States, the Baltic Energy Strategy (BES) has been recently (2007) developed. The BES outlines a framework for the energy sector development and stipulates major joint tasks for the power sector in the three Baltic States. The prime ministers of the Baltic States have also supported an initiative to construct a new regional nuclear power plant in Lithuania. At present the power companies of the Baltic States and Poland negotiate about the implementation of this common project. Politicians and energy officials in Estonia also have begun to debate whether Estonia should consider building its own nuclear power plant as part of the country's long-term strategy to ensure energy independence.

According to BES, it is important to integrate the Baltic electricity system into Central European and Nordic electricity systems. At the end of 2006 a submarine electricity cable between Estonia and Finland (Estlink 1) with a capacity of 350 MW became operational. There are plans to build electricity transmission cables from Lithuania to Poland and Sweden as well as to extend connections between Estonia and Finland. These new connections give a chance to the Baltic electricity producers to sell electricity to the Nordic Countries and Central part of Europe and the EU electricity producers, and in turn, the EU electricity producers get an opportunity to sell electricity to the Baltic States.

Table 1. **Electricity production and consumption in Estonia, Latvia and Lithuania, 2005 (National Statistical Offices)**

	EST		LAT		LIT		Total Baltic States	
	GWh	%	GWh	%	GWh	%	GWh	%
Gross production	**10 205**	**100**	**4 905**	**100**	**14 784**	**100**	**29 894**	**100**
Fossil fuel	10 096	99	1 533	31	3 425	23	15 054	50
Hydro	22	0	3 325	68	820*	6	4 167	14
Nuclear	0	0	0	0	10 338	70	10 338	35
Wind	54	1	47	1	2	0	103	0
Other renewable	33**	0	0	0	0	0	33	0
Other	0	0	0	0	200	1	200	1
Imp/Exp	**–1 608**	**–16**	**2 148**	**44**	**-2 966**	**–20**	**–2 426**	**–8**
CHP share from gross domestic consumption	**1 038**	**12**	**1 533**	**22**	**2 352**	**20**	**4 923**	**18**
Gross domestic consumption	**8 597**	**84**	**7 053**	**144**	**11 818**	**80**	**27 468**	**92**
Energy sector	1 455	14	488	10	2 621	18	4 564	17
Transmission losses	1 103	11	836	17	1 220	8	3 159	12
Final consumption	**6 022**	**59**	**5 729**	**117**	**7 977**	**54**	**19 745**	**66**

* including pumped storage
** 21 GWh from black liquor (paper industry) and 12 GWh from landfill gas

Possible future electricity scenarios

A number of studies have been carried out in the Baltic States to analyse and compare various future electricity production scenarios [14–17]. The results of these studies demonstrate that it is difficult to predict the mix of possible future electricity production technologies because it depends on assumptions regarding growth of electricity demand, future fuel prices, electricity production costs, limitations due to energy security, environmental taxes, national policy incentives for support of renewables, etc. The current study compares two extreme sets of assumptions for future power production scenarios in the three Baltic States for the target year 2020 in order to identify possible marginal electricity sources which can be used in consequential LCAs.

- Current Trends or Business as Usual Scenario (CTS) assumes that the future electricity production is based mainly on conventional fuels and technologies.
- Baltic Sustainable Energy Scenario (BSES) assumes a sustainable, renewable energy oriented electricity production.

Both scenarios are described and compared via energy balance (production, import-export and consumption of electricity). For the baseline projections data from National Energy Reports from 2005 have been used. For the projections of energy sector developments various studies available from public sources, addressing the availability of resources, have been used [18–24]. Estonian energy sector development goals and measures as well as assumptions of possible power production investment projects of major market players have been mainly taken from the National Electricity Sector Development Plan 2005–2015 and new drafted National Electricity Sector Development Plan 2008–2018. For Latvia, the projections within the Current Trend Scenario are based on the recently adopted Guidelines for Energy Sector Development 2007–2016. For the development of Lithuanian energy sector, the projections are based on the National Energy Strategy, adopted by the Lithuanian Parliament in January 2007.

Current Trend Scenario (CTS)

The CTS foresees that current development trends in the three Baltic States will continue. This means that concentrated power production will largely continue to prevail and no significant changes in power supply mix in these countries will occur besides those already agreed within the EU accession process (closure of Ignalina NPP and phase-out of Narva PP old oil shale power units), where phased out power capacities will be replaced mainly by conventional technologies (nuclear and fossil fuel).

At CTS possible energy consumption growth data of official national strategies of the three Baltic States have been used to determine the consumption level for 2020. Investment plans from these strategies of possible new capacities have been used to forecast the share of different production sources and production volumes by 2020. Because of the lack of tangible measures taken by the governments in order to promote and implement energy saving measures, increase in consumption is high. However, due to the rising energy costs, energy saving to a certain extent will take place.

In Estonia additional oil shale based power production capacities (at least 2×300 MW_{el}) will be renovated to meet the necessary needs of electricity consumption. Total capacity of installed oil shale boilers will be about 1,100–1,200 MW_{el}. However, oil shale use will be limited by the high cost of CO_2 quota at the carbon emission market. Also power production from natural gas will increase in order to cover the growing electricity demand and balance the electricity system. Wind power development will be modest due to continuous uncertainty in state incentive policy. Biomass based CHP will take near maximum from the supply market which is restricted by the small heat capacity of district heating systems. A shortage of power supply from domestic suppliers is expected due to the phase-out of old capacities and lack of new capacities. The shortage will be covered by import from Nordpool and later by the new Ignalina NPP. Also a possibility to build a small nuclear power plant in Estonia should be considered. If Estonia were to build a nuclear power plant it would most probably not be operational before 2025.

In Latvia, investments in the new natural gas and coal based production capacities will have been made by 2020. Together with the development of the carbon emissions market, the interest to utilize biomass potential in the country will grow significantly. No big changes will occur as regards a wider use of hydropower. Due to Latvia's participation in the new Ignalina NPP project, a part of domestic demand will be covered by import from Lithuania and, to a smaller extent, by import from Russia and Nordpool.

In Lithuania, after the closure of Ignalina NPP, the modernized Lithuanian Power Plant will become a major source of electricity production, along with the CHPs located in bigger cities. Natural gas will be the dominating fuel at these power plants. The new nuclear capacity of 3,200 MW will be built by 2020, and after that domestic demand will be largely covered by nuclear power. Natural gas will mainly be used to run reserve plants due to NPP breaks and overhauls. Hydro-, wind and biomass energy share will remain small as all government resources will be used to cover the construction costs of the new NPP, thus no state funds will be allocated to support renewable development.

Table 2. **Electricity balance 2020, Current Trend Scenario**

	EST		**LAT**		**LIT**		**Total Baltic States**	
	GWh	**%**	**GWh**	**%**	**GWh**	**%**	**GWh**	**%**
Gross production	**10 230**	**100**	**8 100**	**100**	**26 500**	**100**	**44 830**	**100**
Fossil fuel	9 200	90	4 000	49	3 000	11	16 200	36
Hydro	30	0	3 500	43	900	3	4 430	10
Nuclear	0	0	0	0	22 000	83	22 000	49
Wind	600	6	200	2	200	1	1 000	2
Biomass	400	4	400	5	400	2	1 200	3
Imp/Exp	**270**	**3**	**1 000**	**12**	**–9 500**	**–36**	**–8 230**	**–18**
CHP share from gross domestic consumption	**1 500**	**14**	**1 700**	**19**	**3 400**	**20**	**6 600**	**18**
Gross domestic consumption	**10 500**	**103**	**9 100**	**112**	**17 000**	**64**	**36 600**	**82**
Energy sector	1 400	14	900	11	3 500	13	5 800	13
Transmission losses	1 000	10	1 200	15	2 300	9	4 500	10
Final consumption	**8 100**	**79**	**7 000**	**86**	**11 200**	**42**	**26 300**	**59**
Growth compared to 2005	**2 078**	**26**	**1 271**	**18**	**3 223**	**29**	**6 555**	**25**

Baltic Sustainable Energy Scenario (BSES)

Another way of handling the discussion on which electricity of the future could be marginal is to assume that the aim is towards a sustainable energy production. For BSES the electricity demand level for 2020 is calculated first by reducing it by the assumed energy saving. Energy saving potential assumptions are based on the official national strategies of the three Baltic States. In order to identify the calculated demand, a more sustainable energy production fuel-mix is predicted, taking into account available technologies. The main assumption is that the renewable potential of all three Baltic States can be fully used by available technologies via implementation of proper incentives and lifting of market restrictions (existing 2005-2008) by governments. The decentralisation of power production could in certain conditions reduce the self-consumption of power production and losses from power grid. Governments have established significant incentives to promote energy efficiency and saving.

In Estonia a large part of the oil shale based power production capacities will be phased out, and only renovated blocks (about 400 MW_{el}) will stay operational after year 2015. Oil shale use will be limited also by the high cost of CO_2 quota at the carbon emission market. Wind energy development will be active; about 1,200 MW of wind turbines, many of them offshore, will be installed. Biomass based small size CHP will supply power to district heating, utilising this demand to the maximum, and new large consumer self-supply CHPs will be constructed. Estonia will become a net exporter of renewable electricity due to large-scale wind energy development and new connections to Nordpool. In order to compensate for wind deviations, new connections to larger markets (Nordpool) and cooperation with Sweden and other countries in respect of hydro reserves will play an important role. Without these connections such high share of wind power cannot be realized. Without these connections such high share of wind power cannot be realized. Due to the large share of wind capacity gas turbines will be built, and the share of natural gas will remain relatively high [25]. In the future some gas could be extracted from biomass and oil shale.

In Latvia, investments in new natural gas and possibly also clean-coal based production capacities will have been made by 2020. Together with the development of the carbon emissions market, the interest to utilize the high biomass potential of the country will be significant compared to 2005. No big changes will occur in a wider use of hydropower. Energy saving will be seriously promoted (supported) by the government, thus efficiency measures will be applied by consumers and demand increase will therefore be under control.

In Lithuania, by 2020 no new nuclear capacities will be built and domestic demand will largely be covered by natural gas based power on existing reserve capacities which will be renovated to meet environmental standards. Wind share will increase as all government resources will be used to support carbon-free technologies deployment. The biomass sector will surge upward and new small-scale producers will operate everywhere in rural areas utilizing agro-waste and energy culture in electricity production.

Table 3. **Electricity Balance 2020, Baltic Sustainable Energy Scenario**

	EST		**LAT**		**LIT**		**Total Baltic States**	
	GWh	**%**	**GWh**	**%**	**GWh**	**%**	**GWh**	**%**
Gross production	**9 245**	**100**	**7 000**	**100**	**9 600**	**100**	**25 845**	**100**
Fossil fuel	4 900	53	1 200	17	4 500	47	10 600	41
Hydro	45	0	3 500	50	1 000	10	4 545	18
Nuclear	0	0	0	0	0	0	0	0
Wind	3 500	38	1 000	14	1 200	13	5 700	22
Biomass	800	9	1 300	19	2 900	30	5 000	19
Imp/Exp	**–445**	**–5**	**0**	**0**	**1 550**	**16**	**1 105**	**4**
CHP share from gross domestic consumption	**2 000**	**23**	**2 000**	**29**	**4 100**	**37**	**8 100**	**30**
Gross domestic consumption	**8 800**	**95**	**7 000**	**100**	**11 150**	**116**	**26 950**	**104**
Energy sector	700	8	340	5	800	8	1 840	7
Transmission losses	800	9	540	8	950	10	2 290	9
Final consumption	**7 300**	**79**	**6 120**	**87**	**9 400**	**98**	**22 820**	**88**
Growth compared to 2005	**1 278**	**18**	**391**	**6**	**1 423**	**15**	**3 075**	**13**

Possible marginal electricity sources

Changes in electricity demand and supply can be viewed against changes they initiate in the electricity generation system. Usually, the electricity generated from nuclear or hydropower with relatively low variable cost provides the base load for electricity generation. A power plant that is turned off and on depending on the dynamics in the system (when electricity supply or demand changes) is labelled as the marginal producer. The sources of electricity vary during the day and over the year, and the exact source of given kWh electricity cannot be identified. Therefore, long-term marginal electricity production technologies are difficult to determine.

Changes in electricity demand or supply induced by products and services influence the marginal electricity production technology whereas other production technologies usually remain unchanged. In general, the system response to changes in output demand (e.g. increased or decreased demand for energy) will vary in short- and long-term.

The short-term output responses to electricity demand changes typically occur at power plants that have the highest variable cost among those at the time of the demand change. The position taken is that a fossil fuel, such as coal or natural gas, is the marginal energy source - the most expensive power technology available in the market [5].

In the long term, the response will be changes in the timing, and perhaps the nature of investments in new production capacities. The long-term marginal electricity technology is determined by whether the total market is increasing or decreasing. If the result of the product or system change in the future leads to more demand for electricity, the type of new capacity added will be generally the one which is the most preferred technology, usually the one which satisfies the given load shape at the lowest price. If the demand decreases, the long-term marginal technology will be the least preferred technology [5]. It is important to note that marginal technologies could be the technologies, which are able to respond to the demand instantly. Therefore, long-term base-load electricity production capacity (e.g. nuclear power) could be counted as marginal only when electricity intensive process industry or electricity producing activities are modelled.

Different sources of electricity can be argued to be marginal in the Baltic States. In the short- to medium-term future, the present and predicted future cost structure as well as the existing power production capacity in the three Baltic States indicates that natural gas (in Latvia also coal) is the main marginal electricity source for the region. Taking into account the possible future scenarios of the Baltic energy systems, either reflecting the current trend scenario or a more sustainable future, these fuels will remain most probably marginal also in the long term. As a shortage in power supply from local suppliers is foreseen in a short- and medium term perspective, the marginal electricity sources of possible import markets have to be taken into account. According to different studies [5, 26] in Central Europe and Nordic countries coal-condensing power as the most expensive electricity production technology available in the market is the short-term marginal electricity source. In the Nordic region natural gas is expected to be the long-term marginal source due to efforts to lower emission levels. However, the recent studies indicate that the future marginal electricity source maybe also CO_2 free [27]. The question of possible future electricity import from Russia is still open, but it could be expected that coal will be the origin of the electricity imported from Russia in both short and long term.

It could be argued that in certain situations also other technologies/fuels could be labelled as marginal sources in the Baltic region. Taking into account that the Estonian electricity market is not yet fully open and there is currently insufficient flexibility, it could be argued that in Estonia where the majority of electricity is produced from oil shale this fuel may be counted as the marginal electricity source for a shorter period. The same applies to the current nuclear power in Lithuania. However, the position is that both oil shale and nuclear power are used as a base load technology, which is not adjusted to follow changes in electricity demand. Therefore, normally such technologies are not labelled as marginal electricity sources. However, with growing electricity demand and high cost of CO_2 quota at the carbon emission market, it could be said that the planned nuclear power plants could politically or environmentally (CO_2 free electricity source) be regarded as the preferred technology and therefore defined in certain conditions as a long-term marginal electricity source.

Table 4. **Possible marginal electricity sources in the Baltic States**

Short-term marginal electricity source	Power plants that have the highest variable cost among those at the time of the demand change – natural gas and coal fired power plants. Oil shale for a shorter period in Estonia.
Long-term marginal electricity source	CTS: natural gas and goal fired power plants BSES: renewable sources such us biomass and wind power

In the case of a sustainable electricity scenario, renewable sources meet the demand that would eventually have been met with fossil fuels. Therefore biomass fired CHP plants could be marginal technologies in the long term (for example for heat and electricity production in district heating systems). If wind power obtains a significant share, it could be one of the long-term marginal electricity sources in the future. However, this will take place only after the elimination of the current constraint related to the technical problems of power system steering [25]. Hydropower with relatively low variable costs and limited and inflexible power capacity is not labelled as a marginal electricity source in the Baltic States.

In the future, under a more sustainable and liberal electricity market, there may be more demand for electricity with a lower environmental impact. As a consequence, if electricity is purchased directly from a specifically contracted production plant (i.e. renewable sources, including wind or hydropower), electricity data from these plants should be used in environmental assessments instead of data from marginal sources.

The case of municipal waste incineration

Waste incineration with energy recovery reduces the need for other energy resources and can be therefore expected to have long-term marginal effects on the production of energy carriers such us electricity and heat. To illustrate how the choice between different electricity sources could influence the results of the LCA modelling a case study on municipal waste incineration with energy production was carried out. The study is based on Estonian conditions using the parameters of the planned waste incineration plant in Tallinn area. However, this case is not restricted to Estonia only. It is expected that due to stricter EU waste recovery targets and the need to look for an alternative to fossil fuels a large amount of the household waste will be directed to incineration in all three Baltic States. There are several plans in these countries to build similar CHP plants, which use municipal waste as fuel.

Methodology

LCA is mainly known as a tool for assessing the life cycle impacts of physical products, but the same methodological framework is widely used to analyse also services such as waste management [28, 29] and energy systems [2, 30]. In LCAs of waste management, energy system is an important background system.

In this case study the LCA software tool for waste management planning called WAMPS was used. This LCA model is intended to be applied during the waste management planning process to find optimal solutions and alternatives for waste management systems [7]. It is a model for calculation of substance flows, energy flows and environmental impacts of a possible waste management system from life cycle perspective. WAMPS was developed by the Swedish Environmental Research Institute and is based on a more in-depth LCA model ORWARE [31-33]. WAMPS compares a studied waste management system with a background system. The waste management system can produce different products depending on the design of the system. In the case of waste incineration usually electricity and heat are produced. In WAMPS different recovery options (including incineration) are compared with the background system and potentially 'saved emissions' are assessed. The net emissions from the studied system are calculated according to:

$$E_{net} = E_{waste} - E_{Background}$$

E_{net} – net emission (tonnes/year or kg/year);

E_{waste} – emission from a waste process that produces a certain amount of product/energy (tonnes/year or kg/year);

$E_{Background}$ – emission from the same amount of alternative virgin production in the background system (tonnes/year or kg/year).

This calculation can give negative net emissions. This means for example that the waste incineration could give lower emissions than the corresponding energy production in the background system.

The incineration plant that is modelled in WAMPS is a modern plant that with good margins meets the requirements in the EU waste incineration directive. The emission data are based on emissions from a real incineration plant [31]. The results are shown in different environmental impact categories where emissions have been classified together. The environmental impact categories included in WAMPS are global warming, eutrophication, acidification and photooxidant formation. In this study the focus is only on climate change as one of the most important environmental impact categories of waste management. The basic functional unit in WAMPS is the waste generated within a specific region.

Compared electricity sources and major assumptions

The study is based on a theoretical/unrealistic waste management scenario where all collected combustible waste materials are incinerated. The amount and composition of municipal solid waste included in this study are estimates of the MSW generation in Tallinn region in 2013. It is assumed that the same amount of waste with the same composition is treated in all alternatives. The gross efficiency of energy recovery from the incineration process is assumed to be 60%. 80 MW of useful energy is produced, out of which 20% is produced as electricity and 80% as district heat (105 GWh electricity and 410 GWh heat).

It could be assumed that natural gas (short term) or biofuel (long term) are the marginal electricity sources in the Baltic CHP systems. These possible marginal electricity sources were compared with four other background electricity sources: coal, oil shale, wind and nuclear power.

Results

In this study only the global warming potential (greenhouse gas emissions are expressed as CO_2-equivalents) of different alternatives was studied. The results of this LCA case indicate that the greenhouse gas emissions from incineration will change drastically if it is assumed that electricity produced from the incineration of waste is replacing electricity from different electricity sources (Fig. 2).

If fossil fuels are taken as the marginal source for electricity production in the background system, the net GHG emissions will become even negative, which means that waste incineration offsets the GHG emissions of electricity production. Waste incineration has the highest climate protection

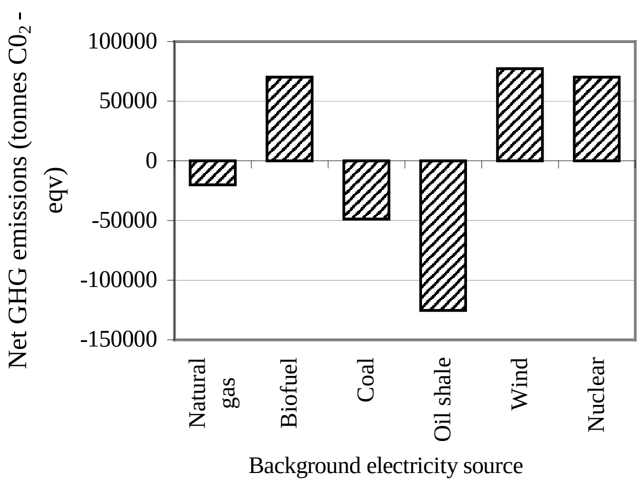

Fig. 2. GHG emissions from electricity production from waste incineration.

potential if the produced electricity substitutes oil shale electricity. The reason is that electricity produced with current oil shale combustion technology (including old boilers) has the highest climate change impact in terms of CO_2 emissions among compared fossil fuels. However, if we assume that marginal electricity is based on non-fossil fuel based sources, then waste incineration will not be an environmentally preferable waste management option any more.

Discussion and conclusions

The described electricity scenarios demonstrate that, no matter what the future energy supply in the Baltic States is based on – conventional or more sustainable technologies and fuels, it is clear that fuel and technology mixes will be more complex than today and thus, the share of today's dominant sources like oil shale in Estonia or nuclear power in Lithuania will diminish and the role of the marginal electricity sources will grow significantly.

Electricity is a major consideration in any LCA. For change oriented or consequential LCA studies it is correct to use a marginal electricity source as input data for modelling. It is quite difficult to predict what will be the possible marginal electricity production technology or source for the three Baltic States in short- and especially long-term perspective. Based on the present cost structure and existing power production capacity and import markets mainly natural gas and coal fired power plans are the short-term marginal sources of electricity in all three Baltic States. It can be assumed that in the long term, despite of the changes in the electricity market and implementation of new connections, the same fuels will remain most probably the marginal electricity sources. With a more sustainable electricity future trend with an additional renewable electricity production capacity or electricity conservation measures undertaken also renewable sources such as biomass and wind power could be labelled as marginal electricity sources.

Since the Estonian electricity market is not yet fully open and there is currently insufficient flexibility, oil shale, the primary fuel for electricity production, could be regarded as a marginal electricity source still for some time. However, the position is that oil shale and nuclear power are used as a base load technology, which is not adjusted to follow changes in electricity demand. Therefore, normally such technologies are not labelled as marginal electricity sources.

The case study of energy production from municipal waste incineration indicates that use of different electricity sources could have a significant influence on the environmental impact, thus also on the results of LCA studies. To ensure that the used electricity data is consistent with the rest of the system analysis, it might be necessary to carry out a separate energy system study specifically for each studied product or service. However, this could add significantly to the cost of the assessment. Therefore, it would be meaningful for consequential LCA studies, where the electricity system is likely to have a significant influence on the results, to test the sensitivity of the results by using two electricity sources: one with high CO_2 emissions (fossil fuels) and one with low or no CO_2 emissions (renewable sources).

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