



Avfall Norge

Assessment of increased
trade of combustible waste
in the European Union



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Sammendrag: Denne rapporten er utført av Profu på oppdrag fra arbeidsgruppe energiutnyttelse i Avfall Norge. Rapporten ser på effektene av å utnytte restavfall fra land der det ellers ville blitt deponert i land som har ledig forbrenningskapasitet og behov for energien i sine fjernvarmesystem. Konklusjonen er at ved å flytte ett tonn avfall fra et land som deponerer avfallet til land som forbrenner med energiutnyttelse, får man en besparelse i klimagassutslipp på 610 kg CO2-ekv/ tonn avfall.			
Godkjent av: Håkon Jentoft	Dato: 20.12.2011	Sign: 	

Summary

The Member States of the European Union are committed to achieve ambitious goals for sustainable waste management, including realizing reduction of landfilling, increasing material recovery, achieving greenhouse gas emission (GHG) reductions, increasing the use of renewable energy, etc. Diverting waste from landfills to Waste-to-Energy plants (WTE), i.e. combustion plants where waste is used for heat, steam and/or electricity production, can be an efficient option that contributes in the work to fulfill several of these goals.

Landfilling is still the most widely used method for managing and treating Municipal Solid Waste (MSW) in Europe. It is a great challenge to find alternatives to landfilling in Europe, especially in the countries where the development towards integrated and sustainable waste management just has started. Increased trade with combustible waste to countries with capacity for energy recovery, together with other efforts, could make a significant contribution to the environmental goals during an interim period.

This report presents a study where the potential benefits from importing waste from “landfilling countries” to “energy recovery countries” are analyzed. The “landfilling countries” selected in the study are those countries in Eastern Europe that landfilled 75 % or more of their MSW in 2009. These countries are lagging behind in their development of integrated waste management systems and currently have relatively low ability to pay for alternatives with higher environmental performance than landfilling.

Six “energy recovery countries” were selected in the study. These countries have come far in their development towards sustainable waste management having high material recovery rates, using biological treatment such as composting and biogas production to a large extent and using high efficient waste-to-energy plants. Less than 5% of their MSW is presently sent to landfills. Also important, these countries have capacity for importing combustible waste. In total, this import capacity is growing according to planned new WTE-plants.

This report presents how much waste that can be imported from “landfilling countries” to these “energy recovery countries” according to their present and future capacities, including assumptions on how much of this capacity will be needed for domestic waste. The report also shows how large reductions of GHG emissions that can be achieved by this import and also what it costs. Finally, the report presents how this import could contribute to reach common environmental goals within the European Union.

The report shows that WTE is an efficient alternative for replacing landfilling and thereby contribute to reaching the Member States’ environmental goals, e.g. the goals for reducing GHG emissions and increasing the use of renewable energy. However, it should be noted that WTE is efficient for a large part of the waste but not for all. A conclusion that can be drawn from recent years environmental studies and also the waste hierarchy adopted by EU, is that waste prevention, reuse and material recovery are options that are even more efficient from an environmental point of view, although sometimes more costly. Biogas production from the biodegradable part of the waste is an option that also can be more efficient than WTE, at least for reducing GHG emissions.

However, the waste quantities discussed for import in this report are small in comparison to the large quantities that are landfilled. Thus, import to WTE plants does not compete with other recovery methods. Instead, import to WTE can be a complement, for waste that otherwise certainly would have been landfilled and not recovered. Moreover, an increased trade with

combustible waste between these countries is preferably an interim solution. Combined with other efforts it gives the “landfilling countries” additional time for developing their own waste management systems.

Furthermore, the report shows that it is more expensive for the “landfilling countries” to export the waste to “energy recovery countries” than continuing with landfilling (with present costs and fees). Thus, the market for increased trade between these groups of countries will not occur without new policy instruments on national or European level. Financial support and/or national fees/bans/regulations etc are needed to reach the gate fees required by the WTE-plants owners.

The general conclusions from the report are summarized below:

- There are Member States within the EU with a surplus in energy recovery capacity that can be used for waste import from “landfilling countries”.
- In the six “energy recovery countries” presented in this report the capacity for import could continue to grow from 2.2 Mton (2010) to 7.2 Mton (2020).
- Replacing landfilling with energy recovery is a powerful measure for reducing emissions of greenhouse gases.
- There are many countries, mainly in Eastern Europe, that still are dependent on landfilling. Exporting combustible waste to “energy recovery countries” can be an efficient option, in a limited time frame, to fulfil common goals for both waste and environment.
- Exporting combustible waste can give “landfilling countries” additional time to move upwards on the waste hierarchy and to develop sustainable waste management systems.
- However, there are today not enough economic incentives for this market to develop.

Contents

Summary	1
1. Introduction.....	4
2. Important data and assumptions	5
2.1 Avoided landfilling in the exporting country.....	5
2.2 Transport from the exporting country to the importing country	5
2.3 Energy recovery in the importing country	5
3. Free capacity for increased energy recovery	6
4. Increased trade of combustible waste in a global warming perspective.....	11
5. Increased trade of combustible waste in an economic perspective	14
6. Contribution to EU directives and goals.....	18
7. References.....	19
Appendix A Landfilling in the exporting country.....	20
Appendix B Transports	21
Appendix C Energy recovery and alternative production of energy carriers.....	22

1. Introduction

In this study, we evaluate how the emissions of greenhouse gases (GHG) change when landfilling of Municipal Solid Waste (MSW) in one country is replaced by transport of the MSW to another country where the MSW is combusted with energy recovery. The environmental impact assessment is thus focused on global warming and other impact categories such as e.g. acidification and eutrophication are not included. Furthermore, we analyze the economics of this export-import to see whether it will take place under different conditions.

In the analysis, the exporting country is assumed to be a country which today faces major challenges of fulfilling the targets of reduced landfilling of biodegradable MSW according to the Landfill Directive (1999/31/EC), and which is located in the former Eastern Europe. Examples of such countries are those that landfilled more than 80% of their MSW in 1995 and have been granted a derogation period of a maximum of four years for each target: Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Poland, Romania and Slovakia.

Six possible importing countries are studied: Norway, Denmark, Sweden, Germany, The Netherlands and Belgium. These countries have in common a low share of landfilled MSW and high share of MSW going to material recycling, energy recovery and biological treatment. Furthermore, these countries have expanded (and are, in some cases, still expanding) their energy recovery capacity as a result of bans on landfilling and/or landfill taxes. Given European and national ambitions to prevent waste and to increase material recycling and biological treatment, all six countries could have potential free capacity for combusting waste from other countries.

The study has been carried out by Profu on behalf of the Norwegian Waste Management Association during the period August-October 2011.

2. Important data and assumptions

2.1 Avoided landfilling in the exporting country

The data and modelling for landfilling in the exporting country is described in Appendix A. These data are used in the modelling for estimating avoided methane emissions when the MSW is exported. A gate fee of 20 euro/tonne is assumed for landfilling in the exporting country.

It should be noted that many factors (e.g. the composition of the MSW and the existence of methane collection systems within the landfill) affect the amount of methane emissions that would occur if the MSW were landfilled. In these calculations, we have used the data as an example of possible methane emissions that can be avoided.

2.2 Transport from the exporting country to the importing country

The MSW is assumed to be baled (wrapped in plastic) and transported by truck from the exporting country to the importing country. For three countries (Sweden, Norway and Denmark) ferry links are used. In the modelling, the transport distance has been modelled as the distance between Warsaw and the capital of each importing country. The data for GHG-emissions and costs associated with the transport are presented in Appendix B.

It should be noted that these transport routes are used as an example of possible distances and transport modes. In reality, both the transport distance and the transport mode could vary to a large extent.

2.3 Energy recovery in the importing country

It is important to note that the energy recovery plants in this report are delimited to incineration facilities with energy recovery, i.e. neither co-incineration plants (cement kilns, power plants) nor specialized plants for RDF or SRF combustion are included.

Furthermore, it must be observed that the import is evaluated using average plant data for each country. In reality, all plants in each country have their own characteristics regarding e.g. energy recovery level, operating costs, revenues for sold energy and transport distances to an exporting country.

The MSW is combusted with energy recovery according to the conditions in each country. The production of different energy carriers (electricity, heat and steam) is estimated using national data. At the energy recovery, GHG emissions occur, mainly originating from the fossil carbon content of the MSW. On the other hand, the production of energy carriers means that alternative production of these energy carriers can be avoided and thus the GHG-emissions associated with this alternative production. Furthermore, by selling electricity, heat and steam, the energy recovery plants receive revenues, thus lowering the overall costs of energy recovery. In Appendix C, data is presented regarding GHG-emissions, costs and revenues for energy recovery.

It is important to note that the marginal effect on energy recovery is evaluated, since the import would utilise free capacity that only constitutes as small part of the total plant capacity. The project thus study how much energy that can be recovered from the added imported amount given that a large share of the plant capacity already is utilised.

3. Free capacity for increased energy recovery

The most common waste treatment in Europe today is landfilling. Approximately 150 million tonnes was disposed on landfills in year 2009. Most of it is municipal solid waste (MSW, approx. 96 million tonnes in EU-27). But there are also large quantities of waste from the industry and other commercial activities that are landfilled. The European countries have made large efforts in finding better use of the waste by implementing schemes for both material and energy recovery and the amount of waste that needs to be landfilled is reduced every year.

Some countries have been more successful than others in their work of diverting waste from landfills. These countries use a mix of different treatment and recovery methods such as material recovery for glass, paper, metal, plastic etc. and energy recovery by generation of heat, steam and/or electricity. Composting and biogas production have also proven to be successful methods for the biodegradable waste streams. Eight of the most successful countries send less than 5% of their MSW to landfilling. Several of these countries have today capacity of also helping other countries with their waste management. This is mainly shown in their capacity for energy recovery.

Figure 3-1 illustrates the share of MSW that was landfilled 2009 in EU27. The figure also shows the six countries that were selected for this study as potential “energy recovery countries” for imported combustible waste. Austria and Switzerland are two other countries that also have come far in their efforts of replacing landfills and they may also be potential countries for energy recovery from imported waste but are not included in this study.

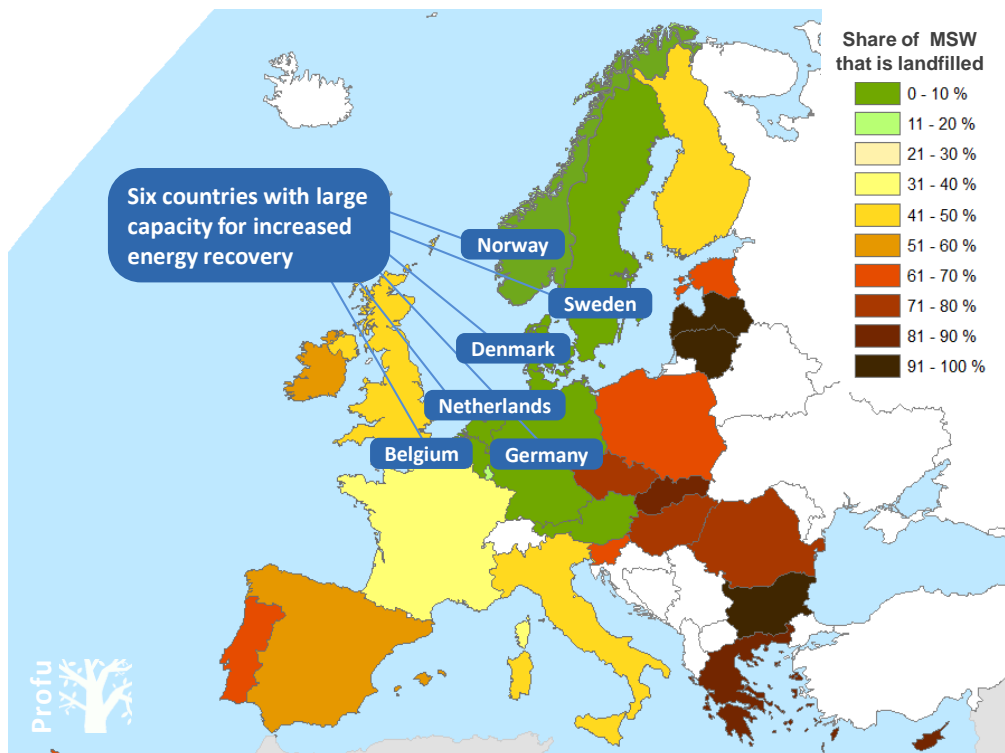


Figure 3-1 Share of MSW that was landfilled in EU27 2009 (Norway 2010) and the six countries that were selected for this study as potential “energy recovery countries” for imported combustible waste from Eastern Europe.

It should be noted that even if Eastern Europe has the largest share of landfilling, as illustrated in Figure 3-1, these countries do not landfill the largest amount of waste. The countries that landfills most waste are England, Italy, Spain and France. However, the topic for this study is to examine how trade with combustible waste can help countries with the largest need of support. That is, countries that today are far behind in their development of integrated waste management systems and currently have low ability to pay for improved waste treatment.

The supply and demand of combustible waste for the six “energy recovery countries” mentioned earlier (Norway, Denmark, Sweden, Germany, The Netherlands and Belgium) is shown in Figure 3-2. Note that both the supply and the demand side in this report is delimited to incineration facilities with energy recovery, i.e. neither co-incineration plants (cement kilns, power plants) nor specialized plants for RDF or SRF combustion are included. The figure shows that there is a large amount of capacity available for import and some of it is used already today. In total, there was an estimated surplus of 2.2 Mtonnes in 2010 and the prognosis indicates that this surplus capacity could grow to 7.2 Mtonnes in 2020. The capacity available for import in these six countries is small in comparison with the quantities landfilled in EU27 (less than 2% for 2010). Some import and export of waste occur, already today, between these “energy recovery countries” as well as smaller amounts of import from other European countries.

The prognosis for supply and demand takes into account:

- The present and planned new capacity for energy recovery.
- Assumptions for how the total domestic waste quantities will change during time.
- National goals for waste management (e.g. waste prevention and increased material recovery and biological treatment)

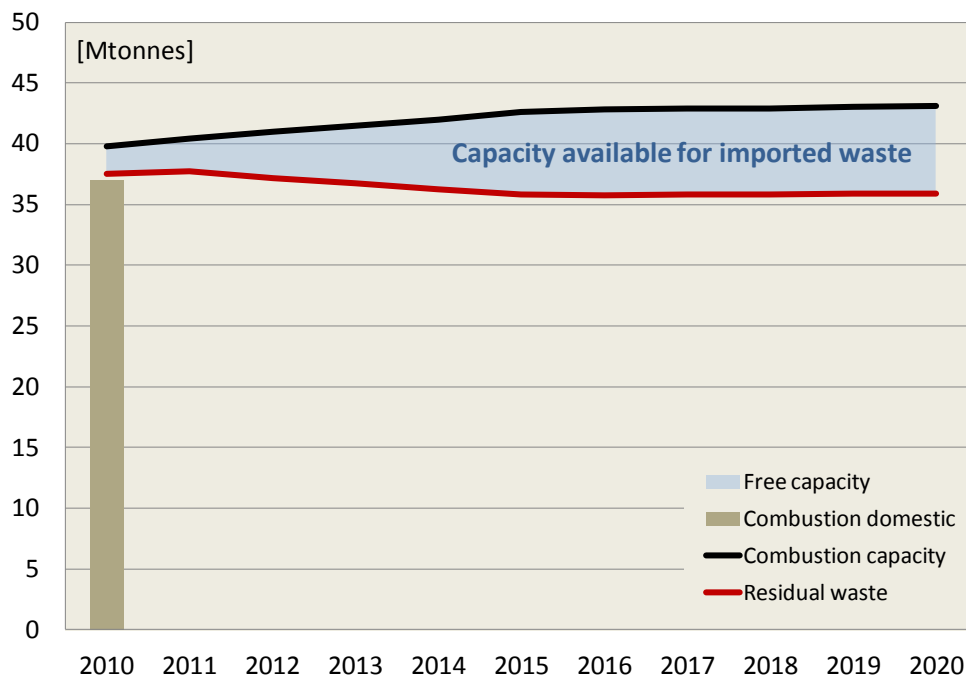


Figure 3-2. Supply and demand of combustible waste for the six countries together. The residual waste (red line) is a prognosis of the total domestic demand in the six countries. The energy recovery capacity (black line) shows the total capacity of both existing and planned plants. The blue area indicates the surplus in capacity available for imported combustible waste.

One way of illustrating the supply and demand for these existing national markets is to divide the six countries into two regional markets, one with the Nordic countries and one with Germany, Netherlands and Belgium. The supply and demand for these two groups are found in Figure 3-3.

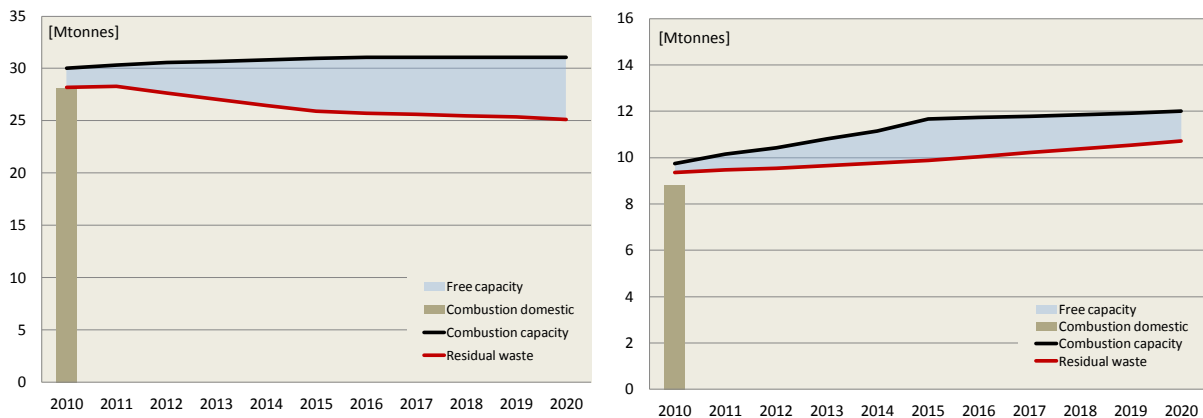


Figure 3-3 Supply and demand of combustible waste for Germany, Netherlands and Belgium (left diagram) and Sweden, Denmark and Norway (right diagram). The residual waste (red line) is a prognosis of the total domestic demand in the countries. The energy recovery capacity (black line) shows the total capacity of both existing and planned plants. The blue area indicates the surplus capacity available for imported combustible waste.

The supply and demand for each of the six countries are found in Figure 3-4. The figure shows that there are large differences between these countries. The dominating country is Germany that not only has the largest energy recovery capacity but also the largest available capacity for import towards the end of the period. Again, it should be noted that the analysis is delimited to incineration plants with energy recovery. In the case of Germany, this capacity is expected to increase very little throughout the period. But the amounts of residual waste are expected to fall as a result of reduced overall waste generation (both due to demographic developments and the further development of waste legislation to resource oriented legislation) and increased separate collection of waste for material for recycling and biological treatment. In the analysis, we have used an average value of two scenarios for the residual waste amounts developed by Prognos AG. Both scenarios assume a general fall in overall waste generation and introduction/expansion of separate collection schemes for biowaste. They differ on how large waste amounts will be separated through introduction of separate collection schemes within a mixed dry recyclable bin. As Germany by far has the highest population, the highest waste generation and the highest energy recovery capacity among the six “energy recovery countries” in this study, it is important to notice that the data for Germany has the largest impact on the results on potential free capacity. Sweden is also a country with large available capacity for import. Although the quantities of domestic waste are expected to increase during the ten years period from 2010 to 2020 there are plans for even more new capacity. The interest for new capacity is driven from the energy sector where high alternative fuel prices makes waste fuels an interesting alternative for both heat and electricity production. The Swedish and Norwegian markets have during recent years become one common market. Even though Norway has less capacity than needed from the domestic market they still have problems of finding enough waste for their own heat, steam- and power production. More and more waste is exported to Sweden that can offer lower gate fees. Denmark has a very large energy recovery capacity per capita but hardly any waste import from other countries. They expect to have only a small surplus capacity available for import during the period

The Netherlands and Belgium can also contribute with import capacity. The Netherlands can contribute in the beginning of the period. There are more or less no new plans for increasing the energy recovery capacity and the gradually increasing need for treating domestic waste will at the end of the period demand the whole available national capacity. In Belgium, on the contrary, there are plans for increasing the energy recovery capacity and the waste quantities are expected to stay at almost the same level as today. Thus, Belgium can contribute with import capacity towards end of the period.

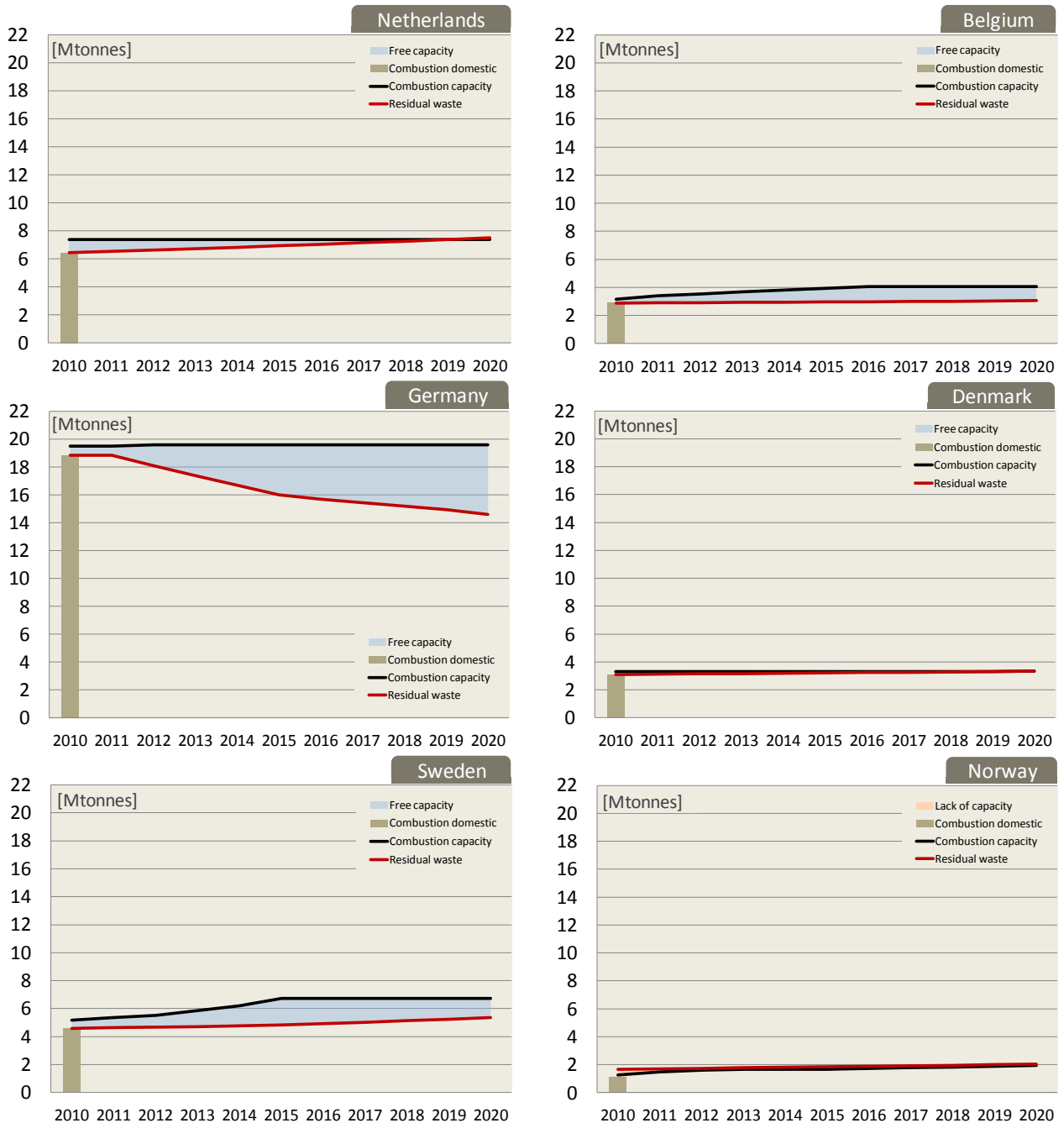


Figure 3-4. Supply and demand of combustible waste for each of the six selected countries. The residual waste (red line) is a prognosis of the total domestic demand. The energy recovery capacity (black line) shows the total capacity of both existing and planned new plants. The blue area indicates the surplus in capacity available for imported combustible waste.

Data and assumptions for supply and demand

Sweden and Norway have been thoroughly examined by Profu in several investigations during the past two years. Publications are available from the Swedish and the Norwegian Waste Management Associations and the Swedish Environmental Protection Agency and from Profu (all publications are in Swedish).

The other countries have been studied through national plans, official EU data, and contacts with companies and organisations. The Germany situation has been studied using data from Prognos AG.

The assumptions for future waste quantities in Sweden and Norway have been calculated using a model that takes into account assumptions of national economic growth and correlations between GDP and waste production. Assumptions for future waste quantities in Germany have been made using data from Prognos AG. Future waste quantities for the other countries are derived from the report "Projections of Municipal Waste Management and Greenhouse Gases" (ETC/SCP working paper 4/2011)

4. Increased trade of combustible waste in a global warming perspective

In Figure 4-1 the aggregated results are shown regarding GHG-emissions. The overall conclusion is that replacing landfilling in one country with energy recovery in another country means an overall reduction of GHG-emissions. This conclusion is valid for import to all the six studied countries Norway, Denmark, Sweden, Germany, The Netherlands and Belgium.

Furthermore, the figure shows that the overall conclusion is a net result of emissions occurring due to the export-import and other emissions being avoided due to the export-import.

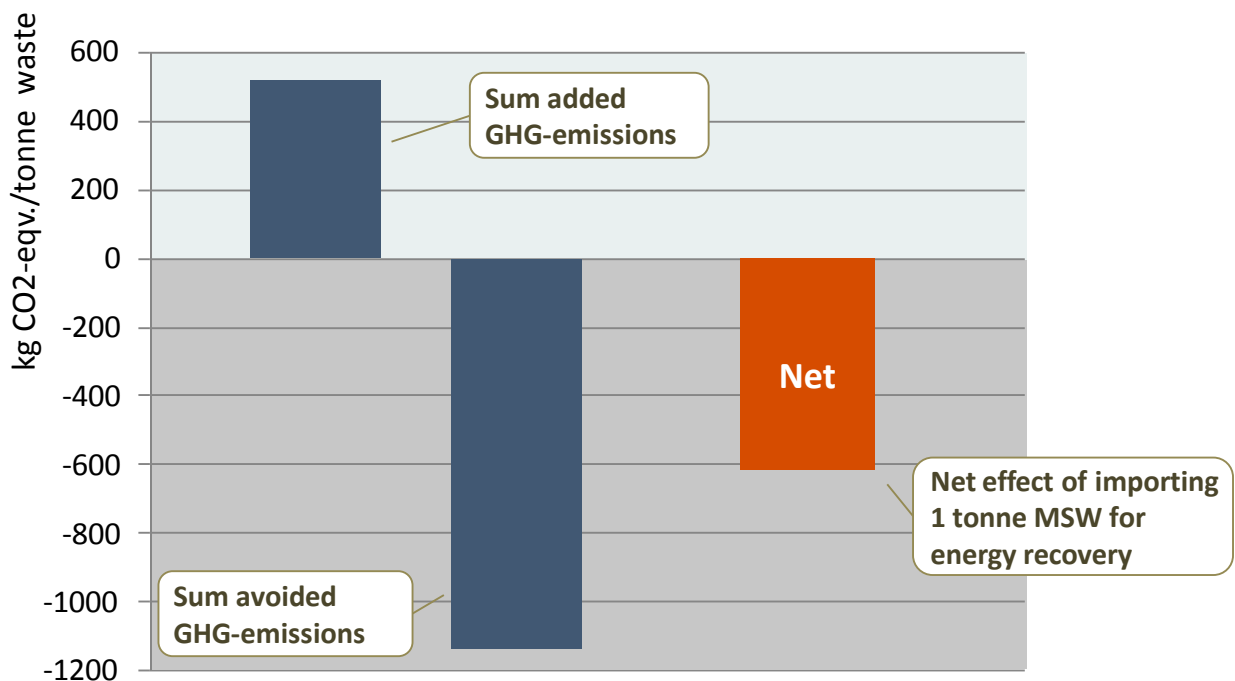


Figure 4-1. Marginal effect of import from “landfilling country” . Summary of emitted and avoided GHG-emissions when 1 tonne MSW is exported from a country where it otherwise would be landfilled. In the importing country, the MSW is combusted with energy recovery. The figure shows the average result for import to the six studied countries Norway, Denmark, Sweden, Germany, the Netherlands and Belgium.

Figure 4-2 shows a breakdown of the results presented in Figure 4-1. From a climate perspective, it is beneficial that landfilling (and the associated methane emissions) is avoided. Furthermore, the energy recovery means that emissions from alternative production of electricity, steam and district heat can be avoided. On the downside, the export-import means increased GHG emissions at the energy recovery plants, mainly due to the fossil carbon content of the MSW. The transport from the exporting to the importing country leads to increased emissions, but these emissions are significantly smaller than the emissions at the energy recovery plant. Finally, there is an additional effect in the district heating systems that lead to increased emissions. When district heat production from energy recovery plants are increased, less district heat has to be produced by other heating plants in the district heating system. A share of these other plants (differing

between each country) is combined heat and power plants, where district heat and electricity are produced at the same time. When the operating hours are lowered for these plants, they produce both less district heat and less electricity. Consequently, the lowered electricity production has to be compensated by increased alternative electricity production.

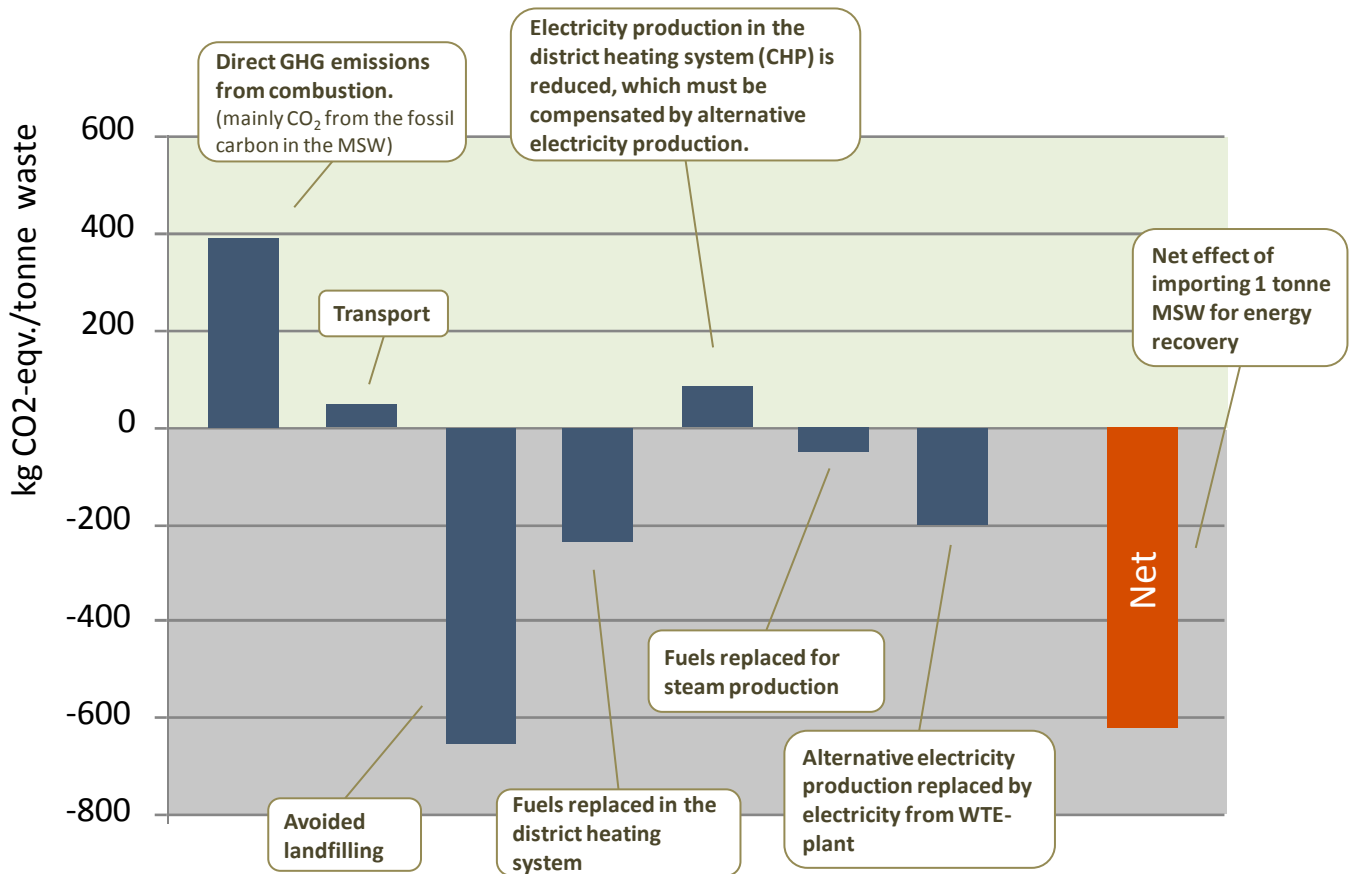


Figure 4-2. Marginal effect of import from “landfilling country”. Emitted and avoided GHG-emissions when 1 tonne MSW is exported from a country where it otherwise would be landfilled, breakdown of the results in Figure 4-1. In the importing country, the MSW is combusted with energy recovery. The figure shows the average result for export and import to the six studied countries Norway, Denmark, Sweden, Germany, the Netherlands and Belgium.

Figure 4-3 shows the individual results for the six importing countries. The different results are mainly due to different levels of energy recovery and what alternative production of electricity, steam and heat is replaced in each country. For example, Sweden has the highest production of district heat per tonne of MSW combusted. But the alternative district heat production is, to a large extent, combustion of solid biomass in heating stations and combined heat and power plants. Consequently, Sweden has the lowest GHG emissions for the alternative district heat production compared to the other five countries. Import to Norway give the largest net reduction of GHG emissions due to a fairly high level of energy recovery and high GHG emissions for alternative production of especially steam and district heat. At the other end of the spectra we find Belgium, which has the lowest level of energy recovery among the countries studied.

From a climate perspective, Figure 4-3 clearly shows that the level of energy recovery and the replaced alternative production of electricity, steam and heat are of much larger importance than the transport distance to each individual country. It should be noted that the total transport distance in the calculations varies from 570 km (Germany) to 1600 km (Sweden).

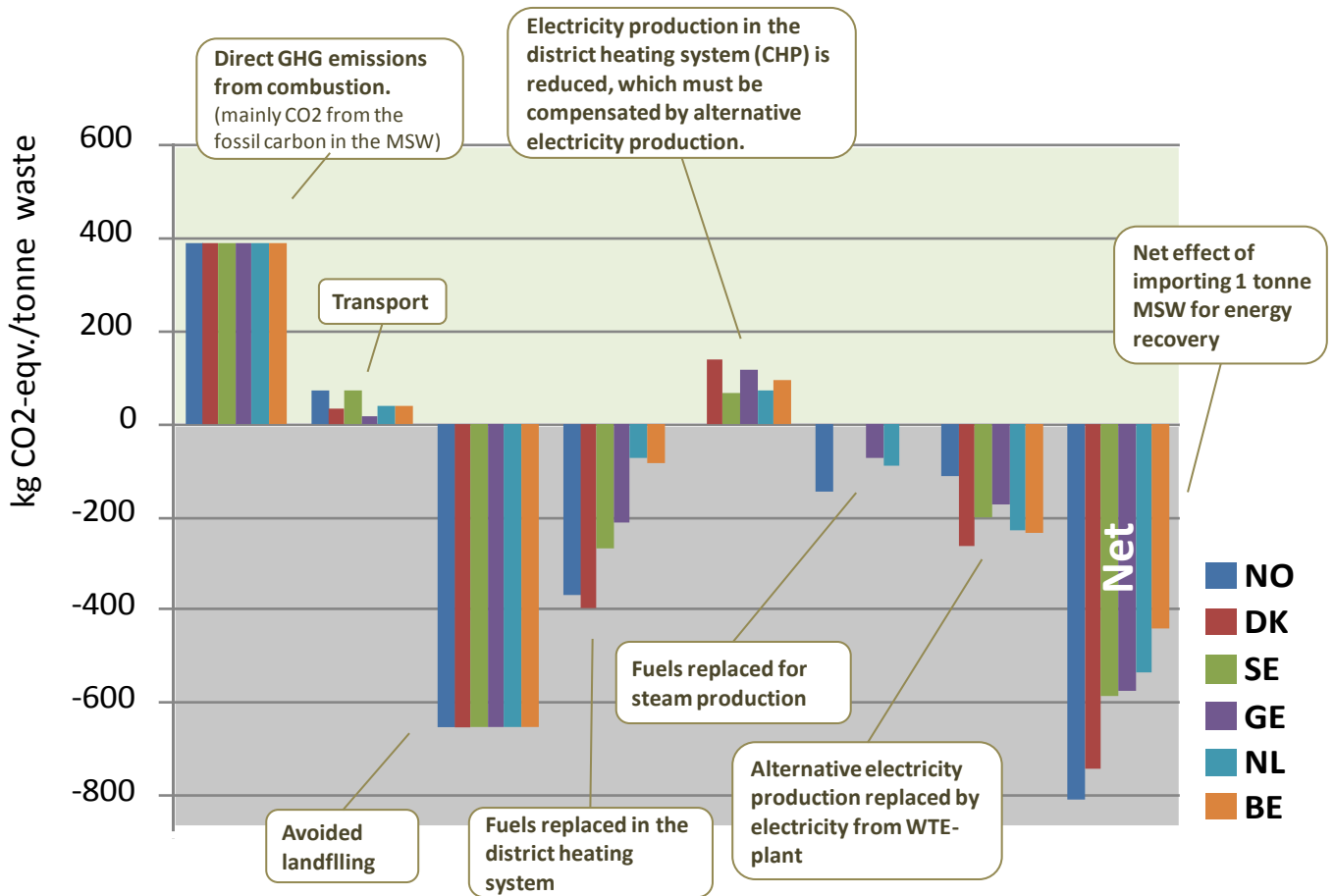


Figure 4-3. Marginal effect of import from "landfilling country". Emitted and avoided GHG-emissions when 1 tonne MSW is exported from a country, where it otherwise would be landfilled, to Norway, Denmark, Sweden, Germany, the Netherlands and Belgium. In the importing country, the MSW is combusted with energy recovery.

5. Increased trade of combustible waste in an economic perspective

In Figure 5-1 the aggregated economic results are shown. The overall conclusion is that increased trade with combustible waste will give an overall increase in net cost. The conclusion is based on that the trade replaces landfilling in one country with energy recovery in another and also on the current economic conditions. Furthermore, the conclusion is valid for import to all the six studied countries Norway, Denmark, Sweden, Germany, The Netherlands and Belgium

This means that it is not cost efficient for the plant owners to import, since the import means a cost increase compared to not utilising the free capacity. It is important to note that only variable operating costs for the energy recovery plants are included. If we were to include also fixed operating costs (such as capital costs for the investment), the increase in net cost would be even higher than indicated in Figure 5-1.

Furthermore, the figure shows that the overall conclusion is a net result of costs and revenues occurring due to the export-import.

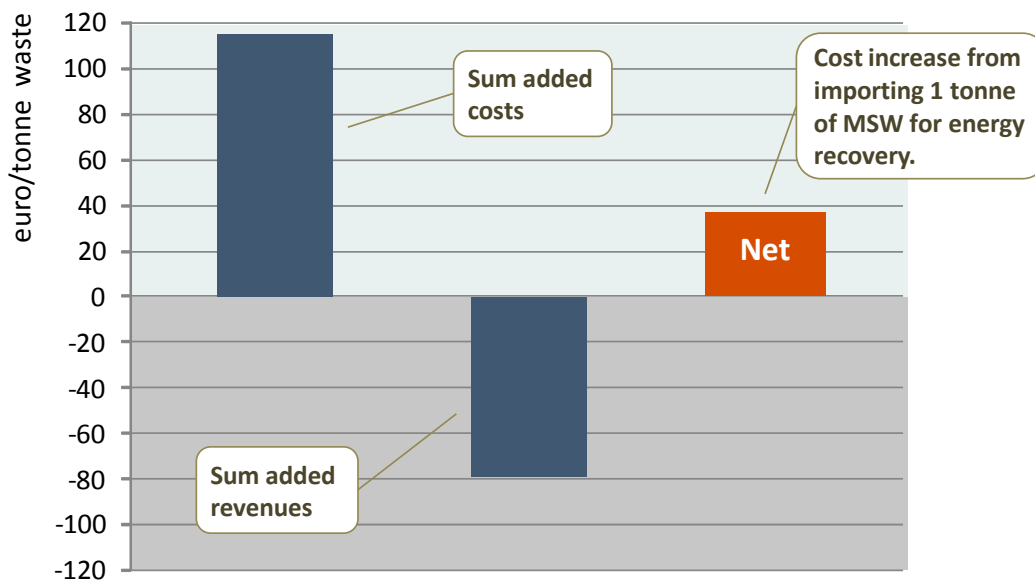


Figure 5-1. Marginal effect of import from "landfilling country". Summary of costs and revenues when 1 tonne MSW is exported from a country where it otherwise would be landfilled. In the importing country, the MSW is combusted with energy recovery. The figure shows the average result for import to the six studied countries Norway, Denmark, Sweden, Germany, the Netherlands and Belgium.

Figure 5-2 shows a breakdown of the results presented in Figure 5-1. The increased costs are due to:

- **Energy recovery:** These calculations include variable operating costs + taxes and fees. This reflects a situation where the energy recovery plants have free capacity that is unused if the import is not taking place. From a plant owner's perspective, these costs arise as direct consequence of the import. These costs should be seen as a minimum and valid in a short term perspective, since the plant owners also have fixed operating costs (e.g. capital costs

for the investment), which must be covered in a long term perspective. Adding the fixed operating costs would mean increasing these costs by approximately 50-90 euro/tonne.

- **Transport:** These costs are dominated by costs for truck transport from the exporting to the importing country. As can be seen in the figure, these costs have a significant impact on the overall result. Furthermore, it should be noted that an important condition for these costs are the use of return transports, i.e. utilising trucks that otherwise would return empty after delivering their original product to the exporting country. Otherwise, these costs would increase by approximately 20-40 euro/tonne (as indicated in Figure 5-2).
- **Production of bales:** Producing bales means a considerable cost increase. This step could potentially be excluded in cases of relatively short transport distances, e.g. in the case of export from the western part of Poland to the eastern part of Germany.

On the upside are the revenues generated by the import. First of all, for treating the waste the energy recovery plants should receive the same gate fee as landfilling in the exporting country. The gate fee level (20 euro/tonne) is assumed to be representative for landfills in the former Eastern Europe. If this gate fee level would be increased, for example by introducing landfill taxes, the economic result for the import would be improved. Given the results in Figure 5-2, a landfill tax of around 40 euro/tonne would be necessary to make import an economically viable option. Secondly, the energy recovery plants receive revenues by selling the generated electricity, steam and heat.

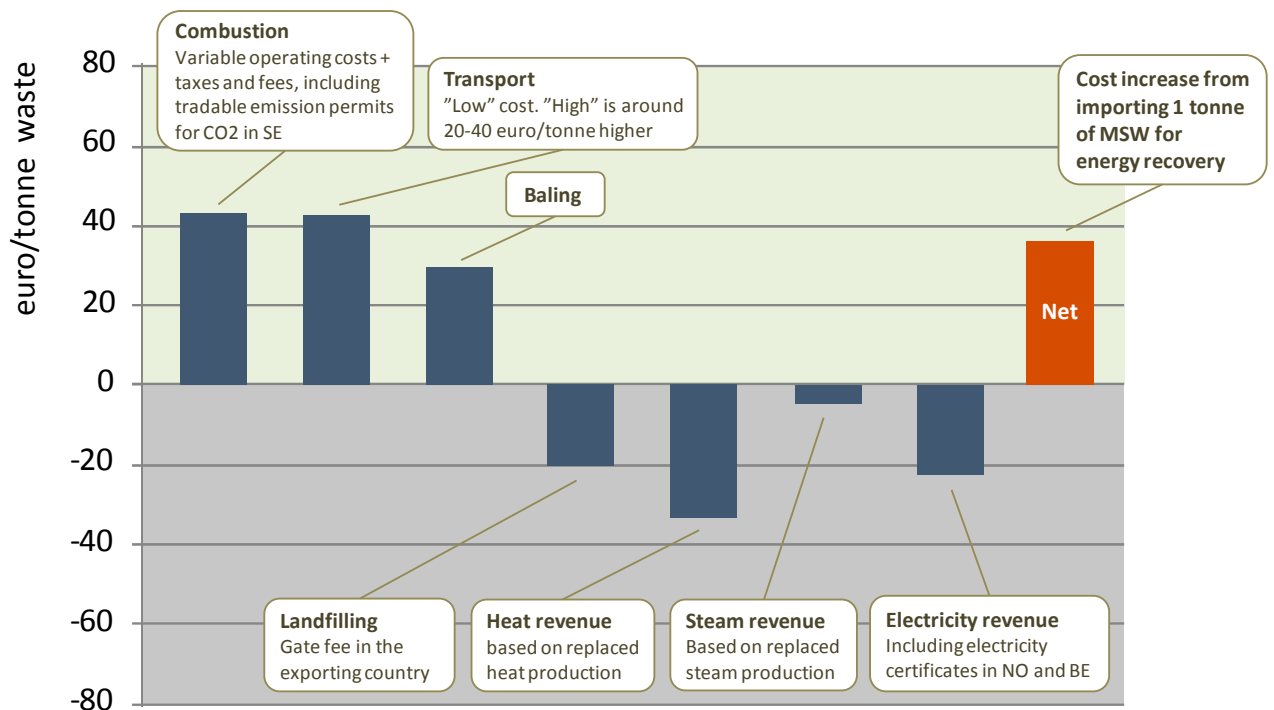


Figure 5-2. Marginal effect of import from "landfilling country". Costs and revenues when 1 tonne MSW is exported from a country where it otherwise would be landfilled, breakdown of the results in Figure 5-1. In the importing country, the MSW is combusted with energy recovery. The figure shows the average result for export and import to the six studied countries Norway, Denmark, Sweden, Germany, the Netherlands and Belgium.

Figure 5-3 shows the individual results for the six importing countries. The different results are mainly due to different energy recovery costs, transport costs and revenues for sold energy.

Regarding energy recovery, Denmark differs notably from the other countries due to national taxes and fees levied on incineration with energy recovery. Belgium has a national tax on incineration, but it is on a lower level than in Denmark. For Sweden, the cost for tradable emission permits of CO₂ is included. Swedish incineration plants are currently not included in the European Union Emissions Trading Scheme (EU ETS), but it is highly likely that they will be included from 2013.

The transport costs are directly linked to the transport distance. In these calculations, Sweden and Norway has the longest transport distance and subsequently the highest transport costs. For these countries, it might be interesting to evaluate boat transport as an alternative, since boat transports generally show lower costs per distance than truck transports. On the other hand, boat transports mean additional costs for loading and unloading the vessel in the range of 10 euro/tonne.

The revenues for sold energy depend on the amount of energy recovered and the price (or alternative cost) for each commodity. The power markets today are international, leading to fairly small differences in the price of electricity between the countries. The markets for district heat and steam, on other hand, are local and depend on the economic conditions in each country (e.g. taxes and other levies on fossil fuels). Sweden has the largest revenues for sold energy. The major part of these revenues comes from sales of district heat, where high energy and CO₂ taxes on fossil fuels make alternative production significantly more costly than in the other five countries.

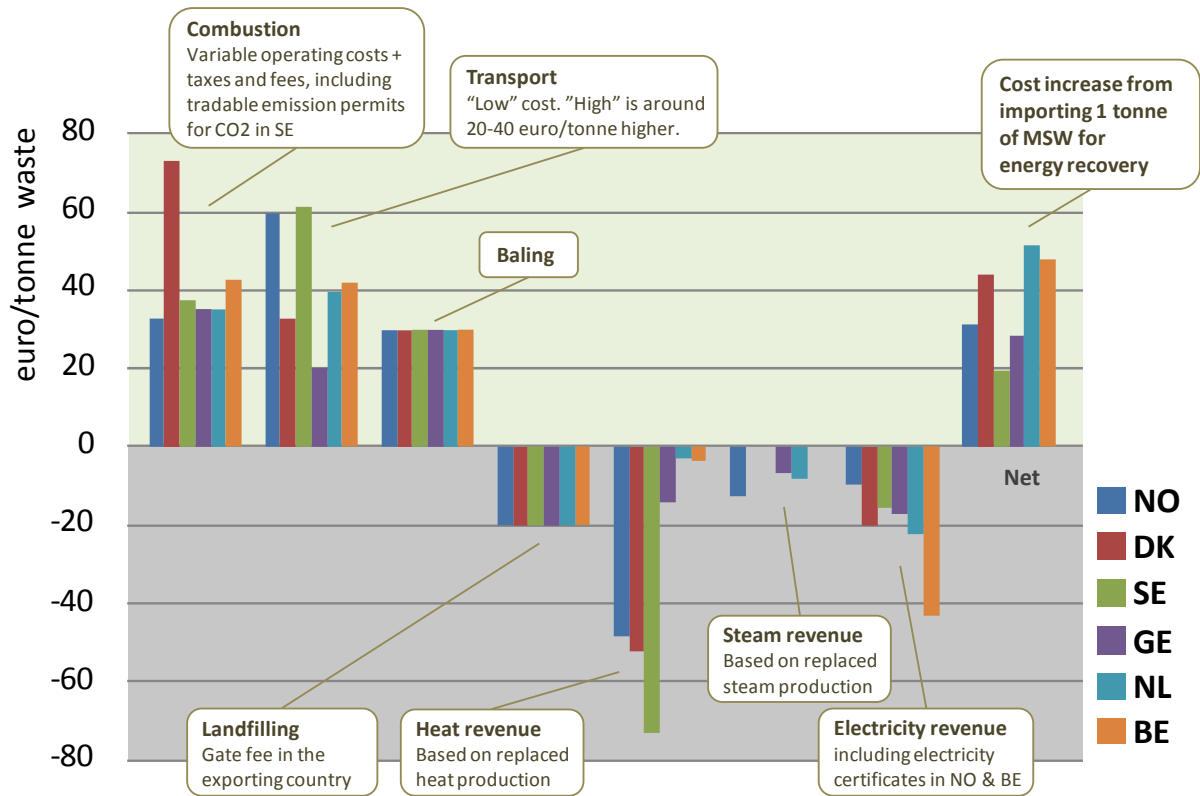


Figure 5-3. Marginal effect of import from “landfilling country”. Costs and revenues when 1 tonne MSW is exported from a country, where it otherwise would be landfilled, to Norway, Denmark, Sweden, Germany, the Netherlands and Belgium. In the importing country, the MSW is combusted with energy recovery. NB1! For Sweden we have added the cost for tradable emission permits of CO2 to the variable operating costs. Swedish incineration plants are currently not included in the European Union Emissions Trading Scheme (EU ETS), but it is highly likely that they will be included from 2013. Excluding this cost, Swedish plants would have lower variable operating costs in the figure than for example Norwegian plants. NB2! As the figure illustrates the consequences when free capacity is utilised, no fixed operating costs (e.g. capital costs on the investment) are included. Normally, the larger the incineration plant, the lower these costs are per tonne incinerated. Comparing the incineration capacity of e.g. Norwegian and Swedish plants, the inclusion of fixed operating costs in the figure would mean higher additional costs for Norway than for Sweden.

6. Contribution to EU directives and goals

The export of combustible waste from countries, where it otherwise would be landfilled, to countries where it is combusted with energy recovery, contributes to several goals within the European Union.

First of all, it generally helps EU to reduce landfilling and “move up” the waste hierarchy as defined in the Waste Framework Directive (2008/98/EC). In the case of MSW (as calculated in this report), the export-import contributes to fulfilling the targets of reduced landfilling of biodegradable MSW according to the Landfill Directive (1999/31/EC).

The potential free capacity in energy recovery plants, as estimated in Chapter 3, corresponds to 10-30 % of the projected total amount of landfilled MSW¹ in Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Poland, Romania and Slovakia in the period 2010-2020. The low figure corresponds to today’s situation and the high figure corresponds to a situation 2020 when the potential free energy recovery capacity has increased and the amount of landfilled MSW in the eighth former Eastern European countries has decreased.

Furthermore, the export-import contributes to the ambitions of reducing emissions of greenhouse gases and increasing the use of renewable energy as laid down in the EU climate and energy package.

Utilising the potential free capacity in 2020, as estimated in Chapter 3, would correspond to around 0.1 % of the total increase of renewable energy² necessary to achieve the goal that 20% of EU energy consumption is to come from renewable resources by 2020. In addition, it would also stand for around 0.6 % of the GHG emission reduction necessary to achieve the goal by 2020 to reduce EU greenhouse gas emissions of at least 20% below 1990 levels.

Regarding GHG emission reduction, the result in Chapter 4 shows that the export-import would lead to reduced GHG emissions. But, as shown in Chapter 5, the export-import is hampered from an economic perspective, since the energy recovery operators would face higher costs from treating this waste than to leave their free capacity unused or, if possible, import from other countries where the domestic cost is higher than assumed for the exporting countries in this study. Some kind of economic incentive could be an option to realize this export-import. The results in Figure 5-3 indicate that this incentive has to be around 30 euro/tonne MSW to realize import to Norway, Sweden and Germany and around 50 euro/tonne MSW to realize import to all six importing countries. The lower level could be evaluated in respect to the GHG emission reduction achieved taking the potential free capacity in each country into account. 30 euro/tonne waste would correspond to a GHG emission reduction cost of just over 50 euro/tonne CO₂-equivalents³. This is substantially higher than the current price for tradable emission permits of CO₂ (around 15 euro/tonne CO₂) but in the same range as options including Carbon Capture and Storage.

¹ According to the baseline scenario in ETC/SCP (2011)

² This is based on the assumption that 50 % of the energy content of the MSW come from the renewable fractions.

³ In this calculation we have excluded the cost for tradable emission permits of CO₂ for Swedish incinerations plants, since this cost otherwise would be double counted.

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Appendix A Landfilling in the exporting country

The data for landfilling in the exporting country is assumed to reflect the following conditions:

- 40 % of the generated methane (landfill gas) is assumed to be collected through gas collection systems
- 15 % of the methane (landfill gas) that is not collected is assumed to be oxidised to CO₂ in the surface layer of the landfill and thus give no contribution to enhanced global warming
- The collected methane (landfill gas) is assumed to be combusted in a gas engine with electricity production. 30 % of the energy content in the methane is assumed to be transformed to electricity.
- This electricity production is assumed to replace other electricity production from mainly coal power, thus leading to reduced emissions of CO₂.

These data are used in the landfill sub-model of the waste management systems model ORWARE (Dalemo et al 1997, Sundqvist et al 2002, Eriksson and Bisailon 2011) to calculate the resulting GHG emissions from landfilling MSW. The model calculates the net GHG emissions, i.e. the net of emitted methane and avoided CO₂ emissions from alternative electricity production being replaced through the electricity production from collected methane. The global warming potential is assessed in a 100 year perspective where 1 tonne of methane has the same effect as 25 tonnes of CO₂ (in line with IPCC 2007).

Observe that the model calculates the total GHG emissions during a “surveyable” time period. The surveyable time period is assumed to be the period until the landfill has reached a pseudo steady state (Finnveden et al 1995). This is, in the case of landfilling, until the major part of the methane production has ceased, which normally is around a century. The results in Chapter 4 thus show the total GHG emissions that are avoided during the surveyable time when 1 tonne of MSW is exported for energy recovery instead of being landfilled.

Appendix B Transports

The following distances are used in the calculations for the truck transport between the exporting country and the importing countries Norway, Denmark, Sweden, Germany, The Netherlands and Belgium:

- Norway: 1570 km (of which 150 km on a ferry link)
- Denmark: 860 km (of which 50 km on a ferry link)
- Sweden: 1610 km (of which 150 km on a ferry link)
- Germany: 570 km
- The Netherlands: 1200 km
- Belgium: 1290 km

The GHG-emissions from truck transport are assumed to be 33 g CO₂-equivalents/tonne, km. It is assumed that return transports are used, i.e. trucks are used that have transported goods from the importing country to the exporting country. This means that emissions are included only for the transport from the exporting country to the importing country and no emissions are added for the transport in the other direction, since the truck is used for transporting other goods in that direction. The emissions are based on using a truck combined with trailer, which in total loads 33 tonnes and has diesel consumption (when fully loaded) of 4.2 litres/10 km. For the ferry links, the GHG-emissions are assumed to be 175 g CO₂-equivalents/tonne, km.

Truck cost data (euro/tonne) are estimated based on Avfall Norge (2011) as:

- “Low” (based on using return transports): $0.031 * \text{distance (km)} + 2.6$
[euro/tonne]
- “High”: $0.055 * \text{distance (km)} + 7.0$
[euro/tonne]

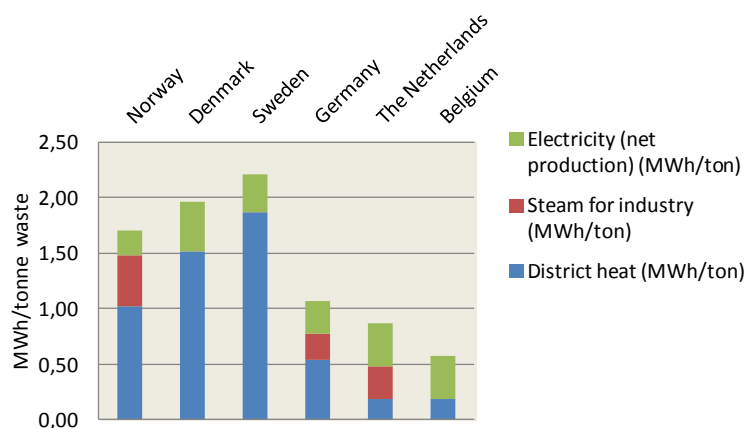
For the ferry link a cost of 4 euro/tonne (Denmark) and 14 euro/tonne (Norway and Sweden) is added to both the “Low” and “High” truck transport cost.

Appendix C Energy recovery and alternative production of energy carriers

Energy recovery

The GHG emissions at energy recovery mainly originate from the fossil carbon content of the MSW. In the modelling, this results in emission of 380 kg CO₂/tonne MSW. Furthermore, the MSW is wrapped in plastic, which also is combusted, adding an extra emission of just over 6 kg CO₂/tonne MSW. This corresponds to a plastic consumption for wrapping of 2 kg/tonne MSW based on data in the ORWARE model (Sundqvist et al 2002). Additionally, 14.5 MJ electricity/tonne waste (Sundqvist et al 2002) is consumed at the wrapping, which results in emissions of just over 2 kg CO₂-eqv./tonne MSW using the emissions of electricity production as outlined in the section “Alternative electricity production” below. Finally, other greenhouse gases (such as nitrous oxide and methane) are formed and released in small amounts during the energy recovery. These gases have higher global warming potential than CO₂ (298 and 25 times higher respectively, in a 100 year time perspective), and gives another contribution of 3 kg CO₂-equivalents/tonne MSW.

The energy recovery is presented in Figure C1 below. Observe that data are reflecting average values for each country and that are large differences between individual plants in each country. Furthermore, Figure C1 shows the calculated marginal energy recovery level when 1 extra tonne MSW is combusted in a potential free capacity that only constitutes as small part of the total plant capacity. The project thus study how much energy that can be recovered from the added imported amount given that a large share of the plant capacity already is utilised. In the case of district heat, this means that the energy recovery level is somewhat lower than what is the case when average data is used. The reason is that in some district heating systems there is a surplus of heat in the summer period, which means that the marginal effect of combusting 1 extra tonne MSW will be that the generated heat is not recovered in the summer period, since there is no demand for it (see also the section “Alternative district heat production” below).



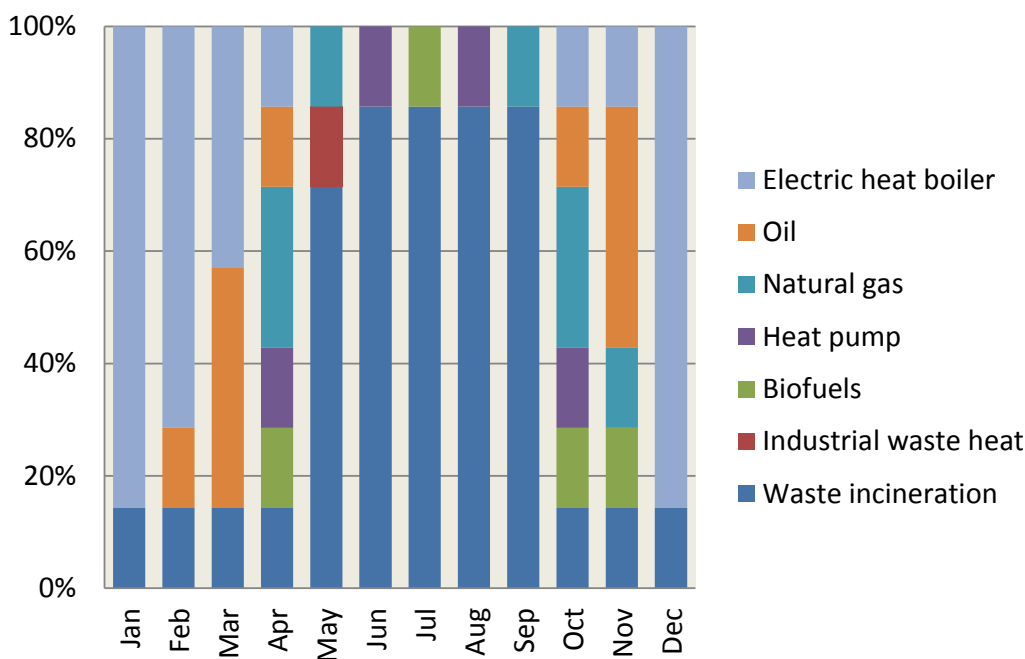
Figur C1 Calculated marginal energy recovery when 1 tonne of MSW is combusted in each country, utilising potential free capacity. The MSW is assumed to have lower heating value of 3 MWh/tonne. The data is estimated based on Avfall Norge (2011), CEWEP (Confederation of European Waste-to-Energy Plants) country reports, Profu (2011), Umweltbundesamt (2007), Euroheat and Power (2011) and Profu’s calculations on alternative district heat production within the project (see section “Alternative district heat production” below)

The variable costs + taxes and fees (as presented in Chapter 5) are based on data compiled from Avfall Norge (2011), Ea Energianalyse (2010), Profu (2011), Umweltbundesamt (2007) and CEWEP country reports.

Alternative district heat production

In the project the quantity of waste for energy recovery varies, resulting in a variation of heat deliveries from combustion to the district heating system. Increased heat deliveries reduce the use of alternative heat production, and vice versa. The reason is that the heating demand remains constant regardless of the amount of waste combusted. The alternative heat production differs from one country to another, and between the district heating systems within a country. The alternatives also vary significantly during the year. In some systems there is a surplus of heat in summer, which means that the alternative is not to generate any heat at all. During the winter, it is usually more expensive options such as wood pellets, oil and electricity which are the alternative to waste fuel.

In order to calculate the costs and emissions from the alternative heat production, a model that has been developed within the research project Nordic Energy Perspectives (2009) is used. The model is based on official statistics of heat production in all the countries that are included in the study (Norway; Norwegian district heat association (2011), Sweden; Swedish district heat association (2011), Belgium, Denmark, Germany and The Netherlands; (Euroheat and Power (2011)). The model identifies the marginal production units for each month (i.e. those which are directly affected by a minor change in heat production from energy recovery plants). Figure C2 below illustrates the monthly mix of marginal heat production in Norwegian district heating systems. Similar results are calculated for the other countries included in the study.



Figur C2 Monthly mix of marginal heat production in Norwegian district heating systems

When the marginal production units have been identified, one can calculate the fuel demand as well as the cost for this production. Country specific fuel prices, taxes, support schemes for renewables etc are included and represent today's situation. A large part of the cost is represented by fuel costs, which are calculated based on fuel use. In addition to this, the model adds costs in the form of taxes and levies, CO₂-allowances and costs for operation and maintenance. Finally, electricity produced in combined heat and power generates a revenue, which lowers the heat production cost.

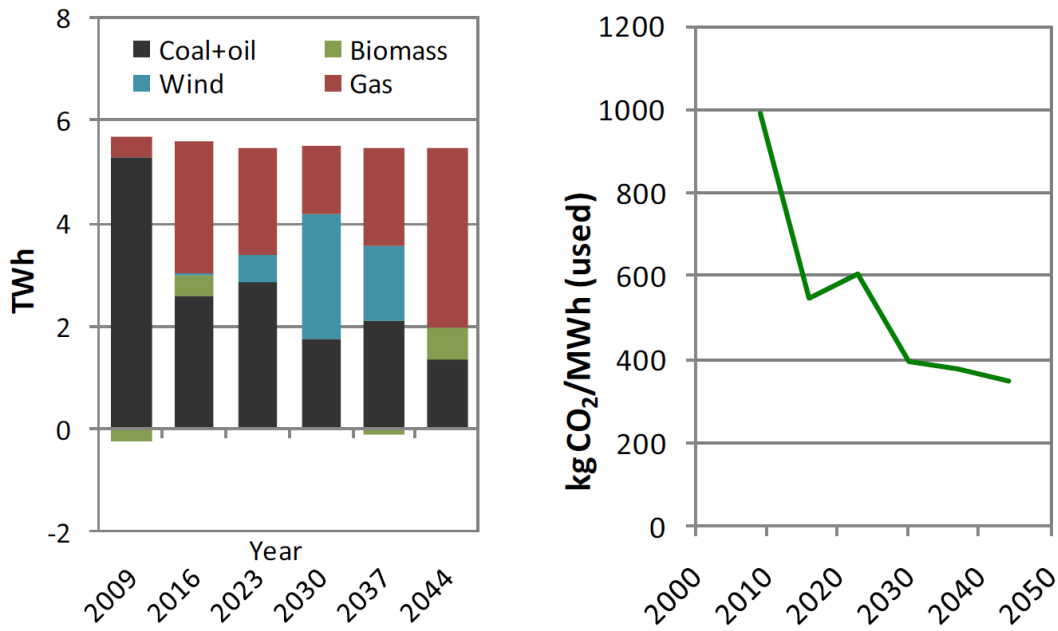
To calculate the emissions from the marginal production the fuel used and the electricity production from combined heat and power has to be calculated. The latter is important since it reduces emissions from alternative electricity production. With knowledge of the type of production unit that produces the marginal heat these data can be calculated.

Alternative electricity production

As the quantities of waste to energy recovery differ in the study, the production of electricity from these facilities will vary as well. Also the need for electricity for alternative district heat production and the electricity produced from other combined heat and power plants will differ. Therefore, one needs to estimate the climate effect of these changes in electricity production. For this, the method of marginal electricity production is being used.

A marginal increase (or decrease) in electricity production may be defined over many years, a single year or over a shorter time period. The definition related to single years (or shorter time) is commonly referred to as the short-term (or "operational") marginal effect, i.e., the change in electricity production does not affect investments in electricity generation. It only involves operation in, at that time, existing power plants, generally the most expensive (alternatively, the least efficient) ones. The analysis of a more long-term change in electricity, typically several years, requires estimates of the long-term marginal effect (sometimes referred to as the 'build margin'). The long-term marginal effect also considers investments in new power plants. Such marginal production (short term and long-term) are important indicators for evaluating the environmental impact of a change in electricity production. This view takes its starting point from the fact that every change in a system (in the demand or supply side) should be valued against the effects it has on the system. Such effects are, therefore, regarded as "marginal" (if sufficiently small) deviations from a reference outcome.

An example of the long-term marginal effect is shown in the figure below. This effect was estimated with the MARKAL-NORDIC model (Elforsk, 2008), including, among other sectors, the North European electricity market. The effect was estimated by increasing electricity demand in a North European country by 5 TWh over the period 2010-2050, and comparing it to a reference case. The long-term CO₂ effect gradually decreases over time. This is due to the fact that the increase in electricity use is met, in the short-term, by existing coal-fired power and in the long-term, by a mix of investments in new technologies, including high-efficiency fossil power (such as CHP schemes), CO₂-lean fossil power, such as gas and/or CCS schemes and renewables, together with the increased utilization of existing (at that time) capacity. The result can be mirrored to describe the effect of an increase in electricity production.



Figur C3 The long-term marginal effect for electricity production, estimated using the MARKAL-NORDIC model. The left panel shows the change in North European electricity production caused by an increase in annual electricity demand of 5 TWh in Sweden, as compared to a reference case. Production is generally >5 TWh due to transmission losses. The right panel shows the resulting change in CO₂ emissions normalized to the use of 1 MWh of electricity.

For more reading, look for example in Alliance for Global Sustainability (2011).

Alternative steam production

GHG emissions and costs are based on the assumption that oil is used for the alternative steam production.