Perspectives on future waste treatment

Waste management in Sweden from 2013 onwards

Waste Refinery

PERSPECTIVES ON FUTURE WASTE TREATMENT

Waste management in Sweden from 2013 onwards

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Project participants:

2013

Content

THE RESEARCH PROJECT:

Perspectives on future waste treatment

Swedish waste management has gone through a big transition. In 10 years time, we see that landfills are closing and energy recovery and material recycling is extensively increasing. We are currently facing great changes, but what will waste treatment look like in 10 to 20 years? This is the issue in focus of the project *Perspectives on future waste treatment*.

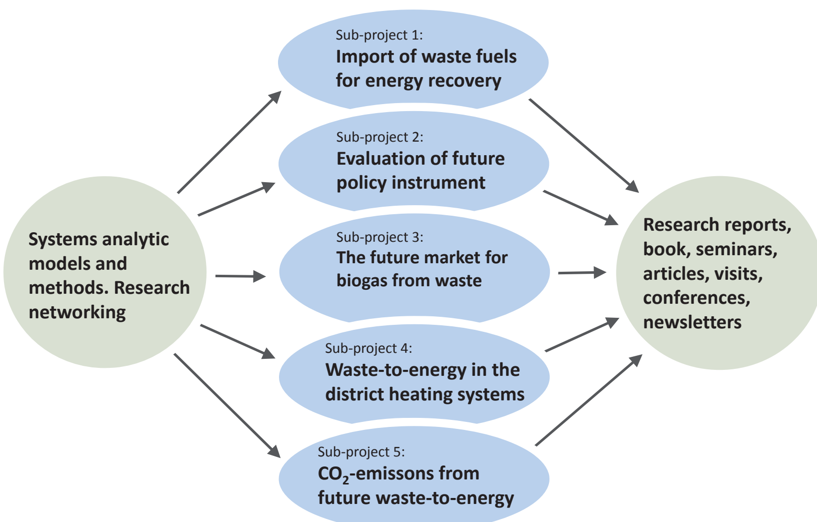
The research project ***Perspectives on future waste treatment*** is looking at the future to show how the waste management will develop, both the development which we can predict but also the development prospects which are more or less likely. Today, there are a several goals and means of controls whose primary objective is to achieve more resource-efficient waste treatment. Given the combination of new technology and new system solutions, there is great potential for great change. But how efficient is the control of today and which technological changes are plausible in this time perspective?

The project, as a whole, covers most of the on-going as well as possible development for the waste treatment until year 2020, and in some cases even to 2030. This time period is too short to reflect a visionary and more comprehensive vision of the future. Much can be improved with our waste management, but only parts of the development potential can be met during this limited time period. But the time period is at the same time long and forward looking if seeing it from the view point of the companies and authorities on how they go about developing their systems. The idea with this project is to end up somewhere in between, that is to say which gives a long-term foundation for the planning of these actors based on what the current systems look like and the visions for the long-term development.

Even if the scope of the project is wide, it does not claim to give the whole picture of the development, but focus is to highlight interesting issues, problems and development possibilities. We have chosen to call these elements perspectives on development. A large array of perspectives has been presented in the intermediate reports of the project and in this compilation we have chosen to present ten of these. It should be pointed out that the focus of the project is waste treatment (material recycling, biological treatment and energy recovery) with emphasis on the two latter methods. A part of the work has also concerned waste prevention measures, but most of the first steps of the waste hierarchy have not been studied within this project.

The project stages

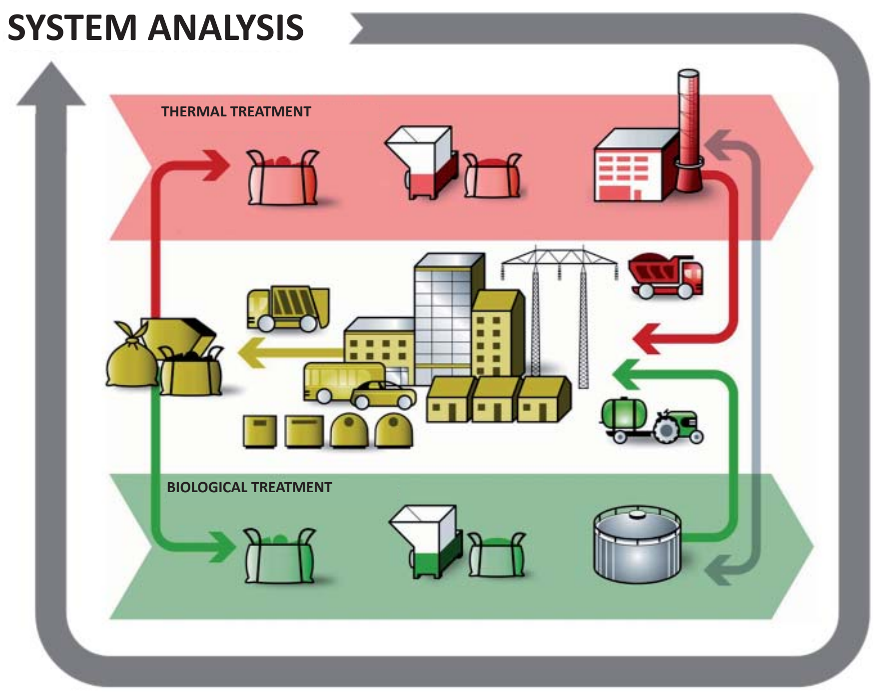
The project has been carried out in 5 subprojects which are shown in the figure below. The sub-projects have been carried out concurrently and by different



working teams. Apart from the studies in the subprojects, the models that were used in the analysis have been developed further and the results from the subprojects have been communicated continuously to the relevant actors.

A system study

The project adopts a system-analytical approach, meaning that consideration is taken to how, for example, new technology and new means of control is affecting the entire waste management system. The estimates are made with a set of models. The models are comprehensive and cover both big and small changes and put together the total influence of the changes. The models, which have been developed by various teams of researchers, describe the influence that a measure has on the energy and material flows, how the emissions are affected and how cost-efficient they are for the system as a whole. The models, which have been primarily used are *ORWARE* (waste treatment system), *NOVA* (district heating system) and *MARKAL* (energy system).



Additional information about the project

During the two years that the project has been running, the results have been presented at conferences and seminars, in articles and in mass media (in total, 75 communication activities). Moreover, newsletters and result letters have been sent out during the course of the project. The most detailed documentation is given in five reports, one for each subproject. The reports can be downloaded from Waste Refinery's website ***(www.wasterefinery.se)***. The five reports are listed to the right. Newsletters and result letters are found at Profu's website ***(www.profu.se)***.

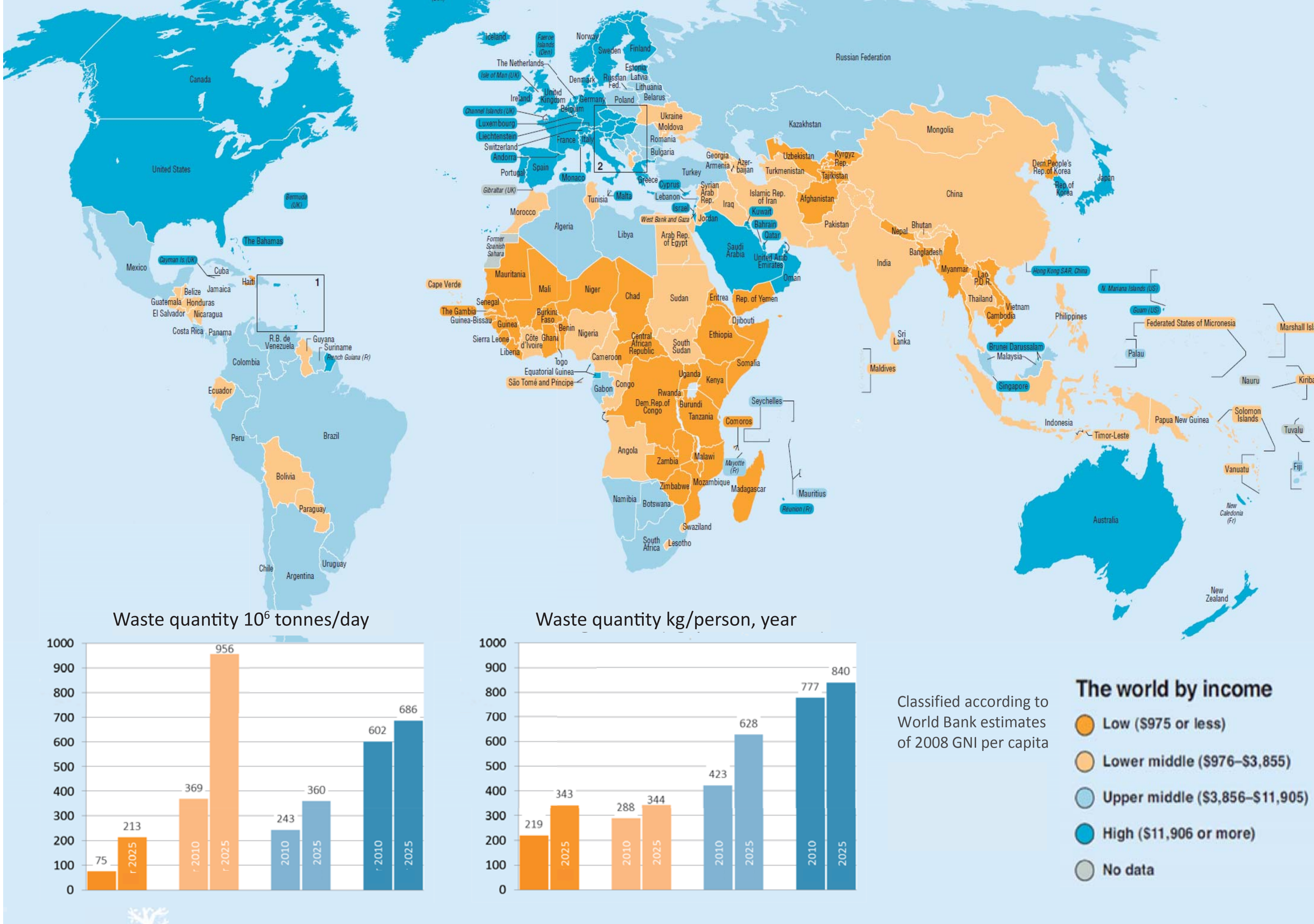
- Import of waste fuels for energy recovery
- Evaluation of future policy instruments
- The future market for biogas from waste
- Waste incineration within the Swedish district heating systems
- Emissions of CO_2 from future waste incineration

Project participants

- Avfall Sverige
- Borås Energi & Miljö
- Energimyndigheten
- EON
- FTI
- Götaverken miljö
- Göteborg Energi
- Göteborgs Stad. Kretslopp
- JTI
- Luleå Tekniska Universitet
- Naturvårdsverket
- NSR
- Profu
- Renova
- SP, Sveriges Tekniska Forskningsinstitut
- Stena innovative recycling
- Svensk Fjärrvärme
- Sysav utveckling

10

perspectives



Source: *WHAT A WASTE - A Global Review of Solid Waste Management*, March 2012 (World Bank Group)

Sweden – No. 1 in the world in waste management!

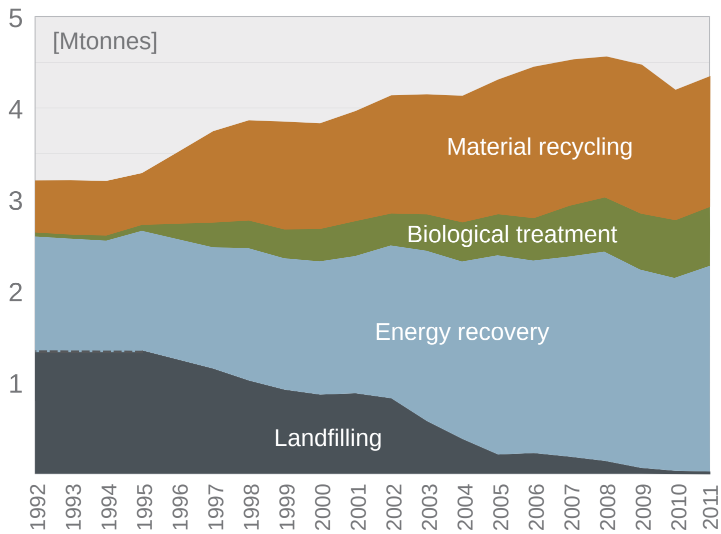
PERSPECTIVE

An interesting insight that this research project has given is that Sweden, from an environmental point of view, has the best waste management system in the world. Together with a few other countries we have, by far, the lowest share of landfilling, the highest share of energy recovery and material recycling, and therefore also the lowest climate impact. It is probable that Sweden also is the best among these high ranked countries due to very efficient energy recovery and material recycling.

This impressive conclusion is relevant if we compare the waste management of collected and treated waste per ton and look at the climate impact. The conclusion is probably also valid for other forms of climate impact, but this is harder to show in unequivocal figures. If we instead compare the waste management per person, we are far from the best. Our high material living standards, with a relatively high production of waste per person, causes a considerable climate impact. To say that we are the best, does not at all imply that that we sit back, the potential for improvement is still great. But we have taken some important steps in the right direction.

From a global perspective, Europe has far better waste management than the rest of the world, and from a European perspective there are seven countries which are considerably better than other European countries. Sweden is one of these seven. It is probable that we are even in the very top of these countries, however, if so, just barely. The obvious follow-up question is: What is it that has put Sweden at this prominent position?

The key factor for the ranking is how far along the transition from landfilling to energy recovery and material recycling has come. But it is almost as important that the achieved energy recovery and material recycling is efficient so that other energy production and raw material can be replaced in a smart way. The figure below illustrates how Swedish waste management has developed the past ten years.



Treatment of MSW in Sweden, 1992-2011.
Source: Waste management Sweden, RVF and Profu

From the figure above, we can establish that landfilling has been replaced by a combination of energy recovery, material recycling and biological treatment. Other countries with clear environmental objectives for waste management, where landfill diversion also has been successful, have a similar combination of these treatment methods. This means for example that countries with high material recycling also are the ones with the highest energy recovery. From this perspective, the competition between the three treatment methods (material recycling, biological treatment and energy recovery) is very small. The methods should instead be viewed as complements which, taken as a whole, can make up an effective waste management system.

The figure above also illustrates the problem with the substantially increased waste volumes. New treatment capacity is needed, not only to replace the previous landfills but also to take care of the increased quantity of waste. This places high demands on society in the form of investments and infrastructure.

Initially, the importance of efficient material recycling and energy recovery was mentioned. There are big differences between the countries in this regard and Sweden excels in many ways. One example of this is the great expansion in biogas production from readily biodegradable organic waste (food waste etc.). The expansion especially stands out due to the fact that Sweden, as only country, uses the biogas as vehicle fuel. The biogas production system that we have is a cost-efficient measure to reduce the emissions of greenhouse gases. If we study the waste incineration, Sweden is the country that has the most effective energy recovery. This does not necessarily imply that we have the most effective incineration technology, but that the most energy per ton incinerated waste is used, both as heating in district heating systems and as electricity in electricity systems. There are other examples of good, and also of not so good, system solutions, but generally speaking Sweden holds a high position in international comparisons.

However, this journey has not been simple. It has required a well-developed infrastructure – an infrastructure that is both extensive and costly. In Sweden, this has led to the development of a collection and source separation system, biogas plants, vehicle gas filling stations, and not the least to an extension of the district heating systems in the cities. The unique position that Sweden has taken is also of help to other countries. We are able to export know-how, technology and system solutions to further the development in other countries, but we can also export the recycling service by offering to recycle waste that otherwise would have been landfilled.

Landfills

Replacing landfilling with some form of recycling should be given first priority, since it has the most significant effect as to reducing the environmental impact from waste management. Despite this, landfills are still the most common treatment method in Europe, and Europe is still significantly better than the rest of the world. Sometimes we might be “blinded by speed” and see our solutions as evident but fact still stands that most countries in the world are far behind in this field. In the EU27 alone, approximately 150 million tons of waste is landfilled every year (90 million tons of household waste and 60 million tons of industrial waste). If we include the new EU candidate countries, the landfill volume increases to approximately 180 million tons.

Sweden has come a long way in closing landfills. Thanks to landfill tax and landfill ban, the landfills of organic material (food waste, paper, plastics etc.) has almost been completely phased out. In 2011, only 0.9% of the household waste went to landfills. Other countries that also have come a long way are Austria, Germany, Netherlands, Denmark, Norway, Belgium, Switzerland and Japan. All of which, with the exception of Japan, are European.

The top map on the next page shows the ***share*** of household waste (MSW) that is landfilled in the European countries. The bottom map also describes the landfills in Europe, but the waste volumes that are landfilled in each country. The maps illustrate that even though Eastern Europe deposit a big share of their household waste, it is south-west Europe that landfills the largest quantities, despite a significant share of recycling. The explanation lies in that the countries in south-west Europe have large populations and a high material consumption which in total results in large waste quantities.

There are some examples of countries around the world which to a greater extent have managed to replace the landfills with some type of recycling, such as Singapore, Hong Kong, China and U.S. In these countries approximately 50%, or slightly less, of the household waste goes to landfill. In many parts of the world there is no functioning collection system and landfills which result in uncontrolled dumping with even bigger environmental impact than landfilling. The introduction of controlled landfilling together with a functioning collection system can in these countries be a more effective way to progress in the waste hierarchy.

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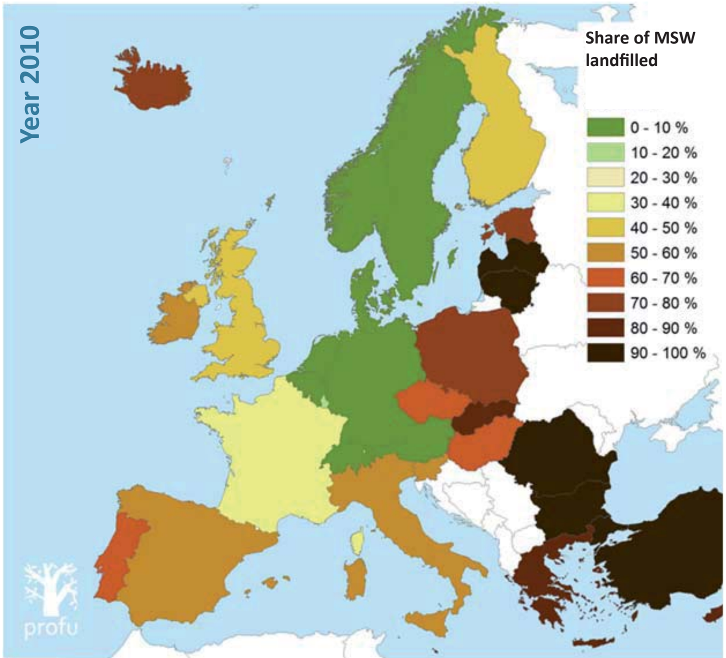
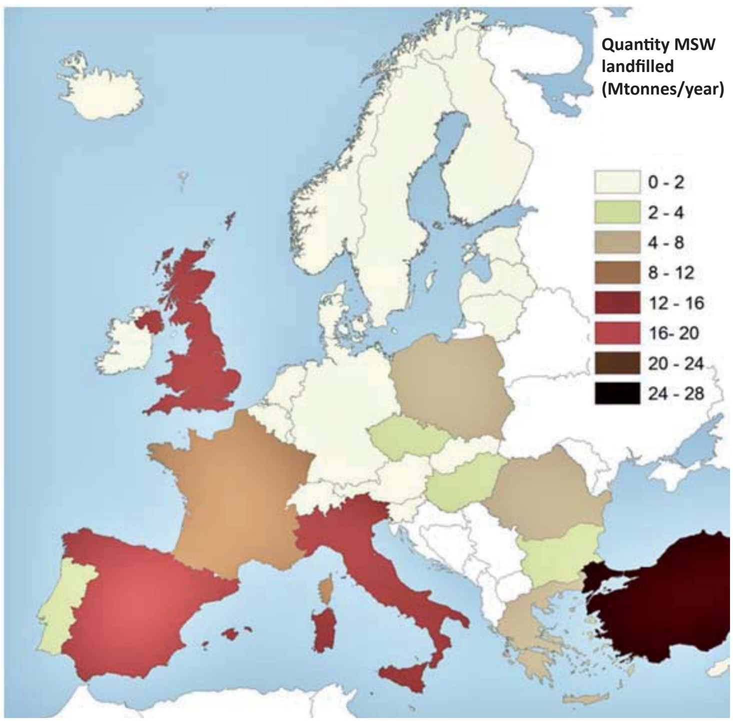
> ”



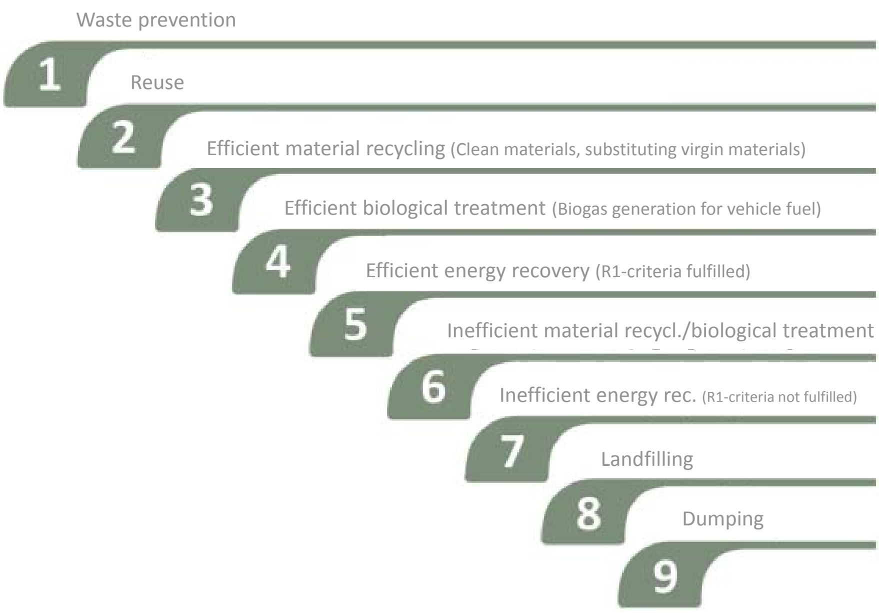


Landfilling of MSW in Europe 2010. The picture above shows the share and the picture below shows the quantity of landfilled waste. Source: Profu (AvfallsAtlas)

Big and small steps

Yet another way to demonstrate important factors in the development of waste treatment, and why Sweden has come somewhat further than other countries, is to study the development from the different steps in the waste hierarchy. There are many different versions of the waste hierarchy which are essentially very similar. The two figures below are two versions of the hierarchy that are based on an overall view of the environmental system analyses which have been performed over the past years. The first waste hierarchy shows the hierarchy between the steps and the second one shows the importance of the steps from a climate perspective. Even if the hierarchies are based on objective system analytical environment studies, the steps only give a general idea of which priorities to make. As concerns other types of waste there might very well be alternative priority choices. It should be noted that the waste hierarchy rank the alternatives from an environmental perspective, but it does not say anything about whether this ranking is cost-effective.

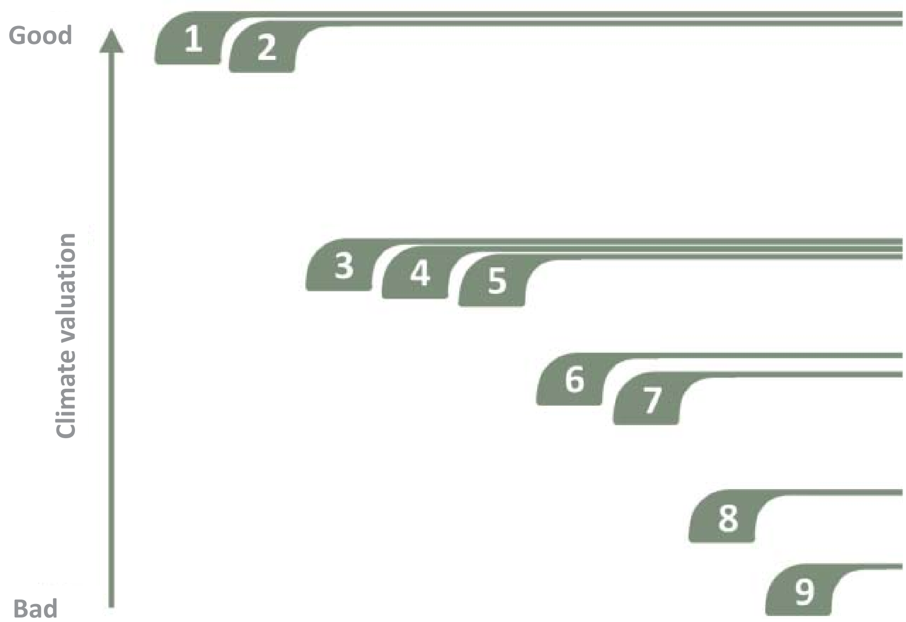
All of the countries mentioned initially as the most advanced have moved several steps up the hierarchy. It should also be noted that the lowest step, landfill (8), is replaced by a combination of other



The waste hierarchy based on environmental systems analysis research during the last years.

steps. However, the activity in the highest steps is low.

The waste hierarchy below is a rough illustration of the how important the steps are from a climate perspective. It should here be emphasized that there are important differences between different waste types. Although, as a guideline value for the bulk of our waste, this illustration gives a good indication of more and less significant aspects as to reduce the climate impact. One conclusion that can be drawn is that the investment in a combination of energy recovery and material recycling as well as biological treatment (3, 4 and 5) is an effective action for replacing landfill (8). Another, and from a long-term perspective, more important conclusion is that waste prevention (1 and 2) is crucial for the development towards sustainable climate-friendly waste management.



Rough estimation of the climate effect from the steps of the waste hierarchy.

Quantity of MSW from Gothenburg. (Year 2008)

Fact: The pile of waste is the total quantity generated in 2008. 76% went to energy recovery, 22% to material recycling and 2% to composting.
Data: Weight: 230 400 tonnes Volume: 1680 000 m^3 Height: 170 m

Swedish household waste in 2020 - the environmental objectives

2

PERSPECTIVE

Historically, Swedish waste management has been strongly influenced by control means on both national and European level. Examples of this are the producer responsibility for packaging, the landfill ban for organic waste and investment support for biological treatment. A clear difference compared to before is that the changes now take place higher up the hierarchy. Can the new objectives give rise to just as big changes and in what way will these have effect? This chapter will present the results for what Swedish household waste management will be like in 2020 if the proposals for new environmental objectives are introduced and complied to.

The last two years, proposals for new objectives for Swedish waste management have been developed within two processes: ***the Environmental Objectives Council*** and the work with ***the National Waste Management Plan***. The focus of the objectives lies on the different waste types which they aim to steer towards different treatment methods. By means of the research project's calculation models a system study has been made to study how the management of Swedish household waste can change if four clear objectives affecting the household waste are attained. These four objectives are described in the short facts below.

OBJECTIVES FOR SWEDISH WASTE MANAGEMENT

• The generated food waste shall be reduced with at least 20% compared to the year of 2010, ***the Environmental Objectives Council – 2011***

• The consumption of textiles from raw material shall be reduced (the objective is set to a reduction of 10% of the waste volumes compared to 2010), ***the National Waste Management Plan – 2011***

• The material recycling of paper, metal, plastics, and glass from households shall be at least 50% in 2020. This objective is today fulfilled for all waste types except for plastic packaging,
the EU Waste Framework Directive

• At least 40% of the food waste from households, caterers, grocery stores and restaurants will be biologically treated so that plant nutrients and energy can be procured, t***he Environmental Objectives Council ¬– 2011***

Two of the objectives aim to reduce the quantities of generated waste. The result shows that these two objectives together can give a reduction of the quantity of household waste of almost 400 000 tons by 2020. The objective for reduced generation of food waste is the largest contributor to waste reduction. It would mean a significant reduction of the waste volume which would be the first large-scale effects of the on-going work with waste prevention measures. Additional control means can become necessary in order to reach these objectives, but as for the estimates and results that are presented here we have assumed that all the objectives will be reached.

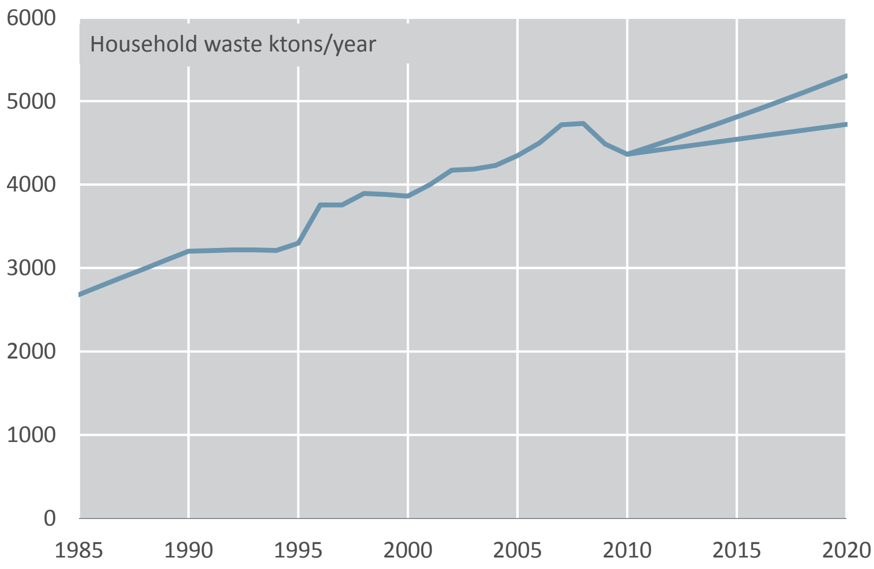
The two other objectives aim to steer parts of the household waste towards biological treatment and material recycling. The volumes and the share of household waste that is biologically treated is expected to increase with this objective, even if the objective for reduced food waste volumes at the same time limits the available quantity of waste which is suitable for this treatment method. The total quantity for biological treatment is estimated to increase by 28% during the period 2010–2020.

The quantity and the share of household waste that will go to material recycling are expected to increase significantly. The quantity increase is primarily due to an increase in the total quantity of household waste and consequently an increase in material recycling. But the increase is also due to increased plastic recycling in order to reach the objective of 50% recycling of plastic packaging. Yet another reason for an increased share of material recycling is a reduced share of generated food waste. As a result, a greater share of the generated waste will go to material recycling. In total, the material recycling is estimated to increase by as much as 25% during the period 2011–2020.

The quantity of Swedish household sent to waste-to-energy plants for electricity and heat production, is expected to remain at their current level throughout this period. However, the total quantity of household waste that is recovered for energy, i.e. Swedish and imported combustible waste, is expected to increase, something which is discussed in more detail in the other chapters of this book. The decreased share of recovery to energy from Swedish waste is a direct consequence of the increase of other recycling methods. The total share of recovery to energy from Swedish waste is estimated to decrease by 5% during the period 2011–2020.

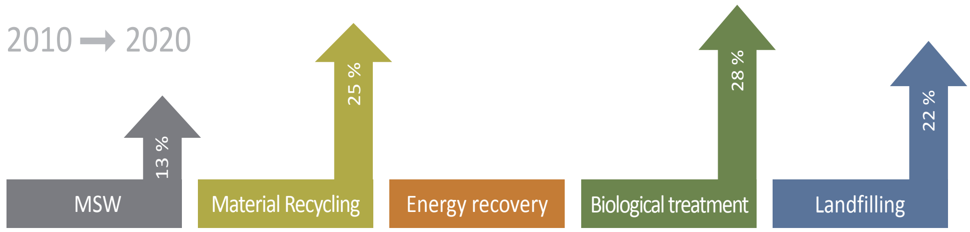
Quantity of generated household wste in 2020 – reduced increase

Two of the four objectives that are accounted for here, aim at having a direct effect on the generation of waste, namely the objective to limit the generation of food waste and the objective to limit the generation of textile waste. The figure below shows that these two objectives would lead to a significant waste reduction by 2020. The reduction represents almost 400 000 tons, compared to a prognosis without these objectives. The food waste objective accounts for the bulk of the reduction.



Prognosis for the amount of household waste with and without waste prevention

Treatment of MSW in 2020:

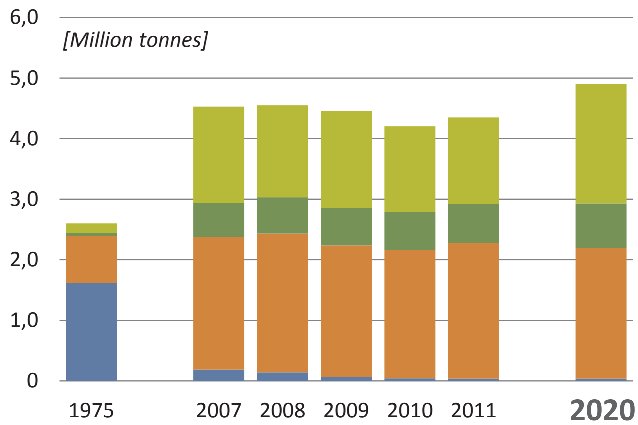


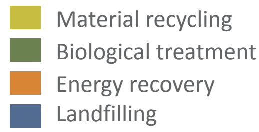
Change (in %) of the generated quantity and treatment of MSW between 2010-2020.

Both of these objectives are to be seen as ambitious for indicating the reduction of food waste and textile waste in volumes. Historically there have been single years when the waste quantities have not increased or even marginally somewhat decreased. 2009 and 2010 were examples of years when, in the wake of the economic recession, there was a small but clear decrease of the quantities. However, the quantities have on average increased with 2% every year during the past 25 years, and there is, still, a strong correlation between the economic growth and generated waste quantities. Compared to the waste quantities that are generated today, the quantity of food and textile waste will decrease with ca. 190 000 tons. But when taking into account that the historical increase of these waste types need to be ceased, the objectives imply a waste reduction of almost 400 000 tons by 2020.

Household waste management in 2020

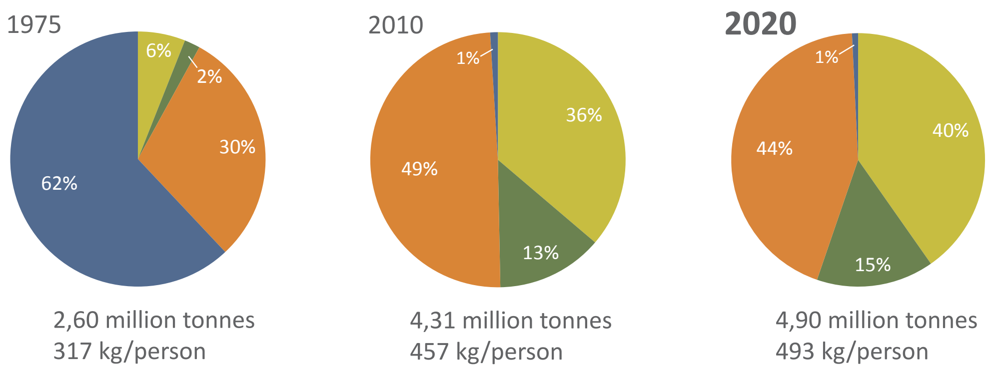
The objectives that have been studied affect, in one way or another, the generated waste quantities and the allocation between treatment options for the Swedish household waste. The last figure and the figure above present the outcome of these objectives, i.e. the change in quantities and the allocation between treatment options. The figures show results for some preceding years as well as a prognosis for the year 2020. The results show increased household waste quantities, increased share and quantity of material recycling and biological treatment and a slightly reduced share of the waste recovered for energy but with unchanged quantity. The reason why the share of material recycling increases is partly because the objective to reach 50% of recycling for paper, metal, plastics and glass not yet has been attained for plastics. But the increased share is also due to the objective to reduce the generation of food waste. The material recycling will increase with ca. 342 000 tons due to increased waste





Change between 2010 and 2020

Material recycling:	+ 25 %
Biological treatment:	+ 28 %
Energy recovery:	0 %
Landfilling:	22 %



Generated quantity and treatment of Swedish MSW between 1975-2020.

quantity during this period and with an additional 47 000 tons to reach the objective for plastic recycling, i.e. a total of 389 000 tons.

The quantity of household waste that goes to biological treatment is estimated to increase with ca. 220 000 tons. Almost two thirds of the increase will be food waste from households, restaurants and stores, and above one third is other organic waste, such as park and garden waste. The quantity of household waste for energy recovery is estimated to remain at the current level. All four objectives that were studies are diverting waste away from energy recovery in one way or another.


FELIX
EKOLOGISK KETCHUP
Estrella
KESO
COTTAGE CHEESE
Apelsin
Frisk och mustig
Mellansmak
28% Fetthalt

Source: FTI

3 The National Waste Management Plan from a climate perspective

PERSPECTIVE

The new Swedish Waste Management Plan "From waste management to resource management" for the period 2012–2017 was published in May 2012. It shows a clear shift towards in that it has a much stronger focus on objectives and measures higher up the waste hierarchy than previous waste management plans. Analyses show that that if the studied objectives are reached, the new waste management will be a clear contribution towards reduced climate impact in 2020.

New objectives are set in the new waste management plan for Swedish waste management which are to be reached the next 5–10 years. The following objectives have been analysed in the framework of the project:

- Reduced food waste
- Increased reuse of textiles
- Increased material recycling of household waste
- By 2018, at least 50% of the food waste from households, institutional kitchens, shops and restaurants must be sorted and processed biologically so that plant nutrients are utilised, with at least 40 % being processed so that energy is also utilised.

The first two objectives aim at the top steps in the hierarchy and signify generation and management of smaller quantities of waste. The third objective signify that material recycling of different fractions e.g. paper, glass, metal, plastic will increase, which also means a shift from waste-to-energy (energy recovery) to material recycling of Swedish waste.

Even if none of the objectives indicate to what extent the quantities will decrease and the reuse and material recycling will increase, analyses performed in the project show that each step in these directions are clear contributions towards reduced climate impact. This is especially valid for the two first objectives where the greatest reduction of climate emissions lies in reduced production of food and textiles.

The objective for material recycling also has clear climate benefits, especially if material recycling of metals and plastics increase. The results are further improved if the transition from energy recovery to material recycling of Swedish waste at the same time releases capacity in Swedish waste-to-energy plants that that is used for treatment of European waste which otherwise would have been landfilled. Swedish objectives and Swedish waste management can in this way contribute to improved waste management also beyond the national borders. An analogy can be made to the Swedish electricity production which, like the Swedish waste treatment, from a European perspective has comparatively low climate emissions. During the period 2010–2030, Sweden is, according to the national energy authority (Energimyndigheten), expected to have a clear electricity surplus which will be exported and replace electricity production in the Northern Europe with far greater climate impact.

The fourth objective is a quantification of the desired effects of the increased biological treatment of food waste. The objective's focus is primarily an increased biogas production from food waste. The project has studied the consequences of attained the objective by 2020. The figure on next page illustrate what this means in terms of generated and treated quantities of food waste in 2020 compared to the actual situation

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Each step in these directions are clear contributions towards reduced climate impact

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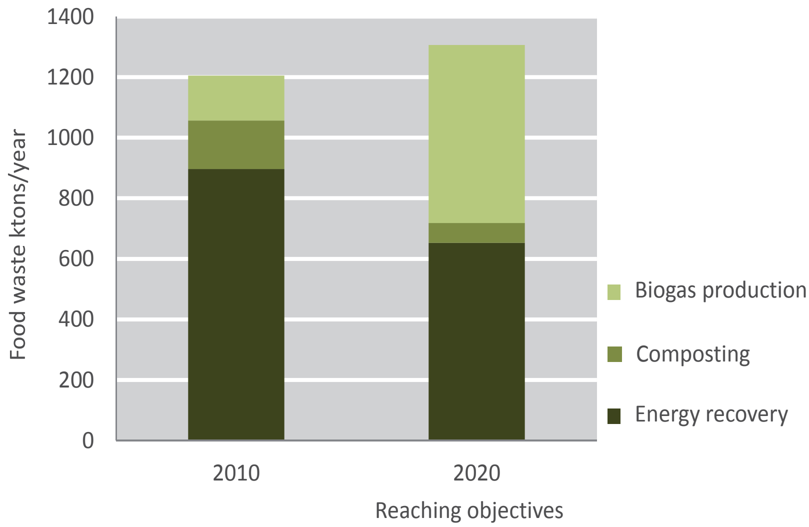


Treatment of household waste year 2010 and year 2020, with respect to governmental objectives

in 2010. The quantity of food waste is expected to follow the demographic trend, hence the increase in total quantities.

The project results further show that reaching the objectives has clear climate benefits. Calculated per tonne food waste, the benefits of food waste prevention are greater, but the objective is still a clear contribution to Sweden's ambitions to reduce climate impact. Just as for the objective on increased material recycling, the climate benefits are increased if the released capacities in Swedish waste-to-energy plants are used for treatment of European waste which otherwise would have been landfilled. Achieving the objective on increased biological treatment of food waste, at a system level, result in a reduction of climate emissions by 170 000 tons of CO_2 equivalents compared to if the allocation of food waste treatment of today would remain until 2020. The corresponding reduction of emissions if Sweden does not use the released capacity for energy recovery amounts to 40 000 tons of CO_2 equivalents.

Waste for biogas production can double by 2020

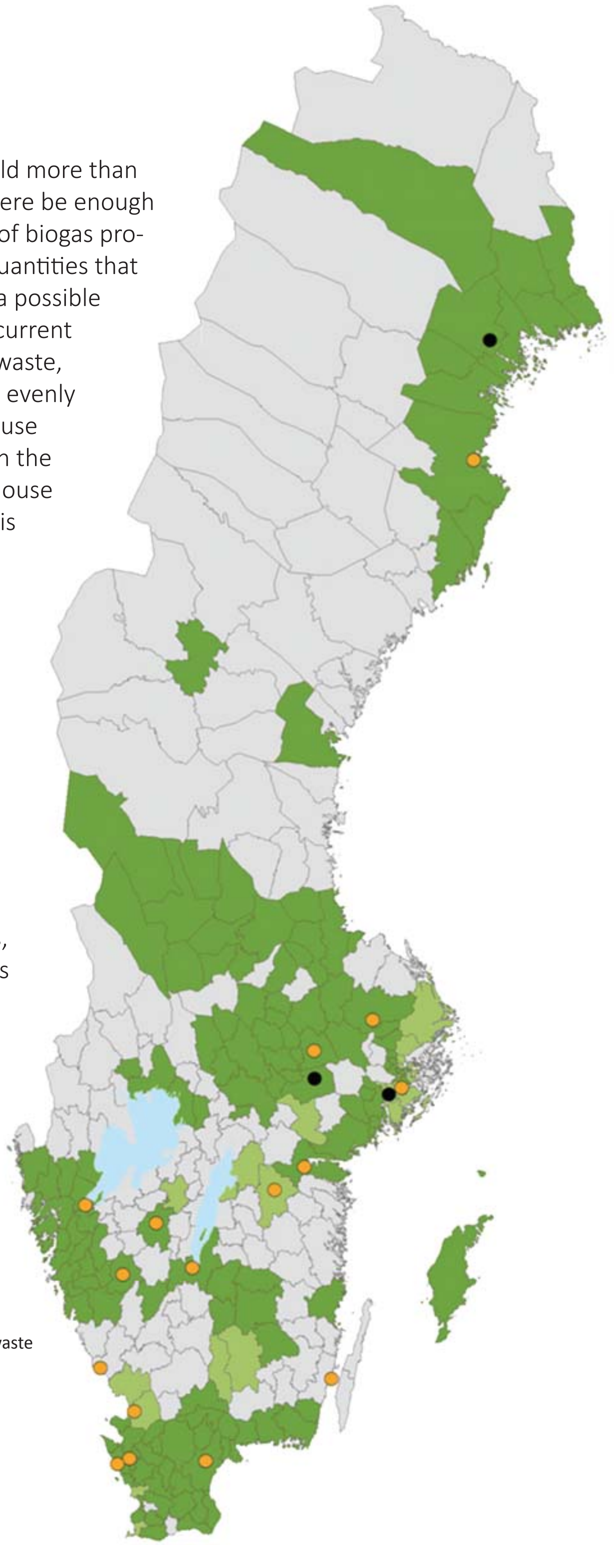
4

PERSPECTIVE

If all the plans for new capacity of biogas production from waste are realized, the Swedish capacity will more than double by the year 2020. But much is still uncertain regarding whether there will be enough volumes of source-separated waste that is suitable for biogas production. Even if the national objective on source-separation of food waste is reached a lot of capacity remains to be fulfilled. This might lead to having to pay for a major part of the waste being treated or treatment of waste with low energy value.

Today there are a total of 19 plants producing biogas from food waste, slaughterhouse waste or foodstuff waste. Most of them are located in the southern half of Sweden. The capacity today is clearly concentrated to the counties of Skåne and Halland. The plants geographical placement is shown in the map on the next page. They also indicate the municipalities that today offer separate collection of source-separated food waste from households, institutional kitchens, and restaurants. Almost 180 of Sweden’s 290 municipalities offer collection of sorted food waste from one of the three sources. 70 more municipalities are planning to introduce such systems within the next five years. That would then mean that 86% of the municipalities in the country will be offering collection of sorted food waste.

Together the existing plants shown in the map digest 750 000 tons of waste per year (excluding sewage sludge). But the expansion of biogas plants is in full progress and by 2020 the capacity could more than double, to 1 600 000 tons per year. Will there be enough waste to cover for the additional capacity of biogas production? The bar chart shows the waste quantities that are used for biogas production today and a possible allocation of this waste type in 2020. The current allocation between food waste, foodstuff waste, slaughterhouse waste and manure is fairly evenly spread. With the exception of slaughterhouse waste, this allocation is expected to remain the same in 2020. (The reason why slaughterhouse waste is not foreseen to increase is that it is considered to already be fully used.) In order to fill the additional capacity of biogas production, the quantities of food and foodstuff waste and manure need to be used in a much higher extent. The food waste quantity (almost 600 000 tons in 2020) correspond to 45% of all food waste generated today. For this to be possible, food waste needs to be source-separated to a much higher extent than is the case today. One incentive is the current national objective of 50% of source-separation of food waste from households, large-scale kitchens, stores and restaurants by 2018. However, this has not yet been complemented with other financial control means at a national level.



Waste collection

Collection from households, institutional kitchens and restaurants

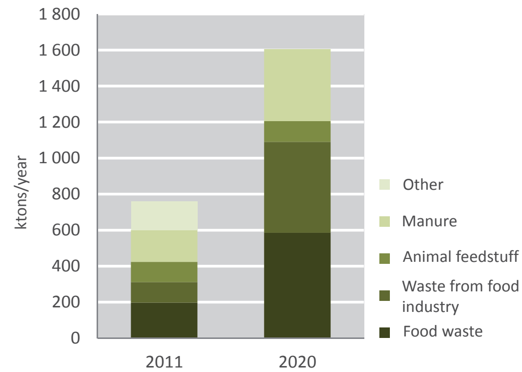
Collection only from institutional kitchens and restaurants

Biogas conversion plants

Sewage sludge treatment plant also digesting food waste

Co-digestion plants

Waste from the food industry is most often well suited for biogas production, especially since it is well sorted at source. Whether or not food waste is used for biogas production is to a large extent due to the conditions of competition in relation to potential outlets. Today, a significant part of the residual products is used as animal feedstuff and where there often is high willingness to pay (up to 2 000 SEK/ton). This means that the biogas producers might have to pay for the waste in order to reach the volumes that are shown in the chart, the alternative being that the need for animal feedstuff is decreased in consequence of decreased animal production.



Waste types used for biogas production year 2010, and potentially use year 2020

Biogas from manure is identified as one of the large untapped potentials for biogas production. The main barrier is for the time being the lack of profitability. Manure has a low energy value per ton which makes it expensive to transport longer distances. Measured in SEK per energy unit biogas, slaughterhouse waste can be transported ten times the distance compared to pig slurry to the same cost. However, potential assessments including financial constraints claim that a manure quantity of 3.1 million tons can be realisable. The figure accounts for a quantity of manure for 2020 that corresponds to the planned treatment of existing and new plants.

” Is there enough waste to fill the foreseen treatment capacity?” ”

The answer to the question ***is there enough waste to fill the foreseen treatment capacity*** is that with the national environmental objective on source-separation of food waste we have come a long way. Apart from this, it requires a significantly increased use of foodstuff waste and manure. For both of these waste types the economic conditions are still very uncertain. It could even be doubtful from an environmental perspective to start using food waste for biogas production instead of as animal feedstuff.


Fordonsgas
Biogas för en
fossilbränslefri stad
BORÅS
ENERGI MILJÖ
Ingår i Borås Stadshus AB

Biogas production is competitive in relation to energy recovery

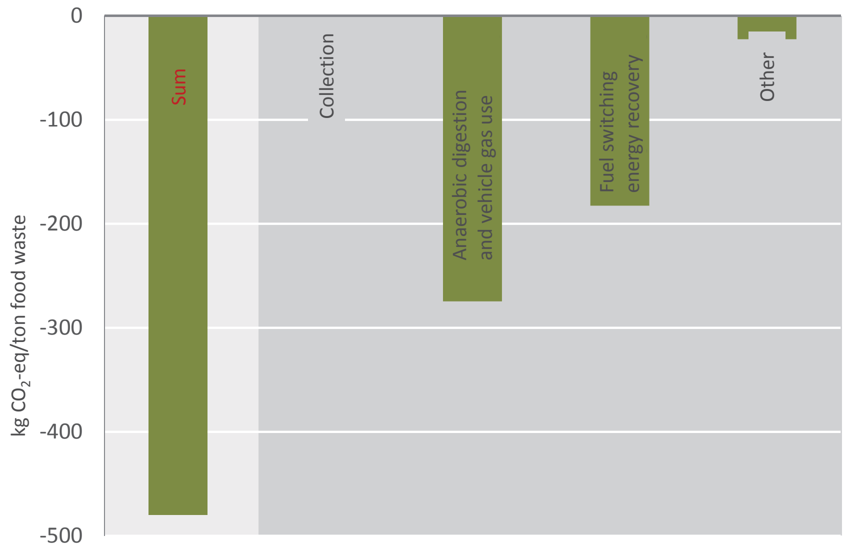
PERSPECTIVE

5

The achievement of the objective on 50% of biological treatment of food waste can by 2020 reduce the emissions of greenhouse gases while at the same time reduce the total costs of the waste management system given the conditions. From a system perspective this means that the climate action has a negative cost.

In April 2012, the government decided upon an intermediate objective on increased resource management in the food chain. According to the objective, 50% of the food waste from households, large-scale kitchens, stores and restaurants should be source-separated and biologically treated by 2018 in order to procure plant nutrients, of which 40% is treated so that also energy can be procured. If the objective is reached the quantity of food waste that is source-separated will increase by 330 000 tons. Moreover, some food waste must be diverted away from composting towards anaerobic digestion, resulting in a total increase of food waste going to anaerobic digestion of 435 000 tons.

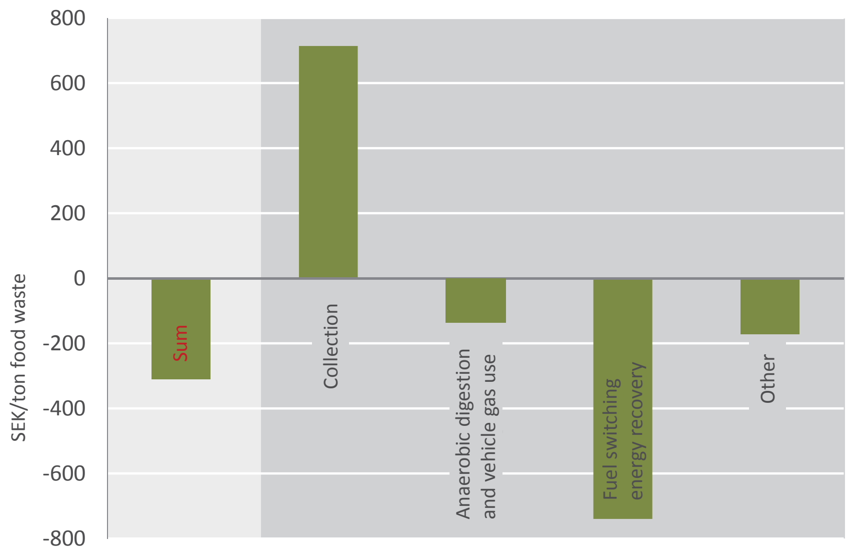
Results at the system level show that emissions of greenhouses gases decrease by almost 500 kg CO_2 equivalents per ton food waste that is diverted away from energy recovery towards biological treatment with biogas production. The



Change in greenhouse gas emissions when producing biogas from 1 ton food waste, compared to energy recovery

results are presented in the figure on the next page. It shows that the emission reduction mainly is due to two factors: the fossil vehicle fuels being replaced by biogas (see the bar ***Anaerobic digestion and vehicle gas use)*** and landfills being replaced by energy recovery (see the bar ***Fuel switching energy recovery***). As regards the latter, increased source-separation of food waste will enable increased import to Swedish energy recovery from countries in Europe where waste today is disposed in landfills. This alone means that source-separation of food waste has climate profits. It should be mentioned that sorting of food waste at source and its transfer are considered to not generate increased transports (hence, the bar Collection is zero), which naturally requires good logistic solutions.

A has been previously mentioned, increased sorting of food waste is required in order to reach this objective. The introduction of such a system is expensive, which is shown by the figure on the next page accounting for sorting and treatment costs per ton of food waste (see the bar Collection). The costs include separation equipment in the homes, new bins, new collection vehicles, information etc. The costs for the entire system are offset by revenues from sale of vehicle fuel produced from the biogas minus the costs for biogas production and distribution of vehicle fuel (see the bar ***Anaerobic digestion and vehicle gas use*** for the net value). The fees for treatment of imported waste fuel also contribute to lower the system cost (see the bar ***Fuel switching***



Change in waste system costs when producing biogas from 1 ton food waste, compared to energy recovery

energy recovery). Included under ***Other*** is first and foremost a reduced system cost from composting of food waste which is estimated to shift to anaerobic digestion. It should be noted that the costs and revenues are estimated given the conditions of the project in 2020 and that the net result is relatively sensitive to different parameters, e.g. costs and technical performance for the whole chain collection–pre-treatment–biogas production–upgrading–distribution of fuel gas from food waste.

The analyses have been performed from a system perspective where increased separation of food waste from residual waste leads to free energy recovery capacity at the waste-to-energy plants. The consequence should then be that the plant owners compensate the reduction with import of combustible waste from Europe. The imported quantity corresponds to the difference between increased sorting of food waste and increased reject quantity from the pre-treatment prior to biogas production. If this does not happen, i.e. if the energy recovery in Sweden instead would decrease, the results still show that the environmental objective leads to reduced climate impact and a lower system cost for the waste management system. The level will fall with-100 kg of CO_2 equivalents and a bit over-200 SEK per ton of sorted waste.

It should be noted that the system analysis above does not claim to account for the profitability of a biogas plant, since several of the costs and receipts that are included in the analysis do not accrue to the owner of the biogas plant.

Swedish energy recovery helps Europe move up the waste hierarchy

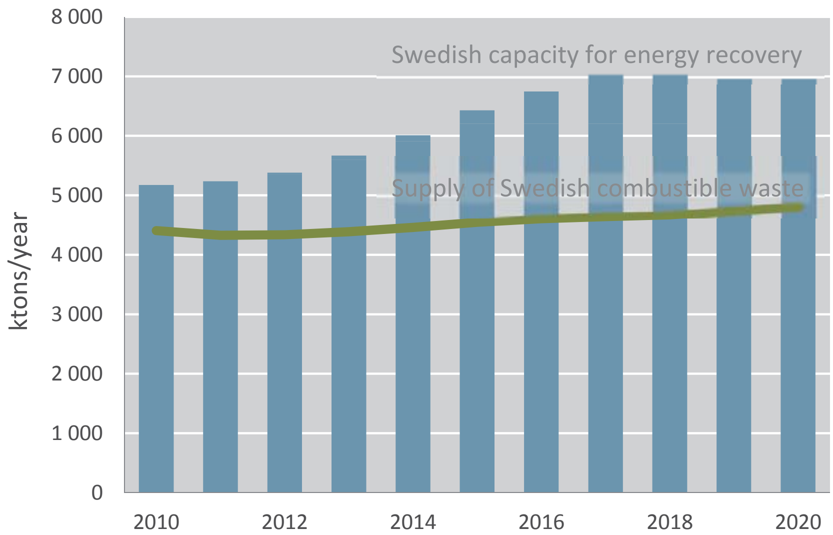
6

PERSPECTIVE

The continued interest in investing in Swedish waste-fuelled combined heat and power (CHP) plants makes it possible for the plant operators to offer other countries the service to treat combustible waste. Waste that would otherwise have been landfilled can therefore instead be used as fuel in Swedish district heating systems. As a result Europe now moves from the lowest step in the hierarchy, landfilling, to the level of energy recovery. All in all, this means a significant reduction of emissions of greenhouse gases.

During the period 2000–2008 the capacity of energy recovery from waste in Sweden more than doubled. The incentive was to divert the waste from Swedish landfills. Once this was achieved the expansion continued. The incentive today is that Swedish district heating companies see energy recovery as an economical and environmentally sound alternative for district heat production. This leads to an increasing difference between the capacity of energy recovery from waste and the supply of Swedish waste that need the treatment.

The figure show how the capacity and supply of Swedish combustible waste can develop until 2020. If all the plans for future capacity for energy recovery from waste are realized, the capacity will grow from 5.6 million tons per year (2013) to 7 million tons per year (2017). The quantity of Swedish waste for energy recovery depends on how the waste quantities and other treatment methods develop. But given that the waste quantities continue to increase in the same pace as before and that Sweden reach today's environmental objectives, the need will increase to approximately 4.8 million tons.

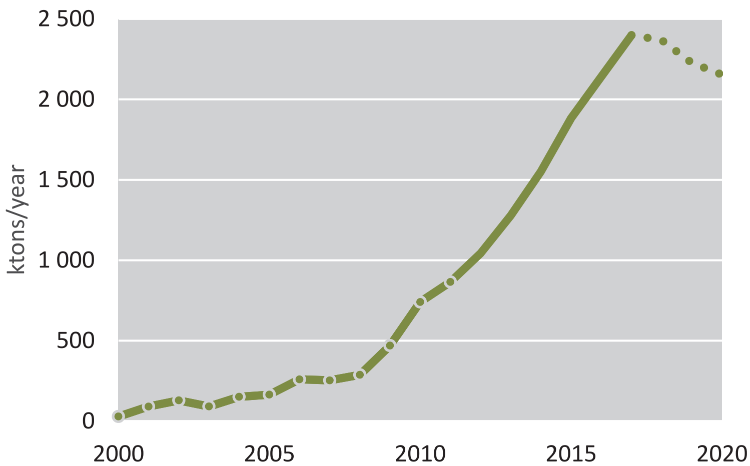


Change in waste system costs when producing biogas from 1 ton food waste, compared to energy recovery

Import of combustible waste to Sweden was a marginal occurrence up until 2008. Since then the import has increased by 200% which is shown in the figure on the next page. In 2008 Sweden had a balance between supply and demand in the national combustion capacity. The change can very fast due to the financial crisis that erupted in the end of 2008. The economic recession led to a sudden decrease in combustible waste quantities which was compensated by a significant increase in import, and the expansion has continued since then.

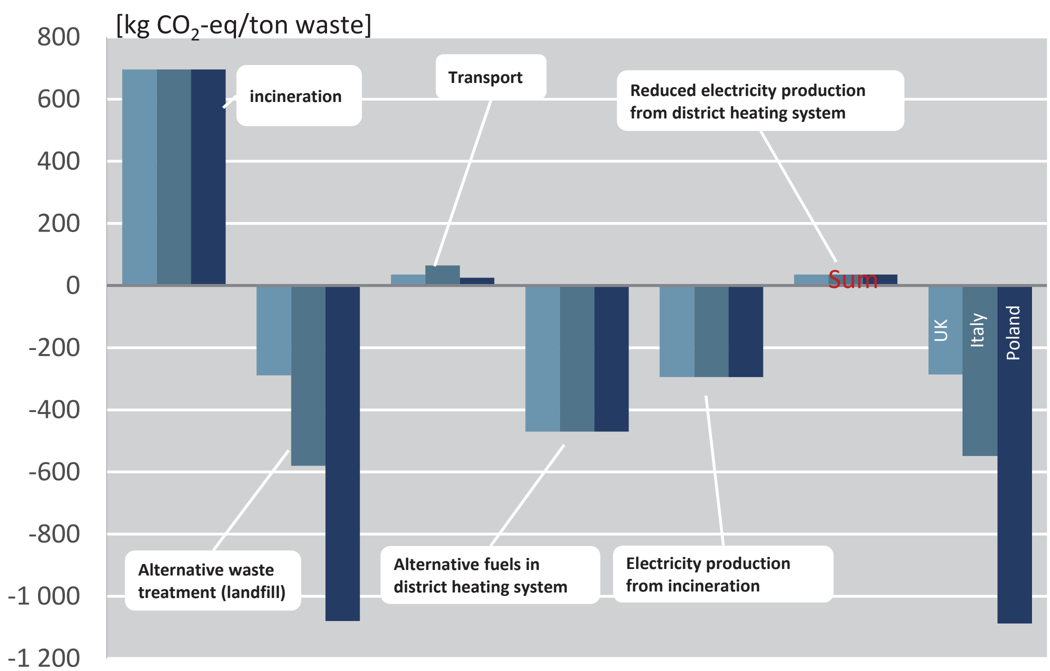
The incentive today is the district heating sector which sees waste as an economical and environmentally sound fuel. The sum of today's expansion plans indicate that the import of combustible waste will increase to ca. 2.4 million tons by 2017. At present there are no known plans of new capacity for energy recovery to be completed after 2017, but more plans could come up. If no more plans come up, the import will steadily decline after 2017 (see the decline during the past three years shown in the figure). The reason is an expected increased supply of national combustible waste which will require a bigger share of the combustion capacity.

> But as regards the large waste quantity ... which today is being landfilled in Europe, import for Swedish energy recovery is an effective measure to reduce our emissions of greenhouse gases



Historical data and prognosis of import of combustible waste for energy recovery in Sweden

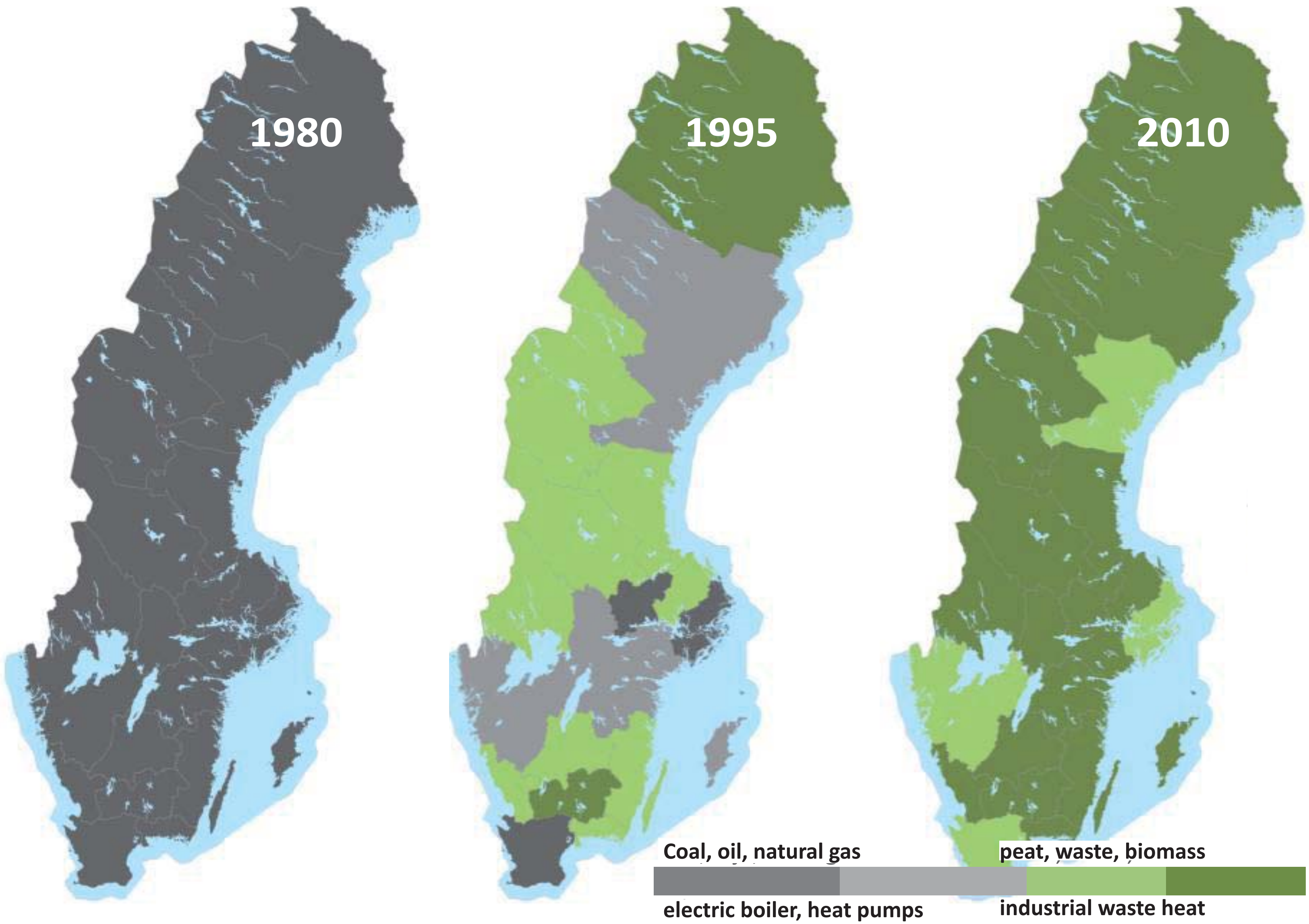
The result of the project show that import of waste, from a system perspective, leads to reduced emissions of greenhouse gases. This is explained in the figure below which shows results from import of waste from three countries. The analysis takes into consideration both the increased and reduced emissions that import of waste leads to. The increasing emissions are the ones that are direct emissions from the chimneys of the waste-to-energy plants (bar 1) and emissions from waste transports (bar 3). However, as we can see here, the transport emissions are of small significance compared to the other system changes. The emissions are reduced at the landfills in the countries from where waste is exported. The emission rates vary between countries due to landfills being differently designed. In England the landfills have a design and technology which gives lower emissions compared to for example Poland where the waste management in general is less developed in terms of the technology and the operation of the landfills. The emissions from the Swedish electricity and district heating system are also reduced in that the energy production



Changes in greenhouse gas emissions when importing combustible waste for energy recovery in Sweden, compared to landfilling of waste in the exporting country from imported waste replaces fossil fuels. The figure shows that the emissions, on the whole, are significantly decreasing rather than increasing. In other words, import of combustible waste result in clearly reduced emissions of greenhouse gases from the system.

To sum up, moving up the hierarchy by minimising the generation of waste, increasing the material recycling or increasing the biogas production are all good options that are preferable to energy recovery if solely seeing to the climate effects. But as regards the large waste quantity that still remains after these measures, and which today is being landfilled in Europe, import for Swedish energy recovery is an effective measure to reduce our emissions of greenhouse gases.

Fuels used in district heat production



Energy recovery increasingly important for district heat production

PERSPECTIVE

7

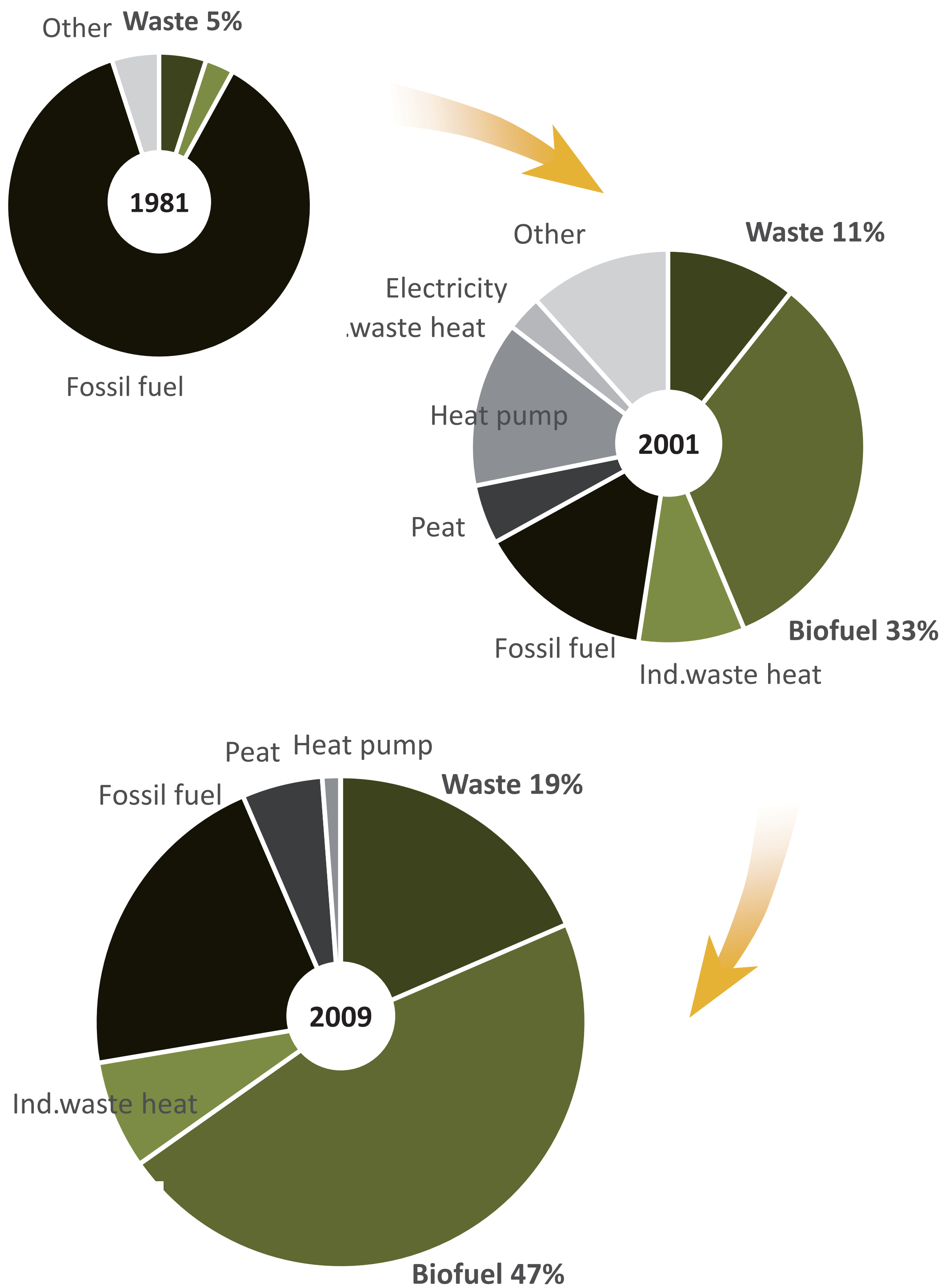
Swedish district heating companies have shown a remarkable ability to shift their production as the conditions in the world change. 30 years ago the main part of the production was based on oil. Today oil is an unusual fuel in district heating systems and the production is instead dominated by biofuels.

But the price of biofuel has steadily increased as the demand has increased. This has led to a willingness to once again change the production. Today more and more are interested in different types of waste fuels that all have in common that their prices are well below the biofuel price. The prognosis shows that waste fuels can get an equally important role as biofuels in Swedish district heat production.

During the initial stage of the expansion of the district heating in the 1970's, the production was to the greatest share using oil-fired heat-only boilers. As the oil price rose, more and more chose to change to alternative energy sources. Initially the use of coal saw a significant increase. But that expansion declined quite quickly and around the year of 2000, the production uses a great variety of different energy sources. Biofuels had started to become the dominating energy source.

During the 21st century the expansion of the bio-CHP has been great. This has been due to the energy tax, electricity certificate system and the ambition to reduce emissions of climate gases. Biofuels are today dominating the various district heating energy sources.

Waste as fuel has steadily increased in popularity since the 80's until today. During the 21st century the expansion has been driven by bans against landfilling of combustible waste. Compared to



Fuels used for heat and power production in the Swedish district heating systems. The size of the circles is proportional to the total fuel use.

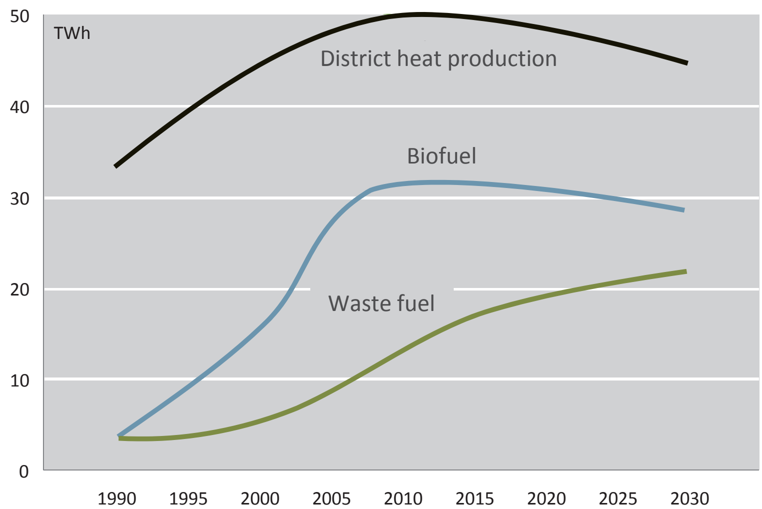
biofuels the use has though increased somewhat more slowly.

During the whole period from the 1980's until present has seen increasing demand of district heating. During the last years, the expansion of CHP plants has increased as well, which has further has increased the district heating producers fuel need. Today more and more prognoses indicate that the heating need in the future will decrease, first and foremost due to the energy efficiency work in existing buildings. The district heating suppliers also meet much stronger competition on the heating market primarily from heat pumps. In the long term a warmer climate might also reduce the need for heating. All in all, this gives a prognosis of slowly decreasing district heating supplies.

Despite a downturn in demand for heating, the model calculations show a continued upturn in demand for waste fuel to the district heating sector. The development will be the strongest during the period 2010–2020. In the long run, however, waste CHP will be limited in that the market will become saturated with base-load production.

> "Biofuel use is squeezed between fewer district heating supplies and increased use of waste as fuel"

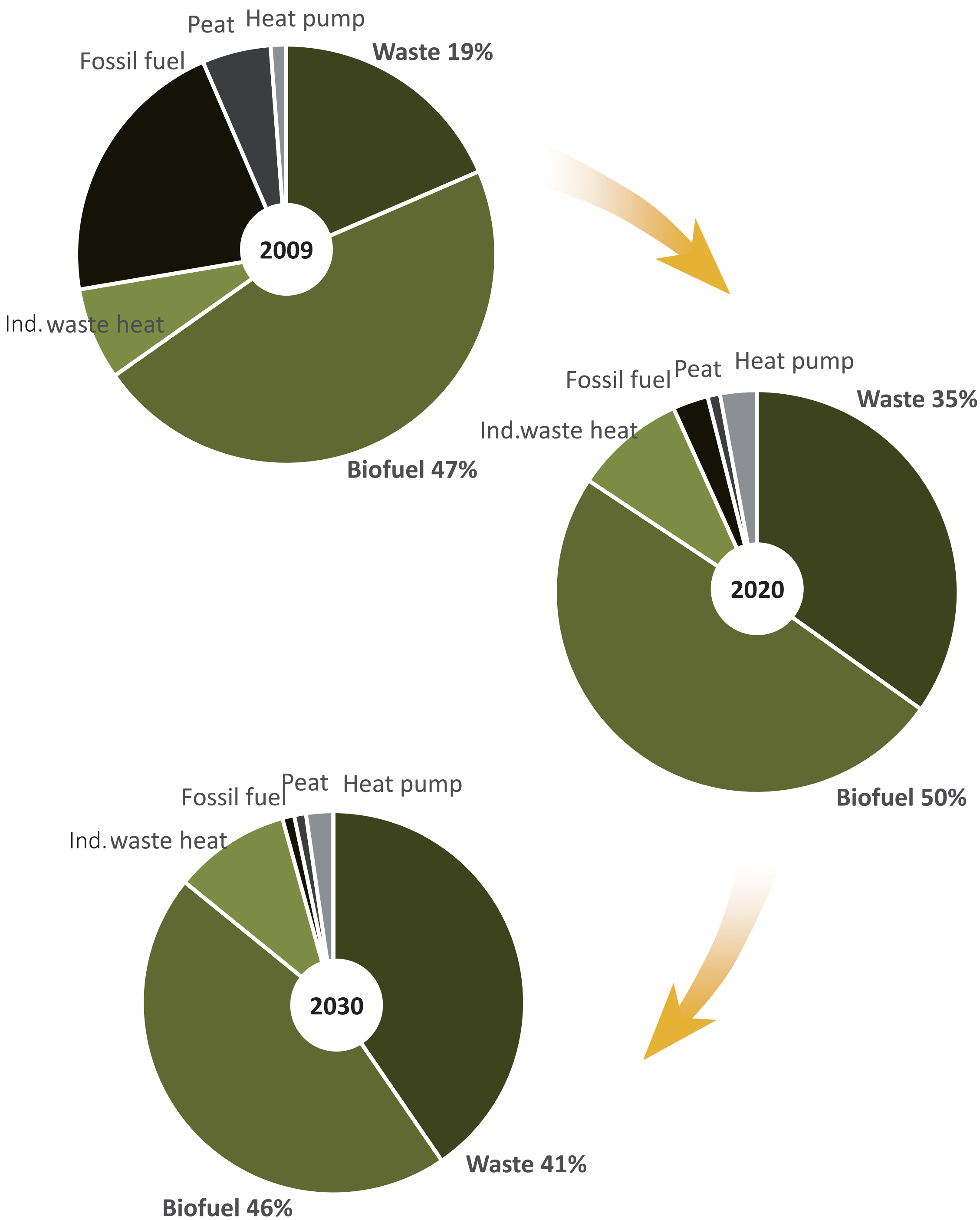
The figure on the next page illustrate how biofuel use is squeezed between fewer district heating supplies and increased use of waste as fuel. The prognosis indicates that a peak for biofuel use in the district heating sector is about to be reached and that the use could become stabilized at today's level.



Prognosis of district heat production and the use of biofuels and waste fuels in Swedish district heat production.

The use of waste as fuel within the district heating sector is expected to be strongly increasing until 2030. At the same time we see a stagnating use of biofuels. Put together, this translates into a forecasted mix of fuels in accordance with the figure to the right. Together waste and biofuel are expected to represent a clear majority of the energy provided to the district heat production. I can be considered as a strength that the district heat production has two legs to stand on, instead of a situation where it is completely dependent on one type of fuel. The waste heat supplies are expected to increase somewhat from this time forward and the heat pumps seem to be able to partly maintain its compatibility.

A small share of fossil fuels is estimated to still be in place as cutting-edge capacity and reserve capacity. However, dependant on the future financial control means, this share might also be shifted to renewable sources of energy such as bio-oil.



Fuels used for heat and power production in the Swedish district heating systems. The size of the circles is proportional to the total fuel use.


ÅTERVUNNEN
ENERGI

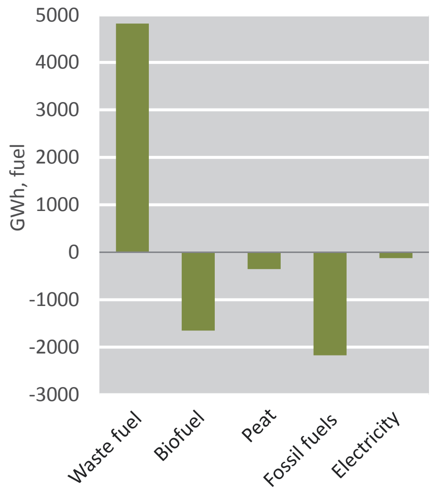
District heat emissions are reduced with new waste CHP

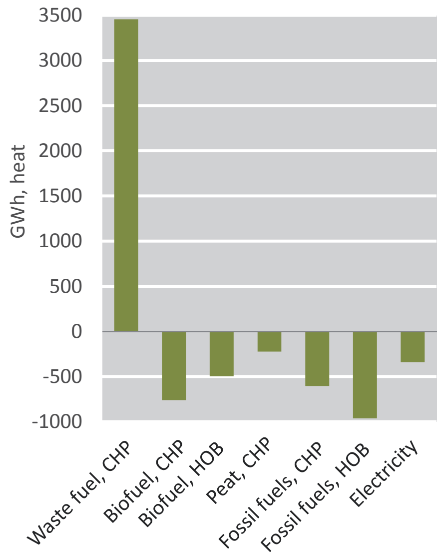
PERSPECTIVE

8

We are in the middle of an intense period of construction of new waste-fuelled CHP plants in Sweden. The waste-fuelled CHP plants are regarded a compatible option for the future district heat production by the district heating companies. Between 2009 and 2020 the energy recovery is estimated to increase with as much as 1.6 million tons or 30%. The expansion will thereby replace existing district heat production and while the electricity production from the district heating system increases. In total, the estimate is that this will result in reduced emissions of carbon dioxide from Swedish district heat production corresponding to 550 000 tons per year.

Today there are a total of 16 district heating systems where new waste CHP is planned for, which together are estimated to generate an addition of energy recovery capacity corresponding to 1.6 million tons per year compared to 2009. All of these plans are thought to be completed by 2020. In total, 7 million tons of waste will subsequently be treated with energy recovery by 2020. The expansion is expected to give an increase in heat and electricity production from waste-fuelled CHP corresponding to 3.4 and 1.2 TWh/year respectively (in 2009 the heat and electricity production was 12.3 and 1.7 TWh respectively). The change in heat production and fuel consumption in the 16 systems are presented in the figure on the next page. It shows that the new plants will replace both biofuel as well as fossil fuels, while replacement of industrial residual heat is expected to be marginal. The electricity production from Swedish district heating is estimated to increase by 0.5 TWh per year.



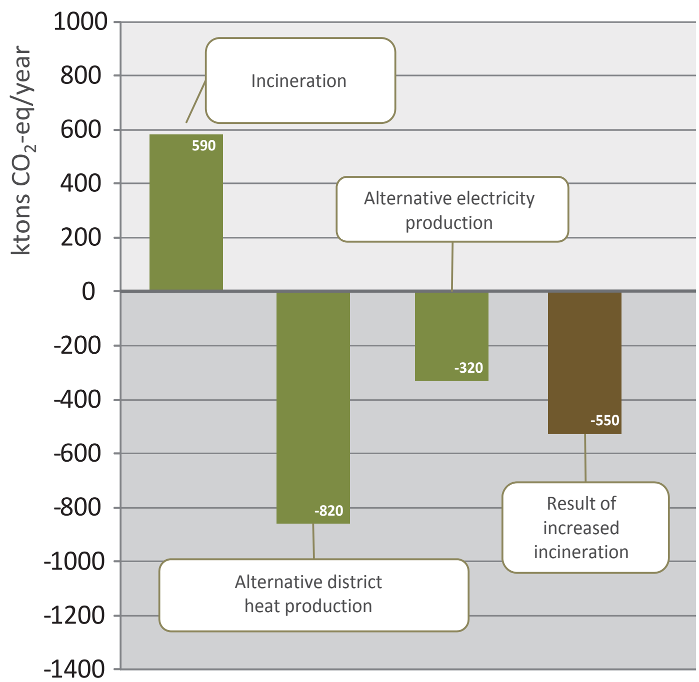


Changes in the Swedish district heat production with the introduction of new plants for waste-to-energy.

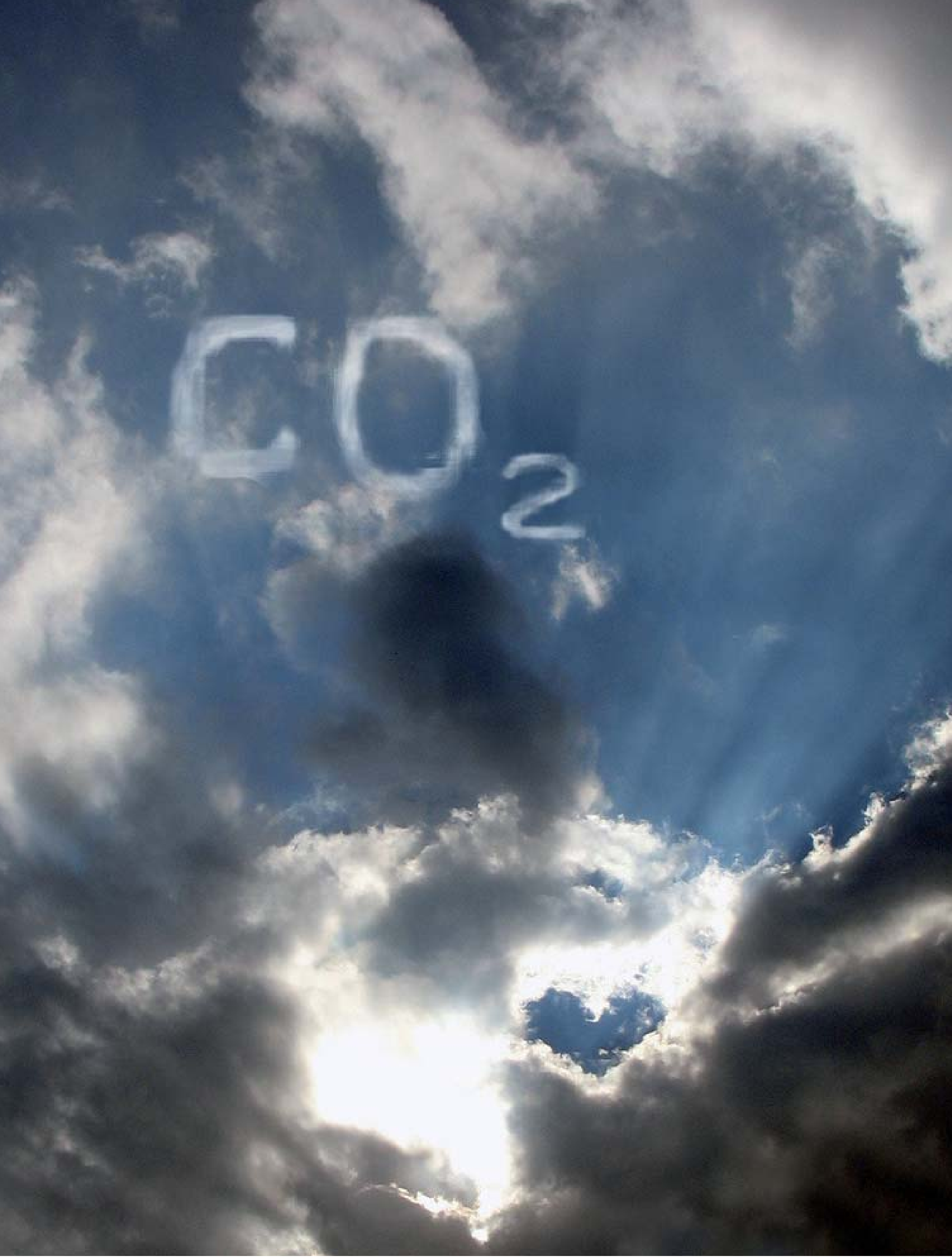
The expansion of the waste CHP will influence the emissions of greenhouse gases from the energy system. The waste that is combusted is a mix between both fossil and renewable material. This is why a part of the emission quantity of carbon dioxide also is a net contribution to the atmosphere. At the same time, the energy from the new plants will be replacing alternative electricity and heat production. The mix of fuels which is replaced in the district heating system has been described in the previous figures. Within the electricity system the mix will consist of a larger share of fossil fuels. However, the quantity of produced electricity from the new CHP plants is lower compared to the quantity of produced heating. Subsequently the emissions from waste CHP is lower than from its electricity production. The right figure presents the extent of the emission change at the 16 planned waste CHP plants and from the replaced district heat production and electricity production. The result (brown bar) shows that the expansion during the period 2009–2020 leads to reduced emissions from the energy system corresponding to 550 000 tons of CO_2 equivalents per year.

It should be noted that the expansion of the waste-fuelled CHP also affects the emissions of greenhouse gases in the waste management system. These consequences are described in Chapter 6 *Swedish energy recovery helps Europe move up the waste hierarchy*.

> The expansion during the period 2009–2020 leads to reduced emissions from the energy system corresponding to 550 000 tons of CO_2 equivalents per year.



Changes in greenhouse gas emissions with the introduction of new plants for waste-to-energy.


CO2

9 Carbon dioxide emissions from energy recovery come with a cost

PERSPECTIVE

As from 2013, Swedish plants for energy recovery from waste are included in the EU emission trading system (ETS) for fossil carbon dioxide emission allowances. Model calculations indicate that the emission allowance trade will increase the variable costs of the waste incineration with 10–200 SEK/ton of waste. The cost is thereby on approximately the same level as the former incineration tax for CHP plants. Analyses of the incineration tax showed that it had very little effect on the waste management. This can be an indication that the EU ETS will not affect the quantities of Swedish waste sent to waste combustion.

But depending on whether the emissions are based on a template, as was the incineration tax, or if they are based on measured values, a certain control is still possible. Conceivable effects are, among others, a decrease in import and an increase in the source separation of plastics.

The trading system also generates receipts to the energy recovery through the allocation of emission allowances. The net profit, the allocation included, will be between –50 to +50 SEK/ton of waste that is combusted during the whole period 2013–2020.

Emission levels

Including Swedish energy recovery plants in the EU ETS means that these plants are charged with a cost for emissions of fossil carbon dioxide. Compared to other fuels, e.g. biofuel, natural gas and coal, the properties of the waste vary to a much greater extent. This is especially true for the content of fossil carbon where different measurements show a wide dispersion.

The table below presents an estimate of the resulting emission of fossil carbon dioxide according to different basic sources.

Based on the dispersion of the table, two of the emission levels for fossil carbon dioxide in waste combustion have been studied:
Low: 0.1 and **High**: 0.5 ton of CO_2/ton of waste, respectively. The level **Very high** (1.0 tonne CO_2/tonne waste) is also illustrated, which could become the case when a plant is unable to meet the measurement requirements of the regulations (in which case the entire CO_2 emission must be classified as fossil).

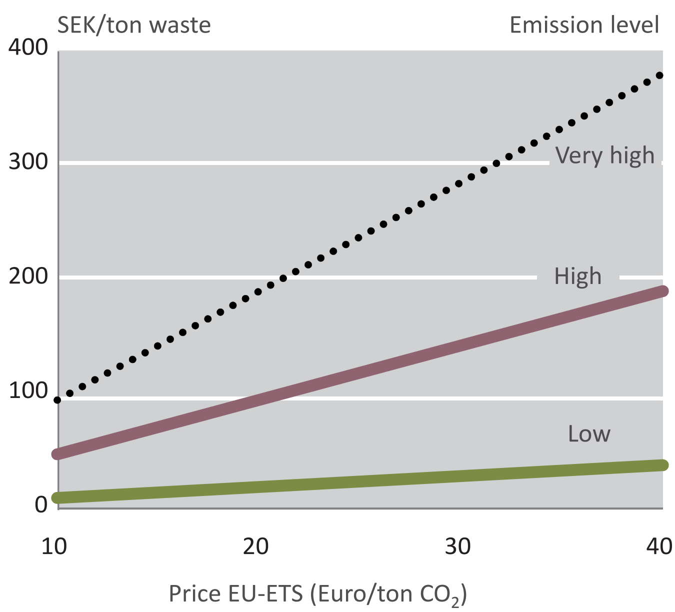
CONCEIVABLE EFFECTS OF EMISSION ALLOWANCES FOR WASTE INCINERATION

- Decreased import of combustible waste?
- Decreased development of waste combustion?
- Increased source-sepration and recyling of plastics?
- Export of pure plastic waste streams for combustion?
- Source-separation and export of plastics for combustion?
- High measurement costs?

Basic source	**Emission level (fossil ton of CO_2/ton of waste)**
Template for household waste in the recently abolished incineration tax, applied to all combusted waste	0,46
Sweden’s official emission value for waste combustion in the greenhouse gas emissions report	0,29
Waste composition analyses	0,38
Results from the project “Determination of the fossil carbon content in waste combusted in Sweden” (Avfall Sverige – Swedish Waste Management)	0,09 -0,55

Emissions costs

The resulting emission allowance cost per ton of waste has been calculated based on the three emission levels (Low, High and Very high) and with a varying emission allowance price. The figure below shows that both the emission level and the emission allowance price are of great importance to the outcome. An emission allowance price of 25 EUR/ton of CO2, gives an emission allowance cost of 25–120 SEK/ton of waste according to the model results, given that the measurement requirements have been met. If the measurement requirements have not been met, the cost will be 240 SEK/ton of waste for the same emission allowance price. The costs does not include any additional costs for e.g. measurement, administration etc.

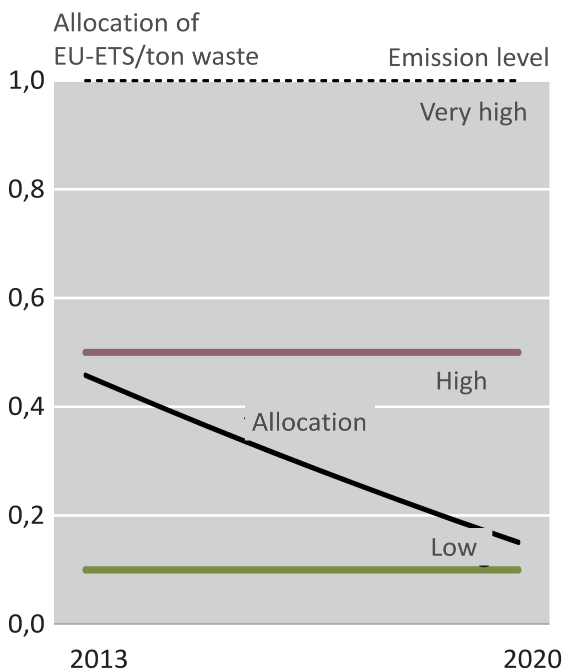


Variable cost of EU-ETS for Swedish waste-to-energy plants.

Allocation

As from 2013, plants included in the trading system and that produce heat to a district heating network are given a free allocation of a certain number of emission allowances. The allocation will be based on a heat benchmark and historical heating delivery, and is therefore not dependent on the actual carbon dioxide emission of the plant. The estimated allocation will decrease during the entire period until 2020. The allocation for Swedish energy recovery is estimated to an average of almost 0.5 emission allowances/ton of waste in 2013.

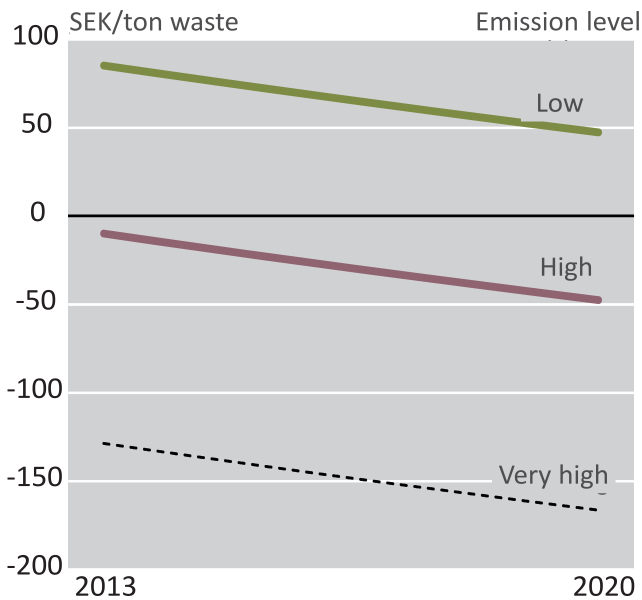
Above was presented the variable cost for waste combustion in the emission allowance system for three different emission levels. In the figure below, the allocation of emission allowances during the years 2013–2020 is set based on the consumption according to the three levels. It shows that a low emission level will result in an allocation of emission allowances that exceeds the consumption during the whole period. The opposite applies in a situation with a high emission level.



Allocation and consumption of EU-ETS for Swedish waste-to-energy plants.

Accumulated net profit

The result above shows that, depending on the number of emission allowances that are consumed for waste combustion, the owner of waste-to-energy plant will have either a surplus or a shortage of emission allowances at the end of the period. To indicate the economical net profit, an estimation has been made where the difference between the allocated and the consumed emission allowances have been multiplied with a probable emission allowance price. The price for an emission allowance has been set to 25 EUR/ton of CO_2 for the entire period 2013–2020. An **accumulated** economical result is shown in the figure. Depending on the number of emission allowances required for the waste combustion, the result will be between ¬-50 to +50 SEK/ton of combusted waste, **for the entire period**.



Net cost of EU-ETS for Swedish waste-to-energy plants (including allocation.

How to reduce the carbon dioxide emissions from energy recovery

10

PERSPECTIVE

Waste that is combusted give rise to emissions of fossil carbon dioxide. This is caused by its content of fossil material, mainly plastics. One way of reducing the emissions of carbon dioxide is to remove the fossil material from the waste. Several different approaches to achieve this have been studied, all of which lead to reduced climate impact from a system perspective. But the methods are proven to be relatively expensive compared to the price for emission allowances in the European trading system.

From a so called chimney perspective, the total fossil carbon dioxide emissions from the Swedish energy recovery in 2011 amounted to just about 2 million tonnes. This is equivalent to approximately 23% of Sweden's total emissions of greenhouse gases from electricity and heat production, and slightly more than 3% of Sweden's total emissions of greenhouse gases. However, from a systems perspective the Swedish energy recovery give a reduction of the climate emissions since other energy production and waste treatment are replaced.

The following measures to reduce the emissions of carbon dioxide from energy recovery have been studied:

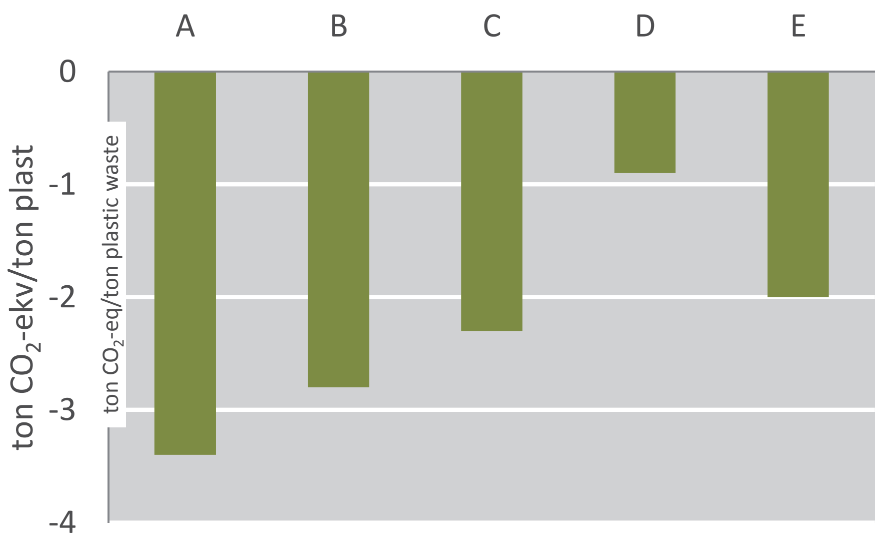
A. Transition of production of plastics from fossil raw material to renewable raw material
B. Increased collection and material recycling of plastic packaging
C. Collection of municipal plastic waste

(plastics other than packaging, for example used in furniture, toys, cans, pipes, buckets, toboggans, crates and pallets) and material recycling

D. Collection of municipal plastic waste for landfilling (this is not allowed in the current regulations but included as an option to separate and dispose of carbon dioxide)
E. Collection of municipal plastic waste and combustion at cement industries
F. Separation and storage of carbon dioxide from energy recovery (Carbon capture and storage, CCS).
G. Increased electric power efficiency in energy recovery.

> ... from a systems perspective the Swedish energy recovery give a reduction of the climate emissions since other energy production and waste treatment are replaced.

The measures A–E involve plastics since it is the dominant source of fossil carbon dioxide emissions. The figure below shows how much climate gas emissions are reduced from a systems perspective per ton of plastics that is subject to the measures A–E. Transition from fossil to renewable plastics (A) and collection and material recycling of plastic packaging (B) show the greatest emission reductions per ton of plastics.



Reduction of greenhouse gas emissions, from a system perspective.

Potentials from a systems perspective

The table illustrates the total potential reduction of climate emissions from a systems perspective. Apart from the measures concerning plastics (A–E) we have studied option (F) for separation of carbon dioxide in energy recovery in Gothenburg and Malmö, where it is stored in geological formations underground (CCS – Carbon Capture and Storage). The technique is still in an experimental stage and there are no full-scale plants for the chain ***separation–gas transport–storage***. The technique could possibly lead to a far greater reduction of climate gases due to its applicability to both renewable and fossil emissions of carbon dioxide. This means that the net energy recovery is a carbon dioxide sink that reduces the amount of carbon dioxide in the atmosphere. The last option (G) does not involve any change in emissions from energy recovery. However, the increased electrical power efficiency is favourable from a systems perspective since it allows for alternative electricity production with higher fossil carbon emissions to be replaced.

Measure	**Total potential reduction of climate impacting emissions year 2020 (ktonne CO_2-equivalents)**
Transition to renewable plastics (A)	60
20% increased recycling of plastic packaging (B)	30
Collection of municipal plastic waste (3 kg/capita, year) (C–E)	30-70
Separation and storage of carbon dioxide from energy recovery (F)	970
Increased electrical power efficiency (with 10%) in national energy recovery (G)	170

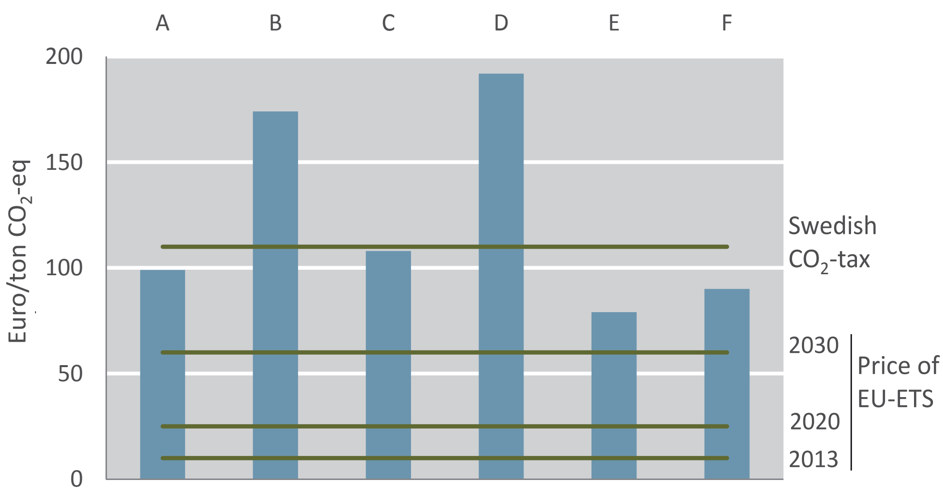
In comparison: Sweden's total emissions of greenhouse gases slightly exceeded 61 000 kilotons of CO_2 equivalents in 2011

Comparatively expensive measures from an international climate perspective

All the measures resulted in an incremental cost compared to the waste management of today. The figure below illustrate the costs of the measurements in relation to the reduction of emissions they generate from a systems perspective (measure G is not included as it hasn't been studied from an economical perspective). The figure also includes graphs for today's emission allowance price, in terms of the research project's reference case scenario for 2020 as well as from a 2030 perspective. The emission price reflects the marginal cost for the measures that are taken within the framework of emission allowance trade to reach the objectives set by EU. The incremental costs are high compared to the international emission allowance price.

At the same time it should be considered that there are different approaches to value carbon dioxide emissions. The current Swedish carbon dioxide taxation equals 110 EUR/ton of CO_2, which is the same level as for several of the measures.

The measure with the lowest incremental cost per emission reduction (just about 80 EUR/ton of CO_2 equivalent) consists of source-separation of plastics at recycling centres, which is later used as fuel for cement manufacturing (E). The emission reduction is mainly a result of the plastics replacing coal as fuel in the cement industry, while the reduced combustion of plastics in energy recovery is partly replaced by renewable fuels (mainly for alternative heat production).



The cost of reducing greenhouse gas emissions from waste-to-energy plants.

The results presented in this book are taken from five reports that have been developed within the research project Perspectives on future waste treatment. These include:

- Import of waste for energy recovery in Sweden
- Evaluation of future control means
- The future market for biogas production from waste
- Waste combustion in the Swedish district heating systems
- CO_2 emissions from future waste combustion

The reports can be downloaded from Waste Refinery’s website (www.wasterefinery.se)

Perspectives on future waste treatment is a two-year research project carried out within the framework of Waste Refinery. A total of 19 interested parties have been involved in this work. The project has studied five different subareas of future Swedish waste treatment. The selected areas are of immediate interest and considered of great importance for the development of future Swedish waste treatment. The areas have been studied from a comprehensive systems perspective to create more knowledge about the future development and insights in how this can and should be influenced. The knowledge can also be used to direct the focus of more detailed research and development projects within the waste treatment system.

Waste Refinery is a national knowledge-centre where the research and development work take place in a common cluster consisting of representatives from the industry, the society and research organisations. The centre aims to systematically evaluate, develop, demonstrate and integrate different strategies for efficient energy and resource recovery from waste. Focus is set on following selected areas: systems analysis and method development of thermal and biological conversion of waste into energy and material products.