Integrated waste management as a mean to promote renewable energy

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Abstract: Management of municipal solid waste is an efficient method to both increase resource efficiency (material and energy recovery instead of landfill disposal) and to replace fossil fuels with renewable energy sources (waste is renewable in itself to a large extent as it contains paper, wood, food waste etc.). The paper presents the general outline and results from a comprehensive system study of future waste management. In the study a multifunctional waste management system integrated with local energy systems for district heating and electricity, wastewater treatment, agriculture and vehicle fuel production is investigated with respect to environmental impact and financial economy. Different waste technologies as well as management strategies have been tested. The treatment is facilitated through advanced sorting, efficient treatment facilities and upgrading of output products. Tools used are the ORWARE model for the waste management system and the MARTES model for the district heating system. The results for potential global warming are used as an indicator for renewable energy. In all future scenarios and for all management strategies net savings of CO_2 is accomplished. Compared to a future reference the financial costs will be higher or lower depending on management strategy.

Keywords: *LCA, Waste management, ORWARE, Martes, Costs*

1. Introduction

Management of municipal solid waste is an efficient method to both increase resource efficiency (material and energy recovery instead of landfill disposal) and to replace fossil fuels with renewable energy sources (waste is renewable in itself to a large extent as it contains paper, wood, food waste etc.).

In this paper the general outline and results from a comprehensive system study of future waste management in the Gothenburg region is presented. The purpose of the system study was to evaluate new waste treatment options for municipal and industrial waste from a system perspective. In the study a multifunctional waste management system integrated with local energy systems for district heating and electricity, wastewater treatment, agriculture and vehicle fuel production is investigated with respect to environmental impact and financial economy. Different waste technologies as well as management strategies have been tested. The treatment is facilitated through advanced sorting (source separation of recyclable materials and MRFs (Material Recovery Facility) for both bulky waste and source separated household waste), efficient treatment facilities (thermal and biological treatment) and upgrading of output products (biogas as vehicle fuel and pelletisation of digestion sludge for use as fuel or as fertiliser in fields or forestry). The future district heating system comprises waste CHP and waste heat (excess heat) as base load and bio-CHP, natural gas-CHP and heat pumps as intermediate load while oil is peak-load. Thermal and biological treatment of waste is included and several scenarios of future waste management have been developed comprising a number of parameters for the background system and different waste amount growth rates.

The project has been carried out as a part of the project Thermal and biological waste treatment in a systems perspective – WR21 [1]. The focus has been set to the waste and district heating system in Gothenburg. The project has been running for 2.5 years with an active group consisting of persons from Renova, Kretsloppskontoret, Göteborg Energi, Gryaab and Profu. The work on development of models and of methods of handling strategic questions within the field has gone back and forth within the group.

2. Methodology

The method used is life cycle assessment (LCA) [2] and financial cost calculation facilitated by computer modelling with the ORWARE (Organic Waste Research) model [3] for the waste management system and the MARTES model [4] for the district heating system including CHPs (Combined Heat and Power). In this study waste streams suitable for thermal and/or biological treatment (including waste water treatment sludge) are included whereas fractions for material recycling are excluded.

ORWARE is a computer based tool for environmental and economic systems analysis of waste management. It was first developed for systems analysis of organic waste management, hence the acronym ORWARE (Organic Waste Research). The model is designed for strategic long-term planning of recycling and waste management and based upon static conditions and on linear programming (LP). The ORWARE model has been developed since the early 1990s in close cooperation between four different research institutions in Sweden (Royal Institute of Technology, Swedish Environmental Research Institute, Swedish Institute of Agricultural and Environmental Engineering and Swedish University for Agricultural Sciences). The waste management is followed from cradle (waste sources) via collection and transport to treatment plants and further to grave (utilisation of products from waste treatment). Treatment facilities included are incineration with energy recovery, composting, landfill, anaerobic digestion with biogas utilisation, spreading of organic fertiliser on arable land, sewage treatment, material recycling of plastic and paper packages, and some additional technologies. The model delivers substance flows, distributed to emissions to air and water, left in growing crops and in recycled material. Energy flows such as energy use and recovered energy is also provided. Single substances such as carbon dioxide or eutrophication substances to water can be tracked, as well as the amount of plant-available nutrients and emissions of different heavy metals. Emissions are also characterised and weighted using Life Cycle Impact Assessment. At the same time financial costs (investment and operational costs) and environmental costs and revenues including savings in the surrounding system can be calculated for the whole management chain.

MARTES is a model for district heating systems with production of heat, steam and electricity. The model simulates the use of different plants to satisfy the demand for district heating during a year. As a result the effects on costs and emissions are calculated, based on the energy conversion in the district heating system. The development of MARTES started on a mainframe computer at the Department of Energy Conversion in 1983. It has been commercially available on personal computer since 1990. Today it is the most widely used tool for strategic planning of district heating systems in Sweden, since it covers nearly 70 % of the produced heat [5]. The MARTES model captures operation of all facilities for district heating generation, given a exogenously given total need for heat. The heat demand is based on a load curve and described with a detailed time slice division into day and night periods. The model includes fuel and electricity prices and policy tools. The simulated plants are modelled with efficiencies (and with part load performance for CHP plants), minimum load for operation, availability, emissions of carbon dioxide, sulphur and nitrogen oxides. Annual fixed costs for equipment purchase and installation as well as variable and annual fixed costs for operation and maintenance are also included in the model. The output from the model is heat generation for all plants, power generation in CHPs, use of electricity in heat pumps and electrical boilers, fuel consumption and emissions to air.

As mentioned above the focus in the study has been the waste treatment and district heating system in Gothenburg. However, to generate a fully system analysis one also has to consider effects that occur in surrounding systems, such as the transport sector (biogas from waste substitutes petrol and diesel oil), the electricity production system (electric power from waste incineration with energy recovery replaces electricity generation from fossil fuels), the agricultural sector (nutrients from anaerobic digestion of waste and sludge are used instead of mineral fertiliser) etc. In this study; two different types of scenarios that reflects the situation of year 2030 has been set up: local scenarios and external scenarios [6]. In a local scenario we define the waste treatment processes that are assumed to be in operation in Gothenburg's waste treatment system in year 2030 (e.g. waste incineration, anaerobic treatment). Furthermore, an external scenario reflects the situation in the surrounding systems (e.g. price of electricity, fuels and CO_2-allowances). The local scenarios thereby describe developments that the actors in Gothenburg can influence, while the external scenarios describe developments that the actors have to adapt to. The main principles of the local scenarios that have been set up are as follows:

-Business-as-usual: This local scenario is characterized of a traditional development of the waste treatment system in Gothenburg, i.e. a significant share of waste incineration. The capacities in existing facilities are adapt to the amount of waste that are assumed to arise in year 2030. Today's central composting is still used for treatment of biological degradable waste from households. Sludge from the wastewater treatment plant is first treated in an anaerobic treatment facility, thereafter composted and finally sold as a soil product.

- Maximized return of nutrients: In this local scenario more of the arising waste is treated in biological treatment facilities, compared to "Business-as-usual". The capacity of the source separation system in Gothenburg is expanded and an anaerobic treatment facility is built that replaces the central composting. The capacity of the anaerobic treatment facility is set to 60 000 tonnes/year. The capacity of waste incineration is thereby decreased in comparison to the case in the local scenario "Business-as-usual". Sludge from the wastewater treatment plant is treated in an anaerobic treatment facility and thereafter used as fertilizer in the agricultural sector.

- Maximized electricity production: the source separation system is expanded and an anaerobic treatment facility is being built, similarly to the local scenario "Maximized return of nutrients". Furthermore a part of the combustible waste is going through a mechanical treatment process to create a refuse derived fuel. This fuel is used in a new waste incineration facility with a slightly higher electrical efficiency than the existing ones. Sludge from the wastewater treatment plant is treated in an anaerobic treatment facility. Thereafter the sludge is dehydrated and turned into pellets that are used as fuel in the new waste incineration facility.

Within the project a number of external scenarios capturing several parameters that describe the state in the economy, the energy system, the waste system (such as waste amounts etc.) etc. were discussed. Eventually three of these were selected for a more careful analysis.

- Reference: is a scenario that reflects a conservative development in the surrounding environment. The background system is changed but mainly the same impact and policy as of today prevails. The Reference scenario is not to be interpreted as the most likely scenario.

There is no valuation of which of the three external scenarios is the most likely one. All three projects constitute a "window of development" which is assessed as possible and realistic.

- Material lean growth: is a scenario that reflects a development where the society in general puts a lot effort in reducing environmental impact on a long term and evident environmental improvements are achieved compared to the system of today by policy measures and a change in values. The most important change in this study is that the trend of increasing waste amounts is broken and a decoupling effect (i.e. the waste amounts are no longer increasing at the same rate as economic growth) is present. This effect means that waste amounts follows the population trend in the region. This scenario also captures savings in energy use and more ambitious environmental targets which in turn affect the results of the system study. The magnitude of the economic growth is assumed to be on the same level as in the Reference scenario.

- Material intense growth: this scenario is characterized by an economic growth in society which exceeds the one in the other external scenarios, and a continuously increased consumption of material based products resulting in a higher growth rate for waste amounts than for the economy. This external scenario should not be looked upon as an opposite of material lean growth, also in this scenario there are assumptions on a development where the society is directed towards a decreased environmental impact.

A vast number of parameters have been studied and varied in the different external scenarios. A vital part that has been kept constant is however the tax system. Present levels of taxes on petrol, diesel, and natural gas to CHP etc. are used also in 2030. In reality these will probably change several times during the period to 2030. These changes are however very hard to predict, thus this conservative assumption.

3. Results

In table 1-2 aggregated results of the analysis for the three local scenarios is presented. Each local scenario has been evaluated from four different aspects: economy, climate, acidification and eutrophication of which the two latter is not presented here. The results are shown in scoreboards where the three scenarios have been given a gold, silver or bronze medal. The local scenario with the best result receives a gold medal while the worst result receives a bronze. The interval between these two results is then split into three. If the result for the local scenario not yet given a medal is placed in the upper third of the interval, the scenario receives a gold medal, a result in the middle interval return silver, while a result in the lover third gives a bronze medal. Each scoreboard is followed by a text that describes the results.

*Table 1. Scoreboard for the economic results from the systems study. The choices for development of the waste management system (the local scenarios) are compared to each other and scored by gold (**G**) silver (**S**) and bronze (**B**) bullets.*

Economy External scenario/ Internal scenario	Reference	Material lean growth	Material intensive growth
Business-as-usual	S	S	B
Maximized return of nutrients	G	G	G
Maximized electricity production	B	B	B

From the economic aspect, the local scenario "Maximized return of nutrients" present the best result irrespective of which external scenario that is being studied. Factors that contribute to this result are revenues for biogas to the transport sector and avoided costs for expanding the waste incineration capacity. It's important to remember that we've been studying a situation around year 2030, which means that new investments in waste treatment capacity must come in place in order to meet a rise in waste amounts. This is another situation compared to today where existing treatment capacity is enough to meet the demand in the region.

The result is sensitive to some input data, where of one can mention the price of biogas, the investment costs for anaerobic treatment and waste incineration, the transport costs for wastewater sludge and sludge from anaerobic treatment to the agricultural sector and the costs for the source separation system.

*Table 2. Scoreboard for the results of emissions of climate gases from the systems study. The choices for development of the waste management system (the local scenarios) are compared to each other and scored by gold (**G**) silver (**S**) and bronze (**B**) bullets.*

Climate gases External scenario/ Internal scenario	Reference	Material lean growth	Material intensive growth
Business-as-usual	B	B	B
Maximized return of nutrients	S	G	G
Maximized electricity production	G	G	G

Table 2 shows that the local scenario ”Maximized electricity production” receives the best results for emissions of climate gases. Also ”Maximized return of nutrients” receives good results. The local scenario “Maximized return of nutrients” receives better results compared to “Business-as-usual” partly because this scenario includes production of biogas that keep out the use of fossil fuels in the transport sector. A second reason is that more electricity is generated within the system that keeps out electricity production outside the system with higher emissions of climate gases. The reason for the increased electricity production is that new waste treatment capacity partly consists of a facility for anaerobic digestion, which decreases the need for investments in waste incineration. With less waste incineration, more district heat will be produced from other combined heat and power plants within the district heating system. These units have a higher electrical efficiency compared to waste incineration, thus more electricity will be produced within the system. The local scenario “Maximized electricity production” receives even better results for emissions of climate gases. The reason for this is that in this scenario the electricity production from the system increases even further. This is partly because we in this scenario study the effects of investing in a waste incineration facility with higher electrical efficiency compared to existing. This is also because this scenario includes investments in a sludge dryer, heated by district heat. This causes an increase in the heat demand, thereby combined heat and power plants within the district heating system may run during a longer period of time.

The local scenarios “Maximized return of nutrients” and “Maximized electricity production” reduces the emissions of greenhouse gases by 4 -7 % (17 000 – 29 000 tonnes CO_2-eq./year) compared to “Business-as-usual”. Another figure to relate to is the total emissions of CO_2 from Göteborg Energi, which in 2009 amounted to 545 000 tonnes CO_2 [7]. As seen before, the local scenario “Maximized return of nutrients” yield a decrease in the system cost, in other words the cost for reducing the emissions of greenhouse gases by choosing this path is negative. In contrast the system cost increases by the local scenario “Maximized electricity production”, hence the cost for reducing greenhouse gases by the measures stapled in this scenario can be calculated to between 80 and 550 SEK/tonne CO_2 (depending on which external scenario you choose to study).

4. Discussion and Conclusions

The following ten conclusions have been drawn from the project.

I. From an economic point of view, new waste treatment technologies have difficulties in the competition with the type of treatment options that already exists in Gothenburg today. The conclusion holds even when comparing new investments in new or existing technologies.

II. Having said so, we can consider that the only new technology found to be economically competitive to existing treatment options are anaerobic digestion of food waste. The conclusion holds for a situation when the treatment capacity has to increase in order to meet the demand in the region. This is not the situation of today, but it is most likely that the situation will arise in future because of increased demand for waste treatment or because the existing treatment facilities become too old.

III. Increasing the share of electricity generated from waste incineration is a clear advantage in order to realize a decrease of emissions of climate gases. This is partly because the fact that the electricity produced from the incinerator keep out other electricity production with higher emissions of climate gases. A second positive factor is that a higher share of electricity production results in a minor share of district heat production, which in turn results in increased production in other combined heat and power plants in the district heating system. Thereby even more electricity is being produced within the system, keeping out other electricity production with higher emissions of climate gases.

IV. Another good way to reduce climate gases is to produce biogas from waste and use it within the transport sector. The reason for this is partly that the biogas is used as a substitute for fossil fuels, but it is also because of the fact that the need for waste is decreased. As described above, this lead to increased use of other combined heat and power plants within the district heating system, resulting in more electricity produced from the system.

V. Results from the project show that today's composting of food waste and anaerobic digested sludge from wastewater treatment result in emissions of acidifying substances. A better option for treatment of food waste is anaerobic digestion followed by spreading of the digestate on agricultural land as fertilizer. The sludge should also be utilised as fertilizer, or alternatively used as fuel in waste incineration.

VI. In a comparison between source separation and central sorting of food waste, the latter turns out to be a better choice when regarding economic aspects. The main reason for this is that the capital costs related to central sorting are lower compared to the costs for a system with sources separation of the food waste. Regarding the environmental aspects, the two systems are almost equal. Uncertainties within the results primarily concern the performance of a central sorting system. Even though it's not evident, the assumption made is that the sorted fractions from the central sorting facility hold an equal quality with the one from a source separation system.

VII. When comparing waste incineration with gasification of waste the latter turns out to be in favour regarding emissions of climate gases. On the other hand, waste incineration is by far the best choice when regarding economy. The reason for the good result for gasification of waste when comparing emissions of climate gases is first of all that the district heat output from the technique is much lower than the output from waste incineration. As described earlier, this results in increased electricity production within the district heating system, keeping out other electricity production with higher emissions of climate gases. Secondly, gasification of waste by itself has a higher output of electricity compared to waste incineration.

VIII. In the analysis we've blocked the possibility of importing waste to the system in study. This restriction has been evaluated in a sensitive analysis, which shows that import of waste for treatment in waste incineration within the system give positive effects on the emissions of climate gases. The main reason for this is that the import of waste results in a decrease of the amount of waste going to landfills outside the system. Since landfilling of organic waste result in high emissions of climate gases it is highly desired to decrease this activity.

IX. Composting of food waste and anaerobic digested sludge from wastewater treatment also result in emissions of substances that leads to eutrophication. However, spreading digested sludge and digestate from anaerobic digestion of food waste on agricultural land will also lead till eutrophication. From this perspective, it is better to use the digestate as fuel in waste incineration.

X. In a sensitive analysis regarding handling of anaerobic digested sludge the result shows that the best treatment method from an economic point of view is to spread the sludge on agricultural land. As discussed above (in conclusion IX), when considering eutrophication it is better to use the sludge as fuel in waste incineration. The different treatment options studied for sludge gives equal results when concerning acidification and emissions of climate gases.

In general we can conclude that the results are almost equal irrespective of which external scenario we choose to study. This means that the results hold even though changes occur in the surrounding systems. The external scenarios differ significantly and create varied prerequisites for the waste treatment system; nevertheless the results show that the same treatment methods should be chosen.

Having said so, we also have to be aware of the uncertainties that exist in the analysis. For example we've not studied how the economic results would react from a change in competitiveness for the waste treatment facilities. It is also important to notice that this, first of all, is a scientific project which points out interesting future waste treatment technologies. This means that the result should not be seen as a comprehensive material for an investment decision. Furthermore, the analysis is based on today's tax system, which of course is a simplified description of the situation of year 2030. It should also be noticed that it's difficult to find valuated data for new techniques. The data can both be overestimated, caused by to ambitious thoughts regarding the technique, and underestimated as further developments of the technique can result in decreased costs and increased performance.

Regarding the results for the aspect of climate change the assumptions for the development of the electricity production system plays a significant role. If the electricity production in northern Europe will transform into a system with less emissions of carbon dioxide the worth of electricity production in Gothenburg will decrease, and vice versa. Furthermore the results for acidification and eutrophication are difficult to interpret as these environmental problems are regional and not global. Therefore the question of where the emissions are made becomes essential. This fact has not been taken into consideration in the main results, however an alternative analysis has been made that describes this factor in more detail.

We will emphasise that many but not all aspects have been analysed for the waste treatment and district heating system. For example we have not included toxic effects or the consumer perspective. Furthermore, we have not included effects from the fact that some natural resources used within the system may be limited on a global scale; this is for example the case for phosphor and biofuels.

Finally we conclude that the three external scenarios that have been created within the project reflect three very different outcomes of the situation in 2030. Most significant we see large differences in the amount of waste that arise and needs treatment. The increase of waste differ from + 24% up to + 80%, compared to the situation of today. This results in large differences in the costs and environmental effects for the waste treatment system. A conclusion from this is that minimization of the increase of waste is essential for a more sustainable development of the society. However, in this project the focus was set on different waste treatment options and regardless of the amount of waste the choice of waste treatment method is solid.

References

[1] M. Bisaillon, J. Sundberg, M. Haraldsson, O. Eriksson, Systemstudie Avfall i Göteborg (A systems study of the waste management system in Gothenburg) (In Swedish with English summary), project report WR 21, WASTE REFINERY, SP Sveriges Tekniska Forskningsinstitut, 2010, ISSN 1654-4706

[2] ISO 14040 International Standard, Environmental management – Life cycle assessment - Principles and framework, International Organisation for Standardization, 2006, Geneva, Switzerland

[3] O. Eriksson, B. Frostell, A. Björklund, G. Assefa, J. -O. Sundqvist, J. Granath, M. Carlsson, A. Baky, L. Thyselius, ORWARE - A simulation tool for waste management, Resources, Conservation & Recycling 36/4, 2002, pp. 287-307.

[4] A. Josefsson, J. Johnsson, C-O. Wene, Community-based regional energy/environmental planning, in: The International Workshop on Operations Research and Environmental Management 1993, Universitè de Genève and Fondazione Eni Enrico Mattei Milan, Geneva, Switzerland. Milan: Fondazione Eni Enrico Mattei, 1994. Nr. 78.94

[5] M. Olofsson Linking the Analysis of Waste Management Systems and Energy Systems, Thesis for the degree of Licentiate of Engineering, 2001, Department of Energy Conversion, Chalmers University of Technology, Göteborg, Sweden

[6] O.Eriksson, M. Olofsson, T. Ekvall, How model-based systems analysis can be improved for waste management planning,Waste Management and Research 2003:21, pp.488-500.

[7] Göteborg Energi, Annual report – part 1, 2010