Biogas production feasibility in food industry clusters

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Abstract

This paper investigates if biogas production is a good alternative to treat food industry by-products and if so, under which circumstances. All food industries in Sweden, with more than 49 employees were mapped. Geographical clusters of industries were identified, and from these five clusters with no or minor biogas production were selected and further analysed. Three different perspectives were analysed for each cluster: economic, energy and environmental performance (Global Warming Potential (GWP), Acidification Potential (AP) and Eutrophication Potential (EP). The analysis was based on a comparison of three systems: BAU (Business as Usual) and two biogas production systems: "CHP" and "Vehicle". In system CHP (Combined Heat and Power) the produced biogas is used to produce heat and electricity and in system Vehicle, the produced biogas is used as vehicle fuel. Interviews were carried out with the food companies in the selected clusters to determine the amounts of organic waste and the present treatment of the waste, as basis for System BAU.

The results show that biogas should be produced in one of the clusters, whilst System BAU has an advantage over the biogas systems in all other clusters. The results for the biogas systems (CHP and Vehicle) are varying depending on the origin of the electricity production, whilst the results for System BAU is robust regarding electricity. The conclusion of this paper is that both the perspective in focus and the system at hand are vital for deciding whether or not biogas production is the best option to treat industrial food waste. Different alternatives can also be "best" from different perspectives. System CHP is a bad economical choice, but the almost always the best choice from an energy perspective for all clusters. This means that invest decisions on biogas production plants have to be made with a broad systems perspective taking existing and potential local value-chains into account.

Introduction

The well-known 20/20/20 goals for 2020, set by the European Commission, includes a target of a 20 % share of renewable energy (European Commission, 2010), as well as the target of a 20 % reduction of greenhouse gas (GHG) emissions in 2020, compared to the levels in 1990 (European Commission, 2010). The European Commission has, however, introduced extended targets to 2030 to include at least 27 % of the energy production from renewable sources together with a reduction of GHG emission of 40 % compared to the levels in 1990 (European Commission, 2014). Biogas production and use may be one way to reach these targets.

Food industry is Sweden's fourth largest industrial branch with more than 50,000 employees (Food industries, 2015). Every year large quantities of primary food products are refined to high quality products. Even though the industry is efficient in terms of energy and primary resources, large quantities of organic waste are produced and need treatment. High protein by-products are used for animal feed, fats are recovered into petroleum replacements, but still large amounts of biological by-products are left for treatment as waste.

One process of converting organic waste is anaerobic digestion to biogas, a process that not only provides fuel that can substitute fossil fuels, but also recovers nutrients that can be used as fertilizers. Anaerobic digestion is not the only possible conversion option of food waste, but given the potential for biogas to contribute to both the share of renewables in the energy mix as well as nutrient recovery, it is therefore of interest to investigate how food waste is treated today and which options for conversion are most beneficial from a systems perspective.

There have been earlier studies on conditions for using industrial substrates for biogas and alternative production. For example, Berglund and Börjesson (2006) made energy performance calculations with an LCA perspective. Tufvesson et al. (2013) analysed environmental performance of biogas production from food industry by-products in comparison to production of animal feed using different methodologies. Lantz et al. (2009) made a comparative system study for different substrates to a potential biogas plant. Viklund and Lindkvist (2015) made a systems study of potential biogas production at a food industry.

This study adds new knowledge into this field by both comparing different system designs and comparing different local settings, hence grasping a large variety of different potential scenarios where biogas production could be an option.

Aim

The aim of this paper is to investigate if biogas production is a good alternative to treat food industry waste, compared to business as usual, and if so, under which circumstances. This is done by studying five different clusters of food industries in Sweden, all with different prerequisites. The clusters are analysed from three different perspectives: economy, energy and environment (which include Global Warming Potential (GWP), acidification potential (AP) and eutrophication potential (EP)).

Research Design

This section summarizes the overall steps in data collection and methodological choices made.

METHODOLOGY

The work in this paper was done according to the process described in Figure 1. The work has been carried out by studying literature (papers, statistics), collecting data through interviews and performing calculations, which is indicated in the sections below. The data collection was made during the autumn of 2014, and the data behind the results in this study can be found to some extent in Alexandersson et al. (2014).

SELECTION OF CLUSTERS

Statistical information of the food industry in Sweden was retrieved from the Central Bureau of Statistics in Sweden (SCB). The statistics were divided according to the SNI-code (the Swedish version of NACE-codes) and sorted based on available statistics at SCB; in this case the number of employees for relevant industries. The number of employees was assumed to give an indication of the size of the companies, and hence an indication of the amount of food waste available for biogas production. To start with, all "larger" food companies in Sweden (with more than 49 employees) were identified and mapped together with all biogas plants treating organic waste. From the map, eight clusters of food companies were identified as those with a potential for organic waste that could potentially be used for biogas production. Two main criteria were used for this selection: there where several large (>49 employees) food companies located close to each other and that there was no existing biogas plant nearby. For each of the regional clusters, the study was extended with one level from the SNI-code (20–49 employees) to get a more accurate picture of the biogas potential in the system and companies with fewer employees than 20 were considered too small to have a significant impact on the results.

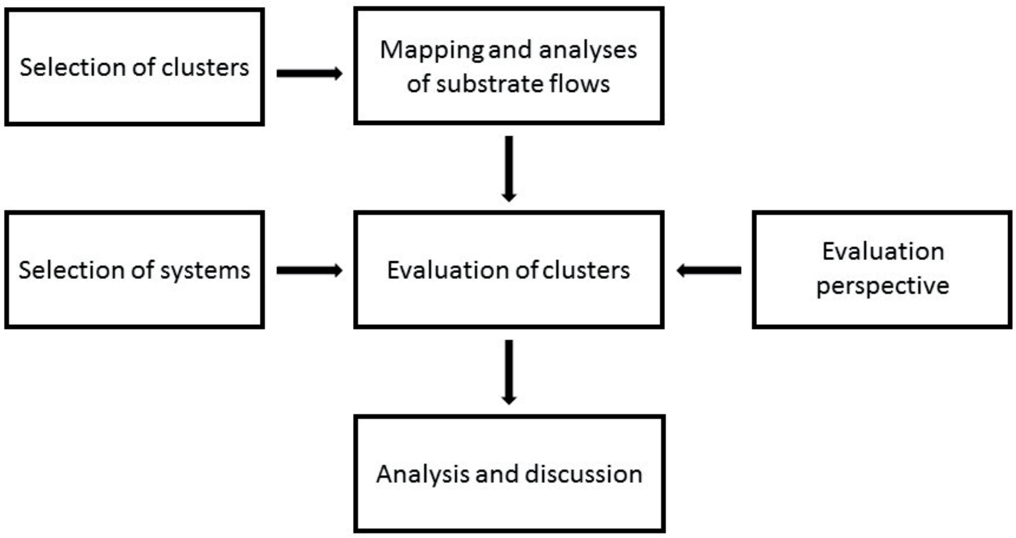

Figure 1. A schematic picture of the working process in the study.

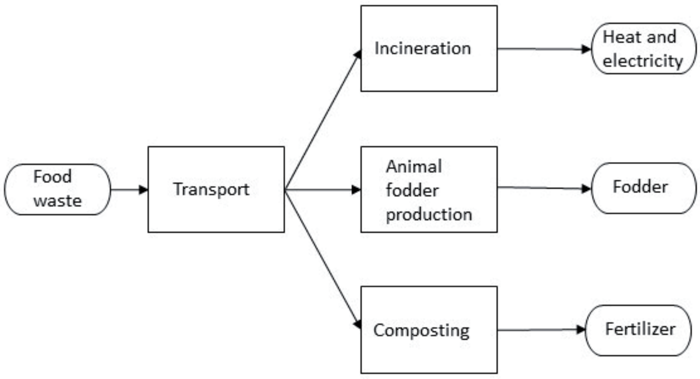

Figure 2. System BAU.

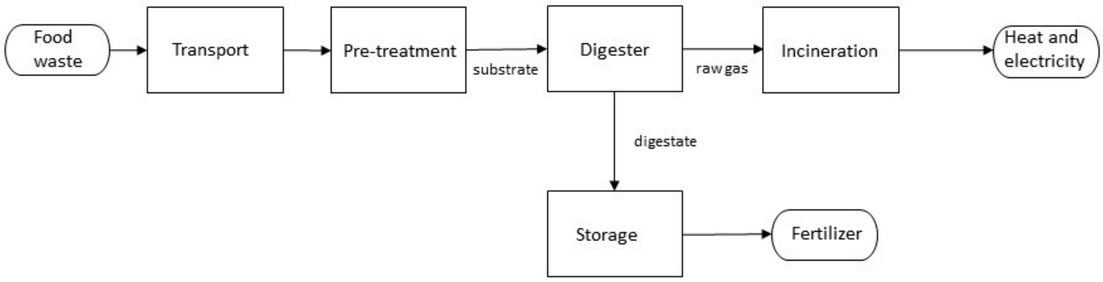

Figure 3. System CHP, where the produced biogas is incinerated to generate heat and electricity.

MAPPING AND ANALYSIS OF SUBSTRATE FLOWS

All identified food companies were contacted by telephone and complementing emails, in total 123 companies. The companies were asked about the amounts of organic waste originating from the processes and the current treatment of the waste. Response frequency from the contacted companies was 75 %. When the information was compiled, three clusters showed very small quantities of available biological waste. These were therefore excluded from the deeper studies. The biogas potential was calculated for all identified potential substrates in the five remaining clusters.

SELECTION OF SYSTEMS

Three different systems have been developed to analyse the different use of the food waste and the produced biogas (System Business as usual (BAU), System CHP and System Vehicle). The contemporary waste treatment is here referred to as System (BAU). In System BAU, the industrial food waste in the five clusters is used as either animal fodder, fuel in a CHP (Combined Heat and Power) or it is composted and used as fertilizer, see Figure 2. The system boundaries are set to include the transportation of the waste to the different treatment facilities, and to include production of heat and electricity, fodder and fertilizer from the food waste. A system expansion was made to include the environmental impacts and energy use from the production of the alternative fuel/fodder/fertilizer, as well as eventual revenue and cost connected to them. For fodder, the food waste is assumed to be replaced with conventional fodder based on soya beans and grain. The fertilizer resulting from the composting process is assumed to replace artificial fertilizer. The produced heat is assumed to replace heat from biomass, in district heating systems (DHSs), in all clusters. Electricity produced in the system is assumed to replace electricity in the Swedish national electricity grid. However, the Swedish national electricity grid is connected to the surrounding national electricity grids implying that the production units in those countries also influence the production mix. To deal with the large differences of the origin of the electricity this study assumes two extremes; (1) the produced electricity replaces electricity from a coal condensing power plant, since it is assumed to be the marginal electricity production in Europe (Johansson, 2016), and (2) the produced electricity replaces electricity from an electricity system totally based on renewables (wind power). By this approach the extremes of electricity production are shown, but it is not presumed that it is a linear relation in between these two extremes.

In System CHP, the industrial food waste is transported to a biogas plant where it is digested. The produced biogas is used to produce heat for a DHS and electricity to be delivered to the grid, and the digestate is used as fertilizer, see Figure 3. The system boundaries are set to include the transportations of the food waste and the utilization of the biogas and digestate. A system expansion is also made to include the economic perspective as well as the environmental impacts and energy use from the production of heat and electricity and fertilizer, which the food waste is replacing. Just like System BAU, the produced electricity is assumed to replace electricity in the grid both from a coal condensation power plant and from wind power, and the heat is assumed to replace heat from biomass in the DHS. The digestate is assumed to replace artificial fertilizer.

In System Vehicle, the industrial food waste is transported to a biogas plant where it is digested. The produced biogas is

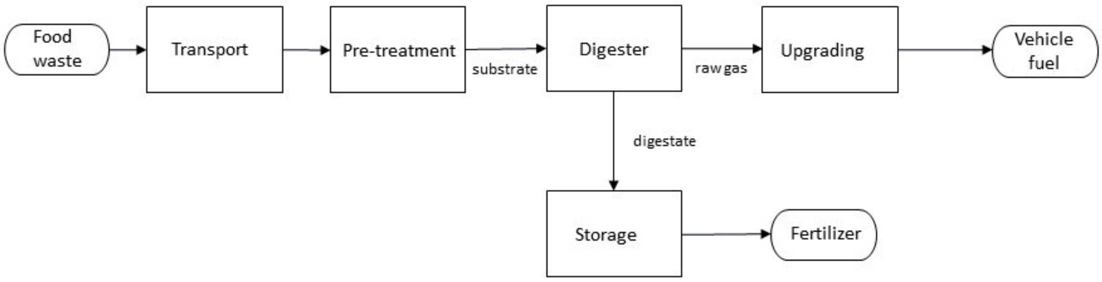

Figure 4. System Vehicle, where the produced biogas is upgraded to vehicle fuel.

used for vehicle fuel and the digestate is used as fertilizer, see Figure 4. The system boundaries are set to include the transportations of the food waste and the utilization of the biogas and digestate. A system expansion is also made to include the economic perspective as well as the environmental impacts and energy use from the production of the alternative fuel and fertilizer, which the food waste is replacing. Because a natural gas grid is only found in the south-west part of Sweden, and not nearby the selected clusters, the produced vehicle fuel is assumed to increase the number of biogas vehicles and replace vehicles that use diesel, since diesel is the fuel mostly used in the Swedish transport sector (Swedish energy agency, 2015). The digestate is assumed to replace artificial fertilizer.

EVALUATION CRITERIA

The evaluation of the clusters has been divided into three different perspectives: energy, economy and environment. The environmental perspective has in turn been divided into Global warming potential (GWP), acidification (AP) and eutrophication (EP).

Energy

The input and output of energy to all processes included in the studied systems has been calculated. To be able to compare high quality energy with low quality energy, all energy flows has been recalculated to primary energy according to Table 1.

Environment

To get a more complete environmental assessment of the systems the environmental performance of the systems has been divided into GWP, AP and EP. All emissions in the systems has been translated to CO_2-equivalents, PO_4^{3-}-equivalents or SO_2-equivalents according to Table 2.

Economy

The total costs and the total revenues associated with the different systems have been calculated and summarized for each cluster. The major costs have been identified as costs of energy, transportation and maintenance, while the major revenues are made by sales of different products (e.g. biogas, fodder, electricity).

EVALUATION OF CLUSTERS

Clusters are evaluated by using results from the previous parts in the working process. The five clusters selected, from mapping and analysis of biogas potential, together with the three selected systems (System BAU, System CHP and System Vehicle) and the three selected evaluation perspectives (economy, energy, environment) produce results showing under what circumstances biogas production is a good alternative to treat food industry waste.

In the calculations, consideration has been made to the different prices of district heating in the clusters. In each cluster a city has been set as a regional centre and the transportation distances for the substrates has been calculated to this city. In the biogas process, pre-treatment, digestion and incineration or upgrading of the biogas as well as refining of the digestate to fertilizer are included. In the biogas processes, electricity, heat and water need has been included as well as costs associated with those.

Studied cases

As mentioned above, five clusters were chosen for in-depth studies. The number of companies contacted in each cluster is shown in Table 3.

CLUSTER A

Cluster A is centralised around one of the major cities in Sweden, and 43 food companies were identified in the cluster. Of them, 35 were interviewed, manly bakeries, slaughterhouses and sugar manufacturers. There is one small biogas plant in the area, located on a farm, and one biogas plant located at an industrial site. The current treatment methods for the food waste in the cluster is shown, in Table 4, except for the amount that is currently transported to other biogas plants (49,000 ton), which are considered not available and excluded from further studies. Number of flows indicates how many different companies that are treating their food waste with this method.

The biogas potential is 513 GWh in the cluster. The biogas potential arises mainly from two flows of fruit and vegetable waste (440 GWh), but also from three flows of grain (41 GWh), six flows of flour/bread (18 GWh), one flow of yeast (4.7 GWh), one flow of dairy waste (4.5 GWh), three flows of potato waste (1.6 GWh) and five smaller flows (0.01–0.5 GWh).

CLUSTER B

Cluster B is, as cluster A, centralised around one of the major cities in Sweden. In the area, there is one large biogas plant, receiving food waste from households and industries. In this cluster, 14 food companies were identified, and of these, 12 were interviewed. The current treatment methods for the food waste in the cluster are shown in Table 5, except for the

Table 1. Conversion factors for primary energy. The factor for coal condensing power is found in Persson (2008) and the rest in Gode et al. (2011).

	Primary energy factor
Biogas (food industry waste)	0.28
Coal condensing power	3.00
Wind power	0.05
Biomass (wood chips)	1.06

Table 2. Conversion factor for CO_2-equivalents (GWP) (Solomon et al., 2007), PO_4^{3-}-equivalents (EP) and SO_2-equivalents (Guinée, 2002).

	GWP [g CO_2-equivalents]	EP [g PO_4^{3-}-equivalents]	AP [g SO_2-equivalents]
CO_2	1	0	0
CH_4	25	0	0
N_2O	298	0	0
PO_4^{3-}	0	1	0
NO_3^-	0	0.1	0
NH_3	0	0.35	1.88
NO_x	0	0.13	0.7
SO_2	0	0	1

Table 3. Number of contacted companies in each cluster.

	Companies in cluster	Interviewed companies
Cluster A	43	35
Cluster B	14	12
Cluster C	24	14
Cluster D	14	9
Cluster E	7	5
Total	**102**	**75**

Table 4. Compilation of current treatment methods for the food waste in cluster A.

Treatment	Amount [ton/year]	Biogas potential [MWh/year]	Number of flows
Animal fodder	151,000	510,000	11
Incineration	1,100	2,800	7
Fertilizer	50	51	4

Table 5. Compilation of current treatment methods for the food waste in cluster B.

	Amounts [ton/year]	Biogas potential [MWh/year]	Number of flows
Animal fodder	2,100	3,900	4
Incineration	100	240	4
Fertilizer	100	120	2

amount that is currently transported to other biogas plants (20,000 ton), which are considered not available and excluded from further studies. Number of flows indicates how many different companies that are treating their food waste with this method.

The biogas potential is 4.3 GWh in the cluster. The biogas potential arises mainly from two slaughterhouse waste flows (2.0 GWh) and sugar from one candy manufacturer (1.7 GWh). Also, seven other smaller sources (0.09–0.2 GWh) are used to create the potential.

CLUSTER C

Cluster C is a region with a lot of food industries, both smaller slaughterhouses and fisheries, but also larger manufacturers of vegetable oil and alcohol. There is one biogas plant in the area, which receives organic household and industrial waste. In the cluster, 24 industries were identified of which 14 participated in the study. The current treatment methods for the food waste in the cluster are presented in Table 6, except for the amount that is currently transported to other biogas plants (9,500 ton), which are considered not available and excluded from further studies. Number of flows indicates how many different companies that are treating their food waste with this method.

The biogas potential is 277 GWh in the cluster. The biogas potential arises mainly from two potato waste flows (163 GWh), four slaughterhouse waste flows (20 GWh) and one draff flow (82 GWh). The biogas potential also arises from one flow of cellulose (6.7 GWh), one flow of vegetable oil (3.6 GWh) and three other smaller sources (0.2–0.67 GWh).

CLUSTER D

Cluster D includes some larger companies. In total, 14 companies were identified and of these 9 were interviewed for the study. The cluster is including three cites, of which two have a biogas plant. The current treatment methods for the food waste in the cluster are shown in Table 7, except for the amount that is currently transported to other biogas plants (1,600 ton), which are considered not available and excluded from further studies. Number of flows indicates how many different companies that are treating their food waste with this method.

The biogas potential is 12.5 GWh in the cluster. The biogas potential arises mainly from two yeast flows (6.9 GWh) from two breweries, three grain flows (5.6 GWh) from food companies. Also, one other small sources (0.07 GWh) is used to create the potential.

CLUSTER E

Cluster E is located around one city. The cluster also includes another city with a biogas plant. In the cluster 7 industries were identified and of these 5 were interviewed. The current treatment methods for the food waste in the cluster are shown in Table 8, except for the amount that is currently transported to other biogas plants (60 ton), which are considered not available and excluded from further studies. Number of flows indicates how many different companies that are treating their food waste with this method.

The biogas potential is 13.4 GWh in the cluster. The biogas potential arises mainly from one grain flow (8.9 GWh) from one dairy waste flow (2.7 GWh), and one yeast flow (1.6 GWh), from a brewery. Also, two other smaller sources (0.02–0.1 GWh) is used to create the potential.

Results and analysis

The results from the evaluation of the clusters are presented below, with the assumption that all electricity production in the systems are originating from both coal condensing power and from wind power. Hence, the produced electricity in System CHP is replacing coal condensing power (top diagrams in Figures 5–9) and wind power (bottom diagrams in Figures 5–9). The economic results presented in the figures shows the net profit for the studied systems in the clusters and the energy results shows the net profit of primary energy for the systems. For AP, EP and GWP, the results show a total reduction (or increase) of the emissions, hence a large negative number is desirable for these perspectives. Worth noting is that the whole system studied contributes to the net results, and not a standalone biogas plant.

CLUSTER A

The result for the studied systems for cluster A is found in Figure 5. As can be seen the results differ between the different perspectives studied. For example, System Vehicle is the preferred system when looking at economy, but when looking at energy, System CHP is the preferred one for both wind and coal condensing power whilst System BAU is using more energy than it is generating. All three systems have similar acidification potential (AP), but in eutrophication (EP), System Vehicle would lead to an increase of the eutrophication potential whilst the other systems would lead to a decrease when the electricity is originating from coal condensing power. When studying GWP,

Table 6. Compilation of current treatment methods for the food waste in cluster C.

	Amounts [ton/year]	Biogas potential [MWh/year]	Number of flows
Animal fodder	301,000	85,000	5
Incineration	12,000	18,000	2
Fertilizer	257,000	167,000	4

Table 7. Compilation of current treatment methods for the food waste in cluster D.

	Amounts [ton/year]	Biogas potential [MWh/year]	Number of flows
Animal fodder	8,500	8,600	3
Fertilizer	5,700	3,900	3

Table 8. Compilation of current treatment methods for the food waste in cluster E.

	Amounts [ton/year]	Biogas potential [MWh/year]	Number of flows
Animal fodder	23,000	13,000	3
Incineration	110	160	2

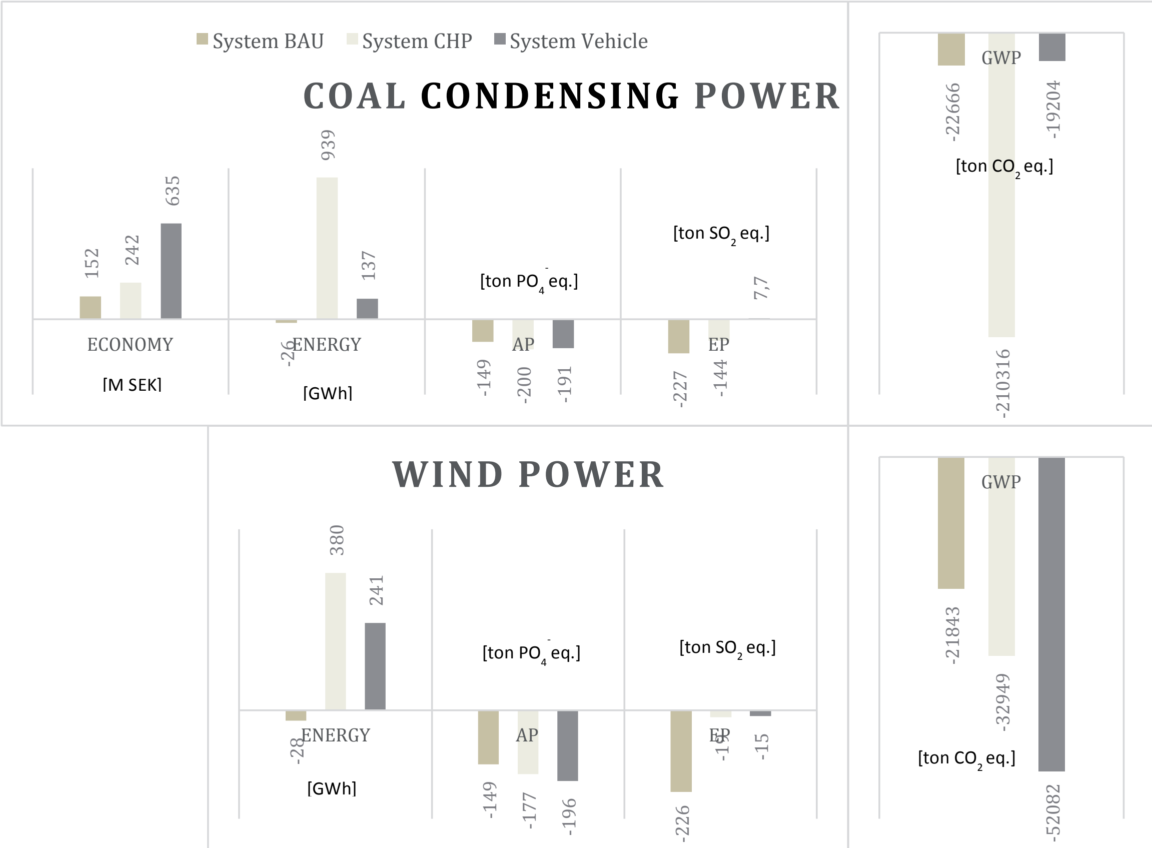

Figure 5. The results from Cluster A. Negative numbers in AP, EP and GWP indicates that the system contributes to a total reduction of the emission, hence a large negative number is desirable.

all systems contribute to a reduction of GHG emissions compared to the alternative fuel/fodder/fertilizer. However, the level of reduction differs quite a lot between the systems and System CHP has the largest reduction of emissions and are hence the preferred system when it comes to GWP when the electricity is originating from coal condensing power. When the electricity originates from wind power, System Vehicle is the preferred system when it comes to GWP. It is worth noting that System BAU is the least preferred system for all perspectives studied in cluster A, except for EP, where it is the preferred system.

CLUSTER B

The results for cluster B is found in Figure 6. As can be seen, System BAU is the preferred system when looking at all perspectives except energy and GWP, where System CHP is the preferred system in a coal based electric system. System Vehicle is the second best system, when the electricity is originating from wind, for all perspectives except for EP, where System CHP is slightly better. However, System Vehicle is the least preferred system in all perspectives when the electricity is originating from coal, but for economy. In an economical perspective System BAU is the best system and System CHP is the least preferred one. When it comes to EP, System Vehicle has an increased effect on the eutrophication potential in a coal based electric system.

CLUSTER C

The results for cluster C is found in Figure 7. As can be seen System BAU is the preferred system for all perspectives except for energy, when the electricity originates from coal condensing power, where System CHP is the preferred system. System Vehicle is the least preferred system in all perspectives with the coal based electricity system. From an economic perspective, System CHP is least preferred since it does not result in a net profit for cluster C but instead in a total financial loss for the whole system. System Vehicle requires more energy than the system generates, and contribute to an increase of both EP and GWP with a coal based electricity system, whilst with a wind based system all systems contribute to a decrease of the emissions and System Vehicle is resulting in a net profit of primary energy, just as the other systems. System CHP is the least preferred system when electricity comes from wind power, except for the energy perspective.

CLUSTER D

The results for cluster D is found in Figure 8. As can be seen System BAU is the preferred system in all perspectives except for energy and GWP when the electricity is originating from coal condensing power, where System CHP is the preferred system. System Vehicle is the least preferred system for all perspectives but economy, where it is the second best system, when electricity is originating from coal condensing power. When the electricity is originating from wind power the AP and GWP perspectives pass System CHP and are second best. Worth noting is that System CHP results in a financial loss and that System Vehicle requires more energy than is generated in the system with the coal based electrical system. System Vehicle is also resulting in increased emissions in the eutrophication and global warming potentials perspectives, with the coal

Figure 6. The results from Cluster B. Negative numbers in AP, EP and GWP indicates that the system contributes to a total reduction of the emission, hence a large negative number is desirable.

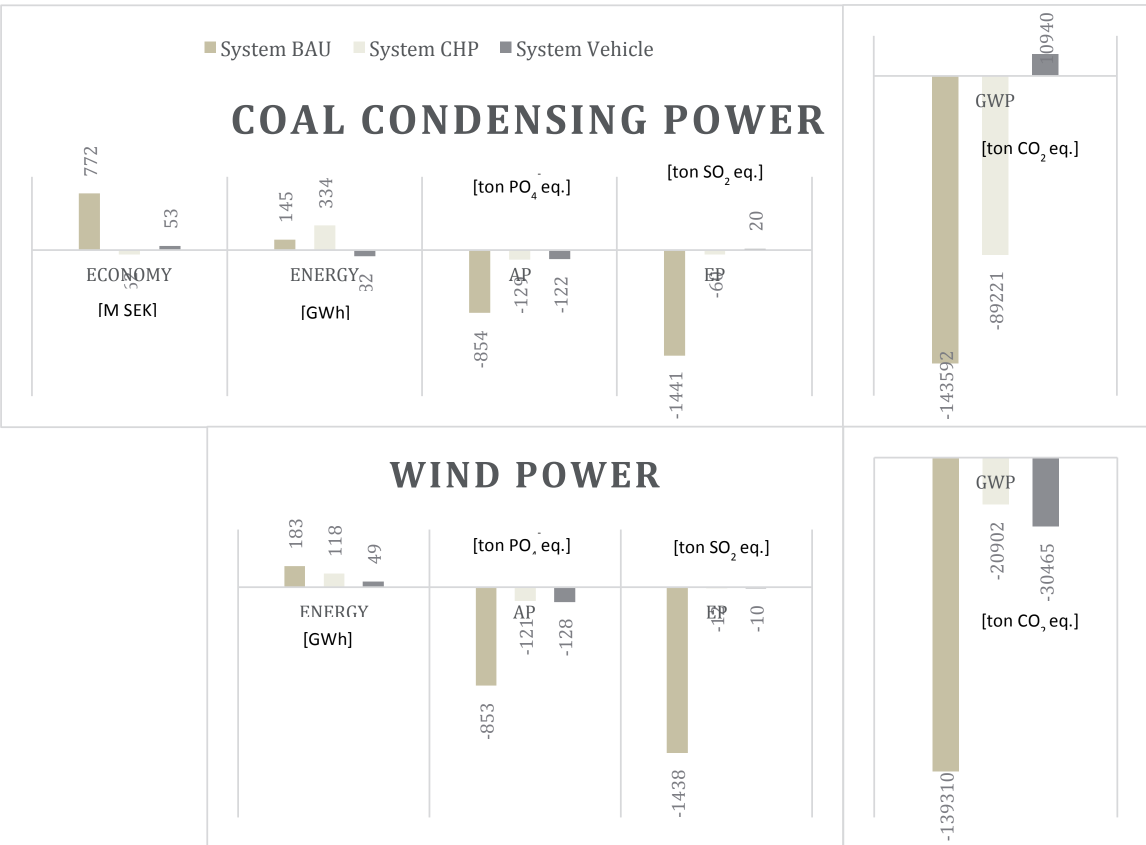

Figure 7. The results from Cluster C. Negative numbers in AP, EP and GWP indicates that the system contributes to a total reduction of the emission, hence a large negative number is desirable.

based electrical system. With the wind power based electrical system, a reduction of emissions for all environmental perspectives are found.

CLUSTER E

The results for cluster E is found in Figure 9. As can be seen System BAU is the preferred system for all perspectives both when the electricity is originating from coal and from wind, except for energy, where System CHP is the preferred system. System Vehicle is the least preferred system from all perspectives except from the AP and GWP perspectives, when the electricity originates from wind. Also, System Vehicle is the second best system from an economy perspective, whilst System CHP is resulting in a total financial loss for the system. System Vehicle is increasing the EP and GWP with a coal based electricity system whilst the other systems are decreasing the potentials to different extents. With a wind based electricity system, all systems studied are decreasing the potential for all environmental perspectives.

COMPARISON BETWEEN CLUSTERS

All clusters, but cluster A, are following the same patterns in the different perspectives; System BAU is making a considerable higher economic net profit than the two biogas systems; System CHP is the system contributing to the highest net profit from an energy perspective (except for cluster C (wind); System BAU is the preferred system from the environmental perspectives (GWP, AP and EP) except for cluster B and D (GWP when electricity from coal). For clusters B–E, the two biogas systems (CHP and Vehicle) are following the same patterns between the both of them; System CHP is better than System Vehicle from all perspectives when electricity is originating from coal condensing power and System Vehicle is better from a AP and GWP perspective with a wind power based electricity system. System Vehicle is better than System CHP from an economic perspective in all clusters.

The results for cluster A differs from the other clusters System BAU is the preferred system only from an EP perspective. Instead, the biogas systems (CHP and Vehicle) are the preferred systems in cluster A, with an advantage for System CHP in a coal based electricity system and for System Vehicle in a wind based electricity system. System Vehicle is the preferred system from an economic perspective.

As can be seen, there are small differences for the GWP in System BAU for the different electricity productions, except for Cluster D. For System CHP, the change in electricity production from coal condensing power to wind power leads to a smaller decrease of the GWP for all clusters studied. For System Vehicle, the change in electricity production improves the result in all clusters, and for cluster C, D and E, the results changes from an increase of the GWP to a decrease.

Worth noting is that System BAU is robust regarding the origin of the electricity used (and replaced), while the results for the two biogas systems (CHP and Vehicle) are influenced by

Figure 8. The results from Cluster D. Negative numbers in AP, EP and GWP indicates that the system contributes to a total reduction of the emission, hence a large negative number is desirable.

Figure 9. The results from Cluster E. Negative numbers in AP, EP and GWP indicates that the system contributes to a total reduction of the emission, hence a large negative number is desirable.

the origin of the electricity. For example, see Figure 6 for Cluster B, the GWP for System CHP is changing from having the largest decrease when the electricity is originating from coal to having the lowest decrease when the electricity is originating from wind. At the same time the decrease for System Vehicle is changing in the opposite way. The decrease for System BAU is almost the same for both electricity systems.

Concluding Discussion

The results show that System BAU has an advantage to the other systems studied in almost all clusters, it is also shown that System BAU is not dependent on how the electricity production is valued. This is the opposite for System CHP, which shows quite big changes between the two studied electricity productions. A reason for this is because of the electricity production introduced with System CHP. Since electricity is produced from biogas, electricity from another source has been decreased, and if that source is assumed to be coal condensing, it will increase the decrease of the global warming potential for the system, compared to if the electricity is produced from a renewable source. For System Vehicle, the results from a GWP perspective improves when the electricity production is changed from coal condensing to wind power. This is because System Vehicle is not producing any electricity, only using it. The results show that biogas is a good alternative to treat food industry waste for Cluster A. For the other clusters, biogas is only a good alternative from an energy perspective.

As can be seen in the results presented in this paper, deciding whether biogas is a preferable and resource efficient option is complex, and there are many variables to take into account. Not only quality and quantities of the biological waste are decisive when it comes to the net benefits of the value-chain: world prices on fuels and feedstock as well as emission allocations to substituted fuels and materials largely influence what can be regarded as most beneficial. It is therefore of greatest importance that a larger systems perspective is applied when deciding on how to utilise organic waste in future value chains.

This means that the food industry itself should not be the only actor involved in making such a decision on how to treat its by-products. On the contrary, utilising biological waste from food industry demands cooperation with both public bodies and the energy sector. The role of public bodies is mainly planning: spatial planning, resource planning, and then taking into account local resources and identifying local value-chains, whilst the role of the industry is to look for strategic alliances where the waste can become another's resource.

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