The 12th International Symposium on District Heating and Cooling,
September 5th to September 7th, 2010, Tallinn, Estonia

BIOENERGY COMBINES IN DISTRICT HEATING SYSTEMS: PROSPECTS FOR A FUTURE GROWTH INDUSTRY?

E. Axelsson[1], A. Sandoff[2], C. Overland[2]

[1]Profu, Gothenburg, Sweden.
[2]Department of Business Administration, University of Gothenburg, Sweden.

ABSTRACT

District heating offers opportunities for integration of bioenergy production (e.g. of biofuel). The aim of this paper is to assess the environmental benefit and the economic value of such integration, in order to evaluate the prospect for bioenergy combines in district heating systems. Since the detailed characteristics of the district heating system are crucial for the feasibility for integration of bioenergy production, the assessment is based on four real district heating systems. The environmental evaluation shows that the decrease in green house gas emissions from a combine are in proportion to the increase in output of CO_2 neutral energy products. However, the CO_2 reduction per used quantity of biomass is higher in conventional combined heat and power production as long as marginal electricity is related to high CO_2 emissions. Also the economic evaluation show ambiguous results: two cases had negative net present value even for low discount rates, while the two other cases showed to be more economically robust. In addition to this, a more detailed analysis of the industrial conditions for the integration shows a need for achieving a fit regarding several operational, strategic and economic circumstances for this type of business ventures. Two important conclusions that can be drawn from this is that: 1) not all district heating systems are suitable for bioenergy combines 2) there are many barriers for a wide spread adoption of bioenergy combines.

INTRODUCTION

District heating is a technology that receives increasing interest as it has great potentials in several ways. One unique characteristic of the district heating technology is the use of low temperature energy flows for large scale energy distribution. In contrast to other energy transformation technologies (e.g. condensing power or distributed gas heating), district heating can interact with energy flows that otherwise do not have any alternative use (e.g. industrial residual heat). Although this is one of the competitive advantages of the technology and a fundamental platform for its business model, this can further enhance the scoop of the business: by backward integration it is possible to increase profitability in other industrial processes with waste heat as a by-product.

One industrial branch that shows promising prospects in this respect is bioenergy production, i.e. production of various kinds of biofuel, biogas and solid biofuel. Integration of bioenergy production to district heating production eventuates in a bioenergy combine were the residual heat from the bioenergy production can be utilised for district heating. Moreover, the integration can, in many cases, offer additional positive synergies, e.g. regarding the use of steam and combustible by-products.

The fact that worldwide bioenergy production as well as the number of bioenergy products offered is increasing is a result of changing demand, which in turn offers new business opportunities. However, one of the great issues with large-scale production of bioenergy products is the growing concern over the negative externalities (social and environmental aspects as well as resource efficiency). Since energy production and consumption shows strong path dependence [1], there is an urgent need to develop and establish production technologies that help minimize the negative externalities. Utilizing the taiga and deciduous forest resources in the Northern hemisphere for this purposes is, arguably, a promising alternative. The majority of these natural resources exist in harvested forests, typically found in regions with, or suitable for, district heating.

This paper investigates the prospects of using district heating production as a base for bioenergy production and its potential to become a wide spread technology. For this purpose, we use data from four existing district heating companies to which a bioenergy production unit is fitted. By acknowledging the complexity of this integrative business venture, it is possible to get credible assessments of the magnitude in energy efficiency, environmental gains and economic profits. Equally important is the possibility to detect potential limitations for bioenergy combines to become a complement to district heating. Finally, conclusions are made to acquire clues to important restrictions to a wide spread adoption.

RESEACH DESIGN

We argue that prospects for becoming a future growth industry are dependent on the environmental benefits, economic attractiveness and fit with existing business context. Hence, these three aspects of joint production are analysed. The environmental benefits are analyzed with a system perspective on greenhouse gases (GHG) emissions, taking into account both on and off site consequences of introduction of an energy combine; see *Environmental evaluation* below. Moreover, the resource efficiency in the form of CO_2

reduction per used quantity of biomass is evaluated for each combine.

The economic benefits of the “joint production” set up are analyzed through both a short and long-term commercial lens. By using discounted cash flow techniques as a base for this analysis, it is possible to account for both the yearly consequences as well as long term economic value; see *Economic evaluation* below.

Fit with existing business context is analysed with respect to input/output markets, production and system configuration and general business conditions dominant in the host industry. The analysis focus on restrictions for short term fit; see *Business context evaluation.*

Since the detailed characteristic of the district heating system is paramount to the feasibility for integration of bioenergy production, we base our investigation on four real district heating systems in Sweden with different compositions. The chosen systems are all of equal size (500-600 GWh of yearly heat deliveries) established in towns with 40 000 to 80 000 inhabitants. These systems are in turn equipped with a bioenergy production unit that best suits ruling company strategy as well as operational characteristics and maximizes energy efficiency. In order to capture the additional values of these investments, evaluation of each combine configuration is made in relation to a reference case consisting of the existing system (complemented with investments to maintain a comparable level of production quality). The reference and combine cases are further described in the *Description of the cases* below.

Much effort was put into indentifying efficient technical solutions that best take advantage of the site-specific conditions in each system. This work included everything from choice of equipment, appropriate size of the integrated production unit and production strategies over the year regarding output of heat, electricity and other energy products. To identify efficient technical solutions an integrative computerized process was applied, including both the district heating simulation software MARTES [2], and detailed spread sheet calculations. In order to guarantee high quality input data, representatives from these four companies gave access to technical, environmental as well as economic data.

Below follows a description of the environmental and economic evaluation procedure. It is important to stress that the input data for these assessments only include the change resulting from the integration of the bioenergy production. One implication of this approach is that the environmental benefit of the heat produced (for district heating) is not included, since one base condition is that the heat deliveries are the same with and without bioenergy production. Another implication is that production units in the district heating system that are not affected (e.g. base load and peak load production units) are not included. This system boundary is also pervading in the *Description of the cases* to follow.

Description of the cases

The four district heating systems with reference and combine cases, respectively, are presented in brief below. The four objects for the evaluation are also summarized in *Table I*. A more comprehensive description can be found in ref. [3].

Table I. Overview of the reference and combine cases in the four district heating systems. Economic and energy data are given for both the reference and combine case, separated with a slash (ref./combine).

CONFIGURATION				
	1	2	3	4
Heat deliv. (GWh/y)	500	530	560	620
Ref. inv.	Bio CHP	None	Bio CHP	Bio CHP
Combine technology	Pyrolysis	Enzymatic hydrolysis	Acid hydrolysis	Gasi-fication
Products	Bio oil	Ethanol	Ethanol[1]	FTdiesel[2]
ECONOMIC DATA, reference/combine				
	1	2	3	4
Inv. (M€)	74/60	0/144	116/310	146/473
O&M (M€/y)	2.3/2.8	0/8.8	3.6/15.8	6.1/11.1
ENERGY CONSUMTION, (GWh/year), ref./combine				
	1	2	3	4
Biomass	397/244	730/1537	470/1271	362/2970
Others	74/135[3]	-	-	-
ENERGY PRODUCTION (GWh/year), reference/combine				
	1	2	3	4
Electricity	125/0	218/209	145/55	99/78
Biofuel	0/90	0/444	0/294	0/1336
Others	-	-	0/384[4]	-

[1] Besides ethanol also biogas and pellets is produced.
[2] Also kerosene and nafta is produced.
[3] Fuel oil (21/15) and industrial waste heat (53/120).
[4] Biogas (0/114) and Pellets (0/270)

System 1
In the current configuration of this system 15-20% of the energy demand is covered with fuel oil, which needs to be reduced. One interesting option could be to convert biomass into bio oil by pyrolysis and then use the bio oil in the existing oil boilers. Bio oil that is not used within the system can be sold (e.g. summer time). If no pyrolysis reactor is built, a conventional biofuel fired combined heat and power plant (bio CHP) will be invested in, building up the reference case.

System 2
In this system, there is no need for new production units, rather there is a high production capacity, allowing for integration of a bioenergy production unit. System 2 has good access to biomass, but might have

difficulties to find a market for large quantities of by-products. Based on these prerequisites, a suitable combine technology could be cellulose ethanol production with enzymatic hydrolysis aiming at high yield and in-house use of energy by-products. Regarding the O&M cost for the enzymatic process in *Table I*, future enzyme price are assumed [4], With today's prices, the enzymatic process will not be profitable.

System 3
In System 3 there is a need for new production capacity, which is represented by a bio CHP in the reference case. This system has good access to a large energy market, which enables output of other energy products. Hence, a cellulose ethanol plant based on acid hydrolysis can complement the reference case investment to build up the combine case.

System 4
This system is in many aspects similar to System 3, but ethanol production is not in line with company strategy. Moreover, System 3 has good access to peat, which could supplement biomass for a large scale production unit. Hence, gasification of biomass for production of synthetic biofuel is evaluated for this system.

Environmental evaluation

The assessment of the environmental implication of introducing a bioenergy production in an existing district heating system focuses on changes in emissions of green house gases (GHG). A system approach for analysing the changes of GHG's is applied. This means that besides changes of the direct emissions on site, also the changes of emissions in affected parts of the energy systems are included; see *Figure 1*. For instance, production of biofuel in the combines ads to the environmental benefit since fossil fuels can be replaced, while reduced electricity production has a negative impact to the environmental benefit in accordance with marginal electricity production.

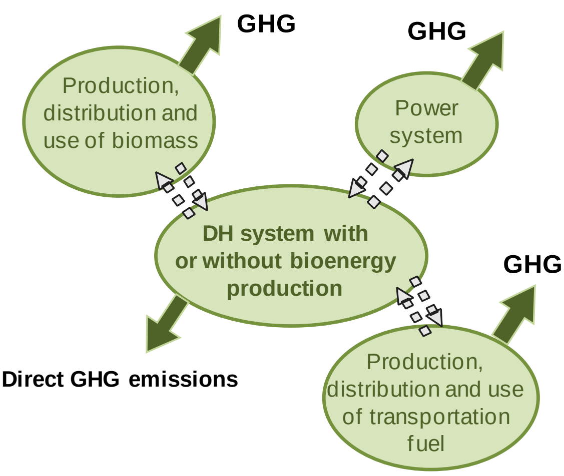

Fig.1. Illustration of the applied system approach for assessing the changes of GHG's.

In the assessment, all GHG's of significance are included [3]: carbon dioxide (CO_2), dinitrogen oxide (N_2O) and methane (CH_4). For all energy carriers, life cycle emissions are considered, i.e. both combustion emissions and well-to-gate emissions such as emissions from fuel extraction, processing and transportation. Also leakages are considered when applicable. How the GHG's for the relevant energy carriers are assessed are described in brief below, a more thorough description can be found in [3].The adopted life cycle GHG emissions associated with changes in consumption/production of the energy carriers are summarized in *Table II*.

Table II. Emission factors for included energy carriers.

ENERGY CARRIER	LIFE CYCLE EMISSION ($kg\ CO_2$ eq./MWh)
Biomass	14-17[1]
High emission elec. (E1)	800
Low emission electricity (E2)	260
Pyrolysis oil	292
Ethanol	307
FT diesel	277
Fuel oil	312
Biogas	207
Pellets	286

[1] The lifecycle emission of biomass is dependent on how the biomass is used in the energy combines (e.g. hydrolysis for fermentation or gasification)

Biomass
The energy input in all four combines is in the form of biomass. Production, distribution and use of biomass is related to GHG emissions. The GHG emission from the use of biomass differs depending on how the biomass is used. Combustion raises emissions of both methane and N_2O (the CO_2 emission are assumed to be neutral from a climate perspective), while hydrolysis and fermentation is not assumed to raise these emissions. Hence, the net lifecycle emission of biomass differs between 14-17 kg CO_2 eq./MWh fuel.

Electricity
In all district heating systems, the electricity production decreases as a consequence of introducing the combine (see *Description of the cases*). Any change in electricity production is assumed to be compensated by changes in marginal electricity production. For instance, if the electricity production decreases by 85 GWh/year, it is assumed that other producers will increase their production by 85 GWh/year. To assess the environmental impact of this, the decrease has to be multiplied with a emission factor for marginal electricity.

There are many opinions regarding the emissions of marginal electricity. Here we have used a high and a low level, based on dynamic response for electricity production with two different developments over a long time period [5]. By using a high and low figure, the impact and importance of changes in electricity can be illustrated in a clear way. For the high figure, the reference case in [5] is used where lifecycle emissions of marginal electricity are about 800 kg/MWh$_{el}$. This marginal electricity is denoted E1 hereon. With more stringent environmental targets the electricity production can be carbon lean [5] implying that the long term lifecycle emissions would be about 260 kg/MWh$_{el}$, denoted E2 hereon.

Biofuel
As seen in *Table I,* the evaluated bioenergy combines have various biofuel products as output. In System 1 pyrolysis oil is produced. The pyrolysis oil is assumed to replace fossil fuel oil (but is categorized as an biofuel herein). If lifecycle emissions are regarded according to the approach in ref. [6] for both pyrolysis oil and fossil fuel oil, the net GHG reduction for replacing fuel oil with pyrolysis oil is 292 kg per MWh of pyrolysis oil exported from the combine. Also the amount of fuel oil used differs in the combine case from the reference case in System 1 (see *Table I)*. The net life cycle GHG of this fuel oil is set to 312 kg/MWh.

In systems 2 and 3 ethanol is produced, which is assumed to replace gasoline with net GHG reduction of 307 kg per MWh of ethanol reaching the market.

In System 4, three biofuels are produced: Fischer Tropsch (FT) diesel, nafta and kerosene. All three products are assumed to replace fossil transportation fuel with the net GHG reduction of 277 kg/MWh. The possible leakage of methane from the gasification process is assumed to be negligible.

Biogas and pellets
In the energy combine of System 3, also biogas and pellets are produced. The biogas is assumed to be used as a transportation fuel to replace both petrol and diesel. The net GHG reduction for replacing fossil transportation fuel with biogas is set to 207 kg/MWh including life cycle emission and gas leakage in the production. The pellets are also assumed to replace fossil fuel, in this case oil with a net GHG reduction of 286 kg/MWh pellets.

Resource efficiency
With the emission factors in *Table II* and the energy flows of the reference and combine case in *Table I,* the environmental benefit of the energy combine can be assessed. However, if biomass is assumed to be a limited resource from a sustainability point of view, it makes sense to evaluate the use of biomass from an efficiency perspective. Hence, the resource efficiency is assessed as the net GHG reduction potential (in kg CO_2 eq.) per used quantity of biomass (in MWh). By comparing this key figure for the reference case with the combine case for each system, the resource efficiency of the combines can be evaluated.

Economic evaluation

In order to analyze whether an investment adds financial value we rely on a standard discounted cash flow (DCF) model estimating the net present value (NPV) for each project so that:

$$NPV = \sum_{t=0}^{n} \left(CF_t / (1+r)^t \right) \qquad (1)$$

, where CF_t denotes the net cash flow in year *t*, *r* is the future weighted cost of capital and *n* is the number of years included in the cost-/benefit analysis. The cash flow at year 0 indicates the initial outlay. Concerning *r*, the weighted average cost of capital (WACC), we do not predetermine a specific hurdle rate; instead we analyze value added for three different levels of discount rates. We do so because any statements on the actual riskiness of the project or an estimation of the WACC for the companies are outside the reach of this study. As stated before, when estimating cash flows the point of departure is a reference object. That is, our NPV calculations only address the differences in cash flows between the reference and the bioenergy combine; this for two reasons. First, only the incremental cash flows are relevant in a DCF analysis. For instance, in the case of System 3 they already decided that they would at least build a combined heat and power (CHP) facility, and the question is if they gain from making additional investments in a bioenergy production unit. Second, by focusing on the differences we do not need to consider the cost structure in the reference case, it is treated as a given. Besides simplifying the analysis, academic access is facilitated as there is no need to reveal sensitive information.

Table III. Assumptions made for non-site idiosyncratic input and output prices (€/MWh).

Ethanol	78	Biomass	19
FT-diesel	78	Fuel oil	57
Kersone	78	Pellets	25
Nafta	52	Electricity	47
Biooil	47	Electricity excise	0.5
Biogas	68	Electricity certificate[1]	21

[1] Premium paid to producers of renewable electricity.

Cash flows
The initial outlay is assumed to take place in full at year 0. Yearly operational cash flows are projected by first estimating an operational cash flow for the first year. As cash flows are the products of price and quantity, this estimation is based on the technical analysis in order to obtain energy flow estimates (see *Table I*), and then multiply them with price estimates, to which we add out-payments for operation and maintenance. We extrapolate this operational cash flow over the 20 year long investment horizon with a three percent yearly growth rate (adjusted for the fact that green certificates are obtained for fifteen years only). All cash flows are conservatively assumed to occur at the end of each year. Next, we add tax payments (assuming an effective tax rate of 26,3%), tax discounts from depreciation (according to Swedish tax code), changes in working capital (approximated by dividing the difference between in-payments and out-payments of year t by 12 and subtracting the corresponding value from year t-1, save for the last year where the difference is set to zero) and a terminal value (5% of the initial outlay). Initial outlays are determined by consulting [7]-[19]. Our price

assumptions for non-site idiosyncratic inputs and outputs are presented in *Table III*. For translation between different currencies the following exchange rates were used: 9.6 SEK/€ and 6.5SEK/USD.

Sensitivity analysis
We then control the robustness of the NPV estimates through sensitivity analysis; that is, we examine how the cost-/benefit analysis is affected when changing a variable at the time, holding all else equal. We do this in two steps for each system. First, we illustrate the changes in estimated NPV by changing yearly in-payments, yearly out-payments, initial outlay and terminal value respectively. Second, we show how yearly in-payments and out-payments respond to price changes.

By this sensitivity analysis, we can to some degree compensate for the uncertainty that surrounds our estimates of initial outlays and terminal value, and we can see for what potential price changes extra concern is warranted. Certainly, a drawback with the sensitivity analysis is that it is just a *ceteris paribus* analysis and does not take into consideration the potential covariance of variables, for instance between ingoing biomass and outgoing biofuel.

Business context evaluation

The environmental and economic analyses of a joint production operation act as a starting point for the business context analysis. A wide-spread adoption demands not only indications of environmental benefits and economic profits, but must also offer a fit with the existing business context. Even though the degree of fit is defined on company level we will not analyze it as such. Rather we use the business context of the studied systems in order to put together a compilation of restrictions and barriers to a wide-spread adoption. The magnitude and importance of these will give important indications of the short term possibilities of realizing environmental benefits and economic profits in making bioenergy combines a future growth industry. The restrictions and barriers are identified through the fit with existing input/output market situation, production and system configuration and general business conditions, (i.e. strategic focus and capacity to absorb additional risk) dominant in the host company.

ENVIRONMENTAL BENEFITS

As already stated in the *Research design*, the environmental benefit from integrating bioenergy production into an existing district heating system is assessed as the reduction of GHG's from a system perspective. As also explained, the net difference depends on the reference case as well as the composition of the energy combine. In *Figure 2*, the GHG reduction for the included parts of the reference case and energy combine case of System 3 is displayed. In the reference case (left bar in *Figure 2*) – a combined heat and power (CHP) plant – biomass is converted into heat (for district heating) and electricity. The amount of heat is the same in both the reference and combine cases and, hence, not considered in the evaluation of GHG reduction. However, the production of electricity will change and the system consequences of that is, as stated, considered by including two different assumptions for marginal electricity. Assuming that marginal electricity is related to about 260 kg CO_2 eq./MWh_{el} (E2), the electricity produced in the reference case results in a yearly reduction of 38 ktonne (dark blue bar to the left in *Figure 2*). If the emissions of marginal electricity instead is assumed to be 800 kg/MWh_{el} (E1), the emission reduction would increase by 78 ktonne/year (light blue bar) to be in total 116 ktonne (dark + light blue bar = E1). The handling of the biomass is related to GHG emissions (see *Environmental evaluation*) and, hence, there is a negative bar of 8 ktonne for biomass. To sum up, the net GHG reduction in the reference case is 30 or 108 ktonne CO_2 equivalents depending on assumptions for the marginal electricity.

The combine case of System 3 has lower electricity production than in the reference case (see *Description of the cases*). Consequently, the GHG reduction from the electricity production is also lower, which is seen as lower dark and light blue bars for the combine case; middle stacked bar in *Figure 2*. Moreover, the negative bar for biomass is larger for the combine since more biomass is used in this case. In the energy combine, however, bioenergy products such as biofuel (ethanol in this system), biogas and pellets are produced. As already explained, these energy products are assumed to replace fossil fuels and the resulting GHG reduction from the combine is significant: 188 or 217 ktonne CO_2 eq. with carbon lean (E2) and carbon intense (E1) electricity production, respectively.

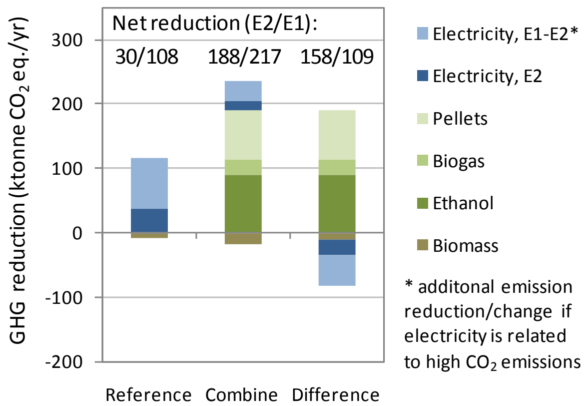

Fig. 2. GHG reduction in System 3 for the reference case, combine case and the net difference for converting to the combine. The dark blue bars are related to marginal electricity associated to low GHG emission (E2). The additional emission reduction/change if electricity is related to high GHG emissions (E1-E2) is indicated by the light blue bars. The total emission/change for E2 is given by the sum of light blue and dark blue bar.

The implication in terms of GHG's of integrating bioenergy production in System 3 can be visualised by moving from the left bar in *Figure 2* to the middle bar. Consequently, the difference of the two bars shows the GHG implication of converting to an energy combine in System 3, which is presented in the right hand bar in the figure. The change from the reference to the combine case gives rise to GHG reduction from the fuel products (green bars) However, the electricity production decreases, implying decreased reduction (emission increase) and, hence, negative bars for electricity. As can be seen in the figure, the net GHG reduction from introducing an energy combine in System 3 is 158 or 109 ktonne/year depending on the assumption for marginal electricity (E2 and E1, respectively).

The equivalents to the right hand bar in *Figure 2* for all four systems are shown in *Figure 3*. As can be seen, the reductions of GHG's are significant in systems 2-4, especially if the electricity is associated with low emissions (E2, dark blue bar only). In System 1, the environmental benefit is negative, even if the marginal electricity is CO_2 lean.

Significant environmental benefits, as displayed for systems 2-4, are expected since the combines in these systems use more biomass, which eventually replaces fossil fuel in the system approach applied (in system 1 less biomass is used which explains the negative results for this system). However, if biomass is assumed to be a limited resource from sustainability point of view, the use of biomass should also be evaluated from an efficiency point of view. As explained in the *Environmental evaluation*, one measure of resource efficiency is the GHG reduction potential per used quantity of biomass. This key figure is presented in *Figure 4* for both the reference case and the combine case for the four district heating systems evaluated.

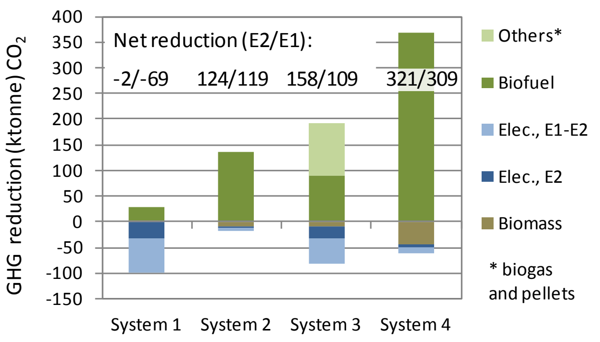

Fig. 3. Environmental benefit from introduction of energy combines.

As seen in *Figure 4*, the energy combines are less resource efficient than the reference cases (generally a biomass fired CHP plant) if the marginal electricity is associated with high CO_2 emissions (E1, dark + light blue bar). However, if the marginal electricity is associated with low CO_2 emissions (E2, dark blue bar only), the combines are more resource efficient than the reference cases. As also can be seen, the resource efficiencies do not differ dramatically between systems 2-4. System 1, however, shows lower resource efficiency, which can be explained by the fact that a major part of the produced pyrolysis oil is consumed internally in the system instead of replacing fossil fuel off site.

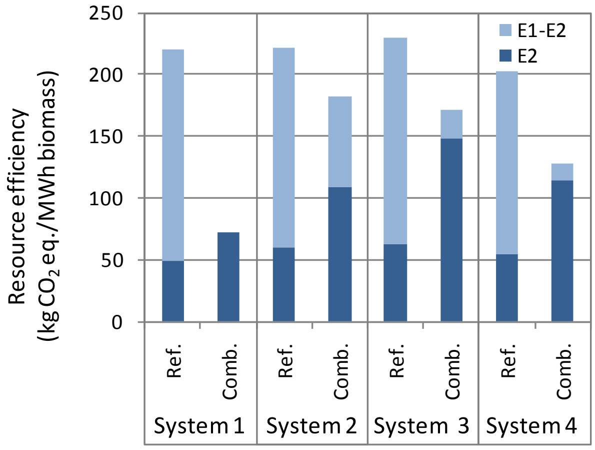

Fig. 4. Resource efficiency of biomass quantified as GHG reduction per used quantity of biomass.

ECONOMIC VALUE

Whether the cost/benefit analyses return positive NPVs depend largely on the hurdle rates assigned to them. In *Table IV* a summary of the economic results are presented including the initial outlay, the expected free cash flow for the first year and estimated NPVs for 4, 7 and 10% discount rates, respectively. With the exception of System 1, where the bioenergy combine is actually cheaper than the reference plant, marginal initial outlays vary between M€ 140 and 330, and expected cash flows for the first year of operations between M€ -3 and 57. The largest addition to existing cash flow (both in absolute and relative terms) comes from the bioenergy combine investment in System 4.

Table IV. Summary of cost/benefit analyses for adding a bioenergy combine to the reference investment in the studied systems.

	1	2	3	4
Initial outlay (M€)	- 13.9	144	194	327
Cash flow (M€y)	-3.4	18.8	15.7	57
NPV (M€) for different discount rates				
4%	-40	76	-62	362
7%	-27	29	-89	207
10%	-19	-4	-108	101

As also can be seen in *Table IV*, only two projects are value adding at a 4% discount rate, and System 4 is the only one that can bear a 10% discount rate. The results for System 1 are a bit upside down, since compared to the reference case the investment cost and net cash flows are negative for the combine. System 3, perhaps being the weakest of cases analyzed, will not show positive figures for any positive discount rate.

For robustness control purposes, sensitivity analyses are performed, here presented for System 3. *Figure 5* illustrates the estimated NPV consequences from changes in marginal cash flows, disaggregated into in-payments, out-payments, initial outlays and terminal value.

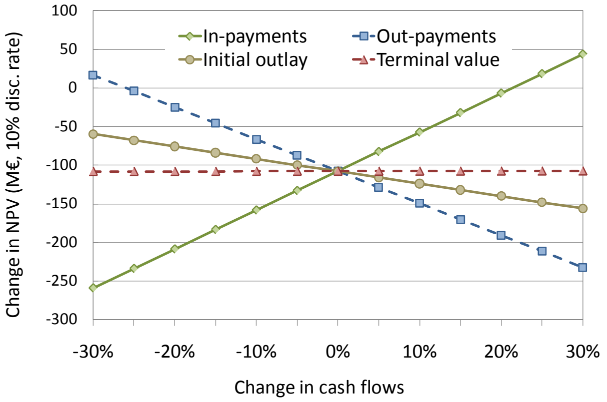

Fig. 5. Estimated changes in NPV (M€) for System 3 as a result of percentage changes in cash flows assuming a 10% discount rate.

A percent change in either of these, results (*ceteris paribus*) in a NPV change, as indicated in the figure. It is clear that the project is most vulnerable for changes in in-payments followed by out-payments. Assuming a hurdle rat of ten percent, a 20% average increase in yearly in-payments would result in an increase in NPV of about € 100 million. Correspondingly, a 20% increase in yearly out-payments result in a NPV reduction of € 84 millions. *Figure 5* also show that the cost/benefit analysis is not very sensitive to changes in initial outlay and leave no visible mark for changes in terminal value. The order of importance of NPV impact of cash flow changes are similar in the other three systems, where in-payments being the most important ones.

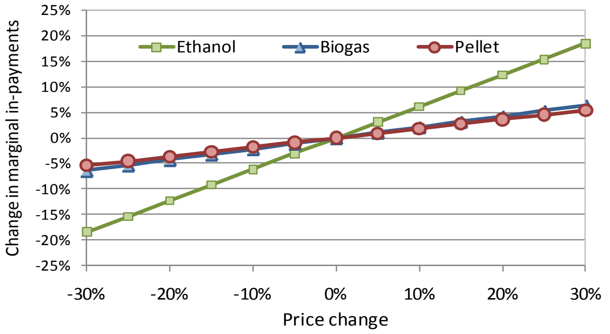

Fig. 6. Estimated percentage changes in in-payments for System 3 as a result of percentage changes in input prices.

Having established the sensitivity to changes in cash flows it follows naturally to examine also to what degree different cash flows changes with respect to changes in underlying prices. In *Figure 6*, the relation between marginal in-payments and prices of ethanol, biogas and pellets are shown for System 3. It is clear that ethanol is by far the most important bioenergy product, where a 20% increase in prices renders a 12% increase in in-payment.

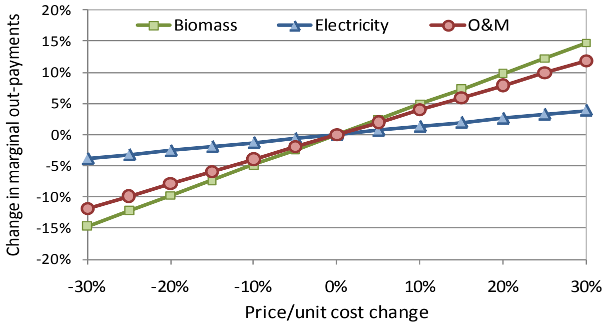

Fig. 7. Estimated percentage changes in out-payments for System 3 as a result of percentage changes in input prices/unit costs.

Similarly, *Figure 7* shows how out-payments vary with input prices. Inputs included in the figure are biofuel, operations and maintenance (O&M) and electricity[1]. Not surprisingly, biofuel is the key input, where a 20% price change results in a 10% change in out-payments, which in *Figure 5* translates to a € 42 million change in NPV.

The sensitivity analyses of System 3 show that minor changes in underlying factors can result in significant changes in the NPV estimates. However, a not insignificant part of the indicated variability in cash flows should be hampered by the offsetting effects driven by the probable covariance between prices for biomass and bioenergy products. To be noticed is that the order of importance of the inputs in the other three systems show a similar ranking, where biofuel and biomass price being the two most important ones.

FIT WITH EXISTING BUSINESS CONTEXT

The environmental and economic evaluations indicate that the integration of bioenergy production into medium sized district heating systems can be associated with both environmental and economic benefits, but the picture is mixed and ambiguous. From an environmental point of view, the results are coherent across all systems: the absolute environmental benefit of bioenergy production is in proportion to the use of biomass, since increased use of biomass implies increased output of CO_2 neutral energy products. However, from a resource efficiency point of view, biomass should not be used to replace transportation fuel as long as the marginal electricity is related to high CO_2 emissions. One important explanation to the coherent environmental profiles of the different bioenergy combine solutions is similar resource efficiency for the four technologies evaluated. Hence, our results suggest that it is possible to find different energy combine with similar resource efficiency.

---

[1] The electricity in out-payments corresponds to the electricity used in the bioenergy production unit. In *Table 1*, only the net electricity export is displayed.

However, these similarities in resource efficiency do not indicate similarities in economic attractiveness. In fact, the economic evaluation seems to suggest that some bioenergy production technologies are not currently economic viable for integration with district heating system. Furthermore, the results indicate that not all district heating systems are suitable for integration with a biofuel production unit. Despite being of the same size, use the same raw material and being evaluated only on marginal effects on the economic situation, differences in district heating system characteristics have a profound impact on the economic possibilities of energy combine integration. In this study we have matched every system with a combine solution in order to maximize the site-specific opportunities in each system. This opens of course the possibility that there exist other matches with less resource efficiency but higher economic profitability. Even if this can be the case, we would like to point out that one of the starting points of this study was to base in-data on the conditions of real systems. This includes taking various kinds of restrictions into consideration. Even though these restrictions vary, the ones prominent in this study can be grouped into four different categories:

- Proximity to input resources
- Proximity to customers or infrastructure for transporting the finished products
- Existing production and system configuration
- Dominant business conditions

Proximity to input resources
Some combine solutions (such as the one for System 4) demand huge amounts of biomass. This requires large areas of regional biomass recourses and little or no competition over it. Import by sea is an alternative but it requires production sites close to a harbour.

Proximity to market for the finished product
The production of biogas is one example of both the importance of proximity to customers and to infrastructure. Only relying on local demand for biogas is considered too challenging at present time.

Existing production and system configuration
Investments in bioenergy combines are seldom green field but, as we have shown earlier, have to be adapted to suit existing heat volumes, demand curves, system configurations and also production site layout. In one of the systems, the production site was too small to house the large amounts of biomass necessary for achieving an economic profitable size of an ethanol operation.

Dominant business conditions
The results of the study show that two business areas have an evident influence on the type of bioenergy combine investments the companies carry out: 1) the strategic framing of the district heating company and 2) the risk that these investments innate. Concerning the first, many of the municipally owners use the utilities to enhance and to some extent even realize the environmental visions that are formed and expressed on the political level. Examples of these found among the companies represented in this study include; phasing out fossil fuels, use of local waste resources and visions of a fossil free cities based around locally produced bioenergy fuels. When present, strategic framing has a visible effect on limiting the number of available alternatives for integrates production.

As stated, the second area that has an significant influence on the type of bioenergy combine that these companies consider is the risk that these investments innate. Due to the municipal ownership, these companies are inherently dependent on stable business conditions. The ability to absorb negative results is strongly limited. The added business risk of bioenergy production must, if needed, be able to be absorbed by cash flows from existing operations or a strong capital base. In principle, this can be done in two ways, either by keeping the investment relatively small, or by only accepting business propositions with cash flows that can be made relatively stable.

In *Figure 8*, the operational risk of the investment can to some extent be visualized by the size of the marginal cash flows of the different investments. The investment in system 4 stands out not only because it is the largest one but also because its in-payment comes from one source only. If the price correlation with biomass is high, this might not be a large problem. However, it is interesting to note the relatively small positive cash flow available from existing operations in Systems 4, and also for System 3. If the company carries through with the evaluated investment, it will dramatically change its operational risk profile and over-all business focus.

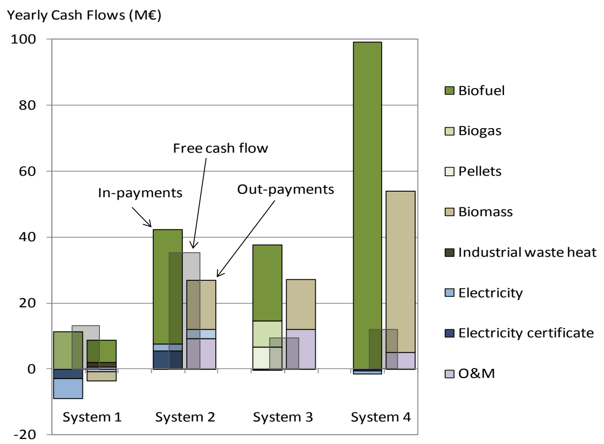

Fig. 8. Marginal cash flows (in-payments/out-payments) for each system in comparison to free cash flow from existing operations in 2007 (shaded bar).

The considerable positive free cash flow of system 2 from its existing operations is explained by the company's sell of hydropower. Although irrelevant for the value of this investment, it could function as a general safeguard against negative results, due to

unfavourable relation between biofuel and biomass prices.
The investment in system 1 was not profitable according to the valuation earlier. Despite this, it is worth pointing out that the risk of this investment should be low since it uses its own products as input. It too has, relatively speaking, a strong free cash flow from its current operation that will decrease the risk of ending up in the red.

CONCLUSIONS

The results of the bioenergy combine analyses show that there are indications for both environmental gains and added economic value of such investments. However, these benefits seem to be limited by several operational, environmental and economic circumstances present in these systems. First, these investments are dependent on the need for making major changes in current production layout, typically the need for new or altered production plants. This limits the available window of opportunity. There are also several limitations related to operational characteristics, availability of input resources and suitable product markets. A closer investigation of existing governance situation also shows that these investments often are made to fit owner strategies regarding environmental goals of the local energy system. Finally, the municipally ownership typically limits the risk appetite which also limits available investments. The doubtful short term environmental benefit is a more general objection based on the valuation of the current marginal power production. Never the less, it will hamper the potential for wide-spread adoption of bioenergy combines.

These circumstances lead us to conclude that not all biofuel production technologies are suitable for all district heating system. Our economic analyses also indicate that not all district heating systems are suitable for bioenergy combine production. In fact the barriers are so many that it is reasonable to assume they will effectively reduce the number of systems adopting this operational design in the near future.

ACKNOWLEDGEMENTS

The main funding for this project is provided by Fjärrsyn, which is a research program organized by the Swedish district heating branch agency. Additional funding is also received from the project “Pathways to Sustainable Energy Systems”.

We kindly thank the representatives from each district heating system for a good cooperation and for providing us with technical and economic data of their systems. Without these inputs, the work would not have been as solid as it is.

We also thank Karolina Nilsson and John Jonsson (both at Profu) for their valuable contribution to the work.

REFERENCES

[1] M. Odenberger, F. Johnsson, “Pathways for the European electricity supply system to 2050”, Int. J. of Greenhouse Gas Control, 2010, Vol. 4:2, pp 327-340
[2] J.Sjödin and D. Henning, “Calculating the marginal costs of a district-heating utility”, Applied Energy, 2004, Vol. 78:1, pp 1-18.
[3] E. Axelsson, C. Overland, K. Nilsson, and A. Sandoff, ”Bioenergikombinat i fjärrvärmesystem”, Fjärrsynsrapport 2009:11.
[4] T. Brandberg, Senior researcher at SEKAB E-technology, Personal communication, 2009.
[5] H. Sköldberg and T. Unger, ”Effekter av förändrad elanvändning/elproduktion”. Elforsk report (2008).
[6] IVL, “Miljöfaktabok för bränslen”, IVL Rapport B 1334B-2 (2001).
[7] Svebio, “Kraftvärmeutbyggnad 2007-2015”, Svebio repport 2008-03-31.
[8] H. Hansson, S-E. Larsson, O. Nyström, F. Olsson and B. Ridell, “El från nya anläggningar - 2007”, Elforsk repport no 07:50 (2007).
[9] M. Zakrisson, “Internationell jämförelse av produktionskostnader vid pelletstillverkning”, Master’s thesis no 29 2002, SLU.
[10] A. Hang and S. Ilic, ”En förstudie för bioetanol produktion i Borås”, Master’s thesis at Institutionen Ingenjörshögskolan, Högskolan i Borås (2008).
[11] M. Lantz, “Drivmedelsproducenters betalningsförmåga för energigrödor”, Miljö- och energisystem, LTH (2006).
[12] J. Benjaminsson and A. Dahl, “Uppgradering av biogas”, Presentation at “Temadag uppgradering av biogas”, Göteborg (2008).
[13] I. Granberg, Project leader at Jönköping Energi, Personal commication (2008).
[14] M. Tijmensen, A. Faaij, C. Hamelinck, and M. van Hardeveld, “Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasification”, Biomass and Bioenergy 2002, Vol. 23.
[15] I. Johansson, S. Larsson and O. Wennberg, “Torkning av biobränslen med spillvärme”, Värmeforskrapport 881 (2007).
[16] E. Sandvig, G. Walling, R. Brown, R. Pletka, D. Radlein, and W. Johnsson, “Integrated Pyrolysis Combined Cycle Biomass Power Systems”, Repport of Alliant Energy, Iowa, USA (2003).
[17] H. Thunman, F. Lind, and F. Johnsson Delstudie energikombinat, Elforskrapport, 2008.
[18] NREL, Research Advances Cellulosic Ethanol, NREL (2007).
[19] P. Sassner, M. Galbe, and G. Zacchi, “Techno-economic evaluation of bioethanol production from three different lignocellolosic materials”, Biomass and bioenergy 2008, Vol 32.