TREN/06/FP7EN/239285/"SOLUTION"

SOLUTION

Sustainable Oriented and Long-lasting Unique Team for energy self suffIcient cOmmuNities

Deliverable D2L.4.1, WP 2L.4

OPTIMISATION OF SME-AREA ENERGY SYSTEM SUPPLIED BY BIO-BOILER/GASIFIER CHP

Bio-boiler and areal DH for SME-region

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1 Summary

Feasibility study and optimisation of the energy system for a smaller SME area shows that gasification plant fuelled by wood chips is the most profitable alternative compared to the bio-boiler and existing fuel oil systems. The profitably is based on poly-generation enabling electricity and heat co-generation as well the direct utilisation of syngas.

In the SME-area, three companies are assumed to replace their oil based energy system with centralised bio-energy production plant and heat distribution network. One of the partners is a bakery consuming considerable amount of electricity, heating energy and oil for ovens. The other two partners consume heating energy for space heating and hot water. An additional feature in the SME area is a greenhouse, which is assumed to be able to buy heating energy if the price is cheaper than its own heavy oil based boiler.

A pilot plant of gasification plant and gas engine/generator has been in successful operation over a year leading to the conclusion that this alternative should be studied for the SME-area in the Solution project. Rated values for gasification reactor is 160 kW gas and for CHP unit 50 kWe and 100 kWth. The heat capacity meets the heat energy demand of the SMEs except some possible peak hours where standby oil boilers are used. The electricity demand varies based on the use of the ovens at the bakery, and own electricity production covers only partly the demand during operation time of ovens. During low electricity hours, electricity is possible to be generated for general grid. The third possibility for syngas usage is to replace light oil used in ovens.

The bio-boiler plant and heat network is more conventional alternative from the optimisation point of view. Wood chip is used as a fuel and total heat demand is covered by the bio-boiler.

A special optimisation model has been developed for poly-generation as well for other alternatives. Optimisation is based on hourly consumption data for a reference year. The total cost comparison includes investment and running cost for a period of 15 years.

The final comparison shows that gasification and CHP-system has the lowest total cost for the period, bio-boiler is in the second place, and existing oil system leads to the highest total costs. Amortisation time of gasification system compared to oil system is 5 – 8 years depending on the assumed wood chip price.

2 Objective of the Work Package

The objective of the work package is to replace oil based energy production system of the SME-industry area with biomass based centralised production system. The area is located about 2 km from Lapua city centre and outside the existing district heating network of Lapua Centre (see Figure 1). The nearest point of existing DH network is located 0.9 km from the SME-area, and the connection to the system is estimated not to be economical.

The SME-area consists of a bakery, a workshop, a repair shed and a greenhouse. Light oil is used in heating and process purposes in the all SMEs, but at present in the greenhouse heavy oil is the main fuel. Oil consumption is 100 m3 in total per year. Figure 2 shows the map of the SME-area and the locations of the selected consumers. A small district heating network is needed if centralised energy production is to be realised.

Figure 1. Location of SME-area in Lapua city.

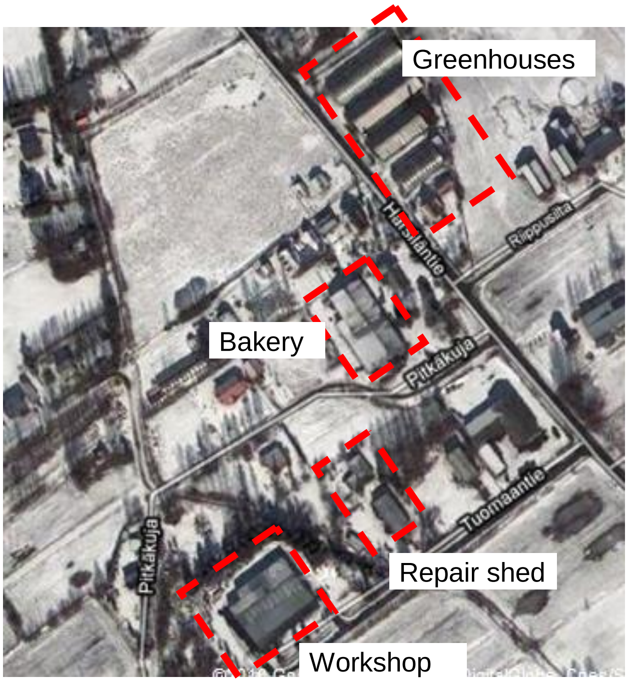

Figure 2. SME-area comprising bakery, workshop, repair shed and greenhouses for centralised bioheating system.

The first task in the implementation of new bio energy system for SME-area is to find out the most interesting energy configuration suited for all the SME-partners. The bakery proved to be the key partner for the centralized energy system. The greenhouse is the biggest energy consumer, but the load is strongly fluctuating, and its oil boilers are needed and used also in the future. The business strategy of the greenhouse doesn’t support any big investments for the new energy system. The other SMEs have a typical space heating profile in the energy consumption, and they are interested in biomass based energy system.

Forest and field based biofuels are available in the Lapua area. Wood ship is the most common type of biomass, and its uncertainty is very low regarding availability, logistics, quality, combustibility and price. Straw could also be available in Lapua, but its use in smaller boiler plants is assessed to cause many problems. The treatment and burning technologies are complicated, and automation of the plant can not meet the level required for unmanned operation. Thus, straw is ignored as a fuel alternative. Reed canary grass is more suitable fuel, but it is not yet available, and new delivery agreements would be needed for that alternative. Thus, wood chip will be the primary biomass for the new energy system in the SME-area. All kinds of trees are suitable for wood chip fuel, Figure 3.

Figure 3. Wood chip is planned to use as fuel source.

Energy production can be realised in different ways. The reference case is the present oil based system including oil boilers and burners as well as electricity purchase from the common grid. Two bio alternatives have been studied in this report: bio-boiler for heating energy production and gasification unit producing syngas with a cogeneration plant with electricity and heat output. In both bio-cases, heat distribution network is needed.

Bio-boiler plant fuelled by wood chip is built as a container type solution, where fuel treatment (silo and feeding equipment), burner and boiler, and auxiliaries are placed to the same hut, Figure 4.

Figure 4. Bioboiler and fuel intake are located in the same container.

Wood chip gasification system is well known in principle, but the problems with gas purity have created an obstacle for electricity production in gas engines and micro turbines. However, some pilot plants have been successfully driven for over a year in

Finland, and the choice of gasification plant as an alternative is based on those experiences. Especially, the capacity of the electricity and direct gas production makes it an attractive option. Figure 5 shows the main components and scheme of the gasification CHP-plant. In the Figure 6, the pilot plant is shown. Syngas can be used as a fuel in the boiler without larger installation works as shown in Figure 7.

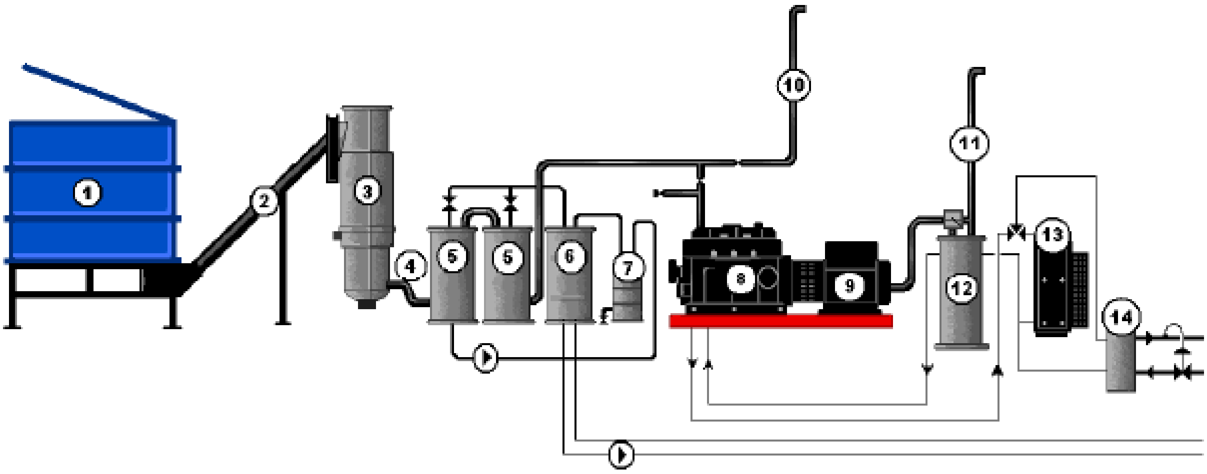

Figure 5. Scheme of Gasification CHP: 1) fuel storage, 3) pyrolyse reactor, 5) syngas washer 6) wash water tank, 8-9) gasengine + generator, 12-13) heat recovery.

Figure 6. Pilot plant of Gasification CHP facility.

Figure 7. Connection of syngas burner to the fuel oil boiler.

Beside the fuels and production plants, energy consumption and its variation belong to the main input data of the optimisation and integration of the energy supply and demand system. Because of possibility to also produce electricity and gas in an plant alternative, the comparisons include consumption data as follows:

- Bakery: electricity, fuel for process, heating energy
- Other partners: heating energy
- Heat network: heat losses

The Finnish electricity network legislation allows to produce electricity for own use, but not for another company without "sell to grid-purchase from grid"-procedure. The bakery is treated as an own electricity producer in this report.

3 Objectives of best and cds sheets

In the definition of the Lapua demonstration cases, SME-area is planned to include bio-boiler and DH-pipelines. However, the poly-generation with a gasification plant seems according to the running experiences at a pilot plant so interesting that it emerged as an equal alternative. The optimisation process is thus much more complicated and the capacities of production plants have been also changed and newly optimised. The business situation at the greenhouse changed their role in centralised energy system, and the greenhouse is treated as heat buyer in the study.

4 Approach to achieve the deliverable

4.1 Description of the optimization model

Energy system modeling and optimization is performed hourly subject to one year in the case of SME-area (Härsilä) industrial area, since characteristics of the demand time series for space heating and oven heating of *Lapuan Leipä (bakery company)* require analysis of this accuracy level. However, in the case of Härsilä energy system has such a straightforward nature that complex KOPTI modeling is not necessary, whereas Excel based optimization is somewhat inconvenient due to the large number of hourly time steps. Therefore, energy system optimization model is constructed by using GAMS modeling language (General Algebraic Modeling System), which enables ease of use for large time series and quick model solving. With this kind of GAMS model several optimization cases with different parameter values can be run easily and quickly, and thus variety of sensitivity and profitability analyses can be performed with minor effort.

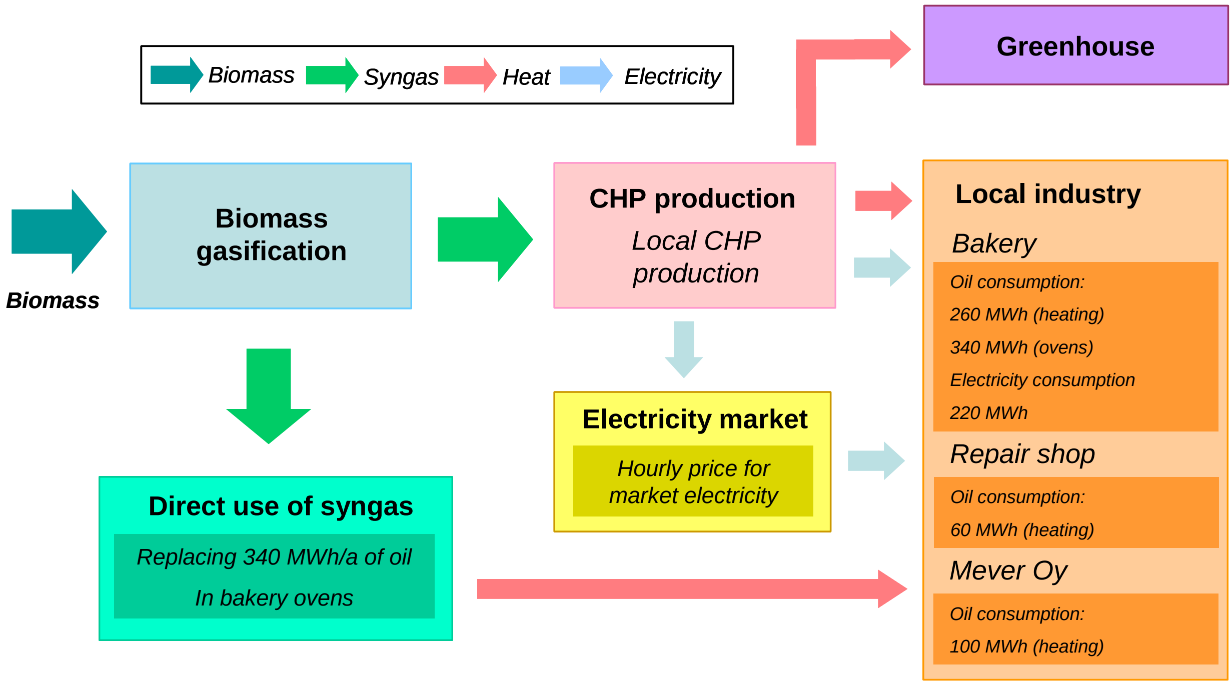

Figure 8. Description of the Härsilä energy system with gasification plant and CHP engine.

In Figure 8 principals of possible energy flows and annual energy demands of Härsilä area energy system are illustrated. At present in this industrial area a bakery, repair shop and *Mever Inc* consume electricity for activity and light fuel oil for space heating. In addition *Lapuan Leipä* consumes fuel oil in their ovens. Into this current model structure a biomass gasification plant producing synthesis gas and a small scale CHP plant producing electricity and heat (50 kW_e and 100 kW_h) for Härsilä's demand are added. Furthermore, in the model an option to feed a local green house with surplus heat is enabled. Thus, having this option enabled excessive heat from CHP plant can be sold to the green house but its entire demand is not required to be fulfilled.

Biomass gasification plant is modeled in a straightforward manner by setting a production capacity of the plant (160 kW_{gas}) and conversion factor between biomass and synthesis gas. Biomass is assumed to be available in order to satisfy the consumption of gasification plant for a fixed price (estimates vary from 18 €/MWh to 25 €/MWh). In the model a balance equation for synthesis gas is set to define availability of gas for use of CHP plant and ovens. Of course, the optimization model chooses hourly based on cost for which purpose is synthesis gas used. Fuel consumption of the ovens is based on pre-calculated demand time series and heating of the ovens can be covered by either synthesis gas or light fuel oil.

Due to the linear nature of the optimization model CHP plant must be modeled in a quite straightforward manner by setting a heat-to-power ratio and maximum value for electricity production. Since the CHP plant is of engine type, excessive heat can be disposed if required. Heat produced by CHP engine is connected to the heat consumption of the industrial area by using a heat balance equation, in which heat from CHP and heat produced by fuel oil summed must equal total heat consumption of the industrial area including heat sold to the green house. In the electricity balance equation electricity produced by CHP and electricity purchased from the market must equal industrial electricity consumption and electricity sold to the market.

In the optimization model balance equations and process equations must be feasible at each time step and with these conditions fulfilled total annual cost, consisting of biomass, fuel oil, market electricity costs corrected with revenues from sold electricity and heat, is minimized. Investment costs of any new infrastructure are not included in the cost function of the model, since these investments are assumed to be on or off in each profitability scenario, and hence irrelevant from the optimization point of view. These external costs are naturally added to the profitability calculations.

By performing multiple operative model runs of one year with changing cost parameters representing future years and combining discounted operative costs from these results with investment costs, various profitability analyses such as amortization time of investments can be analyzed. In the case of Härsilä only the price of light fuel oil and market electricity from the set of cost parameters are changed as time span of 15 years is used for profitability analysis. Price development of fuel oil (1% annual increase) is based on IEA estimates[1] and market electricity price estimates are evaluated by VTT electricity market experts[2].

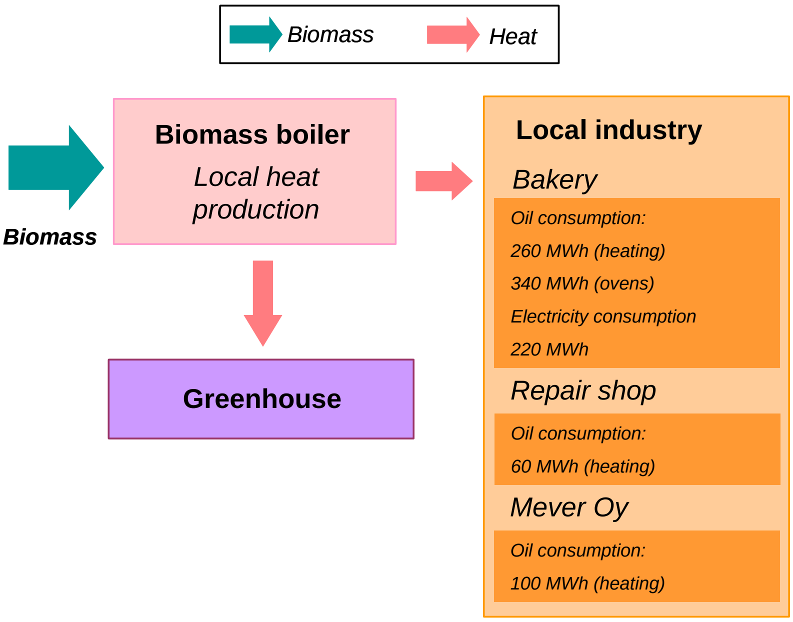

Figure 9. Energy system in the case of biomass boiler producing heat to industrial demand.

In Figure 9 a comparative scenario for the Härsilä energy system model is presented. In this case there is merely a biomass boiler instead of gasification plant and CHP engine. Therefore, biomass boiler provides heat only for the space heating and for the green house demand. Obviously, without the possibility to produce synthesis gas ovens in the bakery are heated solely by light fuel oil. Biomass boiler scenario provides an additional cost reference case in which biomass is used as a fuel.

4.2 Initial data and assumptions made

The Härsilä area consists of four consumers; a repair shop, a workshop, a bakery and a greenhouse. Each consumer has their own oil boiler to provide heating, and the bakery also uses oil to fire the bun ovens. The aim is to reduce the oil usage and investigate the operation and profitability of a centralized local small scale heating system using biomass as fuel. This is done by modeling the local energy system and the heat distribution

[1] IEA. 2008. *World Energy Outlook 2008*. Paris: OECD, International Energy Agency.
[2] Juha Forström, Esa Pursiheimo, Veikko Kekkonen & Juha Honkatukia. *Ydinvoimahankkeiden periaatepäätökseen liittyvät energia- ja kansantaloudelliset selvitykset*. VTT Working Papers 141. Espoo 2010.

network. The existing setup of the area is used as a reference case to compare the alternative solutions. The role of the greenhouse is purely to be a potential user of available extra heat from planned energy supply system; its high heat load variation and consumption make it difficult to incorporate in a reasonable design of the system.

Initial data used in the modeling of Härsilä area were the heat, electricity and fuel consumptions. In addition, the potential of the greenhouse to buy extra heat during a year is fixed. For all these, hourly time series were constructed using measured data and a multitude of assumptions.

The heat consumptions are based on three things; the outdoor temperatures, the assumed hot tap water consumption and consumer specific consumptions of the oil boilers. An assumption was made that no heating is required when the outdoor temperature rises above a certain value. This value was 15 °C for the repair shop and the workshop, and 10 °C for the bakery where the baking ovens contribute to the heating of the structure. The shape of the heating load curve follows the outdoor temperature and as the oil consumption is known and an average boiler efficiency of 0.85 is assumed, the load curve can be established. The heating demand of the bakery was, however, a bit more complicated. As mentioned above, the baking ovens heat the structure when operated. This causes periodical dips in the heating demand. It was assumed that 30 % of the heat provided by the oil burner in the bun ovens ends up heating the indoor space. With the use profile of the bun ovens known, the heating load curve for the bakery was defined. On top of this, hot water use in the bakery was identified as a significant factor in the total heat demand of that consumer. For the repair shop and the workshop, this was omitted as it was assumed to be insignificant. The hot water needs of the bakery were established by investigating the average water use during the past 15 years, found out to be ~3 m3 per day, and by making appropriate assumptions mostly based on discussions with the bakery entrepreneur.

As an example, the heat demands of the consumers in Härsilä area during a single winter week is presented in Figure 10. In hours where the demand exceeds the heat production capacity of 100 kW, consumer specific oil boilers are needed. As can be seen, the heat demand of the bakery varies greatly because of the significant hot tap water use and the heating effect of the bun ovens.

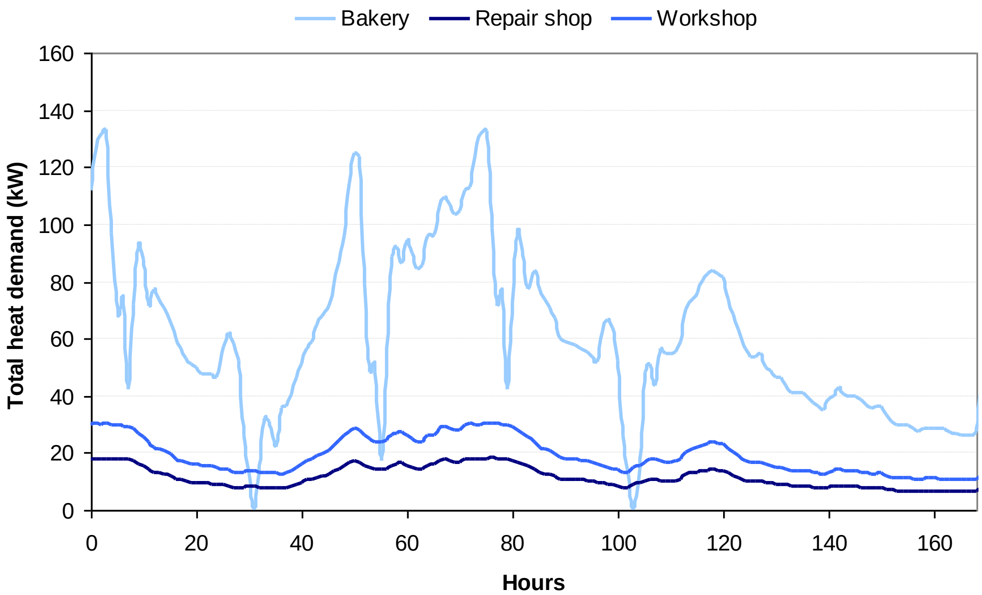

Figure 10. Heat demands for consumers in Härsilä area, a week during the winter time.

The electricity consumption time series were created using measured data from the bakery. The week long profiles were investigated and it was found out that week to week variations are very small. Thus, a year long time series was achieved by duplicating a representative week profile, illustrated in Figure 11, for the whole year. As the electricity production capacity of the planned gas fired CHP unit was 50 kWe and as the unit was to be placed on the same lot as the bakery (by doing this electricity transmission fee are avoided), the electricity consumptions of the other consumers in Härsilä area were considered not to be important from the modeling point of view and thus were left out.

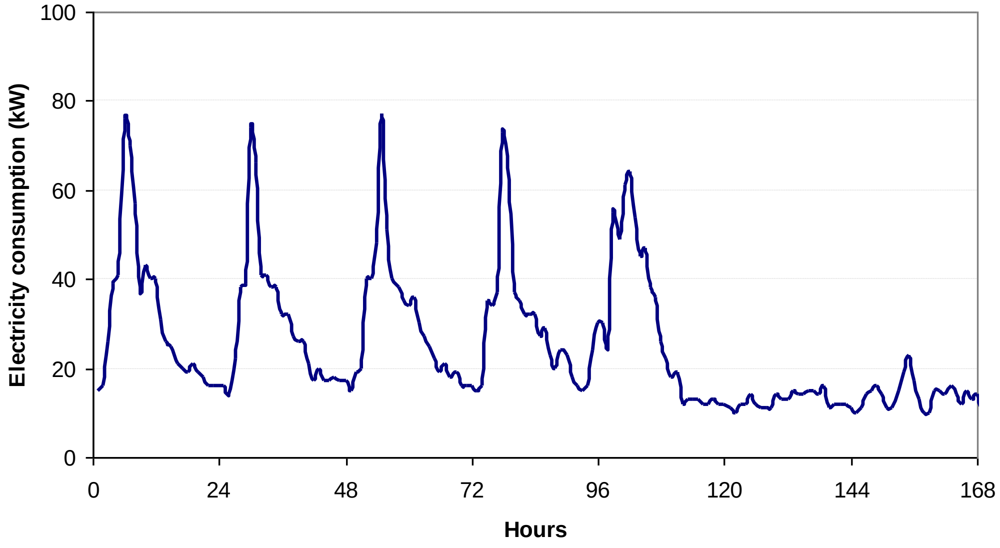

Figure 11. Weekly electricity consumption of the bakery.

Other than in the reference case, the fuel consumption of the Härsilä area consists mainly of the oil consumption of the bun ovens in the bakery. When economically beneficial, the oil is substituted by synthesis gas from the gasification plant. Other than in the bun ovens, fuel, i.e. oil, is used during the peak load hours in the old oil boilers of each consumer. These hours can be spotted by looking at the hours when the heat demand of the area exceeds the heat production capacity and because of this, they don't need to be given as input data for the model. Thus, the fuel consumption time series consist only of the fuel consumption of the bun ovens in the bakery. The hourly values in the time series are based on the yearly oil consumption, the technical specifications and an assumed daily use profile of the ovens. This daily profile is duplicated for the whole year. As apparent from the weekly electricity consumptions, the bakery is not operational during the weekends. The constructed daily consumption profile can be seen in the Figure 12.

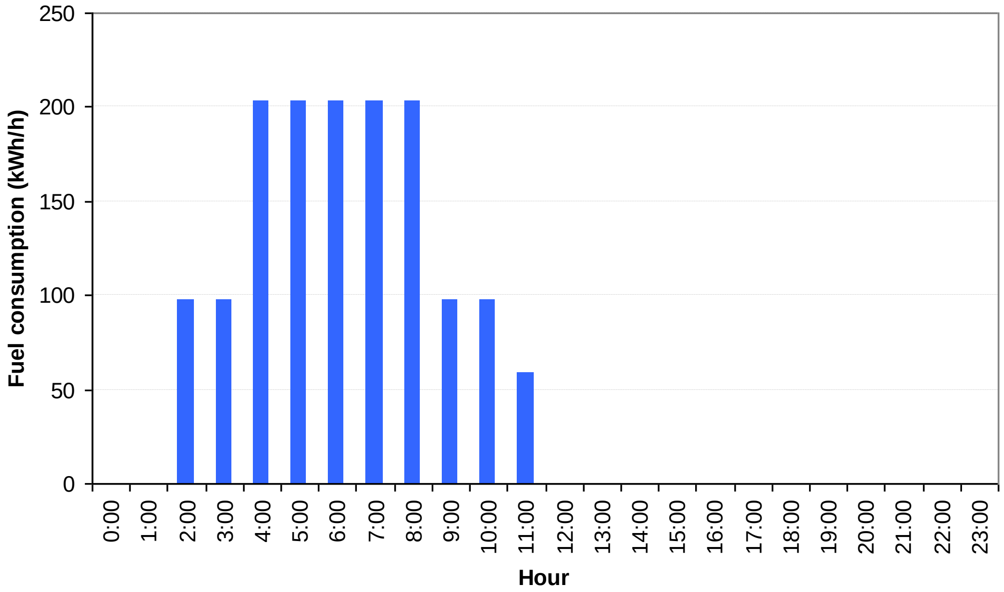

Figure 12. Fuel consumption of the bun ovens in the bakery.

The potential for the greenhouse to use extra heat from the system is based on maximum capacity of the planned heat production capacity and on a notion that there is significant daily variation in the heat demand of the greenhouse. The maximum potential is 100 kWt and the daily variation of 50 % of this, peaking at 15 o'clock. From September to May, the potential stays the same. In June the potential slowly decreases towards the situation in July, when the potential is zero. In August, the situation is mirrored as the potential starts to increase again. The resulting time series is a violently rough approximation of the real life situation and quite flawed as such, but from the modeling point of view it gives a reasonable enough limits for the use of extra heat. The potential around June is presented in Figure 13.

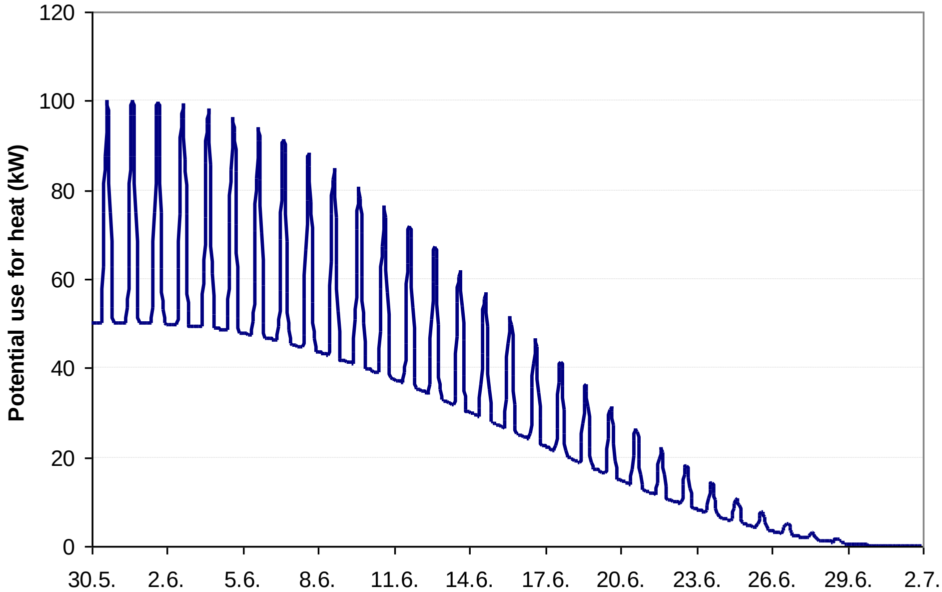

Figure 13. Potential of the greenhouse to use extra heat.

4.3 Local heat distribution network simulation

The Härsilä area heat distribution system was simulated using a dynamic node-and-branch type simulation tool. The consumers were modeled by defining heat exchanger characteristics, secondary side temperatures and heat demands. The heat demand of the greenhouse was calculated by the Härsilä area energy system model. As a result, temperatures, heat losses, pressures and flows were solved. As the pressured drop in a network of this size is very low, the required pumping power was negligible. The temperatures and heat losses were, however, of interest.

The network was dimensioned using a 1-2 bar/km principle resulting in small diameter pipes from DN 20 to DN 32. Twin pipes were used with the current recommended insulation level in Finland (series 4). The total trench length of the network was 325 m or 427 m, depending on whether a connection to nearby greenhouse was included. A rough map of the pipelines in the area can be seen in Figure 14.

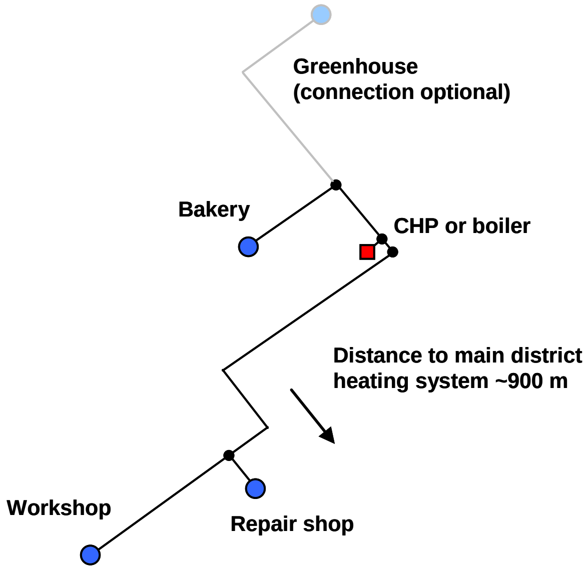

Figure 14. Local heat distribution network.

The supply temperature of the heat production was kept constant throughout the year, at 85 °C. In the heat loss calculation, the undisturbed ground temperature was also constant 5 °C. In order to maintain high enough temperature level during the summer time, a flow-through valve was installed parallel to consumer heat exchanger(s). If the mass flow was too low, some water was circulated through the valve preserving the reliability of the supply system.

The linear heat density of the system is 1.14 MWh/m without the greenhouse and 1.35 MWh/m with the greenhouse included.

The monthly consumptions are presented in Figure 15, with and without the greenhouse, respectively. The increased consumption is apparent in the figures, the year consumption being 357 MWh (no greenhouse) and 612 MWh (greenhouse included).

The Figure 16 shows the monthly relative heat losses, i.e. heat losses per produced heat. This gives an outlook on the efficiency of the distribution system. When calculated for the whole year, the heat losses are 6.5 % (without greenhouse) and 5.3 % (greenhouse included).

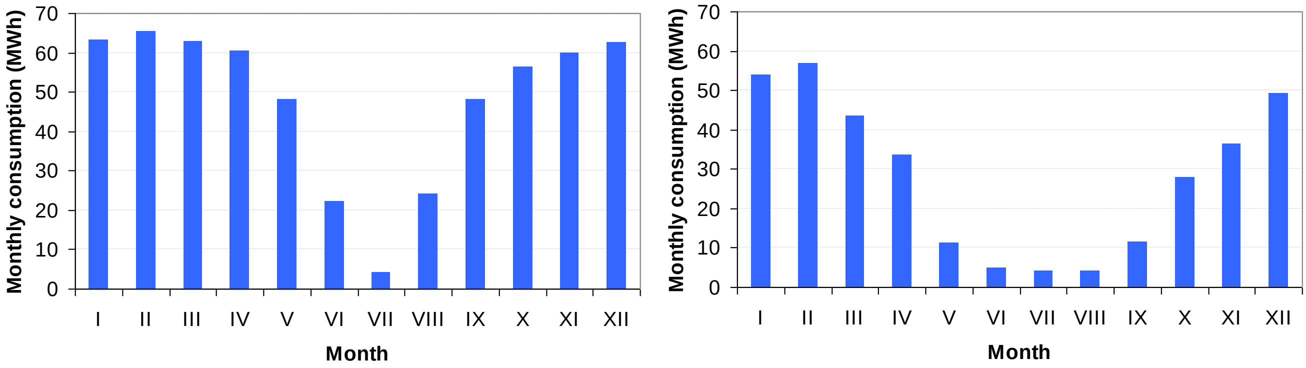

Figure 15. Monthly consumptions of heat in the Härsilä area with (left) and without (right) the greenhouse.

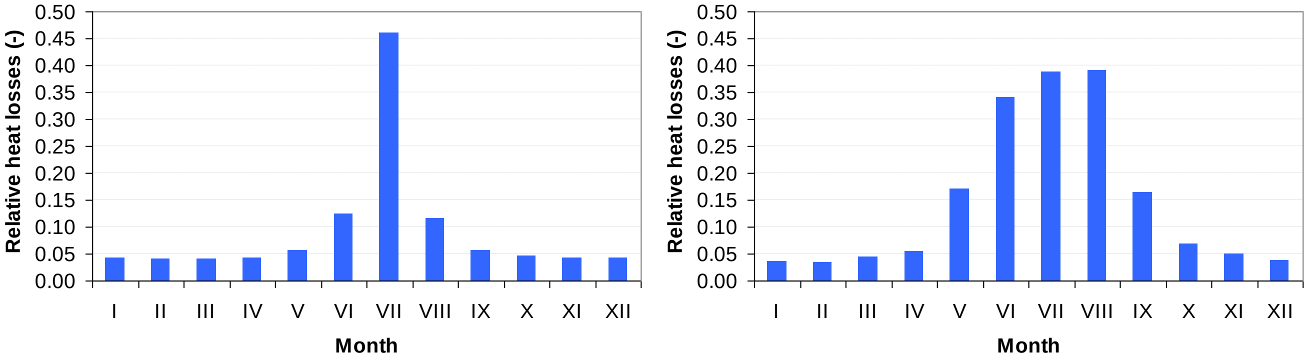

Figure 16. Relative heat losses, with (left) and without (right) the greenhouse.

4.4 Profitability analysis

The profitability analysis presented here uses the results from the Härsilä area energy system model and, as appropriate, discounts the future costs using an interest rate of 5 %. The descriptions of the studied cases are listed in Table 1.

Table 1. Descriptions of the studied cases.

Reference	Business as usual, consumer specific oil boilers and oil fired bun ovens
Case A1	Biomass gasifier, synthesis gas based CHP-unit and bun ovens, peak loads handled by oil boilers and burners, local distribution network, extra heat sold to the greenhouse
Case A2	Biomass gasifier, synthesis gas based CHP-unit and bun ovens, peak loads handled by oil boilers and burners, local distribution network, no use for extra heat
Case B1	Biomass boiler and a local distribution network, peak loads handled by existing oil boilers and burners, extra heat sold to the greenhouse
Case B2	Biomass boiler and a local distribution network, peak loads handled by existing oil boilers and burners, extra heat not sold to the greenhouse

The Figures 17 and 18 represent the cumulative costs between 2010 and 2025 and the total costs at year 2050 when the price of biomass is 18 €/MWh. The Figures 19 and 20 present the same results with a price of biomass being 25 €/MWh. The significant role of the price of biomass can clearly be seen.

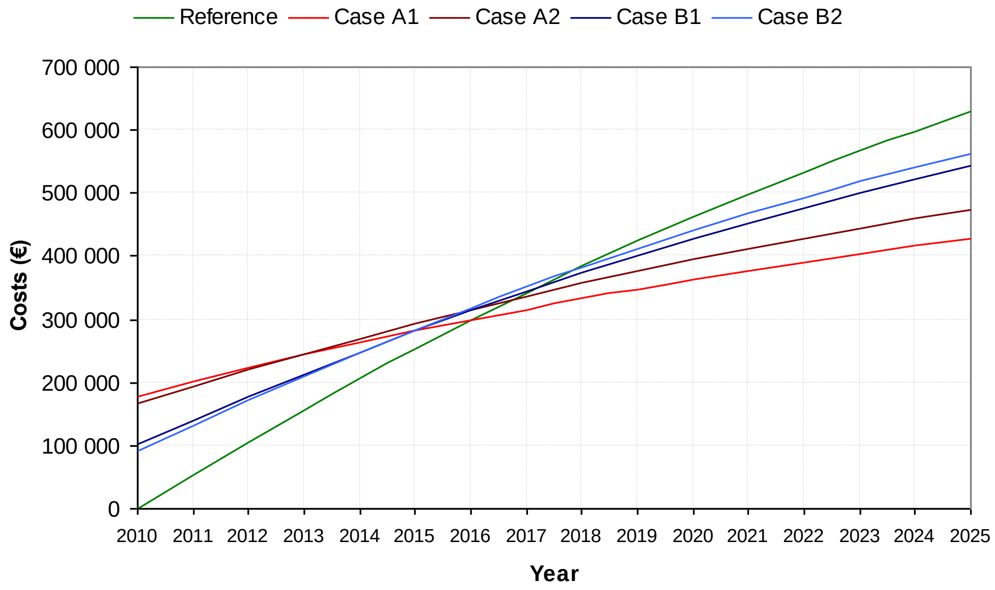

Figure 17. Cumulative costs of the studied alternatives with a biomass price of 18 €/MWh.

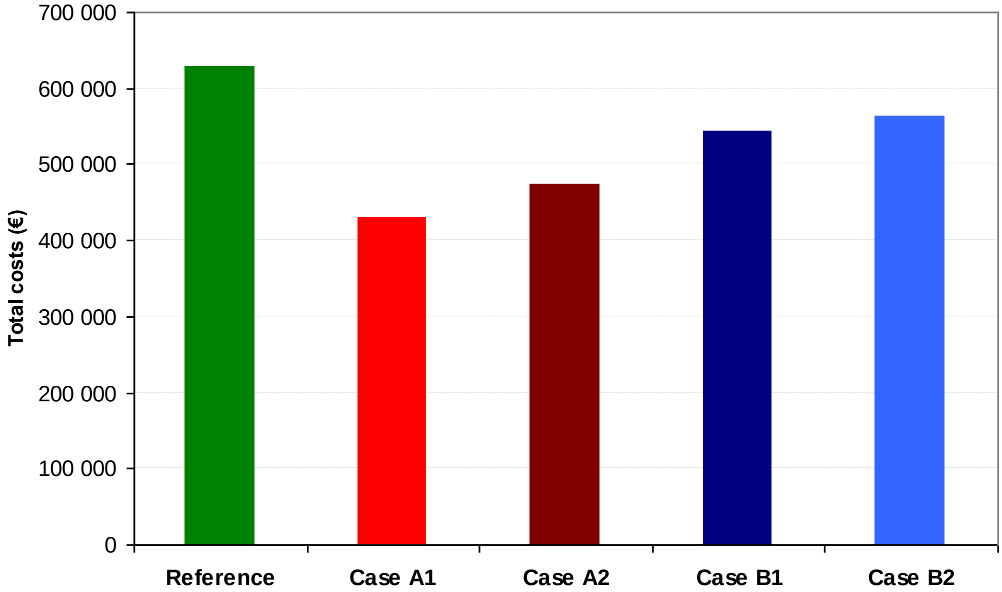

Figure 18. Total costs at 2025 with a biomass price of 18 €/MWh.

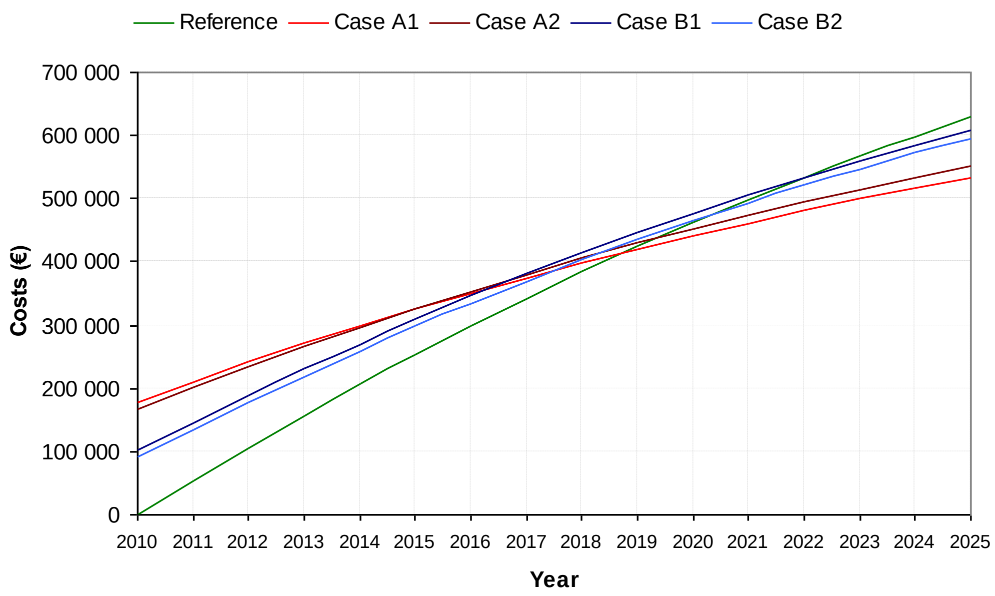

Figure 19. Cumulative costs of the studied alternatives with a biomass price of 25 €/MWh.

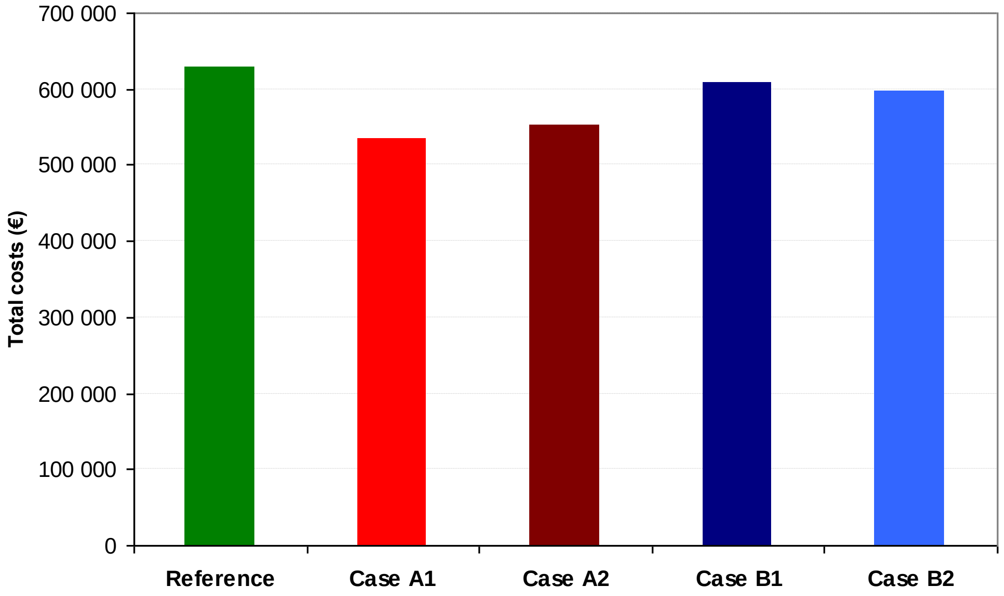

Figure 20. Total costs at 2025 with a biomass price of 25 €/MWh.

Table 2 below contains some key figures of the calculations done with a biomass price of 18 €/MWh with CO_2 emissions of the analyzed cases included.

Table 2. Annual energy and emission figures of analyzed cases with biomass price of 18 €/MWh.

	Reference	Case A1	Case A2	Case B1	Case B2	
Produced heat	356	581	340	781	356	MWh
Produced electricity	0	309	226	0	0	MWh
Purchased electricity	0	56	56	221	221	MWh
Sold electricity	0	145	62	0	0	MWh
Biomass use	0	1480	1163	976	446	MWh
CO_2 emissions	186	0	33	91	91	t CO_2

In Figures 21 to 23 detailed modeling results of the Härsilä case with biomass gasification and greenhouse option enabled from week 8 (168 h) can be seen. In these illustrations the area above the demand curve represents surplus heat or electricity sold. The use of syngas in bun ovens provides interesting volatility in fuel mix of heat and electricity production. This kind of fluctuation of production methods can be difficult to execute in practice from the consumer point of view, and what needs to be emphasized is that these results hourly optimized and cannot be implemented necessarily. This issue naturally affects the costs analysis as well.

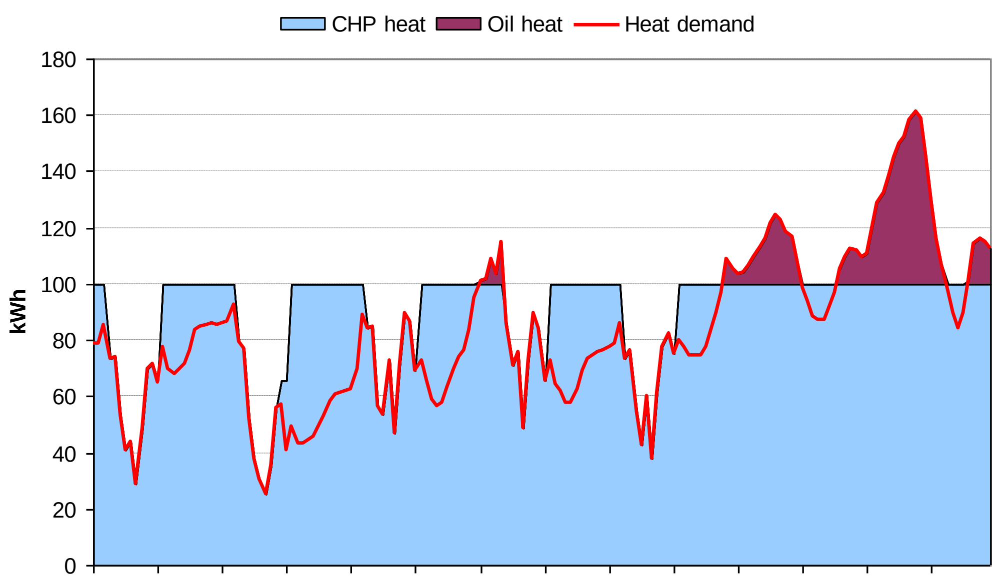

Figure 21. Heat demand and production during an example week (week 8).

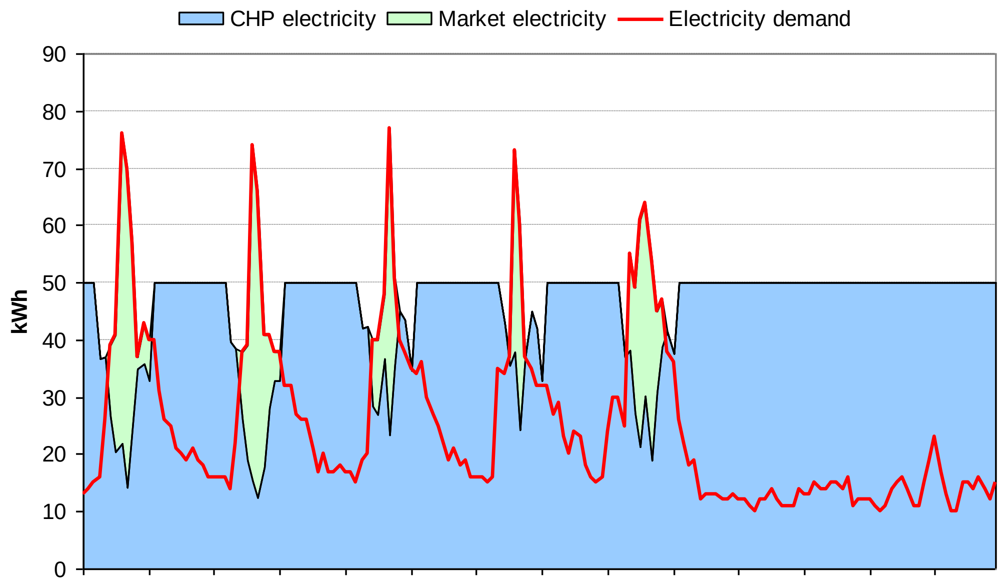

Figure 22. Electricity demand and production during an example week (week 8).

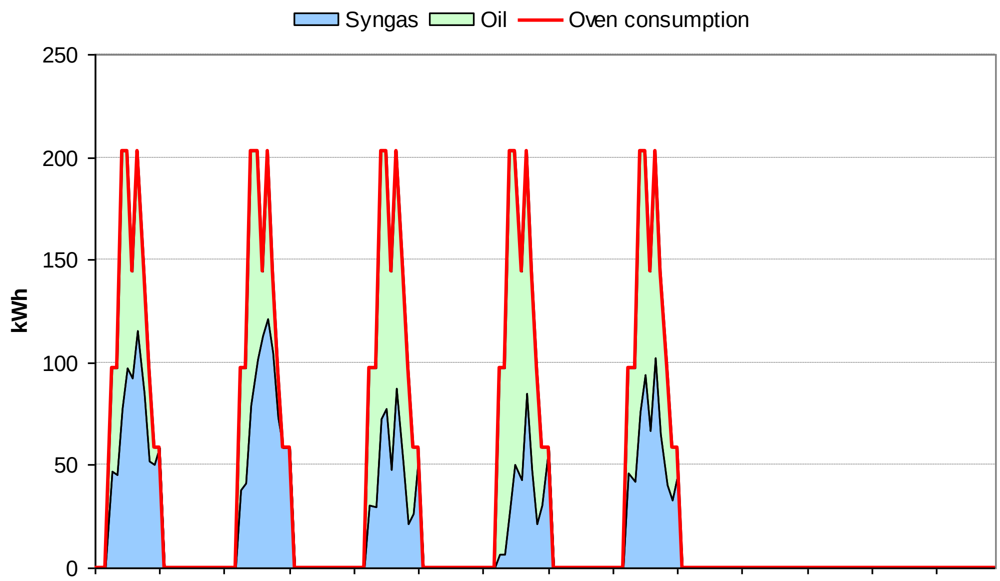

Figure 23. Fuels of oven heating during an example week (week 8).

4.5 Energy storages

Principally, gas and heat energy storages can be connected to the bio-energy alternatives in the SME-area. Syngas from gasification plant has quit low energy content, about 4 kWh/m3, causing a large size for the storage compared for example with natural gas. Compressed gas storage could be an alternative, but then the investment cost are higher.

The simulation with gas storage of 50 kW shows that gas storage produces only small reduction in the running cost of the system due to the flexibility of integration of poly-generation and energy demand in the SME area. However, practical constraints in the running strategy of the bakery oven can lead to the necessity of a gas buffer tank.

Another possibility is a heat energy storage, which enables DH-supply during the periods of supplementary use of syngas in the ovens. These issues have to be studied more detailed after some definitions of the bakery. The heat energy connection to the strongly fluctuating heating load of the greenhouse is also a necessity to provide a heat store.

5 Conclusion

In the SME-area (Härsilä), the target of the Solution project is to replace the existing individual energy production systems with centralised and biomass fuelled energy production plant including local heat network. In this report, an overall optimisation is carried out for the energy system.

The partners involving in the bio-energy implementation are: bakery, workshop, repair shed and greenhouse.

During the feasibility assessment, the formulation of the energy supply and demand characteristics gave the optimisation study some general data. The three main alternatives for energy production as follows:

- The bakery using oil electricity, oil for ovens and for heating proposes is the key element in the centralised energy system.
- The greenhouse is connected to the centralised system, if there is profitability based reasons to replace their existing heavy/light oil based boiler plant capacity.
- The other partners (workshop and repair shed) are connected to the heating network.
- Reference energy system contains the existing oil systems and purchasing electricity.
- Bio-boiler alternative consists of heat production container including wood chip silo and bio-boiler as well as heat energy network.
- Gasification alternative consists of wood chip gasifier, co-generation unit, and heat distribution network.
- Syngas from gasification reactor can be used in ovens replacing oil.
- Old oil boilers can be used during peak load hours and they are on standby.
- Own electricity production can be used replacing the purchased electricity, and the produced electricity can be sold to the grid (surplus electricity).

The optimisation is based on hourly consumption data for electricity, fuel and heating energy. The price of wood ship is assumed to be 18 €/MWh and 25 €/MWh. The calculation period is 15 years, and a defined rise in oil and electricity price is assumed. Comparison cost for all alternatives contains investment and running cost using discounting factors based on 5 % interest rate. Gasification CHP has the capacity of 50 kWe and 100 kWt.

The calculation results show that gasification with CHP is the most economical system with both wood prices. If surplus heat can be sold to the greenhouse, some extra profit can be made. The bio-boiler alternative is also more beneficial compared to the existing oil based system.

Payback period for gasification-CHP system is 5-6 years and for bio-boiler system about 6-7 years assuming lower price for wood ship. The higher price assumption leads to about 3 year longer payback periods.