TREN/06/FP7EN/239285/"SOLUTION"

SOLUTION

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

Deliverable D2L.3.1, WP 2L.3

OPTIMISATION ON THE BIOGAS CAPACITY AND INTEGRATION OF PRODUCTION AND CONSUMPTION

Biogas-polygeneration and end-user integration

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1 Summary

Integration of biogas plant and starch production industry plant contains many benefits. In the collaboration, industry wastes can be treated on site in the bioreactor, and CHP-heat and biogas itself can be utilized locally. The modified starch products have nearly reached RES status and biogas plant can take care of agricultural and food industry wastes produced in the surroundings of the site.

The initial aim is to replace use of propane and electricity consumption of the starch plant with biogas based energy, but from the economical point of view production capacity presents an issue. Propane consumption is about 17600 MWh/a and electricity 13000 MWh/a. The reference option of the biogas and CHP-facilities is the case of capacity of 3.6 MW gas, 1.0 MWe and 1.3 MWth.

The optimization model based on the operational costs gives an optimal share for each energy product, i.e. electricity is produced about 4600 MWh/a and heat energy about 6000 MWh at the CHP plant. Biogas is used directly within the processes (10260 MWh), and the rest of industrial heat demand, 1377 MWh, is covered by propane purchased from the market. This alternative gives also the shortest payback period for the investments, about 5 – 6 years.

From the renewable energy point of view, in another case the capacity of the biogas system has been increased 25%. The results show that propane can be replaced altogether by CHP-heat and direct biogas usage, and only additional electricity is needed from the grid. However, this amount of purchased electricity is smaller than in the reference case. This alternative gives the highest total profit for the period of 15 years.

Also the third alternative, where capacity is reduced by 25 %, was studied. It ranks between the other alternatives subject to payback calculation, and it gives the highest total benefit in the 15 years calculation. The difference between the reference and +25% case is not different while the -25% case has significantly lower total profit.

2 Objective of the Work Package

The work package 2L.3 aims to demonstrate the entire biogas polygeneration system starting from locally produced biowaste (biowaste from starch-industry, food processing plant and also from farms) and ending up to the end-use of electricity, heat, and gas-fuel in the industrial area close to the biogas plant. The biogas plant owned by a SME-ESCO-company is preliminary planned to reach a production of 3 120 000 Nm3 CH_4 yearly (average 3.6 MW). In addition to cogeneration of power (1.0 MW) and heat energy (1.3 MW), the plant will be equipped with gas refining devices in order to produce purified gas for the industry use.

Integration of biogas based polygeneration plant and industrial end users of electricity, heat energy and gas requires optimization for the business operation and capacity planning. This optimization is presented in this report. Polygeneration will substitute propane gas and heating fuel oil, and produce bio based power. CO_2 emission will be reduced significantly thanks to the use of biomass replacing oil and propane gas and electricity in the grid.

Figure 1 shows illustration of the integration. The values of gas, heat and electricity production capacities present one alternative in capacity planning of the integration.

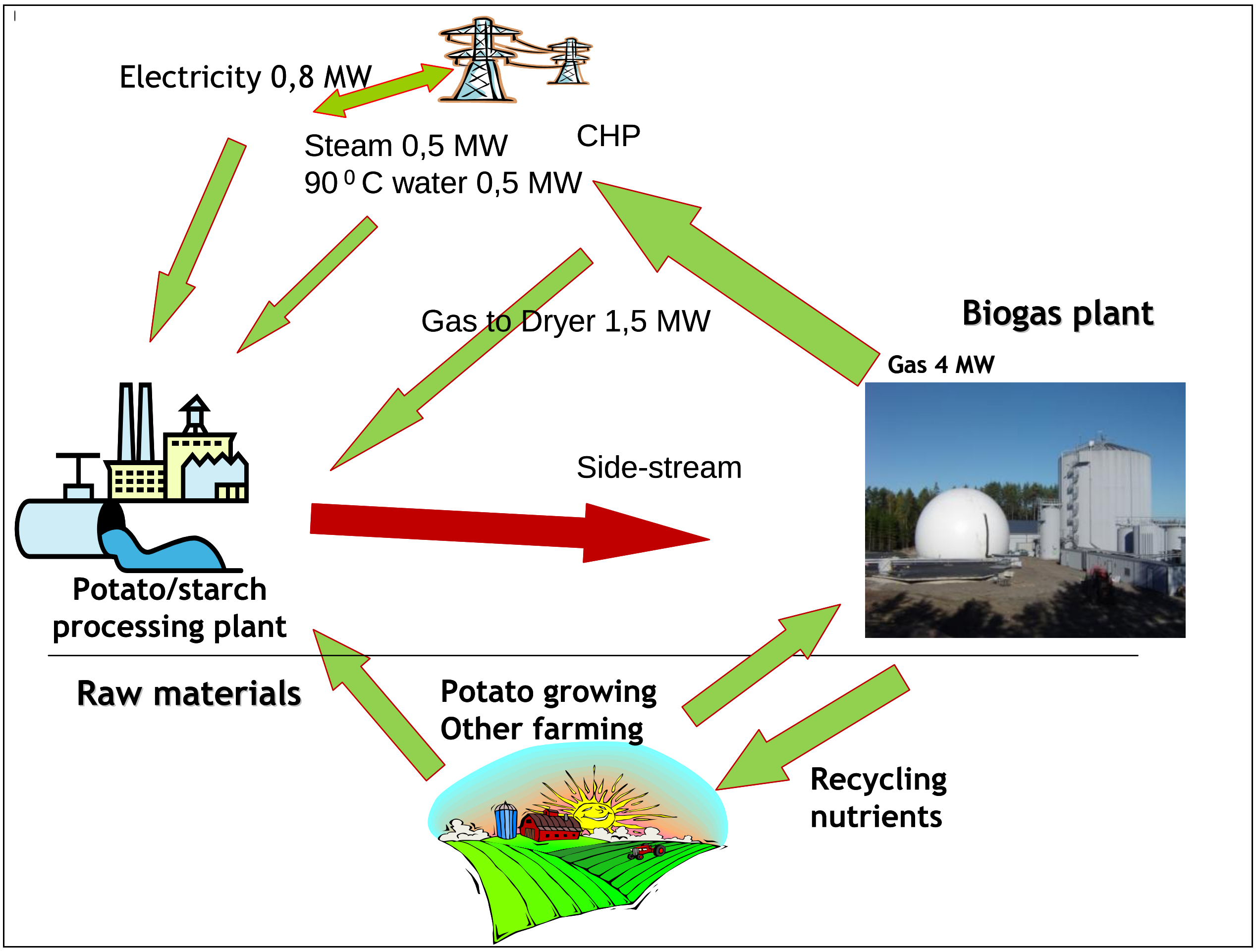

Figure 1. Master plan of the biogas - industry integration.

The main energy consumer in the integration is a starch industry plant. Potato flour is produced in autumn after yielding the crop. Starch processing for industrial purposes takes place during the whole year causing relatively constant power for gas, heat and electricity demand. The capacity of the plant is around 100000 ton of modified starch.

At present, i.e. before some process development and energy integration, energy consumption is as follows:

- Propane: 1300 ton/a, i.e. 63500 GJ or 17600 MWh/a
- Electricity: 13000 MWh/a
- Electricity load variation: in Sep and Oct the demand is 3.5 MW; the rest year: 1.5 MW

In addition to the starch industry, the communal sewage plant is located in the area consuming heating (1000 MWh/a) and electricity (2150 MWh/a) energy.

Raw materials available for the biogas plant are:

- Biowastes from starch industry
- Biowastes from food processing plant (slaughterhouse and meat production)
- Biowastes from farmers
- Some crops from farmers

Figure 1 shows the location of the present industry facilities. The potato treatment plant is located at the southern side and starch processing plant at the northern side of the road. The planned biogas plant will be also located in this area. The sewage treatment plant is located some hundred meters from the industry place.

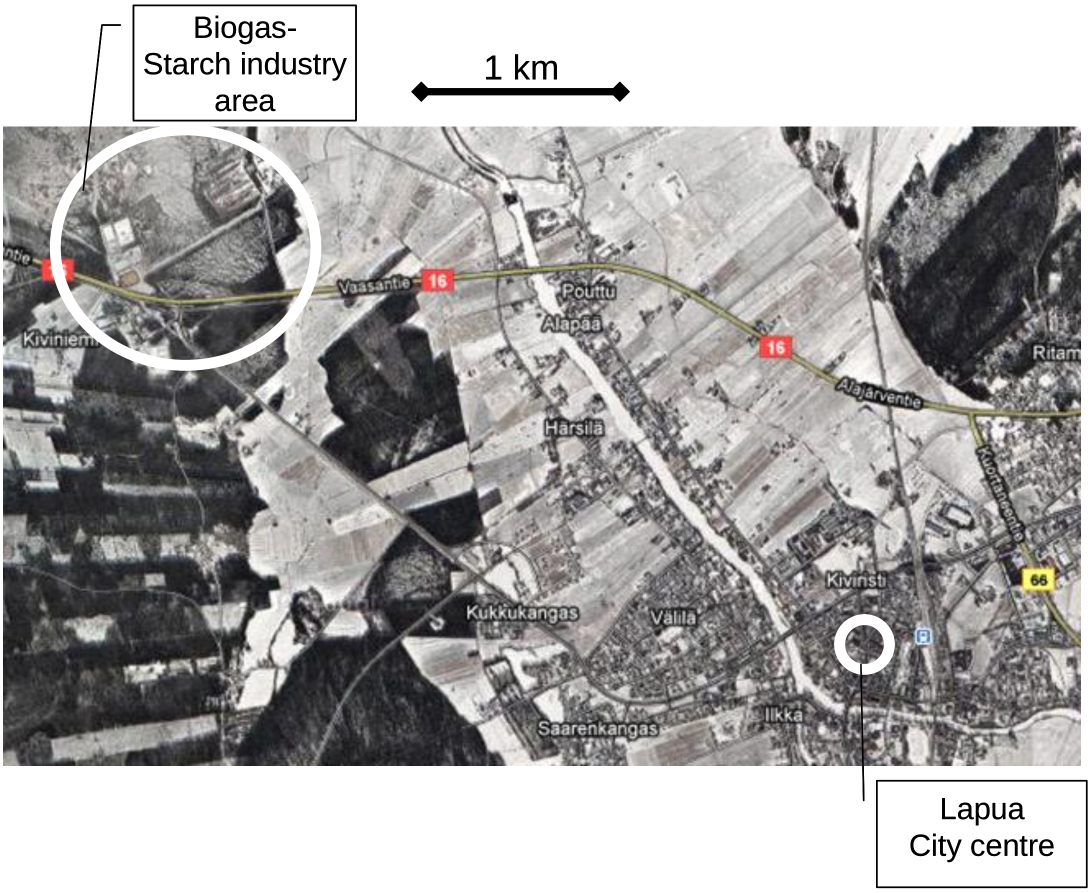

Figure 2. Location of the potato and starch industry plants and the planned biogas plant.

3 Objectives of best and cds sheets

In the CDS sheet in the sector "RES and polygeneration, preferably from RES" and under headline "biogas polygeneration, RES-bioboiler, both connected to local heat network" the biogas polygeneration refers to the integration presented hereby. The values of the supply and demand are the same as the ones used in this report.

4 Approach to achieve the deliverable

4.1 Modeling of Biogas production and CHP biogas engine

VTT has developed for Solution project purposes an *ad hoc* optimization model in order to analyze feasibility and cost effectiveness of an integrated biogas reactor and CHP gas engine system utilized in Case Lapua by starch industry complex in Lapua area. The basic structure of the biogas model is illustrated in Figure 3. Values of energy production capacity and energy consumption are also presented in this figure. The biogas optimization model is implemented by using *What's Best* optimization solver in Excel environment, which enables relatively easy structural modification and parameter based sensitivity analysis of the biogas energy system.

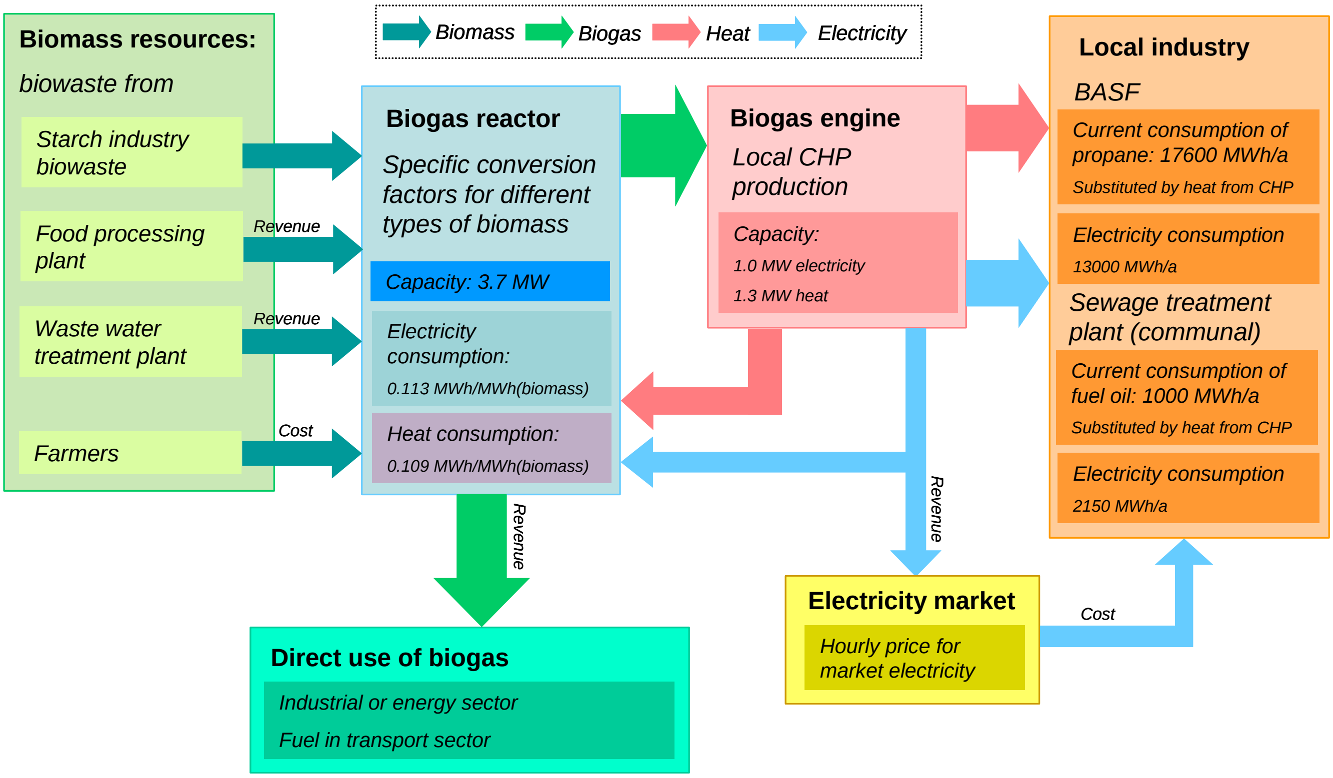

Figure 3. Structure of the model for biogas and industry integration including capacity and demand values in the case of Lapua.

The timeframe of the model is one year divided into 26 two week periods. This is reasonable from the model point of view, since industrial activity does not fluctuate as much as e.g. domestic activity, and therefore energy consumption can be analyzed subject to a more robust time slice. Also, periodical variation of the availability of biomass resources can be estimated at biweekly level.

Biomass model consists of three elements: biogas reactor, biogas engine and local industrial activity (starch industry and sewage treatment plant). In biogas reactor biomass from up to four different sources can be transformed into biogas with specific conversion factors for each biomass type. Biogas reactor (capacity of 3.57 MW of biogas energy) consumes biomass, heat and electricity. Produced biogas is used in a CHP biogas engine located in the industrial area. CHP engine produces heat and electricity for biomass reactor and industrial purposes. In the optimization model biogas engine can be operated at the lowest on 50% part load and model can optimize biweekly shutouts of the engine in the case of low operating level. In starch production process heat from the biogas engine substitutes propane used for drying and general process heating. In sewage treatment plant heat from CHP replaces fuel oil used for space heating. Production parameters of the biogas engine and industrial consumption estimates are presented in Figure 3.

In the model flows of biomass, biogas, heat and electricity are tied with energy balances. Consumption of biomass in biogas reactor is linked with periodical availability of different biomass resource type. Only the biowaste from farming sector adds costs to the model, since other suppliers of biowaste compensate biogas producer for accepting waste. Also, excess biogas can be sold to cover external demand, e.g. industrial and energy producing activity or transport use of biogas. It is effortless to make sensitivity analysis on the cost effect of external price of biogas with the Excel based model. Heat balance of the model is simple, since heat produced must be consumed within the industrial process. Electricity can be sold to or purchased from electricity market in order to fulfill the balance. Electricity market price can be set to vary periodically. However, since electricity produced by biogas CHP receives feed-in tariff for electricity either consumed by the local industry or sold to the market, possible surplus electricity is not sold for market price. In Finland this feed-in tariff is 133.5 €/MWh for produced electricity in the case at least 70% of produced heat is utilized (83.5 €/MWh if below 70%). In the case of Lapua conditions are optimal for feed-in tariff, since starch industry operation provides heat load enabling high utilization rate of biogas based heat.

Since the biogas energy system model produces optimal biweekly operation measures for a full year, results can be used for economical analysis of the investment on biogas reactor and biogas engine. However, this kind of analysis would require assumption of similar and continuous operation for the lifetime of the investment in order to use results of one year optimization in estimation of e.g. the amortization time of the investment. Several model runs with different parameterization discounted over longer time span could be though used for this kind of cost analysis.

Following information is required as parameters in the biogas energy system model:

Table 1. Parameters used in modelling concerning biomass resources.

Biomass type	**Acceptance fee/cost (€/t)**	**Energy content (MWh/t)**
Potato residues	*confidential information*	0.166
Meat waste		0.917
Manure, liquid slurry		0.092
Agricultural biomass, straw		0.392

Table 1 lists the available biomass resources and their energy contents (biogas potential). Potato residues originate from the starch production plant and are available about 6 months starting from September. The meat waste consists of organic residues of meat processing industry coming from a nearby producer. Manure is from piggeries in the area and is in form of liquid slurry. The agricultural biomass, straw, is an option that can be taken if extra biomass is needed. The acceptance fees are a trade secret, but it can be said that the highest fees are gained from the meat waste, the manure acceptance fees are more or less 0 €/t and straw has a cost. The energy content figures are taken from a study[1].

Table 2 presents the parameters used in the modelling of the biogas reactor and engine processes.

[1] Vänttinen, V.H., Optimizing the use of biogas technology for renewable energy production and material flow management in regional scale – case Central Finland, University of Jyväskylä, Bioenergy 2009 – book of proceedings.

Table 2. Biogas reactor and engine parameters used in modelling.

Parameter	Value
Biogas reactor	
Maximum production capacity of reactor	3.57 MW_{gas}
Specific electricity consumption	0.103 MWh/MWh
Specific heat consumption	0.119 MWh/MWh
O&M costs of reactor	2.35 €/MWh
Revenue from industrial use of biogas	25 €/MWh
Waste flow from reactor	1.1 ton per 1 ton biomass consumed
Waste management cost	*confidential information*
Biogas engine	
Capacity of engine	1.0 MWe and 1.3 MWt
Minimum part load of engine	50 %
Total efficiency and electricity efficiency	90.5 % and 38 %
Availability factors (2 week periods)	95 % and 50 % (weeks 25-26)
O&M costs of engine	1.84 €/MWh
Annual fuel substitution potential by CHP heat	17600 MWh
Cost of propane in industrial operation	30 €/MWh
Feed-in tariff of biogas electricity	133.5 €/MWh (>70 % heat used)
Other	
Total investment costs of biogas reactor and engine	8 M€ (EU-support not included)

Since biogas model is excel based, all the parameters can be altered in order to fit the situation of the target community. Furthermore, the structure of the model can be reformed in case there are significant structural differences. For example, due to the properties of Finnish electricity market and feed-in tariffs, electricity consumption of the starch industry is not necessarily required to be analysed, since electricity is purchased from the market and biogas manufacturer receives the feed-in tariff regardless of the possible local utilisation of the produced electricity.

4.2 Results

Cost analysis of the biogas production was performed by running the model and using results from this annual run by discounting profits of the biogas producer for years 2011-2025 and combining these figures with investment costs. It has to be noted that these profits include only costs and revenues of the biogas producer, not the ones of the local industrial operation. In order to study the effect of biogas production capacity on profitability, three cases were optimized: the reference case with capacity values presented in Table 2, the case with 25% increase in capacity and the case with 25% decrease in capacity. In the two latter cases investment costs of biogas production capacity were scaled correspondingly.

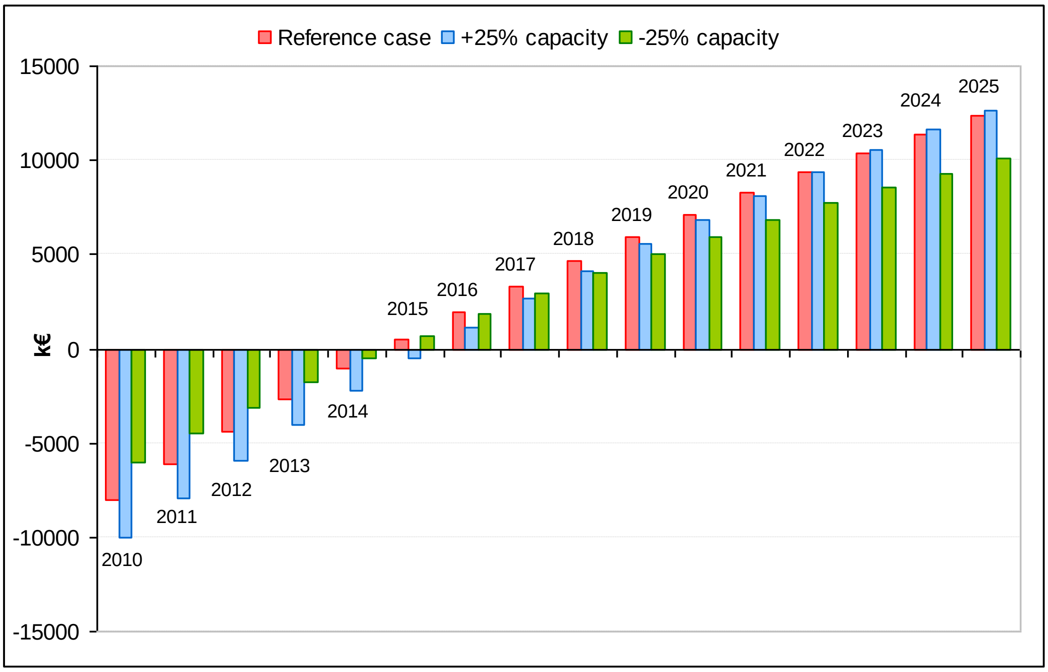

Figure 4. Cost analysis of the biogas reactor and CHP operation for the reference case (3.57 MW_{gas} and 1.0 MW_e) and for the cases of increased capacity of 25 % and decreased capacity of 25%.

Results of the biogas production profitability analysis are illustrated in Figure 4, in which only investment costs are allocated into year 2010. It is evident that current capacity choice of 3.57 MW_{gas} and 1.0 MW_e is quite optimal from the producer point of view, since 25% increase in capacity does not provide any significant improvement in profitability even in year 2025, whereas 25% decrease has more distinct negative effect. Payback period for investment seems to be around 5 years in each case.

In all the cases biogas engine operates at maximum limit, since all the produced heat is consumed in starch industry operation and therefore engine receives the higher feed-in tariff of 133.5 €/MWh. It is evident that this cooperation with local industry which can utilize the produced heat makes the biogas production highly profitable despite the high investment costs. This cooperation also benefits the local starch industry, since it can replace costly propane with CHP heat and biogas. However, only in the +25% case propane was entirely replaced with heat and biogas.

One of the most interesting characteristics of the model runs is the utilisation of biomass. In the reference case biogas reactor consumes all the available meat waste due to the high acceptance fee, but only 15% (35% in the +25% case) of potato residues are used, mainly due to the biogas reactor capacity limitation. However, during the summer weeks when potato residues are unavailable, agricultural biomass is used for biogas production instead of manure even if producer must pay the cost for agricultural biomass instead of getting acceptance fee for manure. This odd-sounding result is based on the waste management cost for biomass residues which in volume depend on the tons of biomass used. Since energy content of manure is fairly low, higher amount of manure must be used to produce biogas than in the case of agricultural biomass. Hence, this volume based waste cost negates the benefit of the acceptance fee.

Naturally, when dealing time span of 15 years there are some uncertainties subject to profitability analysis. For example, availability and acceptance fees of usable and cost efficient biomass such as meat waste. However, considering the cooperation with the local industry and profits from the feed-in tariffs, from the modeling point of view there is relatively low risk on effects of parameter estimates, except for biomass availability.

5 Conclusion

The industrial starch production plant in Lapua consumes propane 17600 MWh/a and electricity 13000 MWh/a. Propane is burnt directly in the processes or used in steam/heat production. Close to the starch plant, a communal sewage plant is consuming heating energy 1000 MWh/a and electricity 2150 MWh/a. The aim is to replace the present energy use with renewable energy sources. The potato and starch processing plant supplies biomass as a side stream, and also other biomass sources are available in the surroundings, e.g. from a food processing plant and agricultural sources.

In the Concerto demonstration, a biogas plant and starch industry will be integrated in order to achieve polygeneration, i.e. biogas and CHP-heat/electricity production, and thus realization of RES in the industry area.

Based on the feasibility studies, in the main option the biogas plant has a biogas capacity of 3.6 MW and a CHP-capacity of 1.0 MW_e/1.3 MW_t. Thus, total biogas production, 31000 MWh, covers main part of industry energy consumption, but a part of energy should still be purchased outside the area. The optimization model is used to find the most economical running strategy for the polygeneration plant.

In the base case, electricity is produced about 4600 MWh/a and heat energy about 6000 MWh at the CHP plant. Biogas is used directly within the processes 10260 MWh, and the rest of heat energy demand, 1377 MWh, is covered by propane.

In the sensitive study, the capacity of the biogas and CHP facilities has been changed ±25%. The increase of 25% in the capacity results in a situation where only additional electricity is purchased outside the area, and propane is not required. CHP-electricity production is about 6000 MWh/a and CHP-heat 7800 MWh/a. Use of biogas in the processes is about 9800 MWh/a.

If the capacity is decreased 25 %, CHP-electricity production is 3500 MWh and 5700 MWh of propane is purchased.

The profitability analyses show that the base capacity case gives the shortest payback time, 5-6 years. However, the higher capacity alternative gives the highest total profit for the period of 15 years.