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Optimizing the energy link between city and industry

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Industries and cities have different functionalities for society but they share several energy aspects. Industries often produce excess energy (low temperature heat in particular) and cities have a considerable heat demand. Linking cities and industries therefore can be advantageous for both sides. Industries can increase their revenue by selling excess heat and cities can integrate this energy in district heating. In terms of emissions there are several advantages: a central emission source for heat production which can be handled much easier compared to several small heating units, as well as the overall improvement in energy efficiency of the city-industry complex.
Important factors for analyzing and optimizing such energy links are the resources for the energy production, district heating costs and time related load profiles. In a first step process synthesis using the P-graph method (Friedler et al., 1995; Halasz et al., 2005, Friedler 2009) is employed to find a stable economical technology network, integrating existing facilities and new technologies (such as CHP and direct solar energy utilization) that use available resources. In a second step this network is evaluated with the help of the Sustainable Process Index (SPI) to indicate ecological hot spots (Narodoslawsky et. al., 1995).
A case study in Austria analyses the feasible energy link between a brewery and the neighboured city including possible energy resources and district heating.

1. Introduction

In a first step of optimization, a basic technology network is generated through Process Network Synthesis, which takes into account already existing facilities and integrates new technologies based on renewable resources within the region. This application uses the p-graph method, and works through energy and material flows. During optimization, available raw materials are turned into feasible products and services, while inputs and outputs are unequivocally defined by each implemented operating unit. The aggregate of implemented operating units represents the maximum structure. By the help of an algorithm for combinatorial process synthesis, where the objective function is the revenue, a solution structure is generated out of the maximum structure. This solution structure represents the most economical technology network.

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In the second step, the generated network is evaluated by the Sustainable Process Index, in order to make the environmental pressure visible. The SPI, as a member of the ecological footprint family, calculates the area which is needed to deliver the product or service unit in question. The software SPIonExcel allows the evaluation of the ecological footprints of different processes.

2. Business as usual scenario

The Austrian case study addresses a comprehensive economical and ecological optimization of the energy system of the historic town centre of Freistadt and a brewery. A special situation applies to the ownership of the brewery: it is owned by the so called 'Braucommune', which consists of landlords from the historic city. This particular situation made it possible to take into account the historic town centre into plans to overhaul of the energy system of the brewery since from an economical point of view common ownership allows the economically most advantageous structure for a system consisting of the brewery and the citizens in the historic town centre. For the brewery, the optimization process aimed to raise the efficiency of the brewery's operations. For the town, the goal was to improve the energy supply based on renewable and regional sources in economic as well as ecologic terms, taking into account that thermal insulation for houses in this area is not feasible due to historic monument preservation ordinances.

Currently the process heat for the brewery is provided by a heavy fuel oil-fired hot water boiler. In 2007 the fuel requirement of the process heat was 30.590 litres, equivalent to around 3.310 MWh/year for heat values of 39,1 MJ/l or 10,833 kWh/l respectively. The heating of rooms within the brewery, which covered an area of 13.600 m^3 in 2007, is currently supplied by natural gas. This area mainly consists of offices and a gallery. The yearly room heating demand is 136 MWh for heat values of 36 MJ/m^3 and 10 kWh/m^3. Both the oil furnace and the electrical cooler, the latter supplying the cooling demand of the beer storage, are to be changed through current development projects. These investment costs were included for the evaluation of the business as usual scenario. Furthermore the calculation involved a higher heat demand of 400 MWh, a value that is expected due to planned enlargements. Electricity from the grid was included at a price of 11 ct/kWh (Annual account of Braucommune Freistadt). Based on the current scenario and the upcoming investments, the brewery itself faces a yearly cost of 137.890 € during the first 10 y, with the 10 y defined as the payout period. Afterwards costs are projected to fall by approximately 30 %.

The historic town can be divided into two regions based regarding its heat supply. In one region a gas network that is supplied by natural gas is already in place. The yearly heat demand of this area is 11.197 MWh. In the other region with no existing network, the yearly heat demand is 2.622 MWh. Oil heating is there still the most common method of providing residential heat and represents the basis of our calculation. While natural gas for households was included at a price of 6.3 ct/kWh, heating oil was included with 5.4 ct/kWh (EUROSTAT, 2nd Semester 2008). We note however that the price of natural gas differs among customers: the brewery for example only pays around 4 ct/kWh (43 ct/m^3) to supply its room heating (EUROSTAT, 2nd Semester 2008).

Adding the costs of district heating to the yearly costs of the brewery, expenses add up to 978.880 €/year.

3. Economical optimization

3.1 Maximum structure

The following structure represents the feasible connections for the economical optimization. It includes technologies based on both conventional energy and renewable sources available in the region. Out of this maximum structure the most economical optimum structure can be achieved based on different scenarios.

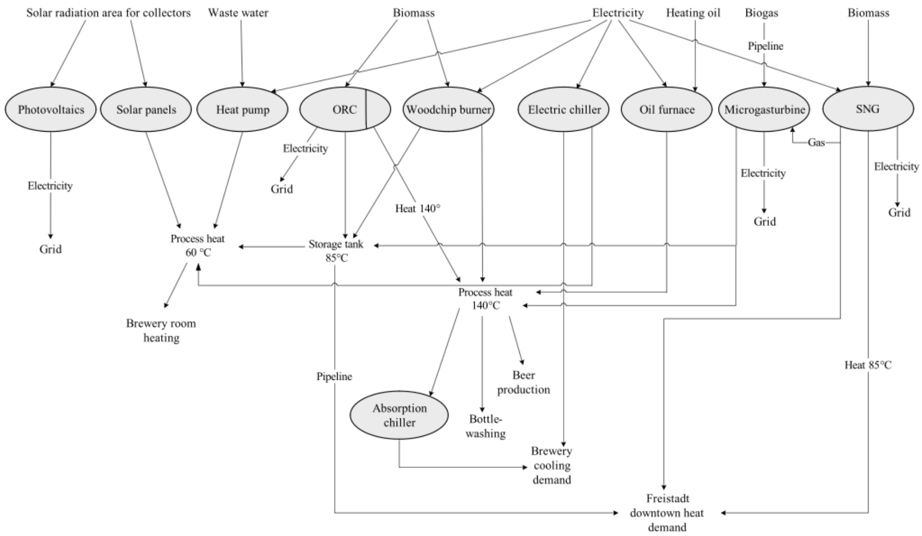

Figure 1: Maximum structure of the optimization process (source: compiled by the authors)

3.2 Optimum structure based on renewable energy sources

The most economical solution structure included a gas burner for peak load supply. However, in order to be attentive to the ecological pressure as well, an optimum is introduced here where the only technology that is not solely based on renewable energy sources was a new electric cooler that had already been ordered by the brewery after having determined an absorption cooler could not be part of the optimum structure due to high investment costs. In the calculation the biomass as the regional renewable resource was woodchips included at a price of 60.4 €/t (Hackgutbörse, 2009).

The solution structure contains:

ORC (Organic Rankine Cycle), with an electrical capacity of 700 kW and a thermal capacity of 4,200 kW supplying the district heat for the historic town of Freistadt, investment costs are 6,500,000 € (turnkey)

Woodchip burner, with a thermal capacity of 1,000 kW, investments costs are 510,000 € (turnkey)

Micro gas turbine, 2 modules, both with an electrical capacity of 65 kW and a thermal capacity of 115 kW, run by biogas, investment costs are 210,000 €
Biogas pipeline from biogas plant to brewery, 1.230 m long, 30 y of payout period, investment costs are 123,000 €/100 m pipeline
Electric cooler, 250 kW capacity, investment costs according to arrangement
During the payout period this scenario requires annual expenses of 781,470 €, around 20 % less than the amount the business as usual scenario represents. After the 10-year payout period, this structure would generate annual revenues of 35,160 €.
As a basis of our calculation we assumed 8,000 working hours per annum. In a given year, periods were determined based on two factors: the brewery's operations and the demand for heat. As for the brewery processes, the following data were estimated by factoring in ongoing projects for enlargement:
80 hl gyle/brew and up to 8 brews/d
daily 640 hl gyle or 600 hl ready-to-sell beer (4-5 % loss of volume during production)
brewhouse operation 3 d/week
The bottle washing process runs 5 d a week, while the room heating is needed every day. According to these circumstances the calculation was based on three periods each month: Monday-Wednesday, Thursday-Friday and Saturday-Sunday. The cooling demand - similarly to the room heating – is continuous during the week. This makes it reasonable to link the waste heat of the electric cooler to the room heating. Figure 2 describes the rate of each technology for the heat supply of the brewery. The available yearly biogas from a plant nearby is limited to 330,000 m^3, sold to the brewery at a price of 24 ct/m^3 (Biogas-Netzeinspeisung, 2009), and funnelled through a 1230 m long pipeline. This amount of biogas is then burned by two modules of Capstone CR 65 micro gas turbines with an electrical capacity of 65 kW and a thermal capacity of 115 kW. On the one hand the electricity produced by the turbines is sold to the grid as green electricity at a price of 15.13 ct/kWh (Energie-Control GmbH, February 2009), and on the other hand the heat produced by the turbines ensures the basic load for the process heat of the brewery. The woodchip burner provides the missing amount of the process heat demand. It has a thermal capacity of 1000 kW which was calculated as a minimum requirement to cover the peak load. On the weekends during the summer months, the waste heat generated by the electric cooler is able to cover the entire amount of heat needed for room heating. Whenever this demand exceeds the amount coverable from the waste heat, it is supplied by the micro gas turbines.
As part of our solution, the district heat demand of the city is supplied by an ORC plant with a thermal capacity of 4,200 kW and an electric capacity of 700 kW. The electricity as output is similar to the micro gas turbines sold to the grid at a price of 14.93 ct/kWh (Energie-Control GmbH, February 2009).

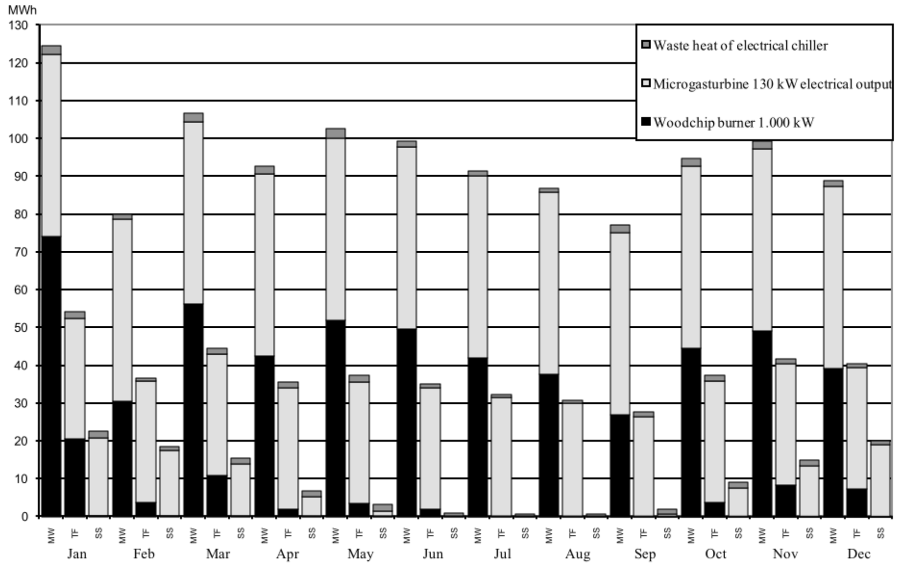

Figure .2: Heat supply constellation of the brewery (source: compiled by the authors)

4. Ecological Evaluation (SPI)

The following graph shows our economical optimization combined with the ecological evaluation.

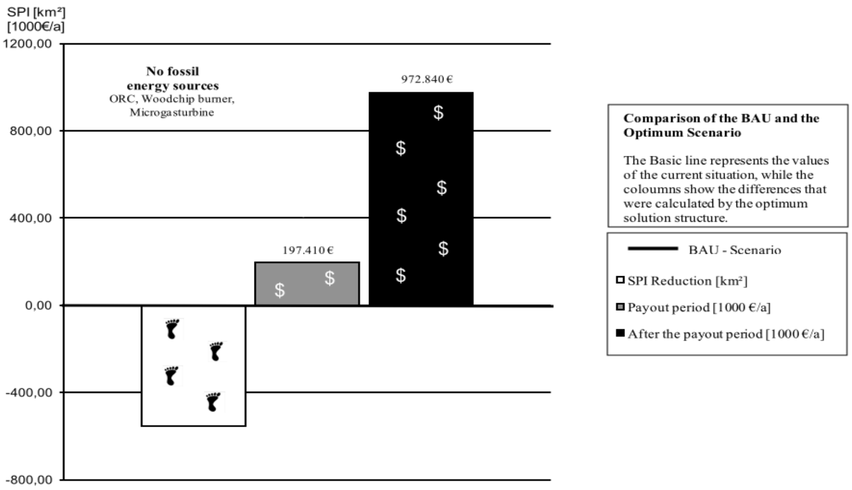

Figure3: Ecological and economical comparison of BAU and optimum scenario (source: compiled by the authors)

With the SPI, the environmental pressures between the business as usual and our optimum scenario are comparable. The SPI in both cases shows the areas needed to supply all processes presented by the scenarios. Based on the current scenario, the total area is 1,062.7 km^2. Only less than half - 503.7 km^2 is needed for the technology network of the optimum scenario. Thus this scenario is not only a profitable solution, but also an ecologically favourable process network.

5. Conclusions

In order for both cities and industries to remain competitive, it is inevitable for them to link up in terms of energy networks. The increasing consciousness of the ecological pressure of human activities on the environment however makes an ecological evaluation equally essential. This paper examined the possibility of linking industry and city through material and energy flows. One of the main concerns during the optimization was to avoid the unused off heat production, and to prove that linking the excess heat of an industrial process to a communal energy supply is a feasible way of improving overall performance of a city-industry complex. In this particular case a process network optimization of a brewery based on renewable resources from the surroundings was combined with the district heating supply of a historic city centre, with excess electricity being sold to the grid at favourable “green” feed-in tariffs. The optimization was based on both economical and ecological aspects, and showed that such linkages, in addition to favouring environmentally friendly technologies, represent a profitable network opportunity for both partners. During the 10 y long payout period the optimum structure stands for an approximate 23 % drop in the yearly expenses and providing considerable revenue after this period. Similarly, a significant improvement is observed in the ecological pressure: the ecological footprint of the optimum network is less than half the current footprint. By considering these results, we can conclude that linking resources and energy lines between industries and communities will play a significant role providing economical benefits while representing a sustainable form of development.

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