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Modeling of energy efficiency increase of urban areas through synergies with industries

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Abstract

Generally waste heat, waste water and waste streams are available as industrial energy sources in industrial companies. Additionally, their roof areas can be used for solar energy harvesting. The energetic linking of industry and urban areas through the usage of industrial energy for covering the energy demand of the cities is hardly surveyed.

Due to the lack of research concerning the symbiosis of industry and cities, no figures are available which enables an economic comparison with other energy production technologies. An economic assessment was carried out using four towns as examples. With the help of the annuity method, amortization times are determined. Additionally levelized costs for electricity and heat under different scenarios are calculated. They reach from 60-91 €/MWh for electricity and 25-38 €/MWh for heat. A sensitivity analysis takes into account possible price fluctuations.

Highlights:

- Levelized costs of electricity and heat are calculated.
- Amortization times of 6-8 years could be estimated for heat related implementations.
- Feed-in tariffs show a large influence on the profitability of PV-power plants.
- Business models for industrial energy allow advantages for all participants.

Keywords: industrial energy, levelized heat and electricity costs, amortization time

1 Introduction

Industrial companies are usually characterized by a high energy input. This is accompanied with residual energy which cannot be consumed within the company. That includes the most widely known energy source waste heat, but also waste and waste water (waste heat bound in water). Additionally these industrial plants have large unused roof areas which can be used for the production of electricity from solar energy.

As far as (economically) feasible these energy streams are already exploited within the companies processes. The unused part, however, is normally available for external application. Here, this “industrial energy” can be used for covering a part of the energy demand of nearby cities or urban regions.

The combined use of all industrial energy streams for covering the energy demand of neighboring urban areas is one opportunity to fulfill the claimed (legal) requirements for more energy efficiency and CO_2 emission reduction. The usage of industrial energy represents an option for increasing the energy efficiency of industrial companies, without compromising their processes and their profitability. This will not only improve the energy efficiency of the industries but also the overall energy performance of the region.

In many industrial companies in the European Union a large amount of waste heat from various processes still remains unused. A recent study in Austria detected an annual technically feasible industrial waste heat potential of around 15 TWh [1]. This is more than 20% of the domestic heat and hot water demand of Austrian households. Reusing industrial energy is essential in order to increase the energy efficiency of the European energy system and to reach the 20-20-20 targets of the European Union. However, up to now economic and non-economic barriers are hindering the uptake of this potential.

The research work of Karner et al., 2015, showed that industrial energy is technically capable of being integrated into local energy systems. The potentials for synergies between industry and city were examined based on four towns (town A-D) in Austria with a population between 7,000 and 12,000 inhabitants and a more or less strong industrial penetration. It was found that in total up to 35% of the total energy demand of the surveyed cities could be covered. This means also a saving of the primary energy demand for the cities in the same extent. The results of the study are summarized in Table 2. Against one’s expectations nearly the total amount of accumulating industrial energy can be integrated in the energy system of the town. Only a few hours a year and in minor height oversupply through industrial energy occurs; storage of this oversupply hardly influence the security of supply whereby they are neglected in further considerations. [2]

Based on the recommendation of the research work of Karner et al., 2015, this paper aims at analyzing the economic viability of the integration of industrial energy into urban energy systems.

2 State of the Art

Low temperature district heating systems in combination with industrial waste heat recovery were analyzed by Fang et al., 2013. The advantage of low temperature DH-grids is the higher recovery rate of industrial waste heat. Thermal efficiency of the industrial factories could be improved by 11% shown on example in northern China. [3]

Rattner and Garimella, 2011 analyzed the potential of waste heat streams for the United States. The availability of waste heat in power plants, industrial plants, in buildings and the transport sector was considered. Power plants release the overwhelming majority of the waste heat potential. The use of low-temperature waste heat for heating apartments, houses and industrial plants and providing warm water offers the most effective approach to increase energy efficiency. 12% of primary energy demand could be saved by using existing waste heat. [4]

At European level, annual excess heat streams from thermal power plants, industrial processes and waste to energy activities were analyzed. The compliance of existing excess heat and local heat demand was considered at a regional level and so-called "strategic synergy heat regions" were identified. It was found that 46% of the total surplus heat from the EU27 could meet 31% of the heating demand of the buildings in the identified synergy regions [5]. With the help of GIS mapping an industrial excess heat potential for EU27 of 753 GWh/a was found [6].

New studies on future district heating (DH) grids also considered the role of industrial waste heat. District heating grids will play an important role in future sustainable energy systems according to Lund et al., 2014. Especially 4th generation district heating systems allow for the use of various industrial excess heat sources and other energy sources. [7] The combination of waste heat from power plants and industry and district heating system is attributed a major role in renewable energy system [8].

The district heating grid of Göteborg (Sweden) is mainly supplied by waste heat. Holmgren, 2006 observed, that a reduction of waste heat usage in DH grids will lead to considerably higher costs of the systems and higher CO_2 emissions [9]. Morandin et al., 2014 found that the operation of DH grids with industrial waste heat is profitable in the entire capacity range [10]. Furthermore, using waste heat from industry with adsorption heat pumps lead to a reduction in fossil energy, CO_2 and NO_x emissions according to Kiani et al., 2004 [11].

Within the framework of energy efficiency measures in industrial companies, waste heat recovery is seen as one option. Karellas et al., 2013 investigated waste heat recovery in industrial processes for reuse inside the company, which is one of the most likely cases [12]. A feasibility study of upgrading low grade waste heat for district heating was done with regard to technical, economical, institutional and environmental feasibility for a city in the Netherlands [13]. With the help of an exergy analysis a waste heat recovery potential was detected which could decrease the domestic natural gas and coal consumption by around 50% [14]. Svensson et al., 2008 showed that external waste heat usage from a craft mill is more effective concerning CO_2 reduction than internal application [15].

The bottom-up investigation conducted by Brunke and Blesl, 2014 proved that fuel savings of 4% and electricity savings of 0.7% for the year 2013 are possible for the German cement industry. This was assessed with the help of 21 energy efficiency measures. Waste heat recovery was only taken into account for internal consumption. [16]

Morrow et al., 2014, used a forward-looking bottom-up approach called “Conservation Supply Curves (CSC)” where energy saving potentials for fuel and electricity are created as a function of marginal costs of saved energy. This approach was applied in order to analyze 22 energy efficiency methods for the Indian cement industry and 25 for the Indian iron and steel industry. Heat recovery was again considered only for the internal use. [17]

Napp et al., 2014, examined technologies, economics and policy instruments for decarbonizing the iron and steel industry, the cement and the refining sector. Waste heat recovery was identified as energy efficiency measure. Besides internal heat recovery measures, waste heat usage for external usage was considered as well. [18]

The usage of low-grade waste heat increases the energy efficiency of industrial companies. According to Walsh and Thornley, 2012, this is connected to a number of barriers. Stakeholder engagement, strategic mapping and the need for capital support for infrastructure were identified as the most critical factors. [19]

Bayulken and Huisingh, 2015 analyzed the concept of "eco-towns" for cities in Northern and Western Europe. In contrast to eco-towns in Asia, European eco-towns follow a less industry driven approach [20]. "Hybrid industries" provide more sustainable communities for their inhabitants. The concept of Fujii et al., 2015 focused on the effects of using urban waste in industrial companies to reduce CO_2 emissions [21].

The development of low carbon towns in China was analyzed by Li et al., 2012. The towns were categorized according to their measures which lead to low carbon emissions. Around 18% of the investigated towns belong to the category "industrial towns". Waste utilization is the most important issue, because this is one of the major concerns. [22]

Industrial symbiosis allows economic gains, reduction of environmental impacts and reduced greenhouse gas emission. Symbiosis between different industrial companies but also between industrial companies and their urban environment were investigated by Dong et al., 2014. Geographic proximity facilitates the usage of residual waste of the urban environment in industrial applications [23]. Yu et al., 2014 analyzed the usage of waste heat between different industrial companies to reduce CO_2 emission in course of industrial symbiosis [24]. Recycling of blast furnace gas is the most effective measure to reduce CO_2 emissions in integrated steel mills. Sensible heat recovery was only of minor importance. [25]

The survey of Lu et al., 2013 studied the development possibilities of Taipei regarding an internationalized green energy industrial hub. The increased usage of electric cars and renewable energy (waste, biomass, solar and PV, geothermal energy) were identified as major items. [26]

The state of the art shows that industrial waste energy was already surveyed in numerous studies. The focus lay on waste heat; other industrial energy sources were hardly mentioned. Furthermore the synergetic link between industries and urban areas is novel. The research work of Karner et al., 2015 considered all industrial energy sources in synergy with urban areas for the first time [2]. Therefore no possibilities for economic comparisons are available to enable general statements about the cost effectiveness of the usage of industrial energy.

3 Business environment of industrial energy

Levelized costs for electricity and heat

Levelized costs are used for comparing different energy production technologies. The study of Alberici et al., 2014 assessed the levelized cost of producing electricity (LCOE) and heat (LCOH) for EU28. Costs for production are calculated assuming that the production plants would have been installed in the period of 2008-2012. The calculation was further based on operational expenditures and fuel costs. Figure 1 presents the results of the LCOE in the EU28 for various technologies. The blue bars indicate the costs at realized full load hours, whereas the grey bars indicates the costs at technical feasible full load hours. Levelized costs for electricity range from around 20 €/MWh for hydropower to 200 €/MWh for offshore wind and biomass plants. The LCOE for PV dropped from 2008 to 2012 by about 60% and ranges now from around 90-120 €/MWh depending on the yield and scale of usage (small scale or utility).

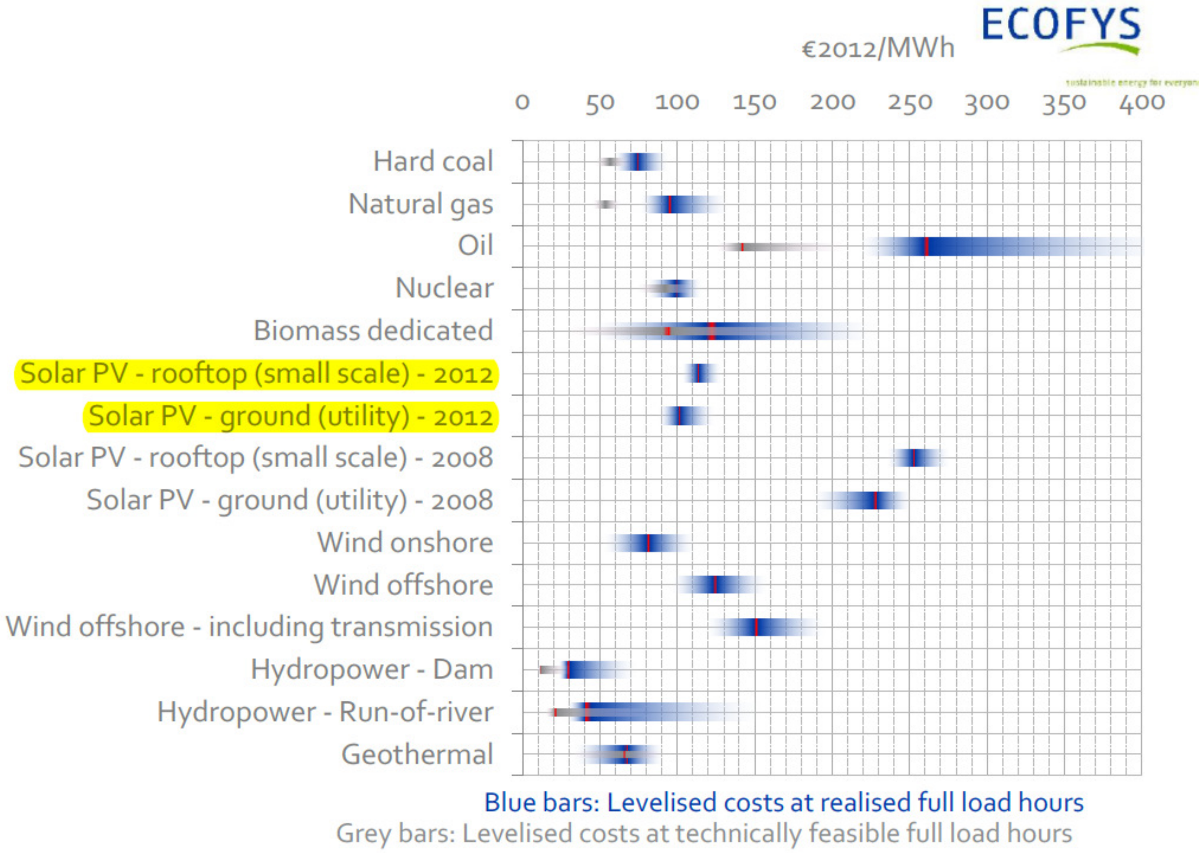

Figure 1: Levelized cost of electricity in the EU28 for various technologies

Source: [27]

The levelized cost of heat ranges from 20 €/MWh for industrial gas boilers to 150 €/MWh for heat pumps and wood pellet boilers in certain climate regions. In general, the cost of naturalgas based technology is largely driven by fuel costs, while for technologies running on other fuels (heat pumps, biomass boilers etc.) capital expenditures play a larger role. [27]

A German study determined LCOE for renewable energies and found that LCOE for PV power plants reach 78-142 €/MWh which confirms the results of the above mentioned study. [28]

Levelized costs of heat are determined by Gutzwiller et al., 2008, for waste heat usage from waste water. Thereby the variants, waste heat use from waste water treatment plants, and, waste heat use from the sewers, were analyzed. LCOH reach 58-141 €/MWh, whereby the profitability of the plant is only given with maximum LCOH of 75 €/MWh, which is only achieved by a few plants. [29]

LCOE and LCOH for industrial energy were not expulsed. In general, these studies can be used to compare and range the calculated levelized cost for industrial electricity and heat.

Business models for industrial energy [30]

Different models for financing and operating plants which uses industrial energy are presented in this section. A distinction is made between electricity and heat.

Electricity:

- Operation and financing done by the company itself: in this case, the on-roof PV plant is funded and operated by the industrial company itself. Generally it can be noted that this variant of business model is rather unlikely, since the capital commitment is too long and the amortization time exceeds the usual amortization time which are often predetermined by the companies. Here one can also distinguish between two variants:
  - Feed-in of the total produced electricity in return of receiving feed-in tariffs
  - Feed-in of excess electricity (only relevant for small industrial units with high electricity prices)
- Operation and financing is done by an external company: industrial company rents its roof surfaces to an external operator who funds and operates the PV system. Feed-in tariffs for green electricity generate annual revenues. External operators may be other industrial companies, plant manufacturers, energy service companies, privates etc.
- Citizen participation: Here the roof surfaces are again rented by the industrial plant. The PV system is operated by the energy service company and financed by means of citizen participation model. Annual revenues are generated by obtaining feed-in tariffs. The advantage of this variant arises due to the conscious-raising of the population, image building for the company, acceptance and direct benefits to citizens.
- Crowd founding: in contrast to the above mentioned citizen participation model only part of the investment costs is financed through public participation. This part is used as equity. The remaining share is financed through banks. Initiator and operator of the PV-plant could be private persons but also energy service companies etc. Disadvantage of this model is that currently the interest rates which have to be paid to the citizens are a lot higher than the interest rates of the banks.

Heat:

- Operation and financing done by the company itself: in this case, all relevant investments concerning the usage of industrial heat are made by the company itself. The distribution of the heat is done via district heating grids, hence the company resume also the operation of the DH-grids. Generally it can be noted that this variant of business model is rather unlikely, because heat extraction is not part of the main business of the companies since the capital commitment is too long and the amortization time exceeds the usual period of three years which are often required by the companies. Therefore, operation and financing are usually outsourced to third (see next point).
- Operation and financing done by an energy service company: Depending on the selected system boundaries the energy service company takes full or partial financing of the project. The operation of the district heating grid is handled by the energy service company.

4 Method

Due to the fact, that the relevant data for comparison is only available for heat and electricity separately, the calculated figures are also presented separately. The descripted method is shown in details for heat, but it is applicable in the same way for electricity.

Data preparation of technical simulation of the synergy potential

Technical data from the simulation of the synergy potential between industries and towns A-D is prepared. Following specifications are used from the technical simulation as input data for the economic analysis: electric power of heat exchangers, electric power and operation time of heat pumps, area for PV-modules, amount of supplied annual industrial heat (H_S) and electricity (E_S), the length of the required DH-grid and the operation time of the DH pump. Additionally the lifetime for each component is researched.

Data acquisition of specific costs and energy prices

In a second step, specific investment costs are researched in order to calculate capital expenditures for the single assets. Therefore specific investment costs for heat exchanger, for heat pumps, for PV-modules and for DH-Grids are examined. Furthermore the actual electricity purchase price is used to calculate the annual costs for running DH pumps and heat pumps. The actual electricity selling price and the heat selling price are used for the calculation of the annual revenues.

The applied data for the calculations can be found in Table 1. Specific costs for heat exchangers vary due to choice of product and field of application (waste heat or waste water). Selling and purchase prices are specific for Austria, but can easily be adapted to other conditions.

Electricity selling price	0.07 [€/kWh]	Heat selling price	0.06 [€/kWh]
Electricity purchase price	0.12 [€/kWh]	Specific costs for heat pumps	330 [€/kW]
Specific costs for PV modules	150 [€/m²]	Specific costs for heat exchangers	8.2-29.3 [€/kW]

Table 1: specific costs and energy prices

Source: [31], [32], [33], [34], [35]

Economic analysis according to VDI guideline 2067

The economic analysis of the implementation and the usage of industrial energy is performed according to VDI guideline 2067, which is based on the annuity method. The first step involves the calculation of the annuity and the second step the estimation of annual variable costs. Finally, the annual revenues will be assessed. The development of the annual revenues is considered for a period of 30 years. Here the annual costs and annual earnings are valued with an inflation rate of 3 %. Finally, the costs are contrasted with the earnings. As a result, one obtains the payback period and the profit for the following 30 years. As an example the result is presented for town B in Figure 2. The last step is related to the calculation of the levelized costs of energy and the gains per unit of sold energy.

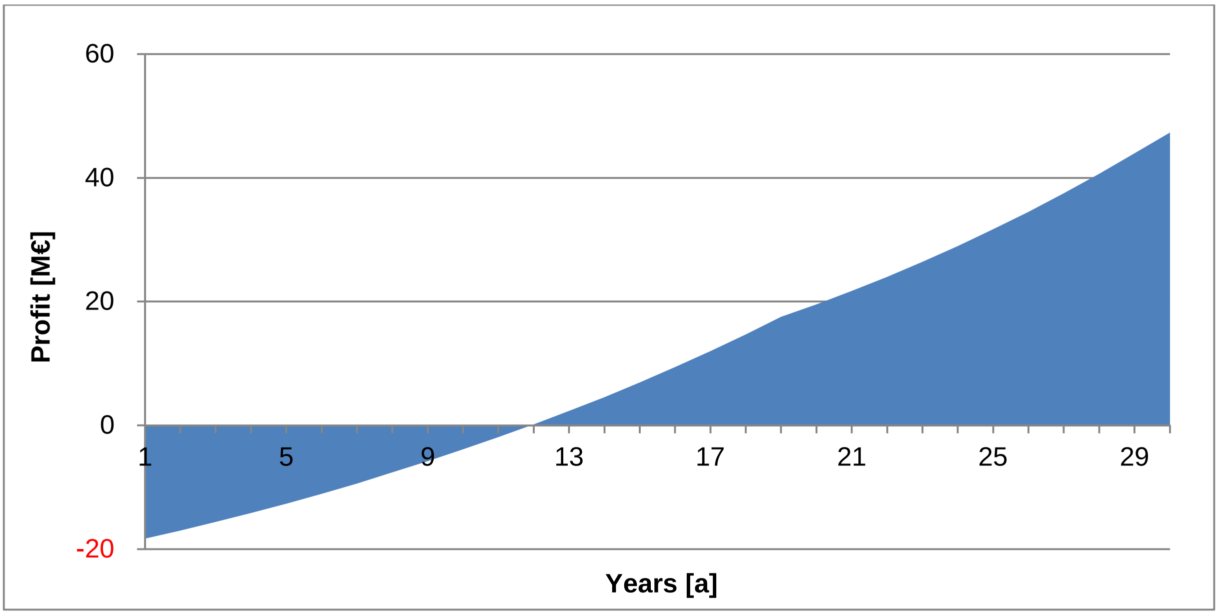

Figure 2: Revenues and amortization time for town B (scenario 1)

1. The information from the first two steps is combined to calculate the investment costs of each asset. The technical rating in kW of one component (T_C) is multiplied with the specific investment costs of the component (C_C) to calculate the investment costs of the component (I_C), see formula (1).

   (1) I_C [€] = T_C [kW] * C_C [€/kW]

   Through summing up the investment costs for every component the total investment costs can be calculated. The connection to the district heating network is linked with costs that are partially supported by the homeowners. This amount will be recorded as a one-time income in the first year and deducted from the investment costs. Additional and eventual costs are added as a percentage of the investment costs.

   The annuity (A) is calculated for every component separately and then summed up to the total. Therefore the investment costs, the life time (n_C) and interest rate (p) are the basis for calculating the annuity of each component (A_C), see formula (2).

   (2) A_C [€] = I_C * [(1+p)^n * p] / [(1+p)^n – 1]

2. The operation of the DH pump and the heat pump causes costs which add to annual variable costs (V_C), see formula (3). Based on the electricity consumption and the electricity purchase price (C_{EP}), those operational expenditures are calculated. Electricity consumption of the heat pumps is calculated based on the rated power (P_{HP}) and the yearly operation time (t_{HP}) of the heat pumps. The Electricity consumption of district heat pump is based on a key figure (E_{DH}) that indicates the consumption of the pump per transported quantity of heat. Annual insurance and maintenance (C_{IM}) costs are added to the annual costs and calculated on the basis of investment costs with a certain percentage.

(3) V_C [€] = C_{EP} [€/kWh] * (P_{HP} [kW] * t_{HP} [h] + E_{DH} [kWh/kWh] * H_S [kWh]) + C_{IM} [€]

3. The yearly revenues (R_A) are estimated from the amount of heat sold and the current selling price for heat (C_{HS}), see formula (4).

(4) R_A [€] = C_{HS} [€/kWh] * H_S [kWh]

4. The last step is related to the calculation of the levelized cost of heat (LCOH). To determine the specific cost per unit of production of different systems the so-called levelized cost of heat are used. This method is widely accepted and applied, since it makes it possible to compare the specific energy costs of different technologies. The calculation is based on the general formula (5).

(5) LCOH [€/MWh] = {A + V_C} / H_S

The annual profits per sold heat unit (G_A) are calculated based on the yearly revenues, the levelized costs of heat and put in relationship according to formula (6). Depending on the selected business model the gains reflect either the profit for the industrial company or the profit for the energy service company. In the latter case, the agreed compensation for the industrial company must be subtracted.

(6) G_A [€/MWh] = R_A [€] / H_S [MWh] – LCOH [€/MWh]

Simulation of different founding schemes in form of scenarios

The influences of different subsidies are considered under different scenarios. Financing will be granted either in the form of investment funding or feed-in tariffs. In Austria, investment funding is only awarded for heat related facilities in a maximum amount of 20% of heat related investment costs. Feed-in tariffs are awarded for PV-power plants which feed-in green electricity in a height of 13.5 ct/kWh [36].

- Scenario 1 (S1): no subsidies
- Scenario 2 (S2): no investment funding, feed-in tariff
- Scenario 3 (S3): investment funding, no feed-in tariff

For town A and C only scenario 1 and 2 is simulated due to the unavailability of heat.

Sensitivity analysis

The sensitivity analysis considers possible effects on the heat and electricity production costs. The costs of the components related to heat recovery (heat exchanger and heat pump), costs for the DH-grid, the electricity purchase price, costs for the PV-modules and the interest rate are changed to a value plus or minus 20% of the calculated average value. The changing of the energy production costs, the gains and the amortization time are recorded for each scenario. The average economic values are presented in the relevant figures as a range.

Concerning the levelized costs for electricity, the sensitivity analysis covers especially future developments e.g. reduction in module costs for PV; regarding the levelized costs for heat, the sensitivity analysis takes into account especially differences in local conditions, such as different load profiles and full-load hours, as well as the proportion of direct heat and heat via heat pumps.

5 Results

Waste is available as energy source for all four towns. Its contribution is that low (< 2 MW), that building and operating a waste incineration plant is in fact technically feasible but inefficient. Therefore it is not put into further consideration. A summary of the adapted results of the synergy potential between industries and urban areas can be found in Table 2.

	Town A	**Town B**	**Town C**	**Town D**
Energy demand industry (% of total energy demand of the town)	12	67	53	71
Waste heat (% of total industrial energy supply)	0	29	100	100
Waste water (% of total industrial energy supply)	0	71	0	0
PV electricity production (% of total industrial energy supply)	100	100	100	100
Heat coverage (% of total heat demand)	0	19	1	28
Electricity coverage (% of total electricity demand)	6	30	16	46
Total coverage (% of total energy demand)	**1**	**21**	**4**	**32**

Table 2: Synergy potential between industries and four Austrian towns

Source: [2]

Town A shows a low contribution of industrial energy demand with 12% compared to the total energy demand of the town. Industrial energy occurs only as electricity from PV. This results in low coverage of energy demand with industrial energy (1%).

More than two third of the energy demand of town B is caused by industry (67%). Waste heat, waste water and electricity from PV serve as potential industrial energy sources for supplying the town. Accordingly coverage of up to 23% of the total energy demand of town B is possible.

Although town C shows a relatively high share of industrial energy demand (53%), still the synergy effect with the town is quite low. The existing industrial companies (manufacturer of ceramic storages, dairy farm and other small factories) cause a huge impact on the energy demand but hardly offer industrial energy. Industrial energy is available as electricity from PV. Waste heat is available as well, but in an amount (1% heat coverage), which does warrant the effort and is therefore neglected in further contemplation. Coverage of urban energy demand of only 3% is achievable.

Town D shows, with 71%, a high contribution of industrial energy demand compared to the total energy demand of the city. Waste heat, waste water and electricity from PV serve as industrial energy streams which can be used for covering the energy demand of the city. The highest synergy effects could be achieved there (34%).

For comparison and better readability the results are presented separately for electricity and heat. It can be recognized, that industrial electricity from PV-plants is available for all four towns whereas industrial heat is only available for town B and D. The calculated figures are quite similar for all four towns; variations occur within 10% for LCOE, LCOH and profits due to minor differences in local conditions and sizes of the demonstration plants. Amortization times are nearly identical for all towns.

5.1 Electricity

The results of the economic analysis for electricity related implementations for towns A-D for the relevant scenarios are presented in Figure 3 and 4.

LCOE reach from around 60-91 €/MWh for all towns. An implementation of PV power plants for urban electricity production on the roofs of industrial companies is completely unprofitable under scenario 1. In average, no profits could be recorded which leads to amortization times well over 30 years. The receipt of feed-in tariffs leads to higher profits and therefore to shorter amortization times. Scenario 2 demonstrates, that the implementation of PV on industrial roofs for electricity production is economical realizable.

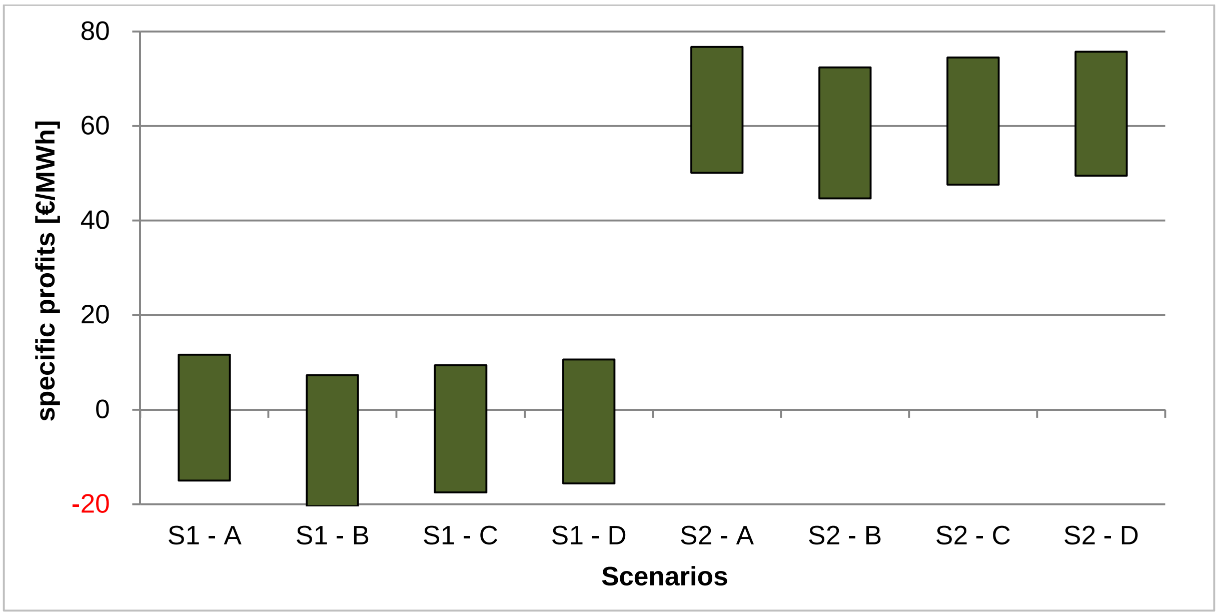

Figure 3: Specific profits of electricity related demonstration plants

Scenario 2 lead to higher specific profits (see Figure 3) and consequently to shorter amortization times (see Figure 4). In average amortization times of 12 years could be achieved. Under the chosen conditions, LCOE are not affected by feed-in tariffs and stay the same.

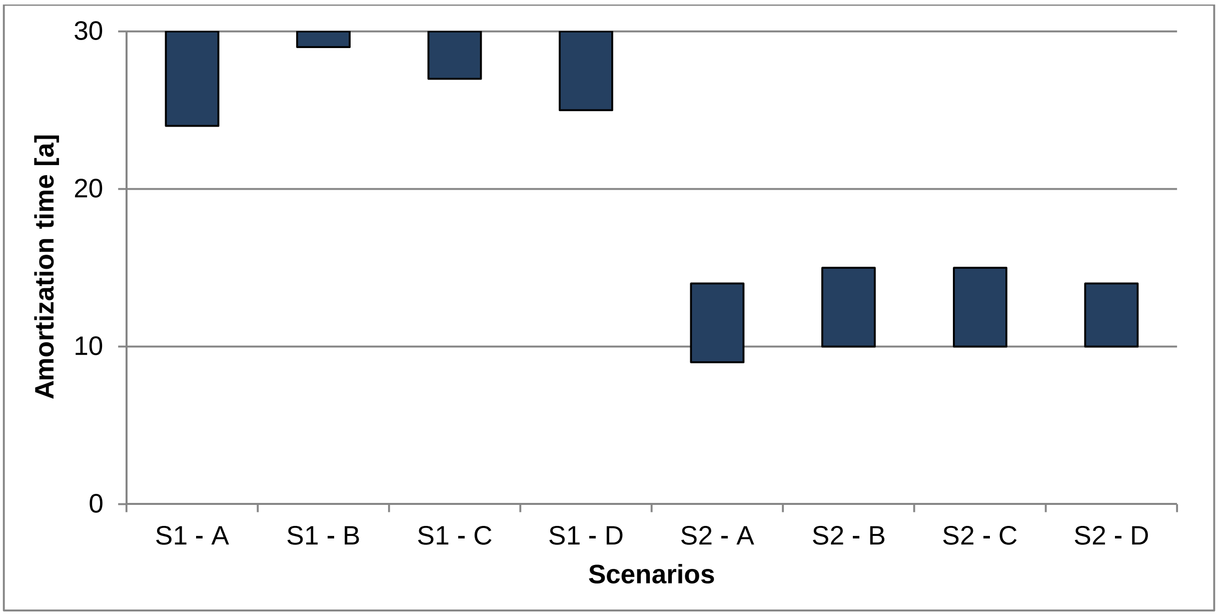

Figure 4: Amortization time of electricity demonstration plants

The allocation of the annual costs for electricity related demonstration plants to single assets is presented in Figure 5. More than three fourth of the annual costs are related to investments for PV-modules. This is reflected in the sensitivity analysis (see Figure 6).

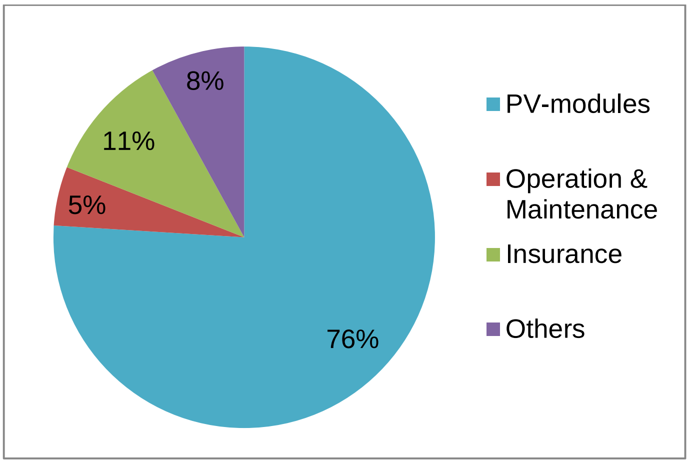

Figure 5: Allocation of electricity related annual costs to single assets

Variations of 20% in costs for PV-modules implicate a change in electricity production costs of 18%. This conclusion can be drawn for both scenarios and all towns.

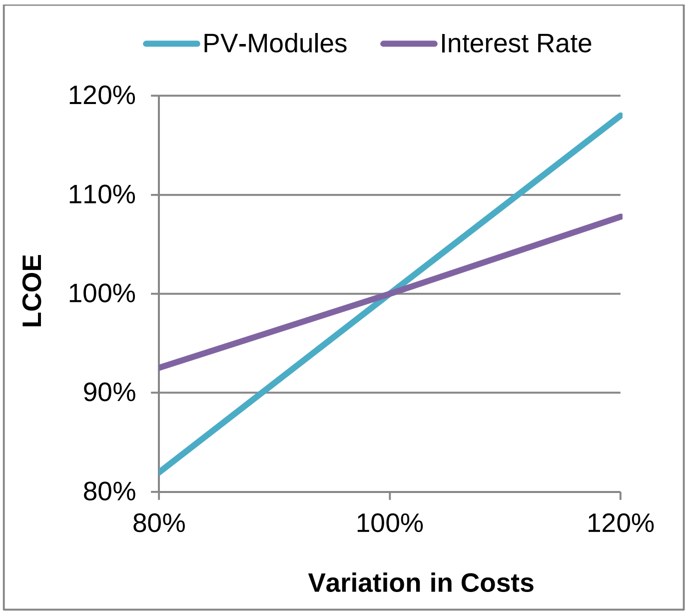

Figure 6: Sensitivity analysis of LCOE

5.2 Heat

The results of the economic analysis for town B and D for heat related demonstration plants are presented in Figure 7 and Figure 8.

Heat related considerations about an implementation would also be profitable without investment funding. LCOH reach 27-38 €/MWh and average amortization times of 7 years could be achieved under scenario 1. Scenario 3 shows the impact of investment founding on LCOH. Investment funding of 20% lead to reduction of around 6% in LCOH (25-37 €/MWh) and to an increase in specific profits in the same height (see Figure 7). No impacts on the average amortization time could be determined.

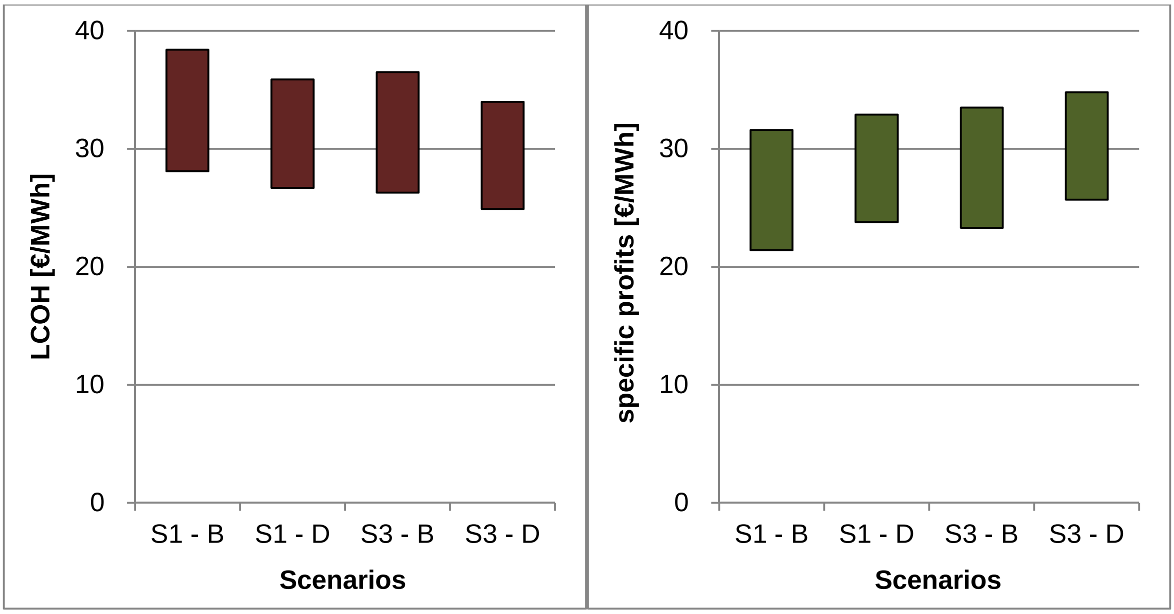

Figure 7: Economic results for heat for town B and D

The amount of heat which is used in combination with heat pumps compared to the amount of heat that can be applied directly has a major impact on the costs. This is mainly due to the cost of operating the heat pump (electricity price). The allocation of the annual costs for heat related demonstration plants to single assets is presented in Figure 8. More than three fourth of the annual costs are caused by the electricity consumed to operate the pumps for the district heating grid and the heat pumps. This is reflected in the sensitivity analysis (see Figure 9).

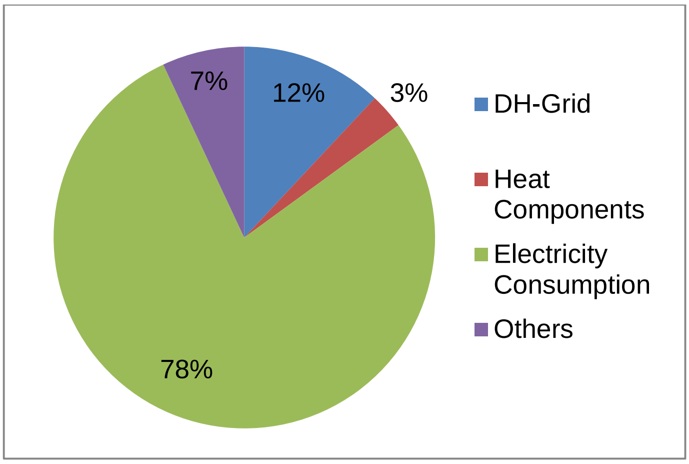

Figure 8: Allocation of heat related annual costs to single assets

Figure 9 presents the results of the sensitivity analyses for the LCOH. Variations of 20% of the electricity price implicate a change in heat production costs of 16%. Price variations for heat components or a change in the interest rate do hardly influence the levelized costs of heat. This conclusion can be drawn for both scenarios.

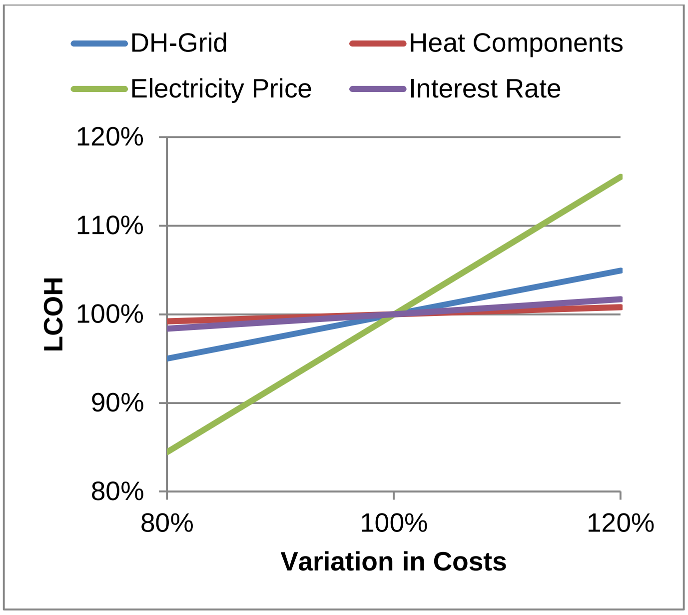

Figure 9: Sensitivity analysis of LCOH

6 Discussion and Conclusions

Implementations for the usage of industrial electricity from roof-top PV are not profitable without the receipt of feed-in tariffs. LCOE stayed unchanged but gains increased dramatically and the amortization time shortened to an average of 12 years which was shown in scenario 2, where a feed-in tariff of 13.5 ct/kWh was taken into account. The implementation of PV plants is linked with minor efforts, so even for town A, which shows the lowest synergy effects, the implementation is profitable under scenario 2. Compared to the EU average for levelized costs for electricity from PV the LCOE for industrial electricity is located at the lower end of the range. The costs are mostly influenced by the costs of the PV modules.

It was found that implementations for the usage of industrial heat are economically feasible independent from the chosen scenario. Investment funding has an advantageous effect on economic considerations of industrial heat, but is not crucial for a decision. In comparison, LCOH for industrial heat are far under the EU average for LCOH. The costs are mostly influenced by costs of electricity which is needed for operating DH pumps and heat pumps.

Building a waste incineration plant is not profitable under a certain threshold value. Even when the industrial waste from all four towns is collected the threshold value is not reached. Here the possibility arises to collect the industrial waste to treat it in an existing waste incineration plant.

Depending on the selected business model a benefit for the industrial companies and energy service provider is to be expected with great certainty. For the calculations, the actual market prices for electricity and heat were assumed. It is possible to offer customers more favorable energy prices, but that reduces the gains (and increases the amortization times) for the industrial companies and the energy service provider.

Nevertheless, the usage of industrial energy offers a affordable possibility to reduce CO_2 emissions, increase energy efficiency and reputation of the industry.

Following recommendations are made concerning further research work:

- The number of analyzed cities should be increased to increase the meaningfulness of the calculated data.
- The surveyed project regions are in close proximity. Regional coupling of energy demand offers a possibility for higher synergy effects. Besides a technical survey concerning the feasibility, the economic impacts need to be analyzed in more detail.
- Oversupply results from electricity production from PV during the summer months. This can either be stored in appropriate storage devices or used for the hybridization (power to heat with reasonable thermal storage units). An economic comparison of the two alternatives needs to be done.

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