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Socioeconomic cost-benefit-analysis of seasonal heat storages in district heating systems with industrial waste heat integration

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A B S T R A C T

Industrial waste heat is primarily available in summer months while district heating demand is greater in winter months. In order to shift heat potentials from summer to winter and thereby make the feed-in of industrial waste heat economically more attractive, the paper explores the use of waste heat with large-scale (seasonal) heat storage. This paper focuses on the case study of the industrial city of Linz (Austria), and demonstrates the advantages and disadvantages of seasonal heat storage. The interaction between the storage system with optimal cogeneration plant dispatch and industrial waste heat integration is explained. Furthermore, the most important parameters of the heat storage in order to achieve economic feasibility are highlighted. One main finding is that the number of annual cycles is crucial for a *seasonal* heat storage. The amortization period is computed to be about 20 years, and is shown to be extremely sensitive to changes in electricity, gas and CO_2 prices.

1. Introduction

For 4th generation district heating networks, waste heat integration is expected to be a common design element [1]. With many practical examples in 2nd and 3rd generation district heating networks, integration of industrial waste heat into these networks is technically feasible. In Austria, the usage of waste heat from the paper industry, forest industry, steel industry, petrochemical industry and food and drinks industry can be observed. Nevertheless, significant thermal capacities and volumes remain unused due to the high flow temperatures of 2nd and 3rd generation district heating networks. Even after excluding low-temperature industrial waste heat, substantial potentials remain [2].

In many people's opinion, it is often assumed that waste heat is a free source of energy and therefore its utilization and integration in district heating networks is always economically efficient. However, it was demonstrated that the feed-in of waste heat is often associated with significant initial investments (upfront costs) and risks (economic uncertainty) for both the district heating company and the providing industry [3]. Moreover, the temperatures in 2nd and 3rd generation district heating networks imply that alternative uses of the waste heat (e.g. power generation on low efficiency levels) or preparation costs (e.g. electricity for heat pumps) are non-negligible [4].

The economic feasibility of industrial waste heat integration depends on multiple parameters. One of the most important parameters is operating hours per year. Heat demand of district heating networks is concentrated in winter months while supply of industrial waste heat is concentrated in summer months: due to lower outdoor temperatures, processes generate less waste heat and the company's buildings have to be heated. Supplying industrial waste heat only in winter implies that revenues can only be obtained in winter. This increases the payback period and often makes waste heat integration economically infeasible [3]. Enormous amounts of industrial waste heat are lost in summer (or even need cooling, implying additional energy input), while the heating demand in winter is still provided primarily by fossil cogeneration (combined heat and power, CHP) plants.

In this paper, a seasonal heat storage (SHS) tank for shifting thermal excess energy from industrial and CHP plants from summer to winter is discussed. The technical starting situation is described. On this basis, the seasonal storage was evaluated from a

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socioeconomic perspective, i.e. an analysis of the systemic advantages and disadvantages, a business-economic evaluation of the storage, as well as a macroeconomic assessment were conducted. Finally, assuming the availability of the storage, it was evaluated how the profitability of the feed-in of industrial waste heat changes when summer heat can be shifted to winter (Fig. 1).

These assumptions are applied to a practical example: Our case study is the city of Linz, Austria. The main local district heating company is currently not using industrial waste heat. However, chemical and steel industries are located inside city boundaries. This paper illustrates the highlights and results of the research project “Future District Heating System Linz” [4]. Hypotheses are that

- Integrating an SHS tank storage in a classic 2nd or 3rd generation district heating network is economically feasible.
- Shifting available thermal energy from summer to winter months by means of this SHS is economically feasible.

2. Case study: city of linz, Austria

Linz is Austria's third-largest city with approx. 200,000 inhabitants. As of 2016, approx. 70% of Linz households are connected to the district heating network of the local suppliers. This paper focuses on the network of the main supplier, which today accounts for approx. 85% of district heating energy provided. Linz is one of Austria's major industrial areas.

2.1. Current situation

In the 1970s, power plants fired by heavy fuel oil were built in Austria's main cities in order to guarantee a secure and sufficient electricity supply. In the case of Linz, CHP waste heat usage was included in the plans and implemented accordingly. District heating nearly exclusively supplemented decentral oil-fired boilers and thus needed to provide high temperatures of more than 100 °C.

Today, the main district heating network operates with a linearly dependent flow temperature between 130 °C and 80 °C with outdoor temperatures of −12 °C (or colder) and +12 °C (or warmer), respectively. Return temperature is always approx. 60 °C. The main local district heating company runs a network of approx. 305 km and provides 1.1 TWh/a to approx. 75,000 households via approx. 3500 delivery stations. Contracted load of all customers amounts to 824 MW, maximum generation has been approx. 450 MW (January 2016) [5]. The heat generation park comprises one waste incineration CHP plant, one biomass CHP plant, five gas-fired CHP plants and three gas boilers. The district heating company was one of the first district heating operators to use a heat storage tank: the 65-m-high depressurized steel tank can store up to 1300 MWh and is used for plant dispatch optimization [6].

2.2. Integration scenario

Industrial waste heat and the seasonal heat storage should be implemented in the Linz district heating network. In order to conduct the technical and economic feasibility simulations, essential parameters for this scenario needed to be defined.

2.2.1. District heating demand

Literature shows that decreasing space heat demands can be an economic risk for district heating in the future [7]. On the basis of the case study-specific desk research conducted, a potential for expansion of the district heating network can be assumed: There are other residential areas that can be supplied by district heating in the next years; moreover, additional customers can be connected in the existing network area of Linz. Connecting new customers means - ceteris paribus - an increase in the volume of energy supplied. At the same time, refurbishments of buildings which are already connected to the heating network decrease total heating demand. The forecast of the local district heating company states that the development of total district heating demand will be constant, implying that the network expansion cancels out refurbishments. Thus, for the analysis, a constant demand for district heating is assumed.

2.2.2. Industrial waste heat potentials

In the next step, sources of industrial waste heat potentials were identified. These potentials supplement the existing heat generation plants. Based on the company profiles, five companies were identified as those potential suppliers of waste heat to be considered first. These companies include a steelmaking company and a chemical industry both inside the city boundary of Linz. A paper manufacturing company is located close to the city boundary. Moreover, two smaller companies, one from the food, the other one from the foundry industry, were identified as potential waste heat suppliers. Based on interviews with these five companies (and including currently tested process modifications of these companies), a mid-term industrial waste heat potential of 40 MW in winter and 55 MW in summer was conservatively defined. Based on the interviews carried out, much feed-in potential was neglected due to economically insufficient amounts of waste heat or its low temperature. Of course, the authors recognize that low temperature potentials are likely to become usable rapidly due to rising efficiency of heat pumps and widespread availability of heat sources (cf [8]. on heat pumps [9], on heat from CHP [10], on mapping of heat sources, and [11], among other sources, on waste heat). Supplementing the biomass plant with cost-effective industrial waste heat was an admissible result for achieving a holistic maximum of carbon-neutral primary energy efficiency cf. [12].

2.2.3. Large-scale heat pump

The scenario includes a heat pump using the glue gases of the biomass and waste incineration plants as a heat source. At the

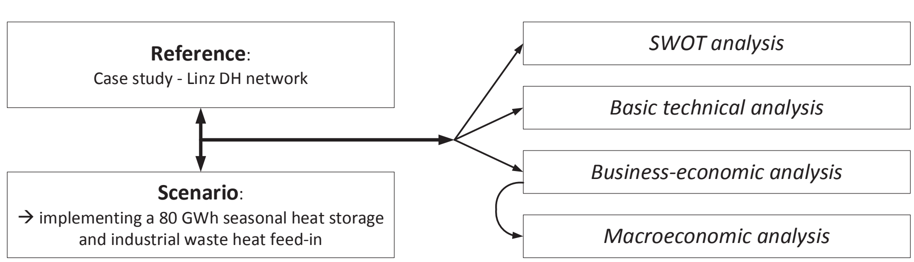

Fig. 1. Starting point and intentions of the paper.

moment, either the biomass or the waste incineration plant provides the base heat load and energy from flue gases is thus available all year (for analogous results see Ref. [13]). The heat pump provides heat to the 60 °C district heating return pipe with a coefficient of performance of 5.5. Its electricity is directly provided by the biomass and waste incineration plants, which are both CHP plants. By doing so, electricity network charges can be avoided.

2.2.4. Seasonal heat storage linz

Alongside the existing 1300 MWh steel tank, which is assumed to be fully operable in the scenario, a seasonal heat storage tank is to be elaborated. Muser et al. [14] elaborated on the technical feasibility of a seasonal heat storage tank in Linz. They conducted research on storage size as well as its design and erection (cf. below for further details). The parameters defined there constitute the basis for the authors' socio-economic analysis of the Linz seasonal heat storage (Table 1).

Muser et al. identified four favorable sites for the seasonal heat storage. Their choice was based on network position, soil conditions, property costs, etc. However, reheating the 97 °C storage discharge flow to 130 °C network flow in winter is crucial and needs other generation plants to do so. Thus, our focus was exclusively on the site directly bordering the main power and heat generation site (which is one of the four sites proposed by Muser et al.) as the issue of reheating can be solved by using the on-site heat generation plants (Fig. 2).

3. Fundamentals and experiences with SHS

Storage systems are the backbone on the transition path to an integrated, renewable, energy efficient and smart energy system [15,16]. Applications of large-scale hot water storages are a well-established and state-of-the-art technology. Water as a medium for sensible heat storage is inexpensive and easily available in most areas. Additionally, water has a high specific heat capacity and thus a high volumetric storage density at temperatures below 100 °C [17]. According to Clausen [18], hot water storages can be integrated in district heating systems in an economic way (note, that current and country-specific energy market prices, basic legal or other framework conditions and subsidies have to be considered). Due to the dependency of thermal losses on the storage surface area, economic efficiency is increasing with storage capacity and thereby decreasing ratio of surface area to volume, which leads to intense research in implementation of large-volume storages. This aspect is omitted for thermochemical storage solutions, as these allow the stocking of the storage medium at ambient temperature. Fundamental assessments assuming certain circumstances find that thermochemical storage can potentially be an economically feasible alternative to conventional hot water storages in combination with district heating in the mid-term future [19]. However, thermal storages of this type are hardly tested or available in industrial-scale. They are still subject to intense research with regard to storage process design and temperature levels [20] and plant system integration (e.g. Ref. [21]) and optimization of operation [22].

Table 1
Seasonal heat storage Linz [14].

Parameter		Approx. value
Volume	[m^3]	2,000,000
Capacity	[GWh]	80
Diameter	[m]	200
Height	[m]	65
Maximum storage temperature (discharge - flow)	[°C]	97
Discharge - return	[°C]	60

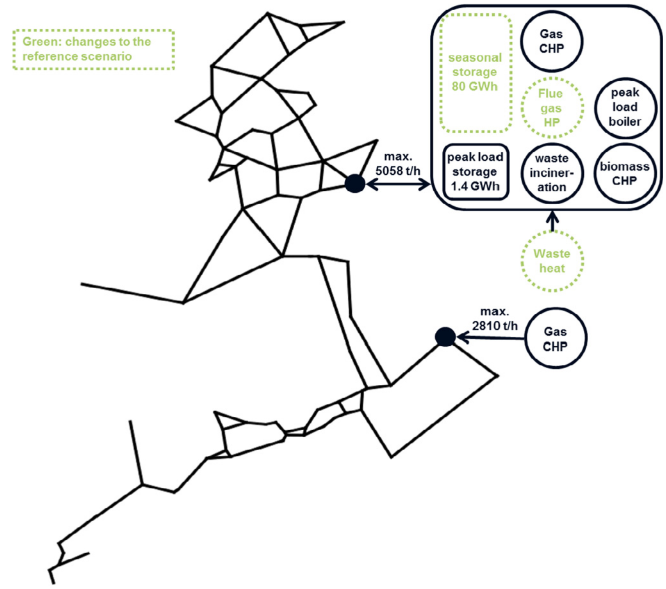

Fig. 2. Diagram of Linz district heating network, showing main pipes and generation facilities; reference system and scenario adoptions (in green) [4].

They show auspicious potential for future applications, but they are technologically, or at least economically [21], not mature enough to use them in praxis large-scale applications. In conclusion, as of today, sensible (i.e. hot water) heat storage systems for storing utilizable thermal energy at temperatures below 100 °C are a well-established and the economically mostly favorable solution [23].

3.1. SHS experiences

There are four stereotypical construction types of hot water storage systems: tank, pit, borehole and aquifer. For seasonal storage in combination with solar energy systems, the pit thermal energy storage system is the preferred option, since the investment costs are comparably low [24]. There have been several projects implemented in Denmark, with the biggest ones being in Vojens (200,000 m^3), Marstal (75,000 m^3) and Dronninglund (60,000 m^3) [16].

However, the space requirement of pit storages is considerable and the range of temperature is limited. Thus, pit storage systems can hardly be directly coupled to the district heating network. In district heating networks, primarily tank storages are used [25]. They can be adapted to meet the system's requirements with regard to temperature, and, if necessary, pressure. They can be used for pressure maintenance and as an expansion vessel in the district heating system and may be directly coupled to the district heating network. However, their investment costs are higher compared to the pit system and they are in need of regular maintenance (depending on operation temperature and pressure) [24]. Some of the largest tank storages in district heating systems known to the authors are in Gedersdorf (Austria, 50,000 m^3), Mannheim (Germany, 45,000 m^3), Potsdam (Germany 41,500 m^3) and Linz (Austria, 35,000 m^3).

The application of storages for bridging a seasonal mismatch between the (solar) thermal supply and demand has been extensively investigated. Basically, sources like solar [26] or waste heat [27] are identified as alternatives to CHP plants and are combined with (e.g. borehole) storages [28]. For the recovery of the heat from the storage system, heat pumps may be applied [29]. Several solar thermal based systems have been integrated in small networks or building clusters in Germany, Denmark and Sweden [30]. For example, the combined system of solar heat generation and a storage to cover 50% of building heating demand proved to be the most cost-effective solar system in Germany [31]. Due to its size (i.e. losses), storage efficiency is difficult to achieve in smaller (district) heating systems [32]. However, solar has more often been used in buildings than in district heating systems [33], but recent trends show cost-effectiveness and accelerated implementation in the latter [34]. Some cases for waste heat integration using seasonal storages have been investigated. Application of seasonal storages (e.g. borehole storages in Ref. [35]) is considered crucial [37] in order to use elsewise wasted energy (e.g. from incineration plants [36]. Only a few demonstration projects for seasonal storages based on waste heat can be found (e.g. Ref. [38]) and “anergy” or “ultra-low-temperature” district heating networks utilizing various heat sources, e.g. Ref. [39].

3.2. SHS application in linz

Muser et al. [14] carried out a feasibility study concerning a large-scale SHS for the Linz district heating network. According to Muser et al., there is an average heat supply of 40–50 MW, which could be fed into the district heating network in the temperature range between 90° and 100 °C. The required storage capacity and low-loss construction thereof, the required backflow-temperature and an average storage period of approx. six months were the main boundary conditions characterizing the requirements for a large-scale SHS in Linz. The study focused on the potential of groundwater heat pumps [c.f. 13] as the main source of heat and evaluated the various storage technologies described above with regard to construction conditions and costs. A concept for a combined pit and tank storage for the Linz site was developed: When considering the investment costs and comparable capacity of already constructed and operating systems, a pit storage would be the favorable SHS in Linz. However, the city-specific (technical) requirements do not allow for the construction of a pit storage, since the storage is to be implemented near the city center (visibility). Therefore, the project focused on a combination of pit and tank, implying that the tank will be partly underground, thus reducing the necessary construction height above ground and benefitting from the insulation effect of the surrounding ground. The construction costs amount to approx. 70–80 million euros.

4. Research methods

Due to the interdisciplinary analyses, discipline-specific approaches were chosen. Technical and economic simulation tools were accompanied by qualitative analyses.

4.1. Technical analysis

In order to analyze the basic functioning of the described scenario for the case study of Linz, a model was designed simulating the existing heat generation plants, the tank storage (1300 MWh) and a simplified district heating network as well as the additional heat pump, the waste heat integration and the SHS (80 GWh) [4]. The design parameters of the SHS elaborated in Muser et al. [14] were adapted based on minor new assumptions and then applied in the project team's analyses. In the simulation model, the SHS can also be used for a more efficient dispatch of the various heat sources, e.g. by intensifying the use of a less expensive cogeneration plant instead of peak load boilers.

4.2. Organizational analysis

There are many advantages and obstacles coming along with waste heat integration and the installation of a SHS, which are not directly associated with the techno-economic analyses. In order to identify these advantages and obstacles, expert workshops were conducted including discussions and joint SWOT analyses. Twenty experts from different affiliations participated in the workshop, aiming to identify the full scope advantages and obstacles: district heating operators, experts from the local and regional governments, researchers from the fields of heat network engineering, heat generation, economics, construction technology. SWOT analyses as a method describe the perspective of a certain actor. As the analysis was conducted from different point of views, e.g. industry, district heating operator, final customer, government, etc. and is very comprehensive. Thus, only the most common and relevant negative and positive aspects identified are listed.

4.3. Economic analysis

Moser et al. [3] investigated the heat network regulation necessary in order to enforce the integration of industrial waste into district heating systems. By analyzing the current and optimal market design, they proposed the usage of a “heat merit order” in order to compensate the non-transparent/non-existent “district heating wholesale market price”: As in other markets, current demand is covered by the units that produce at the lowest *variable* cost. The existing production units are analyzed individually. All variable costs of a unit are summed up. This results in a ranking of the usage of these units, starting with the cheapest one. The most expensive unit required to satisfy current demand determines the fictitious wholesale market price. If this essential price is now known, the value of one kWh of heat stored or withdrawn at a given time can be determined. Also, the asymmetric information (as it is only known to the district heating company) on the value of waste heat can be accurately estimated. This approach is also applicable to any alternative heat source like solar thermal energy, power-to-heat, etc. At the Energieinstitut an der Johannes Kepler University Linz, applicable data and equations were integrated into a “heat merit order tool” (Fig. 3).

4.4. Macroeconomic analysis

The time series-based macroeconomic simulation model *MOVE* and its successors *MOVE2* and *MOVE2social* were developed at the Energieinstitut an der Johannes Kepler Universität Linz. The models allow the estimation of various economic and structural changes within Austria and the analysis of economic, ecologic and energetic effects due to political or investment decisions. MOVE focuses on energy-related issues, which enables comprehensive and complex studies of all aspects of the (local) energy market. See Ref. [40] for further information.

5. Results and discussion

Based on the interdisciplinary analysis, the following results were elaborated from a socioeconomic, technical and business-economic point of view.

5.1. Socioeconomic challenges and benefits of implementing a SHS

Based on literature research [4,41] and workshops, the following challenges and benefits of implementing a SHS were identified. First, any industrial waste heat integration or SHS implementation faces technical constraints like temperature levels and pressure.

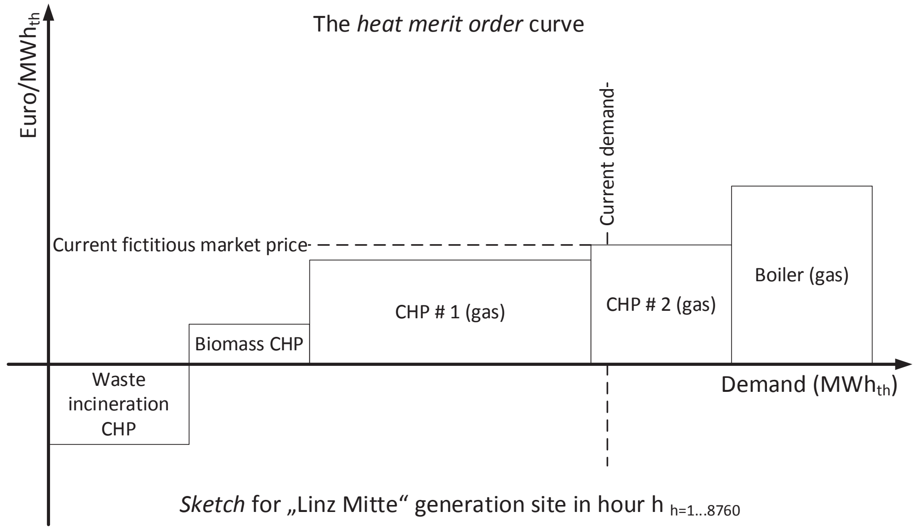

Fig. 3. The heat merit order using a sketch of the district heating production units at the "Linz Mitte" location as an example.

Implementing industrial waste heat integration or SHS means high upfront costs, e.g. for the erection of the storage (including the expensive urban property on which it was built) or the adoption of the industry process for feeding-out. Further, there is a lack of experience with storage systems of the proposed size, which could pose a risk. Finally, there is a need for adequate contracts and tariffs to be drafted in order to ensure a well-functioning and satisfying cooperation between all involved parties. Here, interactions of the tariffs with the technical qualities mentioned and potential risks like short-term reliance (short-term storages and back-up systems) and long-term reliance (guarantee of supply of waste heat to the network and/or the storage, discouragement of process modifications, threat of industry relocation and bankruptcy, energy price risks) are observed.

Socioeconomic benefits of industrial waste heat integration and SHS include an enhancement in primary energy efficiency and a reduction of energy imports. Due to economies of scale, larger units can operate waste heat integration more economically and also SHS are expected to achieve lower costs per cubic meter of storage; therefore, regional welfare is increased by lower district heating prices and increased company revenues. Besides, the heating energy supplied implies less carbon emissions; the generation capacities become diversified, making it less prone to outages and bottlenecks, implying an increase in security of supply.

Considering all above-mentioned issues, it can be concluded that the socioeconomic acceptance is coined by a variety of non-monetary costs (risks, size and location), expected monetary costs (investment), non-monetary benefit (e.g. "greening") and monetary benefit (increase in regional added value, reduction of imports).

5.2. Technical analysis

For the case of using the SHS as a "seasonal" heat storage only, i.e. without using it for optimizing power plant dispatch, the SHS accomplishes approx. 1.8 cycles per year (including charges and discharges in transitional periods), i.e. approx. 140 GWh are stored and reused. For the case of using the SHS as seasonal heat storage and for dispatch optimization, the SHS accomplishes approx. 4.4 cycles per year, i.e. approx. 350 GWh are stored and reused [4]. This supports the results described by Senoner [42], that the technical provisions for quick charges and discharges are essential in order to achieve a high number of cycles.

As indicated above, reheating the discharge flow is necessary when network flow temperature exceeds 97 °C. Although the SHS's discharge performance (in MW$_{th}$) is sufficient to provide enough thermal energy to the district heating network also at low temperature levels, its discharge flow temperature is not. For example, on winter days with temperatures around 0 °C the SHS cannot provide the required thermal energy by itself. This problem is solved due to the location close to the other generation facilities which allow for reheating.

One essential limitation is that our work focused on organizational, economic and network-specific technical feasibility only. Thus, constraints resulting from the construction technology are neglected but important to be indicated: Synthetic materials are necessary to coat the inner walls of the storage. However, today's material technology cannot yet guarantee the necessary lifespans of at least 30 years at temperatures of 97 °C. Expert interviews suggest that today marketable materials achieve these long lifespans up to 93 °C; materials technology is expected to be capable of this in less than five years. From a technical perspective, steel coating is a well-known and often-applied technology and may even offer advantages in operation (e.g. pressure). However, steel coating was neglected due to a significant increase in total costs. Apart from the coating, construction issues primarily concern the storage cap and the technical equipment necessary to maintain water stratification.

5.3. Economic analysis

5.3.1. Investment costs

The investment costs for the construction and the property situated in an urban industrial area are due in year 0. In year 1, the storage is filled with de-ionized water, which takes approx. nine months. De-ionized water is used in order to directly couple the storage with the district heating network and being able to directly use the 97 °C hot water. From year 2 on, the new system is in full operation according to the scenario. Investment costs of the SHS include the costs for the land, construction and associated equipment (pipes and pumps) as well as the costs for filling the tank with de-ionized water. These costs were derived from data of the preceding project by Muser et al. [14]. Based on updated assumptions, investment costs are approx. 106.5 million euros, of which approx. 17 million euros are property costs and approx. 75 million euros are construction costs.

5.3.2. Operating costs (excluding charging energy but including heat losses)

Maintenance is economically infeasible as maintenance works (e.g. replacement of plastic coating) would interfere with the operation of the SHS for approx. two years. The expenditures for pump electricity, heat losses, insurances, residual maintenance (e.g. appearance of the envelope or equipment) and legal assessments amount to 0.7 million euros per year. Due to the lack of experience with storages of this size and type, significant fluctuations in the calculated costs may occur.

Due to the size of the storage, and the resulting optimal ratio of storage surface to storage volume, heat losses are relatively low. However, constant losses of approx. 1 MW are to be expected. Due to the low costs of charging energy (which is assignable to the costs of heat losses), costs of heat losses are approx. 30,000–100,000 euros/a, depending on the method of cost allocation.

5.3.3. Operating strategy

Since the operator of the district heating system supplies the district heating customers, there is no competitive price for district heating. The district heating operator determines the purchase price. In the case of a predefined demand, however, the heat merit order can be used to calculate the current (e.g. hourly) marginal costs of district heating production. The classic storage operation exploits market fluctuations (pump electricity storages use the same mode of operation); the storage is filled when inexpensive thermal energy is available. The storage operator feeds this energy into the network when the most expensive generation is to be substituted. Both charging and discharging are strategical, i.e. the operator aims at low charging costs and high discharging revenues. However, energy can also be stored briefly with smaller margins.

The operator of the district heating system does not automatically have to be the owner or operator of the storage. Regardless of the owner, the use of the storage depends on the same parameters - the current energy prices and the current heat demand. In order to be able to determine the economic feasibility of the storage, the storage operation is allocated to the district heating network operator. Even if the district heating network operator is not the storage owner/operator, the same result can be expected due to the marginal cost orientation.

5.3.4. Revenues (considering charging energy)

Revenues are achieved through hourly, daily and monthly (= seasonal) shifts of the thermal energy. The cost-effectiveness is influenced essentially by the annual storage throughput, i.e. how often the storage is (partly) filled and emptied per year. Based on the calculations conducted [4], a number of 4.4 cycles is assumed. Using the economic “heat merit order” tool, annual revenues (i.e. attributable savings) of approx. 9.6 million euros are achieved. Note that the analysis attests enormous sensitivity to electricity wholesale market prices, gas wholesale market prices and CO_2 market prices (EU emission trading scheme).

5.3.5. Economic feasibility

Based on the above assumptions, the calculated amortization period of the SHS in Linz is 20 years of operation. A discount rate of 5% was assumed. The calculation does not include any (usually available) subsidies from the federal, regional or local government. However, as stated above, SHS revenues are subject to non-negligible energy and CO_2 market uncertainties. Rather small changes in electricity, gas or CO_2 prices lead to variation in the revenues, directly resulting in a variation of the calculated amortization period between 15 years and infinity. The availability of continuous inexpensive thermal energy for charging the storage is an essential characteristic of the regarded system. However, the long-term availability of inexpensive thermal energy (e.g. industrial waste heat) cannot be guaranteed (e.g. relocation or process modification), implying another risk for the net revenues.

5.3.6. Further results

The implementation of the heat pump, which is using the flue gases from the biomass and the waste incineration plants, was found to be economically efficient. The payback period is less than 10 years. Industrial waste heat integration was calculated to be economically efficient. However, the SHS does not contribute much to the economics of waste heat feed-in: Due to the low monetary value of industrial waste heat in summer (alternative thermal heat generation is inexpensively available in summer) only approx. 11% of annual industrial waste heat revenues can be earned in this half-year period by charging the storage.

5.4. Macroeconomic effects

The positive macroeconomic developments are based on (1) additional investment impulses during the first two years as a result of the construction; (2) positive effects on the net export balance as a result of the reduction of energy imports (gas); and (3) dynamic macroeconomic effects from both above-mentioned effects. Compared to a situation without the implementation of a SHS, the macroeconometric simulation analysis shows an increase of the gross regional product by approx. 44 million euros during the construction period (year 1 and 2).

The substitution of the energy carrier imports for thermal energy production by the waste heat stored in the SHS results in positive effects on the net export balance of approx. 15 million euros per year in years 3–12. As a result of the investments and the economic growth, additional employment is generated. Due to the erection of the SHS and its multiplying effects on the labor market, the most significant employment effects of additional 350 employees are recorded in year 2 as a result of the investment activities.

5.5. Restriction

In the analyzed scenario, the implementation of a SHS in combination with the integration of industrial waste heat and thermal energy provided by the flue gas heat pump was assumed. Moreover, the existing 1300 MWh steel tank was also assumed to be in service. Thus, it is not possible to discuss the feasibility of the SHS without taking into account the waste heat integration and the heat pump.

6. Conclusions

Due to the high technical risks and some material's technological immaturity, it is not possible to realize the SHS in the short term. The technical feasibility is essential for the actual implementation, and a complete view of the business management plan. The exact costs of the necessary materials (plastic coating) and the costs or extent of a renovation are unknown and can vary in terms of time (after a few years up to 50 years) and amount (expert interviews and advisory board meetings suggest between 10% and 70% of the investment costs). A realization is thus depending on the further development of the construction materials. However, costs are already estimable and included in the calculation.

The calculated amortization period of the SHS for Linz is 20 years of operation. In order to achieve an amortization period of 15 years, the total cost of investment of the SHS should not exceed 85 million euros, given the above-mentioned annual expenses and revenues as well as a 5% interest rate. Both calculations include neither positive subsidies nor negative risks and uncertainties, e.g. energy and CO_2 market prices developments.

From an operational point of view, the number of cycles is crucial for economic feasibility. In order to achieve the above-mentioned payback period of 20 or 15 years, 4.4 cycles per year were assumed, which were enabled by the dispatch optimization of CHP plants. It can be concluded, that an 80 GWh SHS that makes its revenues purely from the shift of summer heat to winter or during the transitional period, i.e. achieving a number of one or even two cycles is always economically inefficient. A SHS must contribute to CHP dispatch optimization in order to become economically feasible.

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