Energy Related Considerations of Ultra-efficient Urban Industrial Parks

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Abstract: The recent global trends of urbanisation and demographic growth are involuntarily building the pre-requisites for paradigm shifts towards the decoupling of growth rates from resource consumption rates, especially in the manufacturing sector. Therefore, an imperative for action regarding energy efficiency of companies must be followed. Against this background, Fraunhofer developed the holistic visionary approach of the Ultra-efficient Urban Industrial Park. Following this holistic approach, one of the five fields of action defined is energy, aiming to pursue holistic energy efficiency in an industrial park as the target function of improvement. Therefore, a holistic concept for a local energy system was prepared in a manner that it adheres to several conditions with the result of overriding enhanced energy efficiency in the sense of sustainability of industrial parks. Thus, this paper presents the procedure to identify suitable urban manufacturing sites for ultra-efficiency, the methodology used, as well as the results achieved by investigating industrial symbiotic effects in an urban industrial park.

Keywords: Energy Efficiency, Ultra-efficient Factory, Industrial Parks

1 Introduction

The finiteness of resources on earth, the rapid growth in world population, and increasing urbanisation are forcing us to question our current actions and economic activities. These trends are involuntarily building the prerequisites for a paradigm shift towards the decoupling of growth rates from resource consumption rates, especially in the manufacturing sector. Following this most probable arising scenario, a sustainable proportionality between production volume and resource input should be a key goal [1]. Moreover, assuming different policy scenarios defined by the International Energy Agency, their “World Energy Outlook” statistic 2018 shows an ongoing trend in energy demand until 2040 [2]. Besides, 75 % of the global resource consumption are used in urban environments [3]. Therefore, in addition to the intrinsic motivation of manufacturing companies to gain access to markets and resources, it is important to develop new standards of effectiveness and efficiency, including energy efficiency, coupled with a fundamental shift towards enabling the setup of sustainable production sites in urban environments worth living in. This again is understood as the best possible use of resources with minimal environmental impact. Thus, holistic approaches are required, which ensure an environmentally compatible and at the same time financially viable production. Such an approach is represented by industrial symbioses between companies and their environment.

One solution approach for dealing with the initial situation described above is the “Urban Production”. It implies a symbiosis between production and the urban surroundings, in the sense of optimising the positive contribution of production to the environment, more than just minimizing the negative effects [4]. Urban production sites and so-called “eco-industrial parks”, a further development in terms of sustainability, have so far developed towards the approach of industrial symbiosis into over 160 sites, in which economic and ecological advantages emerge [5]. Thereby, industrial and commercial areas are a key factor for a growing economy.

Against this background, Fraunhofer developed the holistic visionary concept of the Ultra-efficient Factory. It defines a loss-free production site, which has a symbiotic-positive contribution, operating in perfect symbiosis to its environment [6]. Ultra-efficiency is thereby defined as the multiplication result of efficiency and effectivity. Aiming a holistic view on production sites, the concept of the Ultra-efficient Factory follows five fields of action, namely material, energy, emission, human/staff and organisation. This fact builds the singularity of the concept and represents an extended sustainability framework. Regarding the holistic perspective, which the concept is following, it includes the levels process, production, facility, as well as the urban environment [6]. While investigations and development of the concept on the first levels have been done during previous research, the view on cross-company interactions, as well as on the interface to the urban environment was extended during recent research activities.

Following this procedure on the field of action of energy, the total energy efficiency of an industrial park and its urban environment was pursued as target function of improvement. Accordingly, the present paper describes the energy related investigated considerations, following the goal mentioned hereinafter.

2 Objectives

The extension of the perspectives of the Ultra-efficient Factory concept towards the urban environment pursed the overriding goal of establishing a holistic concept for the realisation of ultra-efficient urban industrial sites. The subordinate goals included the investigation and assessment of industrial symbiotic effects within industrial parks, as well as between manufacturing sites and their urban surroundings, on all five fields of action considered by the concept. By identifying existing and potential symbiotic effects, e.g. regarding cross-company material cycles or energy sharing concepts including waste heat usage, another subordinate objective was the adaptation of the named developed holistic concept on a suitable pilot location in Baden-Württemberg, Germany. Therefore, the project aimed a purposeful identification and designation of existing or planned urban industrial sites in terms of a sustainable urban community development.

In line with the relevant sustainable development goals of the UN, Affordable and Clean Energy, Industry, Innovation and Infrastructure and Sustainable Cities and Communities (Figure 1) [7], as well as the goals of the ultra-efficiency concept, the following objectives for an ultra-efficient urban industrial park regarding energy aspects were set:

- Energy supply mainly by renewable energy sources;
- Energy storages out of ecologically harmless materials respectively using resources just in a sustainable manner;

- Increased energy efficiency with regards to the self-generated energy and transferred energy respectively taking advantages of local energy sharing concepts.

Figure 1 relevant sustainable development goals of the United Nations [7]

In summary, the objective regarding the field of action energy is added value in the framework of energy sustainability and efficiency in industrial parks at the interface to urban environments.

3 Methodology

In order to achieve the project related objectives mentioned above, suitable industrial areas as well as municipalities in Baden-Württemberg were analysed using a structured procedure, in order to find a suitable pilot location for an ideal adaptation of the holistic concept for the realisation of an ultra-efficient urban industrial site. Subsequently, following the extended solution approach of the Ultra-efficient Factory concept towards urban surroundings, during recent research activities a method to define, identify and assess both existing and potential symbiotic effects within urban industrial parks, as well as with their surrounding urban environment was developed and applied at the pilot location.

3.1 Procedure to identify suitable urban manufacturing sites for ultra-efficiency

Aiming an ideal commitment of project partners from industry as well as municipalities, the structured procedure of the selection of industrial areas was designed in the form of a competition in Baden-Württemberg. Based on a press release from the Fraunhofer Institutes, municipalities and companies were able to apply for the competition using a questionnaire. The basis for this lean questionnaire was a criteria catalogue for “ultra-efficient urban industrial areas” developed during previous project phases. The most important criterion regarding the field of action energy was the question about the existence of cross-company energy networks on site. After the deadline, the Fraunhofer experts systematically evaluated the eleven applications received, using the aforementioned criteria catalogue. Based on the information provided by the respective site representatives as well as the target values and weights of the individual criteria and sub-criteria of the Ultra-efficiency Factory, three existing and one planned industrial area location in Baden-Württemberg could be selected for further investigations. After the deliberately very lean application phase, the shortlisted locations received a more detailed information request. The aim was to record the state of the respective industrial areas with regard to their efficiency as precisely as possible so that the most suitable location in Baden-Württemberg for the realisation of a pilot ultra-efficient industrial area could be identified for the further planned investigations. This was defined as follows: an industrial area that already shows a very high and uniform efficiency across all five fields of action of the Ultra-efficiency Factory, but still has great potential for further measures to increase its overall efficiency as well as the efficiency at the interface to the urban environment. Subsequently, three round table workshops were held at the shortlisted locations. To support the assessment of the overall efficiency, there were also targeted lectures by the site representatives and discussions with all workshop participants – business promoters, city planners, architects, factory planners, energy service providers, representatives of local companies, associations, energy suppliers and other relevant stakeholders. In addition, within the scope of the round tables, municipalities' requirements for ultra-efficient location planning to increase the acceptance of the urban environment were also included. This was done as a formulation of target requirements that were set for all five fields of action of the Ultra-efficient Factory at each of the locations examined. At two of the selected locations, the Fraunhofer experts were also able to visit the industrial areas and thus the possible future research objects and take a closer look at the condition. The results of the respective round-table workshops with the three selected existing industrial areas were prepared in the form of location profiles. These were used as a basis for decision-making in the final selection of one single location. In addition to a graphical overview of the locations, these documents contain general information regarding the urbanity of the areas, as well as precise information on measures that have been implemented as well as on measures that are currently being planned in all five fields of action.

The final selection of an industrial area location to carry out the further investigations finally took place based on the site profiles drawn up as well as by means of a structured assessment scheme. The scheme provides for an evaluation of each sub-criterion of the Ultra-efficiency Factory a percentage, in 25 % steps. A difference in the assessment of the individual fields of action at a location of more than 75 % results in a deduction of 10 % in the overall assessment of the efficiency of the respective location. Thus, for the further definition, description and evaluation of industrial symbiotic effects at the location as well as for the creation of an individual, holistic concept for establishing an industrial urban location in the sense of ultra-efficiency, the industrial areas Rheinfelden and Herten West could be selected as joint, neighbouring objects of investigation.

3.2 Procedure for the design of sustainable energy systems

First, a procedure based on an "if-then" statement for the design of sustainable energy systems was developed and is depicted in Figure 2. Facing an open but firmly determined system with regard to its physical boundaries, a neutral to negative resulting balance of all energy exchange relations on location, in addition to the terms concerning the energy generation, conversion, transportation, utilisation and storage, aims to declare the whole system sustainable. If the system becomes declared as sustainable, there might appear advantages in two different fields: ecological and economic. If the advantages shall appear, several requisites have to come true. The size of the system influences ecological benefits, while other prerequisites are influencing the economic benefits. The hypothesis bases on the following argumentation structure: If the system is determined regarding its boundaries, it has a neutral to negative energy balance and the energy sources are exclusively regenerative, then the energy system is determined as sustainable. Further, if subjects of the system take initiative and keep the system approach transparent with regards on access to all energy flows in a qualitative manner occurring in the system on cross-company and urban level, then soft economic factors occur after a short term period. With this in mind and if the amortisation time of entered investments elapses with regards on innovative energy measures and technologies, then the benefits of hard economic factors occur after a long term period. Eventually, if the system can be determined as sustainable also on a small scale, it has a positive ecological impact on its surrounding environment. If the system is determined as sustainable, there is the fact that system constituent subjects are also sustainable. This is on the one hand a limitation in degrees of freedom but it is a conscious limitation, as the existence of sustainable systems is considered more important than individual interests.

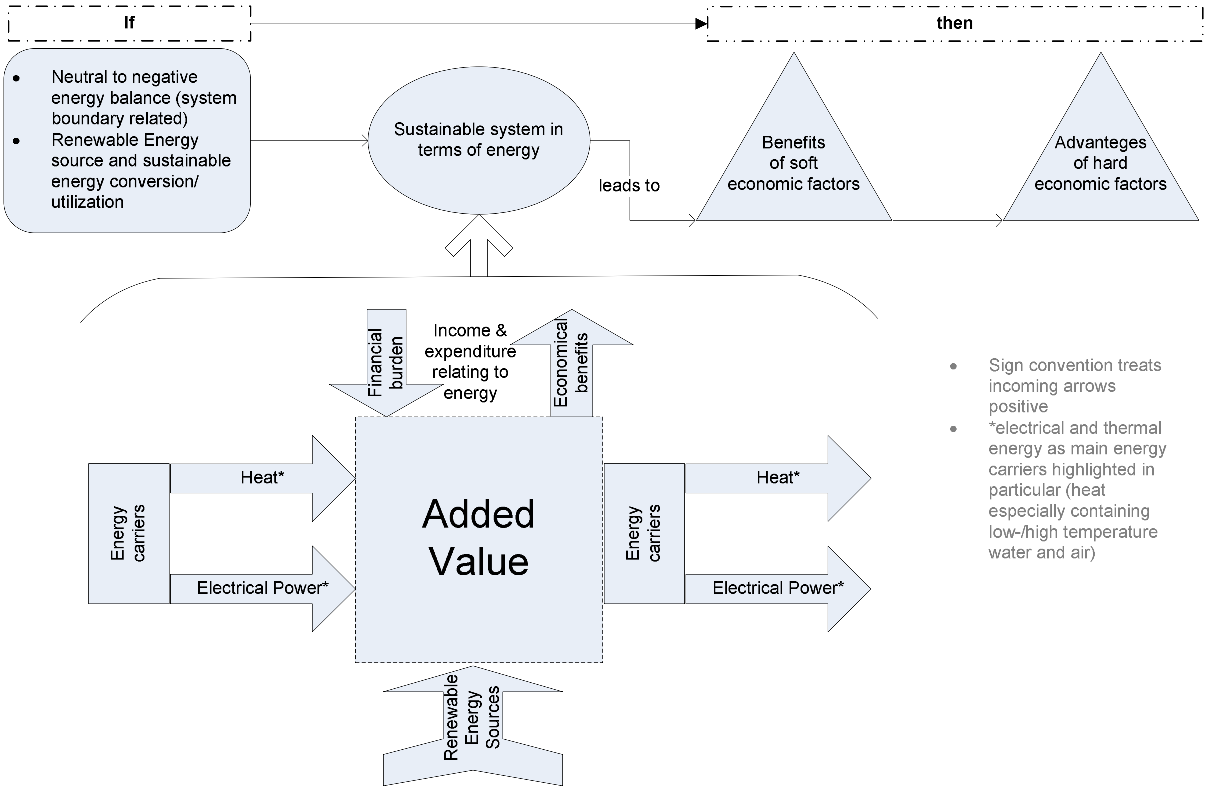

Figure 2 The “if-then” statement as core part of the developed method for a sustainable energy system

The following hypothesis statement shall be emphasized: The smaller and more fragmented a system is and can be determined as sustainable, the more ecological valuable it is. The economic benefits might suffer due to dismembering system sizes. Therefore, an ideal system size has to be found by optimisation, where a size of the system can still “be tolerated” from an ecological point of view and economic benefits are still “sufficiently high”.

In summary, the design of sustainable energy systems envisages three balances, which need to be kept:

- Energy carriers need to be negative to neutral;
- Energy generation needs to be renewable and exploited within sustainable limits;
- Economic benefits need to be higher than economic burdens.

3.3 Investigations on industrial symbiotic effects at the identified pilot location

During following research activities, at the pilot location selected as described, both existing and potential industrial symbiotic effects within the urban industrial parks, as well as with their surrounding urban environment were defined and identified. Therefore, a methodical approach to model the overall system enterprises - industrial area was selected analogous to previous investigations [8]. The procedure recommended for achieving these goals provides for an approach that should categorise companies according to their potential ability to act as synergetic partners. The corresponding model is therefore based on a data-based input-output method for examining not only the energy, but also the material and the emission flows, as well as the personnel and organizational structures at the pilot location. The focus was on determining the fundamental interactions between the local manufacturing companies or between factories and their urban environment. The resolution chosen for this investigation included as smallest, self-contained research objects, the individual companies or the urban surroundings as a directly adjacent environment (Figure 3). The system boundaries chosen for this included therefore the industrial area and the surrounding city.

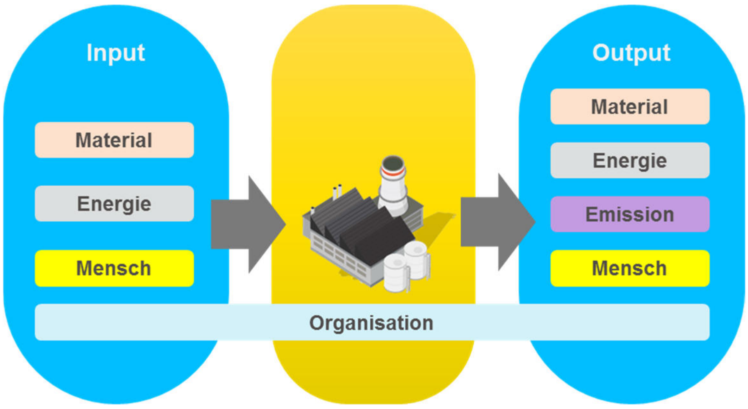

Figure 3 Method and research objects for the definition and description of industrial symbiotic effects (based on [8])

For the application of the data-driven input-output method, an extensive data collection was carried out at the site. All companies based at the pilot location were asked to fill out a data collection form developed by Fraunhofer experts and deliver it to the project team. In addition to statistical company data, qualitative and quantitative information on energy sources, consumptions, flows (sources and sinks) as well as waste energy, emissions and other relevant information e.g. jointly operated generating plants were queried. With the necessary confidentiality, eight participating companies and the city administration provided the data required for the detailed investigation. The data sets thus obtained were evaluated based on the input-output method by means of a graphical visualisation of the systematic linking of all identified energy flows. Both existing interactions between the companies and with their urban environment, as well as potential interdependencies that emerged were identified or defined.

4 Results

The most important interim results of the investigations on the three existing and one planned industrial area pre-selected, in form of measures that have already been carried out or are currently being planned to increase the overall efficiency of the respective locations, can be summarized as follows for the field of action energy:

- Industrial waste heat use for heating residential buildings, schools and swimming pools in the neighbouring town;
- Waste heat use from the waste disposal facility located in the industrial area into the local district heating network;

- Use of biomass from the wider area for the biogas plant at the site; the biogas thus delivers locally generated energy (CHP) for approx. 6,000 households;
- Electricity consumption from jointly operated PV systems: large open space and rooftop systems.

In the further course of research investigations at the finally selected pilot location, using the data-driven graphical method, a diagram was built showing both the existing and potential energy exchange flows between the companies on site, but also with their urban environment, for different useful energy forms (Figure 4). However, the general heterogeneity of the data basis with regard to granularity, depth of detail and quantification did not allow a quantitative analysis and led solely to a qualitative description and evaluation of the identified existing symbiosis effects at the location. The names of all participating companies and the other stakeholders at the location were anonymised when presenting the results due to the sensitivity of the company data recorded.

Specifically, energy sources or media such as electricity, heat, compressed air, steam, nitrogen, boiler feed water and condensate are already being exchanged between individual companies or with the city at the selected pilot location. The following interactions are currently taking place in detail: Company A purchases the electricity from company C and supplies waste heat from in-house production to company H by means of combined heat and power plants (CHP). Company B also obtains the electricity from company C and supplies steam from internal heat recovery to company F. Furthermore, company B receives compressed air, boiler feed water, nitrogen and steam from company D. At the same time, company B supplies condensate to company D. Unused waste heat from company B is currently not being used. Company C generates electricity using the run-of-river power plant adjacent to the site and its own photovoltaic systems (PV systems) and supplies company H with electricity. Company C uses wood pellets to heat its own logistics centre. Company D acts as a supplier of steam, compressed air, nitrogen and electricity through in-house generation using hydropower, gas and steam turbines for company F. Furthermore, waste heat is supplied to the municipality from company D's own processes in different temperature ranges for heating public buildings and facilities. An expansion of this waste heat extraction is already planned. Company F directly introduces waste heat bound in thermal wastewater into the adjacent flowing water. Eventually, company G not only covers most of its own electricity needs with its own PV systems, but also feeds-in electricity into the local network.

After the existing interactions at the location had been identified, potential industrial symbiotic effects between the individual companies and the urban environment were also derived using the same graphic input-output method based on the data collection and evaluation. Also in this case, only a qualitative investigation could be carried out due to the heterogeneous data basis.

The selected pilot industrial area reveals a potential primarily with regard to the compressed air supply and the use of waste heat between the companies or between factories and the city. Specifically, company A has the potential to connect to the compressed air network of the industrial area and to obtain this medium from company D, as well as to enable feed-in in order to optimise the energy consumption for the compressed air generation. In addition, there is the potential of supplying waste heat from in-house generation plants not only to neighbouring companies, but also to the surrounding urban environment.

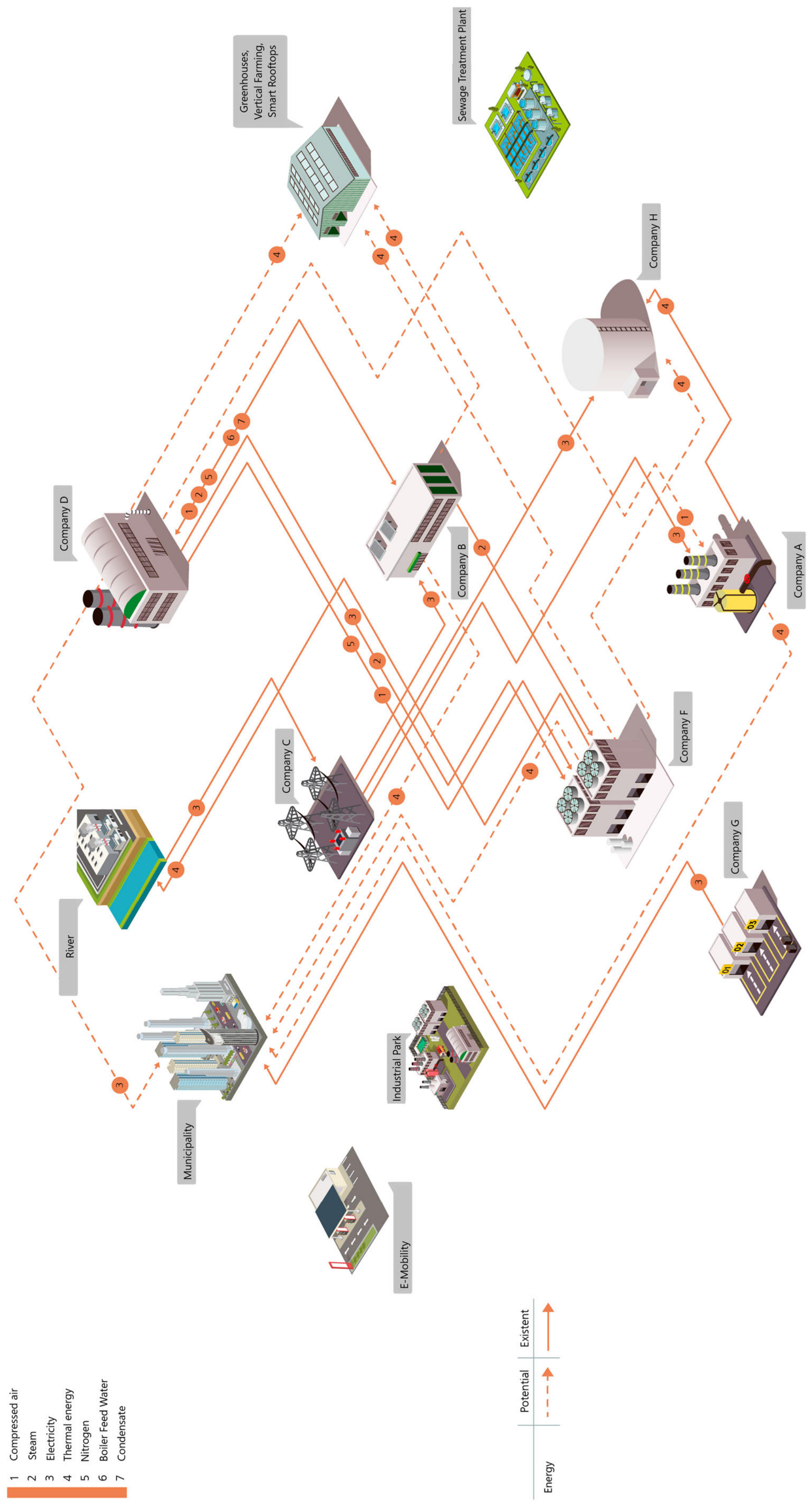

Figure 4 Existing and potential symbiotic effects within the selected industrial park in Baden-Württemberg, Germany

Companies B, D and H also have – by means of an incineration plant – unused waste heat in different temperature ranges, which can be delivered to the city on the one hand, but on the other hand can support e.g. innovative approaches like sustainable plant cultivation in factory roof greenhouses - Smart Rooftop Greenhouses [9]. Company F also has similar potential with regard to waste heat, among others from thermal waste water, which can be exploited by supplying waste heat to company H. Company E also has the potential to obtain renewable electricity locally from a neighbouring company using PV systems.

In addition, during two expert's workshops at Fraunhofer, new technologies and specific research results were assessed, which could contribute to the achievement of an ultra-efficient urban industrial park. This way, seven energy efficiency-increasing measures were derived using the example of the selected industrial park, including topics on energy generation, sharing, storage and recovery, which however can be applied at other locations. Specifically, the expansion of the waste heat usage between more companies and the city was identified. Waste heat recovery from wastewater, thermal energy storage technologies, but also the expansion of the renewable heat generation at the site are important topics to be addressed. Biogas and generally biomass plants can be established on site in order not only to close material loops, but also to increase the overall energy efficiency and to reduce emissions from energy generation. Another renewable technology, which can be implemented on site in order to increase the efficiency is the Ground Source Heat Pump (GSHP). This technology is applicable in both the industrial and the building sector on site. Moreover, the use of solar thermal energy on site has a great potential given the geographical situation of the pilot site. In addition, the electricity surplus can be used in order to extend the electricity linkage on site. Also jointly operated renewable power generation units or larger electricity storage units, e.g. Redox-Flow batteries based on lignin, a by-product from the wood processing industry [10] can lead to a higher energy efficiency, but also to closed material loops in the industrial area. Further, a local »Smart-DC-Grid« [11] can improve not only the integration of renewable energy sources and storage systems, but also can support a more efficient operation of e-mobility and an increased robustness of industrial networks in relation to fluctuating network quality. Additionally, the hydrogen already used on site both as a raw material and as an energy source has a potential to support a flexible, non-polluting electricity generation and usage by being stored or used in local, emission-free mobility concepts. Eventually, a smart network of decentralised compressed air systems of the neighbouring companies can also increase the overall energy efficiency on site. In addition, the digitization of the compressed air system can open up further great energy efficiency potential in the industrial area investigated. In order to first uncover this potential and then to significantly increase the security of supply for this important energy form, the concept »Intelligent Compressed Air Systems« [12] can be implemented.

The accuracy and hence the quality of designing a concept of a sustainable energy system is conditional on the comprehensiveness of data which is provided. The required data include the potential of exploiting renewable energy sources on site and time-dependent values of energy carriers entering and exceeding the institutions and the adjacent urban environment. All these findings were finally bundled as an individual, holistic concept for a sustainable, ultra-efficient energy system for the selected and analysed urban industrial park.

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