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How can urban manufacturing contribute to a more sustainable energy system in cities?

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ABSTRACT

The paper explores future opportunities as well as challenges arising from urban manufacturing (UM) regarding the design of sustainable energy systems for cities. Global trends affect the type of production (e.g. Industry 4.0) as well as the industrial structure (e.g. convergence of services and production) of UM in cities. This causes new requirements but also new options for the urban energy system. The study presented in this paper examines this area of tension and explores not only the potentials of waste heat use, but also additional electricity demand through steadily advancing digitalisation.

The study illustrates, that over the next few years it will be key to improve the interfaces between actors and sectors: between companies ("energy communities"), between industry and grid/ energy supply company/neighbouring settlement areas and between the sectors heat-electricity-gas-mobility through e.g. power-to-x and possible uses of hydrogen. The paper concludes with a concept for integrating urban manufacturing optimally in the urban energy system for a sustainable energy transition in the future.

Keywords:

Urban Manufacturing;
Waste heat;
Austrian cities;
Digitalisation;
Sustainable energy systems

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1. Introduction

In the last decade, the trend towards re-industrialisation has become noticeable in developed cities, including many Austrian cities such as Vienna, Linz and Steyr. It has been increasingly recognized that the industrial sector is one of the key drivers for economic growth and jobs [1] which is also relevant for cities [2]. However, urban manufacturing has to deal with specific framework conditions in cities due to high density resulting in little space and high rental prices, close neighbourhood to residential areas and difficult traffic conditions. Thus, integrating urban manufacturing (UM) into the urban fabric as smoothly as possible, is a must for keeping UM in cities. This also addresses the energy system where an optimisation of demand and supply with high energy efficiency and renewable energy sources (RES) integration must be strived for.

This paper presents the results of a study on “Energetic effects of urban manufacturing in the city - ENUMIS” [3] conducted for the Austrian Ministry for Transport, Innovation and Technology (BMVIT) funded within the research programme “Cities of Tomorrow”. The ENUMIS study focuses on two key questions: 1) How can framework conditions be created to keep manufacturing companies in cities or to promote the establishment of new industry? 2) Which waste heat utilisation potentials from industrial and commercial enterprises are available in selected Austrian municipalities and which changes on the energy supply side can be expected from UM? Based on the study results, the paper explores future opportunities as well as challenges arising from

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Cities of tomorrow need to become sustainable, liveable and prospective. One of the key topics is “urban production”. From an ecological, economic and social point of view, it is more sustainable to produce within the city. The program "City of Tomorrow" is researching and developing new technologies and solutions for future cities and urban developments. Its focus lies on the reduction of energy consumption and the use of renewable energies in buildings and city quarters as well as increasing the quality of living within cities.
The study provides orientation in the context of urban manufacturing and makes a first contribution to the technical involvement of relevant actors in the manufacturing sector. The results will help us to develop political measures for the development of new sustainable energy systems and will share first recommendations how to better connect research institutions with companies and energy suppliers.

Theodor Zillner, Austrian Ministry for Transport, Innovation and Technology. Energy and Environmental Technologies

UM regarding the design of sustainable energy systems for cities.

UM is understood as producing industry that is city-compatible, mixable, embedded in a digital environment, research-intensive and which generates high added value in the city [2]. The benefits of UM are seen in avoiding increasing delivery routes, high land consumption and a better integration and usage of renewable energies [4]. However, cities in transition and global trends are changing the type of production (Industry 4.0, digitalisation, electrification) as well as the industry structure (tertiarisation, convergence of services and production). For keeping UM in the city or even attracting new companies, the provision of a sustainable and secure energy supply is essential. The big challenge is to anticipate changes in the energy demand (and production) of UM and to optimally integrate UM into the urban energy system. Our study addresses exactly this open issue for selected Austrian cities. It is based on two previous studies on UM, which had been carried out by Fraunhofer Austria (FhA) [5] and superwien urbanism ZT OG [6] who were both partners in our project. In the course of these studies a structural analysis of the urban industry had been conducted and the future of UM in cities had been analysed. Our ENUMIS study brings this knowledge into an energy context and explores the effects for the urban energy system. Considering the structural changes, the study researches potentials for waste heat use as well as additional electricity demand expected trough steadily advancing digitalisation. This delivers a comprehensive overview of the effects of these new requirements on the energy system but also of new options for energy supply.

The paper is organized along 4 sections. After this introduction the results of quantitative and qualitative analysis conducted in the study will be presented in section 2. On the one hand, expert interviews and stakeholder workshops with representatives from industry, companies, research and city administration had been conducted for identifying the key issues and discussing opportunities and potentials in a future sustainable energy supply through UM from a practical point of view. On the other hand, the energetic impacts of UM were examined more closely and waste heat potentials from industry and commerce in selected Austrian cities were estimated. These results feed into defining the role of digitalisation in UM for the future energy transition which will be presented in section 3. Special focus is laid on the potentials and challenges for UM trough digitalisation and industry 4.0 and its implications on the urban energy system. Finally, in section 4, the paper concludes with a concept for integrating UM optimally in the urban energy system for a sustainable energy transition in the future.

2. Potentials of UM for the energy system

The City of Vienna commits itself to the provision of attractive and affordable locations for urban production and innovation and aims for an adequate land development strategy with the development of the thematic concept „Productive city“ [2]. However, challenges that UM brings are to be found in the field of transport, economy and environment (emissions): UM causes traffic in the entire city which can lead to considerable traffic obstructions and congestion in mixed residential areas where UM is per definition mainly located. Considering the economic pressure on the cities, land is mostly dedicated to residential use rather than industrial use, as higher profits are to be expected. This leads to the fact that it is becoming more and more difficult for companies to settle in urban areas and find affordable land. However, interviews and workshops with representatives from industry, urban planning, neighbourhood management, energy suppliers and manufacturing companies made clear that UM not only holds challenges, but also promises opportunities and potentials. A location in the city offers direct proximity to customers and highly qualified expert staff which promotes productivity. In the context of energy, the mixed land use is an opportunity for using renewable energies in a local heat network. In new urban areas, the use of locally available renewable energy sources can be promoted by an obligatory energy concept. Furthermore, the definition of the energy supply in the zoning plan or urban planning concepts could ensure the use of locally available energy sources. In general, using energy-political regulatory mechanisms supports the beneficiary use of the synergies from UM. However, it is crucial that the political will on the part of the city is given and a "caretaker" in the company or neighbourhood/town district shoulders the responsibility to engage the stakeholders and to facilitate the process.

In parallel to the qualitative analysis of the potentials, the energetic impacts of UM were examined more closely and waste heat potentials from industry and commerce in selected Austrian cities were estimated using a bottom-up approach. The already available studies are usually based on four basic methods: using publicly available carbon dioxide emission data from the European Pollutant Release and Transfer Register (E-PRTR) [7], estimating the efficiency of the plants, machines and processes [8], sending out questionnaires [9] or doing measurements. Since most companies' data on energy consumption are not publicly available, the methodological approach, that had been developed in the previous project HEAT_re_USE.Vienna [10], was applied. It is based on open data from the Austrian statistical office (number of employees) to calculate industry-specific energy consumption (detailed description in [11] [12]). From this, the amount of waste heat was estimated proportionately, differentiated by sectors as well as by low, medium and high temperature classes. The approach follows these steps:

1. Choosing relevant business sectors based on the NACE classification (European classification of economic activities)
2. Assessment of the energy consumption based on employee-specific energy parameters (kWh/employee)
3. Assessment of the waste heat potentials assuming a sector-specific shares of the energy consumption to be available as waste heat

Due to the use of characteristic sector-specific average values, the waste heat potentials can only be estimated at a rough level. Thus, a detailed examination (measurement, real consumption figures etc.) is necessary in the next step. However, the rough analysis gives a good overview of possible existing potentials and hotspots in the city, which should be considered in detail.

Figure 1 presents the results of selected sectors of the waste heat potential estimation in 8 Austrian cities investigated. The waste heat potentials were evaluated according to their future usability and are therefore divided into the following temperature level classes (1) Low temperature (30-100°C), which is directly in low temperature systems (e.g. underfloor heating) or can be raised to higher temperature levels by heat pumps (2) Medium temperature (100-500°C), lower ranges can be directly fed into a district heating system, higher ranges can be used for converting into electrical energy (3) High temperature (> 500°C), can be directly used for conversion into electrical energy or must be cooled for feeding into a district heating network.

Generally, some sectors such as bakeries and laundries are well suited for a location in the city, while companies in the chemical, rubber and plastics, paper or iron and steel sectors are more likely to settle on the outskirts or in the countryside due to high emissions or space requirements. Nevertheless, the analysis shows that some companies from these sectors can still be found within the city borders. In most cases they have traditionally been at this location for many years or even decades and waste heat could be used to heat neighbouring residential or industrial areas. To discuss the results of the analyses and to receive input from a practical point of view, opportunities and potentials in the area of a future sustainable energy supply through UM were discussed in a stakeholder workshop. The participants gave valuable input to round off the picture derived from desk research and quantitative analysis.

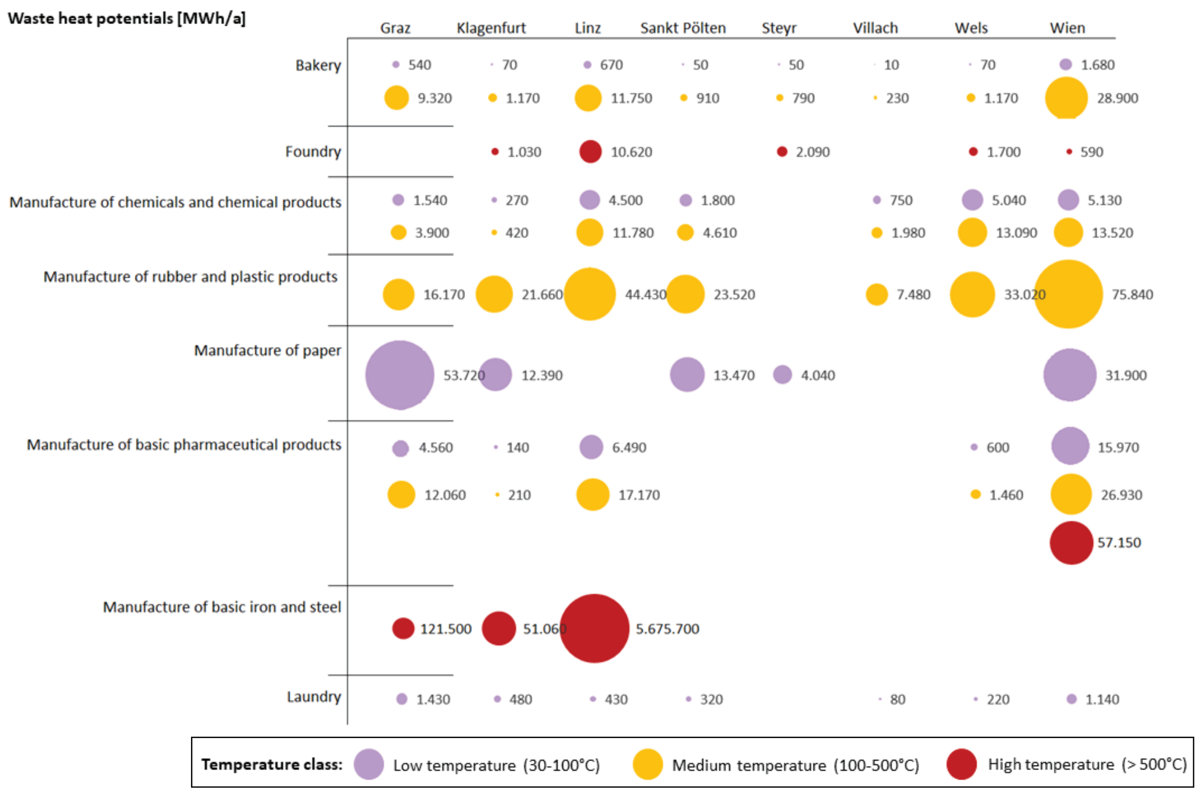

Figure 1: Waste heat potentials of 8 selected Austrian cities differentiated by three temperature classes in MWh/a, own illustration

3. The role of digitization in UM for the future energy transition

According to the Austrian Climate and Energy Strategy [13], the objective is to cover 100% of total electricity consumption (national balance) from national renewable energy sources by 2030. With currently 72% share (status 2017) [14] of renewables for electricity generation, Austria is well ahead in the ranking of EU [13]. However, the Austrian industry sector has a high proportion of energy-intensive basic industry and is still highly dependent on fossil fuels. In 2017, the energy and industry sector accounts for about 45% of the total greenhouse gas emissions in Austria [15]. Energy saving, energy efficiency, integration of renewables and electrification will be key elements for an industrial energy transition [15] and go hand in hand with digitalisation.

The global trend of digital transformation affects UM which will transform to service-oriented production [16, 17]. This change must also be accompanied by a change in the energy supply system. The share of electricity in the energy mix of households and services has risen significantly since 1970. In the future, electricity consumption will increase both in absolute terms and as a proportion of total final energy consumption meaning that the importance of electricity as an energy source will increase [18].

Due to the wave of digitization, which is often described as “Industry 4.0” in the manufacturing environment, the manufacturing sector is undergoing a significant change. It enables the expansion of renewable energies via controlling and regulation of the system to meet the challenges of decentralisation and flexibilization [13]. New technologies and developments such as cyber-physical systems, higher automation, human-robot collaboration, cloud solutions and increased computing power also present opportunities for UM. Digitization is often referred to as the enabler of the energy revolution and offers opportunities to transform the energy sector into the digital age [19, 20]. This leads to the rollout of intelligent measurement systems (smart meters) and the use of smart grids, which enable load management within the distribution network.

Although potentials are high, actual future development and true effects of digitalisation on the energy demand are associated with a high level of uncertainty. Experts are not yet sure how digitization will affect the overall energy consumption. In the study "Digital Transformation to the Energy World" [21] carried out by the Austrian Energy Agency in 2017, around 40 experts were asked about how digitization will affect the energy demand. 35% believe in an increase, 47% think the energy demand will not change and 15% believe in a decrease. The International Energy Agency [20] estimates that energy saving potentials of about 10% can be reached through smart technologies in the buildings sector. In industry further efficiency potentials are particularly seen by improved process controls, 3D-printing, machine learning and enhanced connectivity. However, although the potential savings can be leveraged through digitization, they are overshadowed by rebound effects and the additional demand generated. Research already focusses on how to manage the growing energy by information and communication infrastructures [22]. Experts agree, however, that only digitization will enable the broad expansion of decentralised renewable energy sources and the necessary flexibilization of energy demand [20, 21] and can initiate a backshoring of manufacturing activities back to the European market [23].

In this context data centre play an essential role – they are the backbone for digitalisation and closely interwoven with Industry 4.0. As such they are becoming relevant components in the energy system of UM. The world-wide energy demand of data centres is assumed to be about 1.5% of the world´s electric power consumption and is increasing significantly in the future [24]. As all this energy is ultimately transformed into thermal energy, waste heat recovery is a considerable mean to reduce their environmental footprint. Stockholm provides a good practice example where a data centre operator (DigiPlex) and heating and cooling supplier (Stockholm Exergi) signed a heat reuse agreement for heating up to 10,000 modern residential apartments with recovered data centre waste heat [25].

4. Concept for integrating UM optimally in the urban energy system & Conclusions

The previous research fed into the development of a concept for integrating UM optimally in the urban energy system illustrated in Figure 2. It illustrates that new requirements occur through changes in type of production and in the industrial structure which lead to new demands on energy supply (both electricity and heat). Changing energy demand from UM can be related to e.g. digitalisation in traditional UM sectors or to new sectors like 3D printing, vertical farming or data centres which become an essential precondition for UM. New options for the urban energy system arise through changing roles of UM to a prosumer and producer of waste heat and RES. The trend is clearly in the direction of blurring the boundaries between consumers and producers, between heat, electricity, gas and mobility sectors (sector coupling) and between commercial/industrial and residential sectors. As also Heinisch et al. [26] state in their work, the electricity, heating, and transport sectors in urban areas all must contribute to meet the

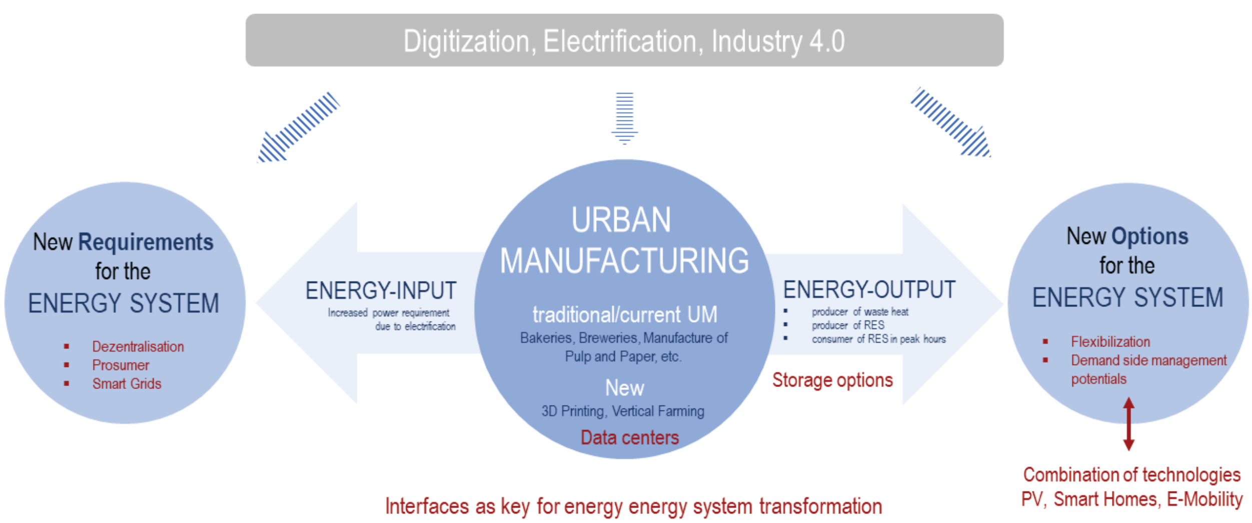

Figure 2: Concept for integrating UM optimally in the urban energy system, own illustration

climate targets. In this context, storage options are becoming increasingly important. This makes it possible to bridge energy generation and demand over time, make better use of fluctuating renewable generation, balance short-term load fluctuations and control production processes in a grid-stabilizing way. UM companies can offer different potentials depending on the sector and production process: many companies need most of the energy during the day, at times when demand from households is low; some have the potential to adjust their production (e.g. in batch processes) to when a lot of energy is available and cheap (power-to-product); they have storage potentials (heating and cooling processes (power-to-heat/cool), own storage) and the possibility to produce and make and offer heat and electricity themselves.

The increased use and integration of renewable energy sources that also come from UM in the energy system create additional new requirements for the energy system. Sector coupling is seen as a key concept of the energy transition and in building carbon-free energy systems [13]. Previously separate systems, the energy consuming sectors buildings (heating and cooling), transport and industry are interlinked with the power sector. The increasing use of electricity from renewable energy sources in all sectors supports the decarbonisation of the energy system but is also associated with new challenges.

According to the Masterplan 2050 from the Swiss municipal utility Swisspower [27], this system change requires a paradigm shift: “In order to efficiently coordinate the large number of new, decentralized energy producers, an intelligent local management of supply and demand across all energy sources is needed.” In the future, the network infrastructure will have to take a balancing and storage function in addition to its transport function and balance fluctuations in energy generation from volatile sources such as wind and sun. All systems must exchange information with each other on an ongoing basis in order to achieve optimal results. The Viennese distribution system operator Wiener Netze GmbH will also focus on similar topics in the future. Smart grids and digitalisation, which enables communication between the individual plants and grids, can significantly optimise grid planning and forecasting, provided that the data is available at all times. Smart grids should also make it possible to consume electricity exactly when it is generated primarily by renewables [28]. Smart technologies are intended to provide both utilities and consumers with the ability to control their systems. The focus will be on the rollout of smart meters and smart homes in order to develop urban smart districts like e.g. in Rome [29]. As a result, data volumes will increase, and more computing power and storage space will have to be made available.

Beside new requirements also new options for the energy system occur (right side of Figure 2), including the possibility of using waste heat from industrial processes. Companies can become energy sources for local microgrids and provide power and heat for other businesses or neighbouring settlements. Among other things, there is also the possibility to generate electricity from waste heat (at low temperature for example via ORC processes) or to feed PV from hall roofs into a local grid. In addition to billing-related issues (billing via blockchain, fees for the use of the public grid), legal issues also arise (electricity seller becomes an energy supplier with associated obligations).

In addition to the production of renewable energy, UM can also become a consumer of a surplus of renewable energy. Either because they can directly use the electricity in production processes at RES peak times or save it for later. For example, heating or cooling processes could be carried out electrically at a time of high RES supply or discontinuous batch processes could be coordinated therewith (demand-side-management).

To focus more strongly on the new role of UM companies in the energy system, targeted district management and forward-looking energy planning (for example for low-exergy systems) can make a significant contribution. It offers assistance and a framework for the energy strategy in companies.

Concluding, research has shown that for most of the solutions, that UM would optimize from an energy perspective, the technological requirements are largely available. However, over the next few years, it will be necessary to intensify the testing of technologies in demonstration projects and to improve the interfaces between actors and sectors: between companies (“energy communities”), between industry and grid/energy supply company/neighbouring settlement areas and between the sectors heat - electricity - gas – mobility through e.g. power-to-x and possible uses of hydrogen. Demonstration projects on load management for heat and electricity, waste heat and surplus electricity use (power-to-heat) in industry should be pushed and be tested under real-life conditions to prepare for large-scale use in the future. The concept for integrating UM optimally in the urban energy system for a sustainable energy transition in the future is already there. Now, above all, political will and implementations for testing and realising optimal technological solutions for UM in a sustainable urban energy system is needed.

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