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## Urban factories and their potential contribution to the sustainable development of cities

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### Abstract

More than half of the world's population lives in cities today with the rate of urbanization further increasing. In urban areas the challenges of sustainable development are concentrated. The importance of sustainable cities and communities are recognized in the sustainable development goals by the United Nations, as are sustainable industrial development and responsible production. Industrial production and urban factories are an essential part of growing cities, though commonly associated with a negative environmental impact. To identify the potential contribution of urban factories to the sustainable development and growth of the cities around the world, the characteristics of urban production systems and their surroundings are matched to the sustainable development goals and their targets. Based on this analysis, the potentials are derived identifying the key action areas in which urban production can support economically, ecologically and socially sound cities of the future.

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### 1. Introduction

Possibly the most important global challenge of our time is to ensure that our planet remains habitable and still provides enough resources for future generations. Against the background of a rapidly growing population and increasing resource consumption, strategies for sustainable development are required [1]. The cities of the world are now home to more than half of the world's population. By 2050 more than two thirds of humankind are expected to live in urban areas [2]. In urban areas, the challenges of sustainability are most evident in all dimensions. The social and economic dimension are nested inside the environmental dimension [1]. The degree of stability

of all dimensions determines the resilience of urban systems. There are many global studies comparing cities on their quality of life based on one or all dimensions. According to the Global Metro Monitor the 300 largest metropolitan areas accounted for almost half of the world's GDP with only a fifth of the global population in the year 2014 [3]. The Sustainable Cities Index ranks 100 global cities according to the triple bottom line based on the categories people, planet and profit [4]. Its rating considers, among others, air pollution, health, education, infrastructure and economic strength. As cities play a major role in reaching the goals of sustainable development based on a high share of the world's population in spatially close and organizationally established structures, the potential

contribution of the functional elements of urban spaces is of high interest. One of these functional elements of a city is the industrial sector. Industrial value creation contributes directly to the economic development of societies. Sustainable industrial development and responsible production are recognized in the sustainable development goals (SDG) by the United Nations as one part of the 17 aims set as a global strategy [5]. Industrial production and urban factories are an essential part of growing cities, though commonly associated with a negative environmental impact. Factories are a place where value creation takes place. Directly and indirectly, not only economic, but also social and environmental impacts are generated. Urban factories can most likely contribute to cities being sustainable in numerous ways as an active part of a stable urban structure. For a targeted utilization of urban factories as an element of cities, it is important to identify in what ways urban value creation can add to the sustainable development of cities and to understand their potential contribution.

## 2. Sustainable development and the SDG

It remains elusive when the concept of sustainability as necessity for future-proof development of humankind was first introduced. Reaching back to the Latin language the word *perpetuitas* meaning continuity or consistency can be associated with what we understand today as sustainability. The modern concept of sustainability goes back to Hans Carl von Carlowitz shaping the principle of sustainable forest management in his *sylvicultura oeconomica* [6]. With the report of the Brundtland Commission sustainability was defined as keeping “environment's ability to meet present and future needs” [7]. Subsequently the triple bottom line stating an environmental, economic and social dimension of sustainability disseminated into common perception. Interestingly, in the report of the Brundtland Commission the “urban challenge” was analyzed in a specific chapter. In the recent past the concept of planetary boundaries received great attention. With the planetary boundaries a compensation ability of environmental systems was recognized and a safe operating space for humankind was started to be defined [8]. Extending the planetary boundaries, more regional system boundaries are being defined, e.g. for life cycle assessment purposes [9]. Before the concept of planetary boundaries was published, the concept of eco-factors or ecological scarcity has been implemented in Switzerland since the early 1990s [10].

### 2.1. The Sustainable Development Goals (SDG)

All concepts and frameworks of sustainability need to be transferred to strategies for implementation to achieve an impact on actual global development. These strategies can i.e. be laws or regulations on regional, national or global level. As a worldwide recognized implementation strategy of sustainability, the sustainable development goals (SDG) by the United Nations are the most influential strategic definition at the moment. 17 goals were defined, each with a specific set of mainly qualitative targets that are set out to be reached globally by the year 2030 [11]. Additionally, quantifiable indicators

were formulated for the targets. These indicators provide the possibility to rate the progress towards the targets. With the review of the indicators in March 2017, 232 different indicators were published that are in general agreement [12]. Examples for the level of detail and structure of goals, targets and indicators are given in table 1. Although being controversially discussed, the SDG are today often referred to as a generally accepted worldwide strategy for sustainable development and applied by governments, NGOs, science and companies. One of the characteristics of the SDG is the interdependency between the single goals and targets. Some of the goals and targets either are so closely connected that an effort in reaching one goal will benefit another or may turn out to be disadvantageous. A scoring approach to rate these interactions between the SDG was proposed by [13].

Table 1. Example of the structure of goals, targets and indicators in SDG, excerpt from [12].

Goal	Target	Indicator
1 End poverty in all its forms everywhere	1.2 By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions	1.2.1 Proportion of population living below the national poverty line, by sex and age 1.2.2 Proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions
	8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.6 By 2020, substantially reduce the proportion of youth not in employment, education or training

### 2.2. Urban spaces and urban factories

With humanity being the decisive factor for sustainability on our planet cities are a major hotspot where strategies to achieve sustainability have to be implemented. These are important places for the effort to reach the SDG. The world cities report 2016 by the United Nations states that cities are operating in economic, social, and cultural ecologies [14], meaning that they are connected to all dimensions of sustainability. There is no consistent definition of urbanity and the perception differs among scientific disciplines and depending on the country. Generally, cities are associated with the inhabitants (“citizens”) living in close proximity to each other. However, not only the concentration of people defines a city. Socio-economic and environmental factors need to be considered in this context as well. A city can be characterized by its functional elements [15]. These elements serve an urban function and provide services in the urban space. The spatial arrangement and overall quantity of these functional elements is specific for each city. Examples of the functional elements are the technical infrastructure, educational, social and cultural facilities, retail, housing, open spaces and commercial

buildings, i.e. factories. The latter not only contribute to the value creation and economic strength of a city, but also are strong drivers for technological and social innovation. The term urban factory literally describes a factory situated in an urban environment, with a factory being a place of value creation. In a factory the inputs of materials, energy and information are transformed into products, by-products, waste and emissions during operation [16]. For the urban factory, the input and output flows of energy, material and people have an impact on the urban surrounding and are influenced by it [17].

### 3. The potential contribution of urban factories to sustainable urban development

As mentioned before, cities consist of many different elements and together these functional elements make up a set of components providing urban services and fulfilling the needs of the citizens. Urban factories are one set of these building blocks. With an integrative approach urban production sites do not only play a role in creating value and wealth in cities, but also offer several other positive impacts to their urban surroundings [18]. In cities, all elements are required to contribute to sustainable urban development in order to achieve the targets of the SDG. Urban factories potentially contribute not only because they are urban elements but also with regard to the high potential impact in all dimensions: economic (e.g. value creation), social (e.g. jobs and social security) and ecological (e.g. emissions). To identify areas of contribution for urban factories to the sustainable development strategy formulated in the SDG, an assessment methodology is proposed in the following. It is important to emphasize that the scope of the framework is to identify and rate the potential positive contributions by urban factories. Negative impacts resulting in the considered categories or even problem shifting to other fields are not evaluated. The aim is to identify the goals of the SDG to which urban factories can potentially contribute. Before any implementation, comparative evaluations have to be performed considering different utilization opportunities of urban spaces regarding their impact on urban sustainability.

#### 3.1. Assessment methodology

For the purpose of assessing the potential contribution of urban based factories to the SDG, the targets specified for each goal as in the 2030 agenda for sustainable development were examined [11]. All formulated targets for all goals were rated regarding the potential contribution of urban factories to fulfill them. For this purpose, a rating classification is defined with four levels. Each level is associated with a numerical value between zero and three for calculation purposes. All targets of a specific goal were assessed regarding the potential contribution of urban factories according to the following scheme:

- High direct contribution potential – score 3
- Medium direct contribution potential – score 2
- Low or indirect contribution potential – score 1
- No significant contribution potential – score 0

These ratings of the targets are then aggregated for the goal under investigation. The overall potential contribution of urban factories to the specific goal is derived from the sum of the ratings of the targets in relation to the possible maximum score. The possible maximum score depends on the quantity of the targets for this goal. This results in a numeric value between one and zero for each goal.

- 1.00 – 0.75: High direct contribution potential
- 0.50 – 0.74: Medium direct contribution potential
- 0.25 – 0.49: Low or indirect contribution potential
- 0.00 – 0.24: None or negative contribution potential

This means that single targets are implicit equally weighted within a goal having the same contribution to the overall score of the respective goal. The system border for the impacts of urban factories is defined by the urban space. Only the contribution to the development of the city where the urban factory is located and the urban impacts are considered in the target rating.

#### 3.2. Rating results and discussion

The results of the rating for the targets is summarized in figure 1. A color code shows the score for the single targets in each goal. The classification of the contribution potential to the goals is also stated in the figure. A high direct contribution potential results for three of the sustainable development goals (8, 9, 12). Together with two goals (7, 11) classified with a medium direct contribution potential urban factories can have an important influence on almost a third of the SDG in urban areas. Five goals are associated with a low or only indirect contribution potential, whereas for seven goals no significant contribution potential was found based on the rating. The results of the classification and the key findings are explained in more detail in the following. It is important to keep in mind that the potential contribution of urban factories to the SDG as set by the United Nations is rated. The consideration of another framework for sustainable development might lead to different results as the goals and targets are different among the published concepts on sustainability. This becomes apparent for example in the rating of goal 4 – quality education. Based on the sustainable development goals, urban factories seem to have no significant contribution to foster education. It would also be possible to argue that factories contribute to quality education significantly as they demand an educated workforce. Further urban factories can offer technical and practical education, e.g. through vocational training. However, goal 4 of the SDG addresses primary and secondary education, including early childhood development and literacy. The potential of urban factories emerges later in the educational lifetime with vocational training, developing practical skills and life-long learning that is only partly targeted by the SDG. Further, the transfer of the SDG, which originally are formulated on a global system level, to the urban system boundary and to sustainable urban development proved at some points to be quite complex. Not all targets can be directly linked to impacts generated by urban factories and in some cases there are many interrelations and interdependencies based on the high complexity of urban systems.

### Goals with high contribution potential

A high contribution potential of urban factories can be identified for the goals addressing the economic dimension of sustainability, specifically the goals 8, 9 and 12. Urban factories can directly contribute to promote economic growth, as this is the core purpose of industrial value creation. Factories contribute e.g. to the annual growth rate of real GDP per capita of a city. Further, the concept of urban factories allows high quality working conditions if integrated with the urban functional elements. The quality of living can be increased for the workers through the vicinity to urban services. Urban factories can also play a key role in promoting sustainable industrialization, supporting the creation of resilient infrastructure and fostering innovation (goal 9). They can contribute to raise employment and GDP within a city and offer infrastructure and services to the urban surroundings (goal 8). A high contribution can also be identified for the targets of the SDG addressing energy efficiency. Methods from life cycle engineering can help to ensure sustainable consumption and production (goal 12). Urban factories can be a key element in many of the life cycle stages a product goes through while being closely connected to the area where most of the consumption takes place. They are also important in end-of-life treatment. Urban factories can close material flows towards a circular economy by collecting and treating waste generated in cities and turning it into new products. The concepts of circulation factories and urban mining can be promising approaches for urban industrial symbiosis [15, 16].

### Goals with medium contribution potential

Urban factories are integrated into the infrastructure of a city to fulfill the demands of e.g. energy supply or transport logistics. Through these interfaces a production site can offer its own infrastructure to the surroundings for public use or act as a system element providing services for the city. A medium contribution potential can be identified for the goals 7 and 11. Urban factories can help to ensure access to affordable, reliable, sustainable and modern energy for the citizens by acting as a flexible component of the energy grid (goal 7). Short time energy storages, the supply of waste heat to a district heating system or the energy flexibility of a production system used as stabilizer for a volatile energy system are examples for possible contributions. If available, surplus energy can be sold to other urban energy demanders. There are already circumstances in which e.g. the filtering technology implemented in a factory also helps to clean the air of cities, thus reducing air pollution [21]. Mixed use strategies within urban areas can reduce commuting time and by that commuter emissions. The resilience of a city can be strengthened by urban factories, which can act as shelter in case of natural disaster if built accordingly. Modern production technology and producing close to the customer can support reducing the environmental impact per capita induced by citizens and their consumption. Locating an important part of the value chain in cities with urban factories, positive economic, social and environmental links between (peri-)urban and rural areas can be established along the material and energy flows (goal 11).

### Goals with low contribution potential

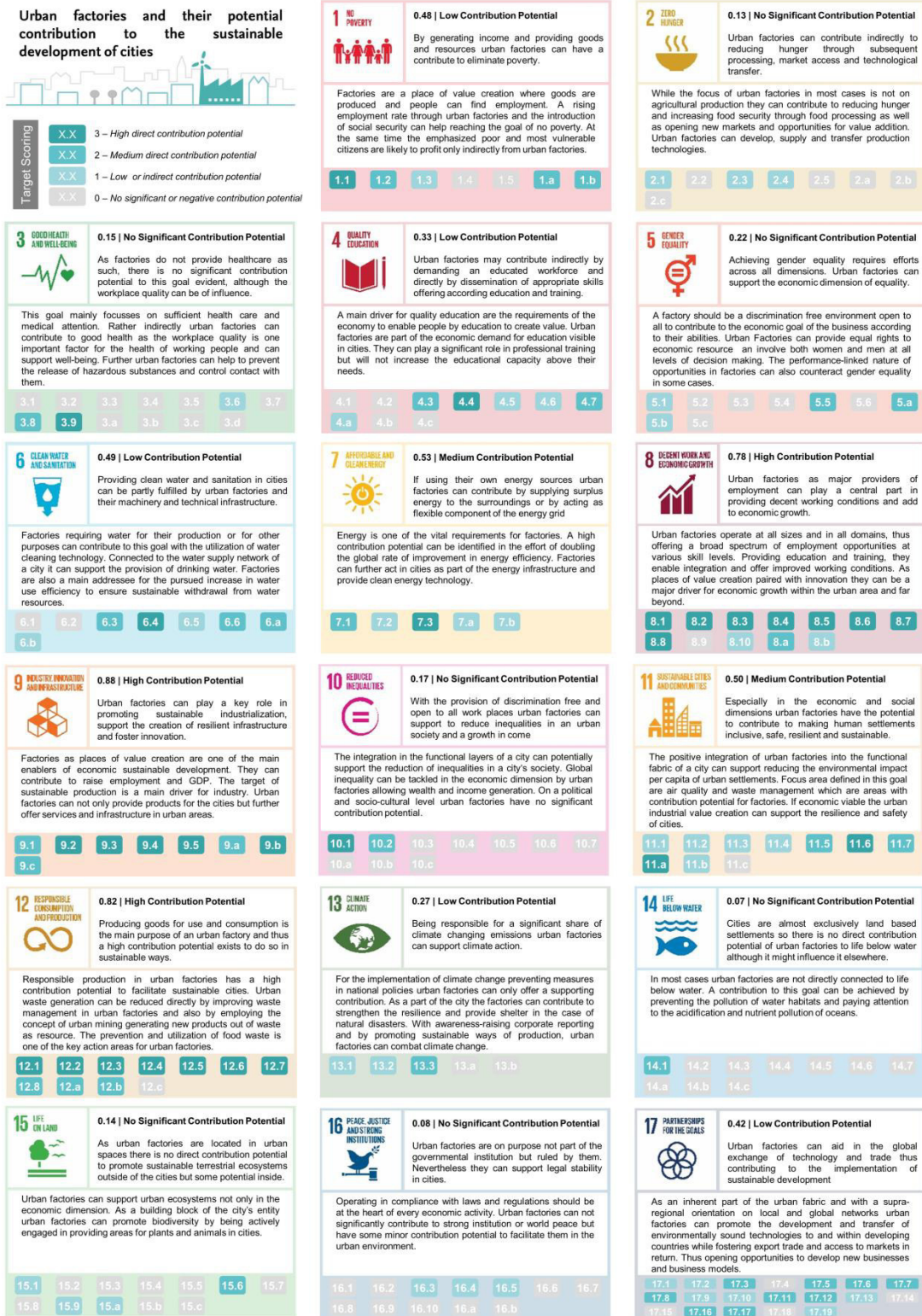
Rather low, but still existing contribution potential is found for the goals 1, 4, 6, 13 and 17. These goals rather focus on the

social and environmental dimension and when examined on city-level, urban factories can support the targets rather on an indirect level. The income generated in urban factories and the products made can support eliminating poverty in cities (goal 1). Urban factories are integrated in a network of manufacturing and service industries. Not only the person directly employed by the urban factory will benefit, but also people who execute services required by it. Furthermore, urban factories can provide jobs on all qualification levels and not only positions in highly qualified urban working markets [22]. The goal of quality education (goal 4) is directly addressed by urban factories on the practical level, e.g. through vocational training. For the targets set on (pre-)school education, only an indirect link can be identified with companies demanding an educated workforce. Similar to the case of cleaning polluted air in cities, factories can provide clean water and sanitation (goal 6) for the urban water system if there is excess capacity in the equipment installed. As the industrial sector is responsible for a significant share of climate changing emissions, a reduction of these by more sustainable production technology and the implementation of methods from life cycle engineering can support climate action (goal 13). Great value is seen in partnerships for achieving the goals of sustainable development and urban factories can act as one of the partners (goal 17).

### Goals with no significant contribution potential

For seven of the SDG (2, 3, 5, 10, 14, 15 and 16) there is no significant contribution potential. Although some targets of these goals are connected to working or consumption, the majority consists of targets that are not directly influenced by urban factories. Some of them are out of the spatial scope of this assessment and focused on mostly rural areas (goal 15) or marine ecosystems (goal 14). Both are outside the system boundary, although some negative contributions can be induced by urban factories, e.g. in the case of pollutant emissions, and can be seen as fields of action. Other goals emphasize healthcare or food supply, which both are not the functional purpose of factories although there are some potential contributions possible. Factories not only manufacture products but in many cases also provide services on-site, e.g. offering food in a canteen for their workforce. In urban areas these internal services can be made available for the public. This could then result in contributions to sustainable city development even for goals that are not within the functional purpose of a factory. The working conditions in urban factories have an impact on the health and well-being of workers as has noise and particle emission on the health of all citizens exposed to them. The working environment and the availability of production technology can be an enabler for reducing inequalities. Nevertheless, there is no potential contribution to be found for most of the targets. Most targets in these goals are out of the functional scope of urban factories.





Icons of the sustainable development goals by United Nations

Figure 1: Overview of the potential contributions of urban factories to the sustainable development of cities according to the sustainable development goals by UN. For a complete list of targets and indicators please refer to [11]

#### 4. Summary and outlook

Sustainable development is one of the main challenges for humankind, which is very evident in urban areas. Urban factories as part of cities can contribute to the goals of sustainable development set by the United Nations. To identify the potential contribution of urban factories to the sustainable development and growth of cities, their characteristics and potential influence were matched to all targets of each sustainable development goal. The findings indicate that the potential contribution of urban factories varies across the specific goals. Naturally, a high contribution potential can be identified for the goals addressing the economic dimension. Urban factories are a key player in cities for reaching productive employment, decent work, and economic growth, build resilient infrastructure and foster innovation. High contribution potential also exists for promoting responsible consumption and production patterns. This could be used to positively influence urban development.

The assessment methodology based on examining each target proved to be functional for the identification of the potential contribution of urban factories. Challenges and limitations were encountered in transferring the SDG to the system boundaries of urban space. Some of the targets address global relationships that are out of scope for urban factories. Others are focused on matters that are out of the functional scope of industrial value creation, such as providing healthcare. In these cases no or very low contribution potential was found by single urban factories, as for example for achieving zero hunger or establishing peace. There are high uncertainties on how actual implementations of urban factories will influence urban systems. Eventually the identification of areas with high contribution potential enables the next steps of evaluating these areas regarding (i) the comparative evaluation with consideration of alternative utilizations of urban space and (ii) the investigation on negative impacts connected to other goals of sustainable development and how these interact, counteract or neutralize the overall potential.

Different methods can be employed to quantifiably compare different utilizations of urban spaces. For example, life cycle assessment (LCA) has been used in [23] to compare the impact of urban agriculture and photovoltaic energy generations per unit urban area. Further research is required on urban factories and their possible positive contributions to the sustainable development of cities besides their economic value. Factories should be seen as active components of the city that can offer services and positive impacts in all dimensions. One key element for the utilization of this potential is the structured analysis of the interfaces of production sites to the surrounding neighborhood. The identification of best practice examples of positive integration will help to illustrate this. Extending the analysis in more detail on the level of the indicators assigned to each target should be a next step. In addition, there are more strategies and concepts for sustainability to be considered to gain deeper insights on urban factories and their potential contribution to the sustainable development of cities.

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