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Towards Smaller Value Creation Cycles: Key Factors And Their Interdependencies For Local Manufacturing

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Abstract

The unpredictable occurrence of a global pandemic and trade conflicts have currently shown us the fragility of global, industrial value chains. In contrast to this, local value creation structures have numerous potentials to meet present ecological, economic and social challenges (e.g. increasing the resilience of the manufacturing sector, reducing CO_2 emissions through smaller loops of value creation, empowering regional stakeholders). This paper presents a study on local manufacturing designed to achieve a better understanding of the internal systematics of value creation in a local context using a sensitivity analysis. By modelling the causal effects, the direct and indirect influences of internal and environmental factors of local production as well as their independencies can be shown. This in turn will enable scenario analyses that show possible developments for local production systems arising due to changing social, political and technological factors. In the future these options may aid in decision-making processes aiming at a sustainable circular economy.

Keywords

Local Manufacturing; Distributed Manufacturing; Re-Distributed Manufacturing; Urban Manufacturing; Value Chain; Sustainability, Sensitivity Analysis

1. Introduction

Recently, local value creation has been discussed as an instrument to reduce the increasing risks of complex global value chains (e.g. resource scarcity, trade barriers) and to expand the possibilities of sustainable production (smaller value cycles, empowerment of regional actors) [1]. Current societal trends and challenges (individualisation, sustainable consumption) and technological innovations (flexibilization of production systems, new communication technologies, smart systems) could potentially promote this development [2–4,1] . Thereby local value creation can have various forms: These may include regional value creation clusters (e.g. Hamburg Aviation or Life Science Nord in the Hamburg region), decentralised production sites of globally operating enterprises, value creation through local crafts and the participation of citizens through fab labs or makerspaces.

Reducing the size of the value creation cycles has the potential to improve the sustainability of product manufacturing [5]. If a value creation system is aligned with the local context in terms of product manufacturing, producers and demand, this forms a particularly good basis for small value creation cycles; local context meaning local production of goods, utilisation of local resources, addressing of local demands [6]. In this paper, we examine local production as a phenomenon that gravitates towards these three characteristics and can thus be distinguished from global value creation.

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2. Research Question and Motivation

There are different and diverse approaches looking at the phenomenon of local value creation: e.g. Distributed Manufacturing, Re-Distributed Manufacturing, Local Production, Urban Production. Thereby the focus of consideration varies [6]. This variety of perspectives offers a broad picture of the different forms and characteristics of local manufacturing to the reader. But at the same time, the reader does not achieve a clear understanding of the object of study as the different foci (technological, economic, social perspective) distort the actual relevance of the key factors of local manufacturing. As a result, the attributes of local manufacturing bear the risk of being under- or overvalued depending on the viewing perspective.

This paper presents a study that aims to contribute to a better understanding for the systematics of local manufacturing. A holistic perspective is taken on the object of study, in which political, social, economic and technological factors and their interactions are considered. Therefore, the research question is: Which internal and external factors of a local value creation system have a major impact on the implementation of local production, in the sense of:

(A) The local production of goods (on site)

(B) The use or inclusion of local resources in the production processes (equipment, actors, materials)

(C) And the fulfilment of local demands

3. Method

The study is based on a systematic analysis that is guided by the methods according to Vester for the assessment of complex systems [7–9]. Vester's sensitivity analysis [8–10] facilitates the determination of interdependencies between system dimensions in complex systems [8]. That way, options for a targeted development of the system can be described [8]. The approach not only considers direct connections between system factors but also indirect causal effects as well as feedback effects and self-reinforcing (or self-weakening) loops. The goal is to identify **representative patterns for the functioning of the value creation system** in order to finally show possibilities for development of the system.

Step 1 - System description: The system description serves to capture and also delimit the object of study [10]. The object of this study corresponds to systems of local value creation, which are characterized by the following attributes that can be viewed as dimensions [6]: (**A) Local production of goods**, **(B) Utilization of local resources (stakeholders, materials)**, **(C) Addressing of local demands**.

A value creation system aims to provide a material or immaterial service in a systematic and structured manner [11]. Value creation systems can be categorized as socio-technical systems [12]. They behave partly deterministic and partly probabilistic so that the predictability of their behaviour is limited [13][14].

Step 2 - Identification of influencing factors: To identify the influencing factors [10] about 90 texts were scanned that deal with different concepts of local manufacturing (e.g. Urban Manufacturing, Distributed Manufacturing, Re-Distributed Manufacturing) and thus take different perspectives regarding the object of study [6]. For the deeper analysis of the content those texts were chosen from which characteristic factors influencing local manufacturing could be derived. The choice of texts followed the principle of theoretical saturation [15]. The relevant influencing factors on local manufacturing were identified from the texts through a process of itemization, abstraction and condensation (further illustration of the approach, see [6]).

Step 3 - Modelling of the causal network: The identified factors are put together in a causal network to capture the systemic interaction between them. This is based on the idea that a value creation system – while it is not deterministic – still has an inner order that can be uncovered to better understand the underlying systematics [14]. In the causal network the type of the different influencing factors, their causal effects among each other and the development over the course of time is assessed [10].

Based on the literature review, the identified factors and their described interdependencies were transferred into a model that visualized the causal network using the software iModeler. The model was consolidated in moderated, interdisciplinary workshops (based on [10]) in order to achieve a realistic representation of the causal network. Through this process, the influences between factors that were often described as **indirect influences** in literature were **successively reduced to their direct causal effects**. Indirect effects between system factors were represented by causal chains based on the developed direct influences.

The differentiation of direct and indirect factors in the model was important in order to determine the strength of the causal effects. This was done by comparatively assessing the causal effects of all input factors of one particular system factor. Therefore, the partial effect of an input factor was categorized into levels of impact (low 5%, moderate 10%, relevant 20%, significant 35%, essential 50%). The sum of the influences of all input factors is limited to a maximum of 100%. Throughout the assessment of the factors' impacts, the sum was usually kept below the maximum of 100% to account for all influences not depicted in the model. Furthermore, the causal effects between system factors over the course of time were considered (short-term: 1 to 5 years, mid-term: 5 to 10 years, long-term: > 10 years). When several factors are connected in causal chains, the influence of indirect factors is calculated by multiplying the percentages of the influences along the chain. The influence of these indirect factors decreases depending on the distance. As a result, the strength of influences can be modelled more realistically by differentiating between direct and indirect factors.

Step 4 - Evaluation of the causal effects in the model: Based on the developed model, the influences between system factors were analysed to answer the research question listed in Chapter 2. The aim is to identify the most important internal and environmental factors influencing local manufacturing, which can be described by three dimensions: **(A) Local production of goods**, **(B) Utilisation of local resources**, **(C) Addressing of local demands**. These dimensions are represented in the model by five **main attributes** of local manufacturing: **Production at the place of need**, **Use of local (raw) materials**, **Implementation of production by local stakeholders**, **Production of individualised / locally adapted products**, **On demand production** (refer to Table 1). The relevance of the impact of the system factors on the five main attributes of local manufacturing was assessed by evaluating the strength of influence of the direct and indirect input factors. The result is a **comparative assessment** of those factors influencing the main attributes of local manufacturing, which will be presented in the following.

Table 1: Dimensions of local production and their depiction in the model

Dimension of local manufacturing	(A) Local production of goods	(B) Utilisation of local resources	(C) Addressing of local demands
Main attributes of local manufacturing	○ Production at the place of need	○ Use of local (raw) materials ○ Implementation of production by local stakeholders	○ On demand production ○ Production of individualised / locally adapted products

4. Findings

The model includes a total of 160 factors. The characteristics of local manufacturing are represented by five main attributes in the model (refer to Table 1). The model also includes target factors of a local production (i.e. prosperity in the region, sustainable production), current trends (i.e. digitalisation, dynamization of the markets/the environment of value creation, individualisation, urbanisation) as well as other relevant factors (of technological, political, economic and social influence). Figure 1 shows an exemplary section of the model depicting the main key attribute ***production at the point of need*** with selected interactions.

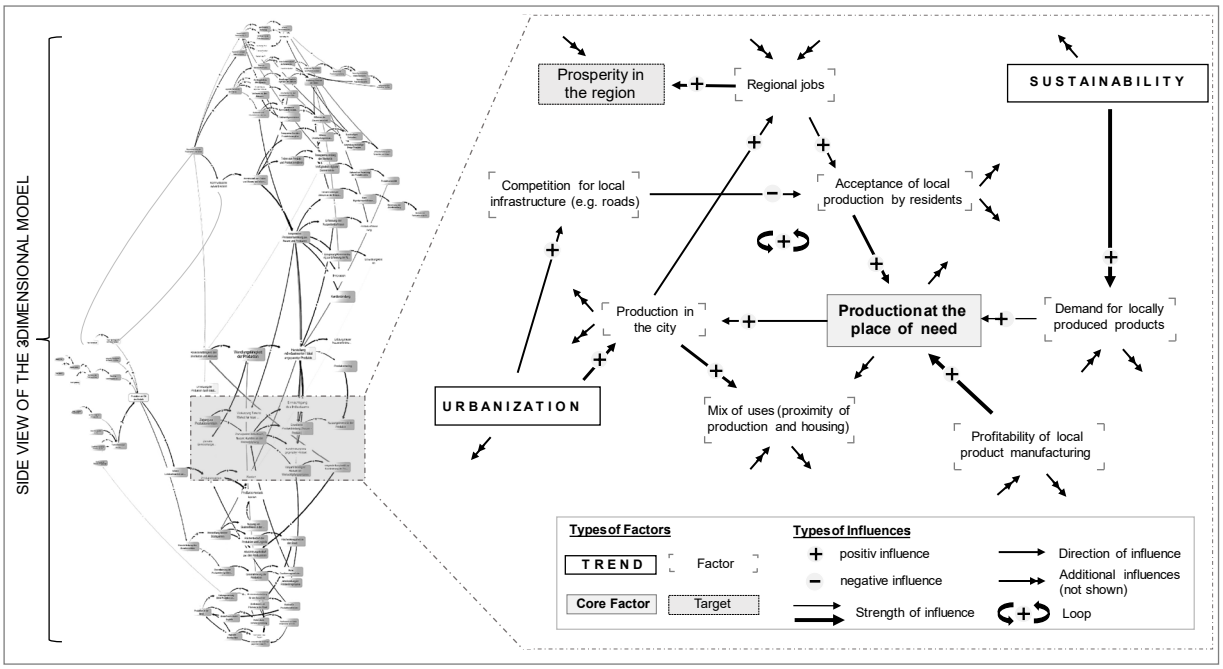

Figure 1: Model of Local Production with an example close-up of an effect chain, showing production at the place of need as the central factor and selected direct and indirect influences

4.1 Key factors influencing the local production of goods

The dimension of **local production of goods** describes the spatially concentrated production at the place of demand. In the model, this dimension is represented by the factor ***production at the place of need***. Driven by the trend of *urbanization* [16] *production at the place of need* will increasingly become *production in the city* in the future.

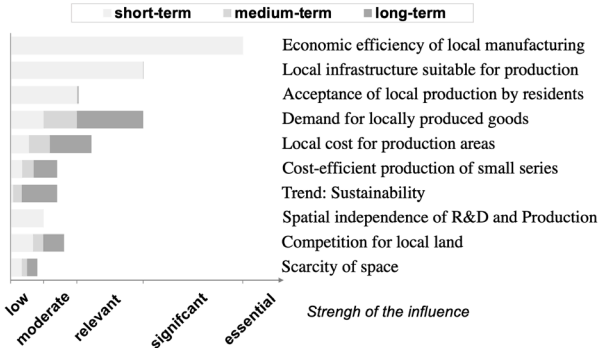

Diagram 1: Top 10 factors influencing production at the place of need

Diagram 1 shows the most important influences on the factor ***production at the place of need*** according to the model evaluation. The influences are intentionally not marked as positive or negative, since the manifestation of the factor determines that, e.g. *if the local cost for production areas* is low, the influence on ***production at the place of need*** is positive, but if the cost is high, it is negative.

Production at the place of need stimulates *sustainable product manufacturing* by avoiding transport [17,18]. It reduces *risks and costs of global logistics* [19,4] and strengthens regional value creation structures and thus provides *prosperity in the region*. Furthermore, it has a direct impact on *high quality of local life* [20,21]. This factor is significantly determined by the *economic efficiency of local product manufacturing*. By reducing the sales market to the local area, *cost-efficient production of small series* [22] and the *spatial concentration of demand* (through urbanization) will have an increasingly, reinforcing influence on ***production at the place of need*** [23]. In contrast, *rising costs for land in urban areas* (trend: *urbanization*) [24,20,25,26]

will negatively influence *economic efficiency of local product manufacturing* in the future. Current trends toward more *sustainable consumption*, which will intensify in the future, will promote the emergence of a ***production at the place of need*** by increasing *demand for locally produced products* [3,4]. The availability of a *local infrastructure suitable for production* [24,21] and the *acceptance of local residents [27]* towards these forms of production remain essential for the development of local manufacturing [27].

However, some influences of ***production at the place of need*** mentioned in the current academic discourse could not be confirmed within the model. I.e. *urbanization*, which has an ambivalent influence on production on site. On the one hand it promotes the *emergence of local agglomerations* and thus the *spatial concentration of demand*. On the other hand, it increases *competition for local land* [28,25], which increases the *cost of local production space* [20] and reduces the *economic efficiency of local manufacturing.* Furthermore, the increasing *risks and costs of global logistic* do not significantly influence ***production at the place of need***, as they only affect *the economic efficiency of local product manufacturing* to a small to moderate extent.

4.2 Key factors influencing the utilization of local resources

The **use of local resources** in a local production encompasses the ***use of local (raw) materials*** and the involvement of regional actors, companies as well as workers, represented in the model by the factor ***implementation of production by local stakeholders***.

Use of local (raw) materials and ***implementation of production by local stakeholders*** strengthen the local value creation, support the creation and retention of *regional jobs* [3,29,17] and ultimately increase the *prosperity in the region* [20]. Additionally, the ***use of local (raw) materials*** through the downsizing of value-added cycles and *reduction of the global transport of goods* leads to *sustainable product creation* [4,23].

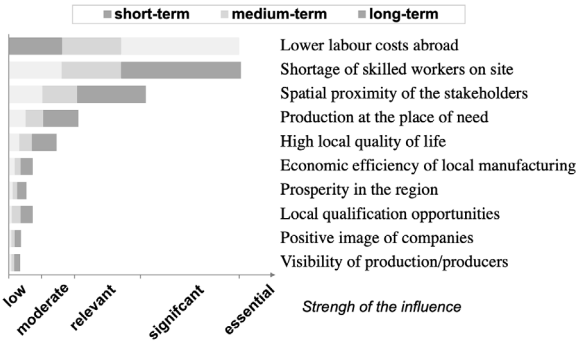

Diagram 2: Top 10 factors influencing the implementation of production by local stakeholders

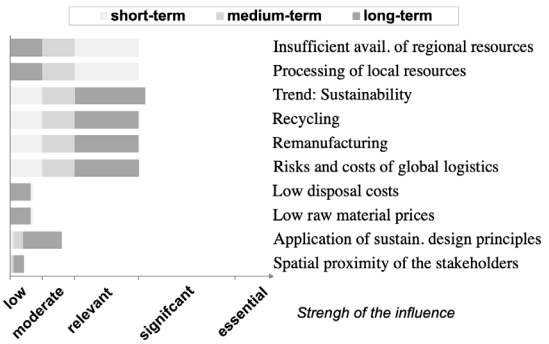

Diagram 3: Top 10 factors influencing use of local (raw) materials

Diagram 2 and Diagram 3 show the comparative influence of the key factors on ***implementation of production by local stakeholders*** and ***use of local (raw) materials*** respectively.

At the moment, the ***use of local (raw) materials*** in local value-added cycles is especially determined by the *(insufficient) availability of regional resources* [30,22,1] and by *possibilities for the economic extraction and processing of local resources.* The relevance of local resource extraction, however, will decrease in the future while the recirculation of materials and products into value-added cycles will be raised. The increase of currently *low disposal costs* and *low raw material prices* as well as the consistent *application of sustainable design principles* [30], the *modularity of products* [31,4], the enhanced *transparency along the value chain* [32] and *along the product life cycle* will mid- to long-term significantly boost the relevance of *recycling* as well as *remanufacturing* for the ***use of local (raw) materials*** in the context of local value creation.

While the *spatial proximity of the stakeholders (producer and user)* does promote *recycling* as well as *remanufacturing* [33], it holds only secondary relevance compared to the aforementioned drivers (refer to

Diagram 3). The *trend: sustainability* and the related change of values will influence consumer behaviour long-term in so far that consumers will specifically call for the use and re-use of local resources [3].

The ***implementation of production by local stakeholders*** is dominated by the mostly *lower labour costs abroad* [4,34]. This factor's relevance will however lessen in the future due to the assimilation of labour costs and due to attempts to impose standards along the value chain through regulations (e.g. supply chain law). The *shortage of skilled workers on site* will determine the ***implementation of production by local stakeholders*** mid- to long-term [35,27]. The involvement of local stakeholders will additionally be impacted by the ***production at the place of need*** and the related *spatial proximity of the stakeholders* [3,20,27].

4.3 Key factors influencing the addressing of local demands

The dimension **addressing of local needs** is represented in the model by the following factors: ***on demand production*** and ***production of individualised / locally adapted products***. The ***production of individualised / locally adapted products*** refers to the potential of local manufacturing to adapt to the local or individual requirements of regional users (e.g. in terms of function, design). ***On demand production*** represents the ability to respond to local demand quickly and in the required quantities.

Responding to local demands promotes *sustainable manufacturing* by avoiding overproduction and warehousing through ad hoc demand-driven production (on-demand) [28]. In addition, local, specific user requirements are fulfilled and customer acceptance of locally manufactured products is increased [4,32].

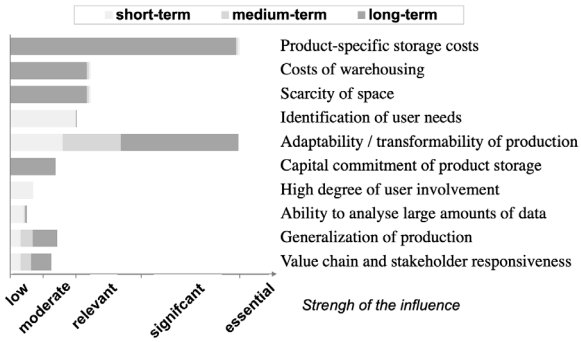

Diagram 4: Top 10 factors influencing on demand production

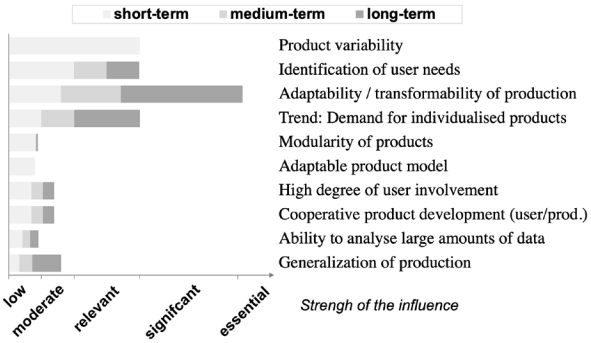

Diagram 5: Top 10 factors influencing production of individualised products

Diagram 4 and Diagram 5 show the compared relevance of the main factors to ***on demand production*** and ***production of individualised / locally adapted products*** in the context of a local production over time.

The *adaptability* of local production determines its potential for the targeted **fulfilment of local needs** [30]. In the future, the importance of this factor will increase due to *new, highly flexible production technologies* [4,22,34], the *generalization of production* and the increased use of *modular product structures* [31]. The *variability* of locally produced goods also promotes **addressing local needs,** for instance through functional variability (e.g. through software customisation, modular product design) and product scale variability (e.g. the possibility to choose the production process depending on the production quantities) [34]. Knowledge about local needs is gained through targeted *identification of user needs*, which has a high impact on **addressing the local needs** by concepts like *co-creation or co-design* [19,30,18] and the increasing *ability to analyse large amounts of data* (data mining, artificial intelligence) [34].

In the future, changing consumer demands for *individualisation* and *immediate availability of products* will promote the emergence of *demand-driven, ad hoc production* in local contexts.

The *scarcity of space* and related *storage costs* also have an important influence on ***on-demand production*** [18] in systems of local value creation when located in urban areas.

In contrast to some views in the literature [30,4,18], our model did not show that *spatial proximity between producers and consumers* facilitates **addressing local needs**. Instead, it can be assumed that knowledge of local needs can primarily be generated in ways other than spatial proximity (e.g. virtual cooperation between customer and producer in co-creation formats).

4.4 Summary of the findings

For an easier comparison of the analysis' results, the most important factors of local manufacturing, the primary target factors and the key factors are summarized in Table 2.

Table 2: Summary of the main attributes, target factors and key influencing factors of local manufacturing

Dimension of local manufacturing	**(A) Local production of goods**	**(b) Utilisation of local resources**		**(c) Addressing of local demands**	
Main attributes of local production	Production at the place of need	Use of local raw materials and materials	Implementation of production by local stakeholders	Production of individualised / locally adapted products	On demand production
Primary target factors	o Sustainable production of goods o Prosperity in the region	o Sustainable production of goods o Prosperity in the region	o Prosperity in the region	o Sustainable production of goods o Fulfilment of local consumer demands	o Sustainable production of goods o Fulfilment of local consumer demands
Key influencing factors	o Economic efficiency of local manufacturing o Local infrastructure suitable for production o Demand for locally produced goods o Acceptance of local production by residents o Local costs for production areas o Cost-efficient production of small series o Trend: Sustainability o Spatial independence of R&D and Production o Competition for local land o Scarcity of space	o Recycling o Re-Manufacturing o Risks and Costs of global logistics o Trend: Sustainability o Availability of regional resources o Processing of local resources o Application of sustainable design principles o Disposal costs o Prices of raw material	o Lower labour costs abroad o Shortage of skilled workers on site o Spacial proximity of the stakeholders o Production at the place of need o High quality of life on site o Economic efficiency of local manufacturing	o Adaptability / transformability of production o Identification of users need o Product variability o Trend: Demand for individualised products o Generalization of production o High degree of user involvement o Cooperative product development o Modularity of products o Adaptable product model o Ability to analyse large amounts of data	o Product-specific storage costs o Adaptability / transformability of production o Cost of warehousing o Scarcity of space o Scarcity of land o Identification of users need o Generalization of production o Value chain and stakeholder responsiveness o Capital commitment of product storage o High degree of user involvement o Ability to analyse large amounts of data

The key factors influencing local manufacturing can be differentiated by being based primarily on technological, economic, political or societal developments.

Product manufacturing **addressing local needs** is mainly driven by technological developments that focus on the adaptability of local value creation systems and the recording of the user's needs.

The development of **production at the place of need** is primarily influenced by political and societal drivers. While the adaptability of value creation systems does have a relevant influence on the economic production on-site, the negative influence of rapidly rising costs for local production sites caused by the merging of conurbations is more important. This challenge cannot only be solved technologically (e.g. by the downsizing and adapting of production technologies), but through political regulation. The availability of a suitable infrastructure for local manufacturing is also dependent on political decisions. Relevant societal drivers are the changing consumer behaviour and the rising demand for locally produced goods.

The **use of local (raw) materials** benefits on a technological level from material and process innovations in order to achieve effective and efficient recycling and remanufacturing processes. The central drivers are rising costs for raw materials, energy and waste disposal (economic drivers), which depend on political decisions (e.g. CO_2 taxes, export bans on plastic waste). The implementation of production by local

stakeholders can benefit from the growing assimilation of labour costs as well as the political measures to avert the worsening shortage of skilled workers on-site.

The differentiation between the key drivers of the main attribute of local manufacturing shows, that forms of sustainable, local value creation are not primarily driven by technological, operational or business model innovations, but by a combination of political and societal developments. In the end, political decisions will determine a production at the place of need (availability of space and of a suitable infrastructure) by local actors (international assimilation of labour costs, aversion of a shortage of skilled workers) while using local resources (promotion of a regional circular economy) for the fulfilment of local demand.

In order to base such political decisions to promote local manufacturing on scientific findings, further research is needed on the actual potentials and implementations for local production systems. In particular, multidimensional benchmarks must be developed in comparison to a global, industrial value creation.

5. Discussion

Although the model shows the strengths of the influences of the mentioned factors in comparison to one another and describes potential short-, mid- and long-term developments of these factors, is has some limitations. With its qualitative nature it sharpens the understanding for the systematics of local manufacturing, but it does not say anything about the probability of the actual occurrence of concrete developments. Therefore, quantitative prognostic methods are needed. The complexity of the causal effects of the object of study, however, would not allow for a consistent quantification, which is why a qualitative approach was chosen here. In a next step, the model could be expanded through a systematic analysis of especially relevant subsystems, which are aimed at the quantification of the causal effects in order to be able to make more concrete statements regarding the development of the system within defined borders.

6. Outlook

The presented model is able to sharpen the understanding for the key factors of local manufacturing on a technological, societal, political and economic level. Using these findings various scenarios can be generated to show different paths of development for local production systems. From these options concrete recommendations of action for political, societal, operational and technological stakeholders can be derived in order to reach the goals mentioned in the introduction of this paper (e.g. reduction of CO_2 emissions, empowerment of local actors). Nevertheless, the model cannot be considered complete since factors such as business taxes, etc. have not yet been depicted and would have to be added in the course of further text analyses.

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