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Planning for sustainable urban food systems: An analysis of the up-scaling potential of vertical farming

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Food production and consumption related environmental challenges have come to the forefront of policy discourse in the past decade. This links primarily to concerns in terms of agriculture fueling climate change, but also in terms of long-term food security and availability for growing populations. A proposed solution to these pressures at the urban scale is Vertical Farming (VF), in the understanding of this article, a high-yield form of controlled environment agriculture, staked on multiple layers, which promises to produce leafy greens and vegetables within cities, with potential to reduce the resource intensity of urban food production and consumption. The particular contextual conditions required for VF to be sustainable have not as of yet been holistically assessed. Accordingly, by analyzing these contextual conditions in the Global North, this research assesses how VF can be up-scaled for the sake of sustainability – particularly climate mitigation – by viewing urban food systems through the Multi-Level Perspective. The article presents three findings in relation to the up-scaling potential of VF. Firstly, singular VF interventions in cities should have further functions integrated at the scale of the farm for the sake of viability. Secondly, VF interventions carry the most potential for climate mitigation if they are viewed through urban-level systemic food planning, which sheds light on the contextual conditions needed for VF to contribute to sustainability. Finally, the globalized dynamics of the neoliberal political economy, and in turn the localized effects for food systems, have implications for VF that need to be taken into consideration in framing up-scaling policy.

KEYWORDS: Vertical farming; up-scaling; climate mitigation; low-carbon urban development; food systems

1. Introduction

In 2019, the IPCC released a report stating that the world is facing an unprecedented challenge in having to mitigate a destabilized climate system and eradicate hunger and poverty on a global scale (IPCC 2019). With 23% of global greenhouse gas (GHG) emissions resulting from the agricultural sector (IPCC 2019), the link between these two challenges is clear and is further intensified by projections of population growth

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as well as migration flows toward urban areas (UN 2018). The twenty-first century will be decidedly urban in focus, and therefore global food-related challenges – such as climate change, diminishing food security, growing demand for comfort and varied (out of season) produce, growing population levels, and intensified resource and energy use – will both originate and have their biggest impact in cities. These developments also carry clear implications for land use change (LUC) related GHG emissions (Rothwell *et al*. 2016; Gardi *et al*. 2015). Vertical Farming (VF), a high-yield form of controlled environment agriculture (CEA), which promises to produce leafy greens and vegetables within cities through hydroponic, aquaponic, or aeroponic growing methods, through stacking layers of crops on each other. The technology promises to address several issues as it requires less land, less transport, and less water than traditional agriculture. A number of studies do highlight, however, that these promises are conditioned on the right recipe of contextual factors (i.e. water scarcity, abundance of renewable energy, alternative supply chains and distribution logistics, packaging materials, etc.) (Coley, Howard, and Winter 2009; Goldstein *et al*. 2017; Barbosa *et al.* 2015; Mohareb *et al.* 2017). Currently, VF is only implemented at small scale sites. In appreciating the potential tradeoffs resulting from these contextual factors, this research looks at how this technology can be upscaled in urban agriculture for the sake of enhancing the sustainability of food systems in the Global North – and in doing so assesses what aspects should be considered in the process of governing these systems.

VF is a divisive technology in terms of benefits and shortcomings. Early proponents of VF, such as Despommier (2010, 2011), take a clear supportive stance from a holistic perspective on the applicability of the technology. Focus is put on year-round crop availability, the elimination of agricultural run-off, reduction of fossil fuel use from transport, reduction in weather-related crop failures, and the returning of farmland to nature, amongst others. More generally, urban agriculture is seen as having the potential to disrupt the conventional food system (Pfeiffer, Silva, and Colquhoun 2015; Opitz *et al*. 2016) and to provide an opportunity for redistributing resources and power by commoning urban resources (Mancebo 2016). Yet, there are also criticisms of VF, as it could potentially lead to a further commodification of agricultural products, further segregation between the experience of food and its modes of production, and its catering to the wealthy (Horst, McClintock, and Hoey 2017).

Considering that VF is a novel technology, no explicit attempt has been made so far to scope the necessary governance milieu in a qualitative manner for the successful expansion and upscaling of VF in relation to its potential. This research aims to (1) provide an indication of how VF can be applied in order to contribute to reducing the impact of food systems in terms of anthropogenic climate change, and (2) understand whether and how VF can be upscaled in the sense of spatial reproduction and in terms of institutionalization. This is done by analyzing the accounts of 17 experts working in the field.

Toward this end, we use the multi-level perspective (MLP) developed by Geels (2002, 2011) as a theoretical framework. This theory assesses sociotechnical transitions through differentiating between *niche* novelties, incumbent *regimes* and *landscape* pressures. As outlined in the second part of this article, a number of shortcomings are present in this theory, principally on the line of assessing specific factors relevant for the measurement of transitions as well as in terms of correctly and reflectively assessing social and power relationships in the process of transitions. The first critique is addressed by utilizing a taxonomy developed by van Doren *et al*. (2018) assessing specific factors that can result in the successful upscaling of Low-Carbon Urban Initiatives

(LCUIs). The second critique is addressed through using an abductive research design, where the abovementioned taxonomy is amended by emergent factors, in order to provide a more complete picture and measuring the social and power relationships within sustainability transitions. This approach is detailed in the third, methodological section.

Along the lines of the three-tiered structure of the MLP, three core findings are presented in the fourth section. On the *niche* level, a set of integrative functions, necessary for the potential success of a farm are sketched. These include elements targeting marketability, environmental sustainability, the built context, education, and community engagement. At the *regime* level, the necessity to view urban food systems as a whole and envision the utility of VF within this context is outlined. Finally, on the level of *landscape* pressures, the clear implications of the neoliberal political economy and the resulting blocking elements are delineated. These primarily shed light on how competition among startups may hinder the development of an overall industry without any coordinated effort toward within industry standardization.

In the final section, we contextualize the results in wider outsets of urban food systems and the implications this carries for successfully planning climate mitigation at the level of an urban food system. The discussion also provides an insight into what types of transitions VF and urban food systems face and suggests how the upscaling framework of van Doren *et al*. (2018) can be amended by seven further factors. This section is followed by a brief conclusion.

2. Defining vertical farming

Considering that Urban Agriculture can take multiple forms, it is imperative to arrive at a clear definition of Vertical Farming. Al-Kodmany (2018) puts forward three types of vertical farms: (1) tall structures with several layers of growing trays commonplace involving supplemental lighting on each layer, (2) the repurposing of roofs on buildings, and (3) the design of multistorey buildings. In line with these categories, Mohareb *et al*. (2017) suggest that a Vertical Farm is characterized by "controlled-environment food production with supplemental heating, integrated into structures built for other primary functions that involve purpose-built infrastructure for yield improvement towards commercial availability" (3). Building on this definition, Gentry (2019) differentiates between two types of hydroponic and aquaponic systems, both of which are considered in our analysis: the nutrient film technique and the drip irrigation system. These systems involve the hanging and emerging of plants into nutrient enriched water, which is driven through a number of levels or fed down columns to supply the plants. The water exiting the system is recirculated with additional nutrients added – in the case of an aquaponic system from the waste products of fish. The plants receive their lighting needs from LED lights and the whole system is enclosed in a temperature controllable chamber. Examples of such systems are outlined in Figure 1.

Direct benefits of such systems include year-round availability of produce, limitation of agricultural run-off, reduced crop failures and nutrient recovery (Despommier 2010). Indirect benefits include the returning of freed farm land to nature and reduced emissions resulting from transport if farms are located close to consumers (Despommier 2010). Next to this, urban agriculture in general raises the average nutritional value of food consumed in urban areas, generates substantial revenue for local producers and serves as a pedagogical tool whilst building a sense of community. Under the right conditions these aspects can arguably be incorporated into VF too.

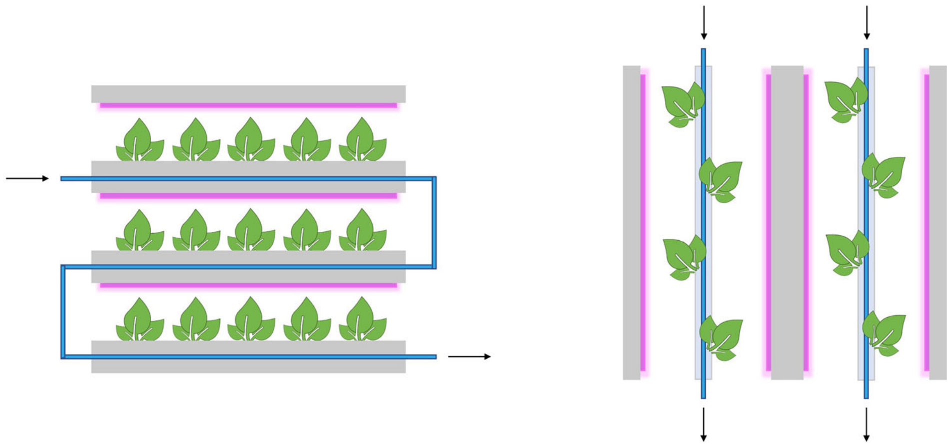

Figure 1. Examples of nutrient film technique and drip irrigation systems in Vertical Farming (based on Gentry 2019).

These benefits are substantially overshadowed by the complexity of food systems and the production and consumption patterns of food therein. To begin with, the discussion surrounding food miles highlights the complexity involved with bringing production closer to end-consumers. As Coley, Howard, and Winter (2009) discuss, localism is conditioned on logistics networks, where a round trip in a car to a grocery store can many times be replaced by mass distribution, and delivery of food may indeed be a more suitable approach in certain cases. Next to this, Goldstein *et al.* (2017) argue that the environmental impact reduction of urban farming in general is minimal. They suggest that it cannot simply be assumed that local production substantially alters supply chains. Similarly, Barbosa *et al.* (2015) have found that the energy requirement of hydroponic systems is approximately seven times higher than that of traditional agriculture. Water savings are however abundant, which again points to the necessity to scope the appropriate conditions for the use of this technology (i.e. a setting where water is scarce but there is an abundance of renewable energy). Similarly, in a comprehensive exploration of potential research avenues, Mohareb *et al.* (2017) explore how cities can best exploit wasteflows to reduce the impact of food production on the food-energy-water nexus. Their exploration highlights the tradeoffs, the types of production systems, the resource requirements alternative irrigation systems have, the manner in which packaging materials can be foregone, and how supply chains and transportation of food can be improved through local production. The key matter at hand is that each of these elements opens up a Pandora box of complexity and unintended consequences, which require careful consideration of contextual conditions for the appropriate applicability for a technology such as VF. Hence, the commonplace communication of VF practitioners regarding the sustainability of their systems should be judged in the light of an appreciation for the contextual complexity of their systems. In exploring the scaling potential of VF this article sets out to contribute to a better understanding of this complexity.

3. Embedding vertical farming in the multi-level perspective

The following section outlines the two broad theories utilized in the research. The Multi-Level Perspective provides the frame for understanding the upscaling potential of VF, whilst the upscaling taxonomy of van Doren *et al*. (2018) serves as an operational framework for the study.

3.1. The multi-level perspective and its application to vertical farming – a theoretical backdrop

The Multi-Level Perspective (MLP) serves as a basis for the analytical approach. It primarily assesses sociotechnical transitions from a three-tiered perspective of *regimes, landscapes,* and *niches* (Geels 2002, 2011; Hodson and Marvin 2010; Rotmans and Loorbach 2009; Smith, Stirling, and Berkhout 2005). This theoretical approach allows for explaining how experiments and innovation emerge, and how they challenge existing socio-technical systems in broad terms. Dominant sociotechnical *regimes* entail the *status quo* in terms of constellations of various actors, market forces, technologies, policy, science, culture, and industry (Geels 2011). *Landscapes* describe broad overarching processes, which put pressure on the dominant *regime* on the one hand and open up opportunities for transformations of this constellation on the other. *Niches* describe novelties, which ultimately challenge the dominant *regime* through establishing alternative constellations of the given sociotechnical reality. In the field of urban agriculture, a number of *niche* processes are underway. These include technical innovations such as VF, but also social innovations such as Alternative Food Networks (Goodman, Cruz, and Goodman 2009; Forssell and Lankoski 2015) or Community Supported Agriculture (Tregear 2011), which arguably carry lessons for VF as well.

In the case of VF, the dominant *regime* can be understood as the current food system, fed by extensive food miles and industrialized farming, concentrating produce in a small number of distribution centers, and ultimately distributing this produce through carefully orchestrated assemblages of retail points, such as supermarkets (Steel 2008). The *landscape* in this context can be best understood as phenomena, such as the approaching food crisis, globalized neoliberal capitalism, or the increasingly present misbalance in the nitrogen cycle. These seemingly independent and disconnected phenomena create a certain type of *milieu*, which under certain circumstances enables or blocks *regime* change. These *landscape* pressures are outlined below for contextualizing the *niche* in this research: vertical farming. In this sense, this alternative form of food production carries elements, which under the right circumstances could challenge the current *regime* and could contribute to reconfiguring food production and consumption in cities. The key point here is that with sustainability in mind, the upscaling potential of VF becomes grounded in the right mix of contextual factors. One might assume that if coal and natural gas make up a substantial part of electricity generation, and there is lengthy transport involved for the produce, scaling has no concrete use toward sustainable development.

Accordingly, to understand the conditions within which transformations of urban food systems can take place, it is essential to contextualize this reality by elaborating on *landscape* level developments. These developments refer in particular to those related to the neoliberal political economy. As Peck, Theodore, and Brenner (2009) outline, the "geographically variable, yet multiscalar and translocally interconnected, nature of neoliberal urbanism" (49) produces different contextually dependent realities, with overarching elements of actually existing neoliberalism throughout. Among these realities are globalized food chains, issues related to the ownership of technological solutions for effective urban food production, and the structural constraints resulting from the relationship between climate change, growth-oriented economic models, and the investment structures producing technologically intense interventions aimed at climate mitigation. The interlinkage of these elements points toward the need for community-level development of food resilience strategies (Reis 2019).

First of all, globalized trade with food commodities has resulted in the one-directional nature of long food chains. As Steel (2008) outlines, this has created a "one-directional food highway" (310), not a two directional relationship between producers and consumers of food. This can further be understood in two ways. On the one hand it can be seen as an elevation of the linear modes of economic production to the social level, while on the other hand it can be understood as a direct manifestation of a rift between natural and social processes.

Next to this, unequal access and an escalation of the corporate rule of food production in the domain of urban agriculture are serious risk factors. The resulting potential imbalance in power relationships can be traced back to conditions of the political economy. As VF is one of the most capital-intensive modes of agricultural production (Despommier 2010), it is essential to critically examine the implications of common forms of investment schemes for wider access to VF and the societal effects of these developments. As Despommier (2010) outlined, venture capitalists are at the end of his list for potential funders. This being said, this type of investment is common in the VF industry – especially in the North American context. It is particularly important to question the potential implications of not only ownership of land and real estate in urban areas under such investment schemes, but also what this means if combined with ownership over the means of food production, and ultimately the intellectual property necessary for building and operating these farms. Can a truly sustainable vision for an urban-focused food system accommodate such types of investment and ownership structures and can social inclusion and equitable access to the produce be ensured? These aspects are discussed in detail below.

The final point, exemplifying the structural pressures of the political economy, lies at the core of the current neoliberal political economy: growth. Multiple theorists and academics have pointed to the problematic nature of growth-centered economic thinking, and its environmental implications and direct linkages to climate change (Meadows *et al.* 1972; Klein 2014; Phillips and Rozworski 2017). It is necessary to reflect on the core, systemic problem that necessitates interventions such as VF in cities. If a growth-centered economy is the principle cause of environmental problems but also the enabler of the necessary interventions, is this not ultimately a self-fulfilling prophecy? Under the conditions of the current political economy, innovations such as VF should result in more growth, which brings all the ills of overconsumption and overproduction with it. This in effect risks contributing to further climate change through the intensification of resource use. It is clear that this is a simplification of a much more complex reality; however, the point of such a theoretical exercise is to reflect on the core guiding principles of the socio-technical experiment of vertical farming. Placing such innovations in the wider landscape of the political economy enables us to better assess the sustainability potential in broader terms than resource efficiency. In this sense, it becomes clear that it is inept to focus on singular technological interventions, and expect systemic solutions from them, as wider, external and unexpected consequences are a risk factor when planning with these types of interventions.

3.2. Critiques of the MLP and potential solutions

As briefly outlined above, the MLP provides an analytical lens for understanding the interrelationship between broad *phenomena* with potentially global reach and *niche* innovations. The three-tiered analytical perspective allows for a nuanced understanding of sociotechnical reality, with a particular focus on the *niche-regime-landscape* triangle. Nevertheless, this approach has also been criticized on multiple occasions. The first major critique relates to the social and political nature of transitions and can be summarized for VF along four major limitations (Lawhon and Murphy 2012).

Firstly, the MLP can be seen as representing the opinions of the elite, who are in a position to initiate transformations. In the context of VF, this means that it is necessary to see the perspectives of a wider array of actors, exemplified by consumers, activists, and workers. This thought ties in closely with the critiques put forward by Smith, Stirling, and Berkhout (2005) and de Haan and Rotmans (2018) on how this approach substantially disregards the role of actors and agency in the transition process. Building on this critique, a central question of a political nature becomes evident: How do pioneers and entrepreneurial actors actually take the lead in exploiting opportunities to the best manner possible? Secondly and closely related, the MLP also focuses on the role of technology as independent of social and political processes. In this sense, VF should not only be understood as a transformation of technological processes but as a phenomenon with transformative power in the societal sphere. Thirdly, contextual spatial factors are missing from this theoretical framework, even though they are essential when studying transitions in the urban setting. The deceptive focus on national level processes ignores the potential for different geographical scales to carry different implications. Hence, by studying VF in the urban environment and by situating urban reality in a wider context of anthropogenic climate change a contextually embedded conception of desired transitions and potential pathways emerges. Finally, the role power relationships play, and the productive nature of political struggles are also often neglected in the MLP. With a focus on rules and regulations, there is insufficient space given to actors challenging these frameworks in the process. Hence, it is necessary to continuously reflect and ask, if VF becomes a *regime*, who benefits from this? How can the benefits of VF be distributed in the most just way? Studies into sustainability inherently have to assess the social and political reality surrounding the given transformation. Considering cities are the sums of natural resource flows, as well as socio-political processes (Swyngedouw 2006), the political and social nature of this transition is also assessed in this research.

These points of critique – specifically in the social and political realm – are catered to by the use of an abductive research design. As detailed in the method section, this type of design allows for the use of predefined theory, whilst also allowing for further variables to emerge in the course of the research. By applying this critique as a backdrop to the collected data, a more concrete assessment of social and political factors can also be considered within the MLP.

The second major critique relates to how the MLP fails to outline the manner in which the three levels of the framework interrelate; and in effect fails to sketch the specific types of scenarios that lead to pathways to transitions (Berkhout, Smith, and Stirling 2004). This critique has been catered to by a refinement of the MLP by Geels (2011), suggesting four different types of pathways to transition – *transformation*, where incumbent *regime*s react to *landscape* pressures and adjust; *reconfiguration*, in which *niche*s are sufficiently developed for *regime*s to adapt their characteristics due to *landscape* pressures; *technological substitution*, where *niche*s either react to opportunities opened up by *landscape* pressures or build their own momentum sufficient to break down the *regime*; and *de-alignment and re-alignment*, under which *landscape* pressures dissolve the *regime*, and leave space for multiple *niche* innovations to take its place, ultimately leaving one new socio-technical system in place (Geels 2011). Despite this refinement of the MLP there is still the crucial and outstanding question as to how to apply this theory: what to measure and how? Catering to this final shortcoming, the up-scaling framework of van Doren *et al*. (2018) is chosen as an operationalization of the MLP, due to the specific factors it outlines and the manner in which it differentiates between the spatial reproduction of *niche* experiments (or horizontal pathways) and the institutional embedding of *niche*s (or vertical pathways).

3.3. Up-scaling low carbon urban initiatives – an operationalization of the MLP

As indicated, the taxonomy developed by van Doren *et al*. (2018) is used as an operationalization of niche-regime relationships. This framework establishes a classification of different elements that can contribute to the spatial expansion and reproduction of LCUIs, as well as the institutional and regulative embedding of these initiatives, both of which are necessary for enabling the transition process of the MLP. Next to this, as mentioned, the up-scaling framework tends to a number of the above-mentioned critiques of the MLP in the process of operationalizing it.

Theories discussing the scalability of LCUIs speak directly to the role "pioneers" or "leadership" carry in assessing, and ultimately overcoming potential barriers and utilizing opportunities in the context of sociotechnical transitions (van Doren *et al*. 2018, 2016). In this sense, actors and agency are given a much bigger role than in the traditional MLP. And while the up-scaling literature conceives of LCUIs in a similar manner to how the MLP sees *niche* experiments, it gives greater attention to the community aspect of bottom-up initiatives that are ultimately aimed at "strengthening community networks and ownership" (van Doren *et al.* 2018, 177). Finally, the literature outlines specific factors that influence the barriers and opportunities for up-scaling and allows for a more tangible and practical approach to analyzing the data. These factors are given in Table 1.

Van Doren *et al*. (2018) conceive of Low Carbon Urban Development (LCUD), as a" reconciliation between urban development and the mitigation of anthropogenic climate change" (van Doren *et al.* 2018 176). For this reconciliation to take place, a focus on LCUIs is necessary, as these are the *means* to achieve this reconciliation. There are two types of scaling-up pathways: *horizontal* and *vertical*. Horizontal up-scaling entails the spatial growth of an initiative. This means it can grow in size, or it can reproduce itself in quantity. In terms of VF, this could mean (1) having a larger farm sufficient to feed a greater geographical area than before (e.g. neighborhood instead of a street) or (2) having greater numbers of farms within a city. Vertical upscaling entails the structural learning and institutional transformations necessary for establishing a wider impact by LCUIs. This means that ideas, values, policy, and institutions are all meant to be transformed in the process of vertical upscaling, ultimately creating an enabling environment for Low Carbon Urban Developments (LCUDs) (van Doren *et al.* 2018). In terms of VF, this could mean favorable zoning regulation, subsidy schemes targeting this type of agriculture specifically, or even education activities.

At this point, two essential aspects of the linkages between the theories should be revisited. First, from the above emerges that within the MLP framework vertical upscaling entails a movement of *niche* innovations to the *regime* level by

Table 1. Factors in the up-scaling framework of van Doren *et al.* (2018).

Categories and factors	Description of factor
Measures for LCUD	
Financial Advantage	The profitability of investing in measures for LCUD by project developers and end-users
Reliability	The reliability of measures for LCUD in terms of technical, environmental and economic performance (at scale)
Low Complexity	The degree to which measures for LCUD are difficult to install by the project team and used and managed by end-users
Operational arrangements	
Leadership	A person who guides or directs a group in realizing and scaling-up the initiative
Stakeholder Involvement	The participation of representatives of organizations, communities, or interest groups that have a direct interest in the initiative
Resource Mobilization	The mobilization of financial, human, information, and technical resources
Communication	The exchange of information and ideas within the project team ('internal communication') or to external actors ('external communication')
Policy context	
Regulatory Policy Instruments	Policy instruments that use authoritative force to promote LCUD
Financial Policy Instruments	Policy instruments that influence the profitability of actions by providing financial incentives
Informative Policy Instruments	Policy instruments that make use of information and communication strategies conducive to offering actors insights into the environmental and economic implications of their behavior
Political Leadership	Government leadership in promoting LCUD at the national and/or local level
Trust in the Policy Framework	The level of trust in the stability and reliability of the policy framework by professional actors in the given sector
Market context	
Low Capital and Installment Costs	The purchase and installment costs of measures for LCUD
Expertise and Skills of Supply Actors	The level of expertise and skills regarding measures for LCUD of supply actors
Information Availability	The level of objective and reliable information available on measures for LCUD
Access to Credit	The extent to which project developers and consumers can access credit to invest in LCUIs and measures for LCUD
Energy Price	The financial price paid for energy consumption
Social-cultural context	
Environmental Awareness and Values	The level of awareness and values of citizens concerning environmental sustainability
Natural and Built Context	
Technical Compatibility	Compatibility of the measures for LCUD with geographical conditions and technological infrastructure

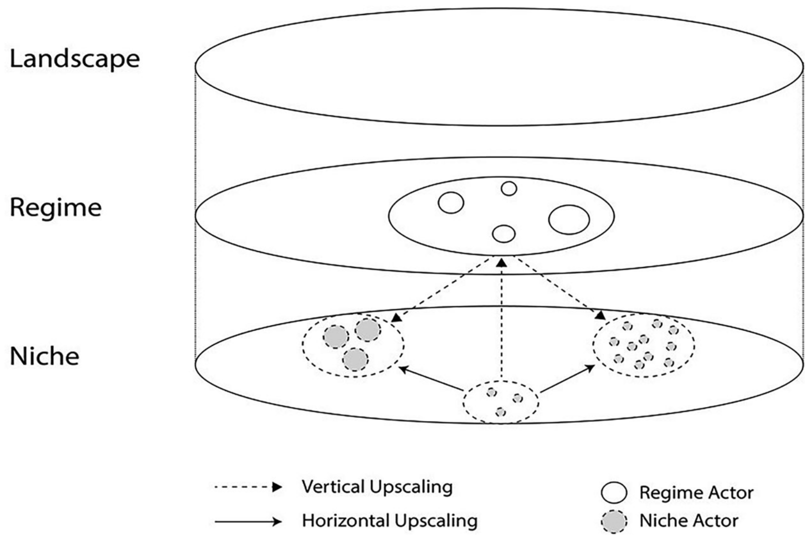

Figure 2. Interrelation of up-scaling and the MLP.

institutionalizing a number of factors of the given *niche* experiment; whilst horizontal upscaling entails the quantitative reproduction and growth of the *niche* experiment to an extent that it produces a critical mass sufficient to challenge and alter the existing *regime*. Second, it is essential to point out that in transforming *niche* experiments to *regime*s the two different pathways do not follow in a linear manner. They form a dialectic relationship, as the growth in the spatial presence of LCUIs (in the horizontal pathway) potentially informs institutional and regulative changes (in the vertical pathway) and *vice versa,* closing the loop. This relationship is outlined in Figure 2.

4. Methodology

This research uses an abductive research design. An abductive approach entails making a connection between theory and data in a reflexive manner (Teddlie and Tashakkori 2009), to the extent that a research problem can be approached through a theoretical lens – carrying elements of deductive thinking, whilst the findings of the research can also contribute to refining the theory – adding elements of inductive thinking. The primary reason for taking this approach lies in the fact that the upscaling theory developed by van Doren *et al*. (2018) – is based on an extensive literature review and while the set of factors that emerged from this review has been tested empirically, the juvenescence of the theory suggests that additional empirical analyses can add refinements to the set of analytical factors and variables. The abductive research design allows for the emergence of further explanatory variables. It opens up an opportunity to contribute to the upscaling framework on a theoretical level by allowing for a new set of explanatory factors to emerge.

In order to understand the upscaling potential and desirability of VF, 17 semi-structured key informant interviews have been conducted with prominent actors working in the field of UA and VF particularly. The interviewees were selected through a mix of purposive and snowball sampling. The interviewees consisted of three

Table 2. Profiles of interviewees (anonymized due to ethical considerations).

#	Position	Constituency/context	Type of actor
01	Professor of Urban Planning	The Netherlands	Researcher
02	Professor of Food Planning	Germany / Europe	Researcher
03	Systems and Sustainability Consultant	The Netherlands	Private Consultancy
04	CEO of networking firm working with vertical farming	The Netherlands	Private Consultancy
05	Food Urbanist	The Netherlands	Independent Consultancy
06	Founder/Owner of Greenhouse technology supply company	US / North America	Private Business
07	Independent Agriculture Consultant	The Netherlands / Spain	Private Consultancy
08	Founder of a startup incubator with vertical farm	Global	Private Business
09	CTO Vertical Farming Startup	Global	Private Business
10	Professor Horticulture and Product Physiology	The Netherlands / Global	Researcher
11	Founder of a vertical farming company	Finland / Global	Private Business
12	Aquaponics expert	The Netherlands	Independent Consultancy
13	Global Director of multi-national company working with vertical farming	Global	Private Business
14	Business Growth Manager	Germany	Private Business
15	EU Affairs Officer	Belgium / Global	Industry Association
16	Innovation Manager Horticulture Business	Germany	Private Business
17	Planner	The Netherlands	Municipal Actor

researchers, five consultants, seven private business actors, one municipal actor, and one industry association representative. Their profiles are outlined in Table 2.

The interviewees represented European, and North American regional contexts primarily. By assessing the perception of these actors based on their experience from working with VF, the deeper contextual understanding, going past public discourse and policy documents has been explored.

In order to cater to the abovementioned abductive design, the first part of the interviews covered open-ended questions to allow for the emergence of explanatory factors that the interviewees found relevant in terms of opportunities and barriers when it comes to upscaling VF. The final set of questions was based on the analytical factors outlined by van Doren *et al.* (2018) in their upscaling theory. The sequence of the questions was structured in this manner to avoid influencing respondents and to allow for non-theorized factors to arise. Overall, the interviews were recorded with the participants' permission, and transcribed. If consent was not provided, notes were taken, and a write-up of the interview was drafted within 24 hours after the interview in order to preserve all relevant information.

Initially, the interviews went through a process of coding, which was done digitally. As a first step, the taxonomy was applied as a predefined set of codes to the interviews, in order to extract and categorize the information in a deductive manner. This being said, due to the abductive approach of the research design, a separate pool of codes was opened in order to ensure that information not fitting within the framework of the taxonomy can also be utilized – in an inductive manner. The extra pool of codes, which emerged from the data, was refined by an axial mode of coding. This

Table 3. Summary of potential actions for integrative functions.

Function	Action
Marketability	Developing a narrative around sustainability Marketing sustainable produce Producing high-value crops
Environmental Sustainability	Applying principles of circularity at the level of the farm Maintaining the lowest level of complexity possible
Built Context	Utilizing available waste streams (e.g. thermodynamic, household-level organic, etc.) Utilizing excess energy (from grid, or from decentralized production systems) Incorporating renewable energy sources without raising complexity Assessing the role of the farm for grid loads of wider urban environment
Education	Granting access to the technology to widen consumer understanding Creating open nurseries Creating visitor centers
Community Engagement	Engaging members of the local community Mobilizing relevant public institutions Partnering with local businesses

means that generic similarities between the remaining pool of codes was assessed based on conceptual overlaps (Charmaz 2006), ultimately resulting in seven new factors.

5. Findings

The findings are organized along the lines of the three-tiered lens of the multi-level perspective (MLP). First of all, on the *niche* level, in this early phase of innovation, the upscaling of VF solutions has the most potential by integrating functions at the farm level, for the sake of establishing reliable and viable farms. Secondly, in terms of viewing the *regime* of the food system, when planning for sustainable urban and regional food systems, VF should be considered as one element of wider, planned systemic solutions, and not a *one-size-fits-all* answer to food production related sustainability challenges – this is particularly the case in light of the contextual conditions, which were mentioned in section 2. Finally, in terms of *landscape* pressures, processes in the (neoliberal) political economy directly affect developments in the field of VF. This becomes particularly evident through the connections emerging between global dynamics of trade and growth and localized social, economic, and environmental effects in food chains. The embedding of these three key findings are further elaborated in the sections below, with accounts of the interviewees indicated by 2-digit codes.

5.1. Integrative functions of vertical farming on the niche level

As already mentioned, most interviewees indicated that at the immediate level of the farm, they integrate further functions, or envision the utility of doing so in hypothetical scenarios. This is necessary in order to ensure reliable and viable business models in the innovation phase. In broad terms, these functions can be broken down into five categories: Integration for a) marketability, b) environmental sustainability, c) the built context, d) education, and e) community engagement (see Table 3 for summary).

First, in terms of marketability, the farm should integrate functions in a manner conducive to creating sufficient markup in monetary terms. Seeing that the profit margins in traditional horticulture industries are relatively small (015), an even more technologically intense mode of food production runs the risk of becoming cost inefficient. Hence integrating functions that enhance profitability, such as developing a narrative around sustainability and focusing on the marketing of sustainable produce is a key element for success at this stage (01, 03). Next to this, focusing on produce quality, by producing high-value crops, non-edible medicinal plants, or greens that cannot be transported long distances carries opportunities in this phase of innovation (03, 02, 09).

Second, functions enhancing environmental sustainability, and particularly principles of circularity at the level of the farm also carry opportunities (03). A concept such as the Polydome (Except 2011), an integrated greenhouse utilizing principles of poly- and permaculture, with plants, animals, and fungi producing a wide variety of products and simultaneously fulfilling ecosystem services, illustrates this. A further example is the BioMakery concept, which is a type of circular farming system that not only aims at producing greens in the urban environment but also fulfills ecosystem services, such as water purification (Biopolus 2018). Furthermore, integrating waste heat to and from farms also carries opportunities. This can be done at the building level or even potentially at the district level, as suggested by Gentry (2019). This suggestion was reflected by a number of interviewees who suggested the integration of cooling water into district heating, or the use of excess heat from server farms for example (01, 03, 09). This being said, as also outlined by the experts interviewed, it is essential that integrating such functions does not result in raising the complexity of the farms to an unmanageable level, as this has been suggested to be one of the key sources of failure in the past (16).

Third, contextual factors, particularly with regards to the built context have to be taken into consideration when planning viable farms. This factor points toward *regime*-level dynamics, as the contextual factors can be divided into farm-level factors and wider urban and regional level factors. Here the first set is discussed as this is directly related to *niche* level processes, while the latter is discussed below. At the scale of the farm, utilizing general waste streams derived from the built environment carries great opportunities. This means, for example, utilizing thermodynamic waste from industry or incorporating elements of nutrient recycling from household-level organic waste. Next to this, utilizing excess energy from power plants from, for example, hydropower plants placed close to cities also carries prospects for enhancing the viability of a farm. Finally, incorporating renewable energy sources – particularly if available on a wider urban scope - also has potential. Nevertheless, related to this last point it should be stressed once again that integrating functions should not raise the complexity of the farm directly, as this can result in unwanted effects, or even failure. Ultimately, those working with VF should ask how an energy consumption node such as a vertical farm could contribute to balancing peaks and dips in the grid-system, and uptake clean energy for its demand.

With regards to the last two integrative functions – integrating functions for education and functions for community engagement – the clear opportunity lies in the fact that such functions open up the black box of the vertical farm, whilst they also do not directly raise the technical complexity of the farm. By this, they do enhance the acceptability of a technology, which is generally met with skepticism (16). With regards to educative functions, if one envisions VF as a part of future urban food systems, it is essential that the black box is opened up and the consumers gain a degree of understanding of the technology, conducive to its acceptance. By creating nurseries and visitor centers for example, the general understanding of the technology can be enhanced at the public level and the exposure to food production can stimulate reflection on the dynamics of food production. However, these activities should be designed with food safety regulations in mind.

Finally, integrating community engagement into VF carries opportunities for upscaling, due to the social function food carries, as outlined by Steel (2008). She argues that historically, food from market place to dinner table has been a key element in forging cultures and communities, and that with the emergence of longer foodchains and the supermarket culture, societies have lost these breeding grounds. Hence, engaging immediate stakeholders in a farm – members of the local community, public institutions, and even small-business owners – can result in greater legitimacy in the public eye. By engaging the public and opening up the black box of VF, there is a great opportunity for reconnecting people with food, as well as with their immediate communities.

All these points are summarized in the table below. They highlight that opportunities, when it comes to planning interventions in urban and regional food-systems, have to be multi-dimensional and take a systemic perspective. In this sense, when planning to introduce VF into cities, one should consider wider environmental, social, and economic implications and see that the emerging field of food planning and technologically intense interventions such as VF lever opportunities, but also create implications. As Ilieva (2016) fittingly outlines,

> not only can agrifood system infrastructures be integrated into the built environment, but, most importantly, they can provide the basic principles for steering new urban development. (65)

5.2. Food systems and vertical farming on the regime level

Seeing the above outlined list of integrative functions, it becomes apparent that there are clear opportunities on the *niche* level for upscaling VF by adding further functions; but the true power of such socio-technical interventions lies in the fact that they also carry wider systemic implications. This section argues that on the *regime* level, when planning for sustainable urban and regional food systems, VF should be considered as one element of wider, planned systemic solutions. A growing body of research is emerging on the front of urban and regional food planning (Amsterdam Institute for Advanced Metropolitan Studies (AMS) 2018; Forster and Escudero 2014; Cohen and Ilieva 2015). This thinking, resonating with the accounts of the interviewees, conceives of food planning most suitable through urban and regional scale systemic solutions (01, 03, 04, 17). Hence from such a perspective, the true potential of VF lies in contributing to shorter food chains from global to local, by introducing supply-end solutions in cities and the direct food-related resource flows of cities. However, this also holds true for other types of interventions, such as roof top farms or community gardens.

Steel (2008) discusses the risk of one-dimensional conceptions of food systems, producing seemingly fitting, simple solutions in the framework of monocultures. As she suggests, these perspectives are doomed to fail, as they do not recognize the contextual, historical and social reality of food systems. Such conceptions promise singular interventions with the promise of systemic solutions. This is a direct critique of the types of one-dimensional accounts put forward by Despommier (2010) c.s. about feeding the world by introducing VF. As mentioned before, this critique and the adjoining awareness of the limitations of single socio-technical interventions also resonated through multiple interviews (13, 16). Hence, it is clear that the complexity of urban reality necessitates that VF, while carrying potential both from the perspectives of reducing resource use and of localizing food production, should not be assessed from the perspective of single supply-end interventions.

A further point that reinforces this dynamic is to be found in the high upfront costs of VF solutions (01, 05, 08, 10, 02, 16) alongside the (so far) lacking financially viable and independently profitable farms (02, 13). This means that VF as a technology can be useful, but primarily as a component of a system where these costs are counterbalanced through carefully planned interventions involving the necessary political support for wealth redistribution in the form of subsidy schemes targeting supply-end solutions (03, 09, 17). However, this requires conceiving of VF as an element of a wider urban or regional food system. For example, when conceiving of necessary interventions in systemic terms, alternative scaled logistic systems can come in handy. Connecting the newfound producers with end consumers is a key component of such systems; hence it is not enough to introduce VF solutions in and among themselves. Seeing that established food chains work with established logistics systems, it is essential to create and scale this alternative logistics system in order to connect local producers with local consumers (03).

Moreover, it is essential that on the *regime* level, accounts and perceptions of growing consumer interest in local, fresh, and organic produce should be treated with skepticism (04, 06). Here, social and power relationships play a great role. As Cohen and Ilieva (2015) outline, economic standing and urban food *landscape*s overlap substantially. Parallel to the upper-middle class shifts in perceptions of food, accounts of fast-food culture and rising rates of obesity in OECD countries resulting from processed foods and unhealthy diets sustain (OECD 2017) (01, 03). This means that growing rates of inequality (Cohen and Ilieva 2015) have produced parallel urban realities, when it comes to food. Food culture and food systems, from supply-end solutions to the dinner plate and beyond carry clear implications in terms of socio-economic standing (03, 04) and these implications primarily manifest in uneven geographies of power (Cohen and Ilieva 2015). This is one of the great risks of VF in the current political-economic setting, as is outlined below. Hence, it is essential to make interventions with the above outlined socially focused integrative functions in mind. Cohen and Ilieva (2015) recommend the strategic management of food practices as a potential solution, however adapting elements from alternative *niches,* such as Food Networks (Goodman, Cruz, and Goodman 2009; Forssell and Lankoski 2015) or Community Supported Agriculture (Tregear 2011) carry potential too.

This recommendation falls in line with *regime*-level developments in terms of political institutions. As mentioned, the emergence of municipal-level food councils and national food strategies (02, 15, 17) contribute to the creation of the necessary governance *milieu,* which systemic-level planning interventions require, and which can ultimately alter food *landscape*s and systems with sustainable and socially inclusive principles in mind.

Finally, closely related to the previous section, contextual factors should also be taken into consideration on the *regime* level (03, 09, 10, 11, 14, 15). This means that the geographical context of cities necessitates different kinds of VF interventions and different kinds of systemic solutions on the regional-urban scale. The primary factors to consider here, which emerged from the interviews, are crop availability (both in terms of variety as well as distance), the density of the given city, the geographical size of the city, the reliance on imports of fresh produce, and the type of electricity supplied to the grid. The latter is a key factor if conceiving of VF in a city, which is locked into a fossil-fuel heavy grid, where renewable energy production or import is unavailable. In this type of context, VF may actually contribute to GHG emissions. These types of factors should clearly be considered when planning VF interventions, as well as urban and regional food systems.

5.3. Global dynamics of the political economy and local implications for vertical farming on the landscape level

The final finding is related to conditions of the (neoliberal) political economy, which directly affects developments in the field of VF. These findings can be clustered into two broader groups – the first relates to how farms and their operating companies function and relate to each other, whilst the second assesses the interactions of farms with other actors, such as governments, the developing industry association, and actors in peripheral industries. Both clusters highlight the structural constraints of the current political economy.

First, in terms of their functioning and the relationships between farms; the competitive nature of the industry is an inherent given due to the structural conditions of the political economy. This competition can either drive innovation and result in a race to the top or create silos lacking cooperation and result in a race to the bottom. A number of interviewees indicated the risk of the second in the field of VF (04, 15). This is essentially a consequence of a number of structural conditions, in particular distrust, competition and resulting knowledge silos (04, 09, 10) ensuing the patenting of intellectual property, and the lack of a much-needed platform for knowledge sharing and cooperation. A further point mentioned is related to the short-term profit focus of the industry (06), which closely ties in with the previously mentioned structural condition of venture capital financing, resulting in the creation of farms able to raise investment and capital, but rarely profitable operations (06). Closely related, the extractive tendency of the industry was also highlighted, as certain companies utilize the upcoming food crisis to market their product with short-term profit generation in mind (09).

Secondly, regarding external actors, a number of interviewees working directly with farms mentioned an industry-level distrust toward the Association for Vertical Farming (AVF) (06, 09). This is due to the juvenescence of the AVF, which has not yet been able to reach the desired level of functionality common in more established *regime*-level arrangements. Next to this, the reallocation of finance in certain cases results in a resistance toward VF-related innovations. This is primarily manifest in agricultural subsidies, such as the Common Agriculture Policy (CAP) of the European Union targeting traditional agricultural actors and blocking the way for innovative practices to disrupt the *status quo* (01, 15). Finally, developments in peripheral industries, due to the liberalization of regulation, such as in the case of the North American cannabis industry, also hold opportunities for food production-related VF (06). As outlined, the liberalization of this industry has led to great interest in VF growing systems, which in effect hold the potential to further the technological aspects of the farms, ultimately also allowing for their maturation and more effective use in the field of food production.

All-in-all, all these elements reflect structural conditions, which primarily constrain the development of VF into a mature, *regime*-level industry. These constraints are reflected in the core qualities of the current globalized, neoliberal political economy, which favors competition over cooperation and knowledge sharing, risky short-term investments over long-term returns, and extractive business models over socially inclusive and truly sustainable ones.

6. Discussion

The three core findings herald three take-aways. Firstly, interventions aimed at reducing the resource use of cities require carefully calculated planning with a focus on not only one-dimensional interventions aimed solely on resource reduction; but ones, which also consider further positive and integrated effects. In this sense, conceiving of wider inclusive societal effects, for example, is clearly low-hanging fruit for VF entrepreneurs, and should be embraced not only for the sake of external impact, but also for the internal viability of the farm. Secondly, viewing VF within the *regime*-level processes of food systems is particularly useful, as this sheds light on the fact that singular VF interventions do not carry the necessary solutions for mitigating the climate impact of food in cities. By apprehending that the city is a complex web of resource flows, planners can also grasp the complexity of required interventions from the perspective of reducing the intensity of these flows, as is also outlined by Giezen and Roemers (2015). VF can potentially be a valuable contribution to such systemic restructuring; however, it will clearly not be a one-size fits all, singular solution to food induced climate change in cities. This is particularly so as contextual variables such as the source of energy fueling the electricity grid, water scarcity, logistics and distribution infrastructure all play a key role in the sustainability potential of VF. Finally, in general, VF has arisen in the current political economic system as a potential technological contribution to sustainable food production. Hence, systemic elements – such as the availability of funding and competition – have been conducive to the emergence of this phenomenon. Nonetheless, it is also essential to understand that if climate change is conceived of as a symptom of systemic problems, climate mitigation stops being a matter of solely technological interventions. In this sense, focusing on the social and political outcome of expanding such technologically intense modes of food production in cities becomes a key element in planning for sustainable cities.

All-in-all these take-aways suggest that in its current state, VF faces a mix of two potential pathways of transition. These carry (1) elements of *technological substitution* and (2) elements of *de-alignment and re-alignment*. As can be seen, a number of key *landscape*-level drivers, such as climate change, urbanization, population growth, etc. opened up opportunities for experimentation in the field of agriculture. Nevertheless, the principle *landscape* pressure – that of the current political economy – serves as resistance toward disassembling the incumbent *regime* as would be expected under a pathway of *technological substitution*. Another set of increasingly apparent *landscape*

Table 4. Summary of findings (amended framework of van Doren *et al*. (2018)).

Categories and factors (amended framework of van Doren *et al*. 2018)	Description of new factors	Examples of actions and tradeoffs when scaling VF
Measures for LCUD		
Financial Advantage		- Building business models dependent on availability of land and real estate - Building business models focused on charging premiums (e.g. for herbs)
Reliability		- VF installation is constructed in self-contained, replicable, modular units
Low Complexity		- Elements and technology from horticulture industry is incorporated in VF - Standardization of components
*Integrative Functions**	The degree to which LCUD integrates further elements to ensure its resilience	- Integration of thermodynamic waste - Integration of educational activities in operations
Operational arrangements		
Leadership		- Visionary and powerful individuals vested in the success of the farm
Stakeholder Involvement		- Including immediate citizens in the operation of farms
Resource Mobilization		- Availability of components such as LED lights at a decreasing cost
Communication		- Communicating the proximity of produce to end consumers
*Logistics**	The presence of accompanying and complementary logistics infrastructure	- Development of alternative logistics networks that provide sustainable last mile solutions
Policy context		
Regulatory Policy Instruments		- Adjusting zoning to reflect the complexity of VF (industry and agriculture) - Developing city-wide food strategies
Financial Policy Instruments		- Subsidies targeting Urban Agriculture with a yield focus - Subsidies targeting GHG emission reductions with stringent conditions
Informative Policy Instruments		- Informative packaging and labeling of produce conducive to enhancing acceptability of VF as a technology
Political Leadership		- Progressive leadership at the municipal-scale
Trust in the Policy Framework		- Institutionalization of food in public administration (through municipal food councils)
Market context		
Low Capital and Installment Costs		- High installment costs generally result in venture capital funding models

(*Continued*)

Table 4. (*Continued*).

Categories and factors (amended framework of van Doren *et al.* 2018)	Description of new factors	Examples of actions and tradeoffs when scaling VF
Expertise and Skills of Supply Actors		- Integration of a wide-variety of knowledge (planning, engineering, horticulture, etc.) - Working with instead of in competition with established horticulture actors
Information Availability		- Shift to collaborative development models instead of competitive ones - Focus on plant physiology instead of engineering as starting point
Access to Credit		- Creation of financing methods from traditional lenders (past venture capital funding)
Energy Price		- Scoping of low-cost electricity with potential in regions with subsidized renewable energy sources
*Market Dynamics and Conditions of Peripheral Industries**	The degree to which LCUD integrates elements from close industries to ensure its resilience	- Growth of markets that use similar growing components (e.g. cannabis or floriculture)
*Insurance**	The extent to which insurance is available for high-risk investments in the LCUD	- Making a viable business case to insurance companies (e.g. why retrofitting a building is suitable)
Social-cultural context		
Environmental Awareness and Values		- Assist end-consumers to better understand the black-box of VF technology and under what conditions it can contribute to sustainable development
*Consumption Culture**	The attitudes of citizens linked to the product or service of the LCUD	- Focus on nutritional needs and food culture of given region
*Product Qualities**	The qualitative attributes of the product or service of the LCUD	- Admission that VF produces plants and cannot satisfy all nutritional and gastronomical demands
*Social- and Power Relations**	The degree to which LCUD considers power positions between producers and consumers	- Social acceptability of technology conditioned on availability and accessibility - Shifting from extractive to collaborative industry model
Natural and built context		
Technical Compatibility		- Consider contextual elements such as availability of sun hours, share of renewable energy in grid, density and fresh produce availability

pressures, such as long food chains, and the resulting unsustainable production technologies put pressure on current food systems, essentially opening space for experimentation on the urban scale with technologies such as VF. This means that there is potential for elements of *de-alignment and re-alignment* to emerge in urban food systems, leaving space for new technologies to emerge.

Finally, due to the abductive research design, the above results also indicate that in broader terms, when studying LCUIs and the resulting LCUDs, there is space to assess a number of different factors, which ultimately serve as a theoretical contribution. The empirical testing of the upscaling framework resulted in the necessity to update it, and in effect further cater to some of the abovementioned critiques of the MLP. In the process of data collection and analysis seven additional explanatory factors emerged. In and among themselves these seven emerging factors create an extra layer of depth when assessing the potential for upscaling VF in cities. Nonetheless, by re-embedding them in the framework developed by van Doren *et al*. (2018) their true utility for further applications of the taxonomy can also be explored. The revised taxonomy including emergent factors is outlined below, with the emergent factors being marked with an asterisk. The key considerations in terms of upscaling VF are also outlined in this scheme. (see Table 4).

Regarding the emergent factors, first of all, integrative functions can be seen as an extra factor informing measures for LCUD. The reason for this is that by ensuring that LCUIs become means to multiple ends, extra benefits can be reaped through seemingly singular interventions. Second, with regards to logistics, it can be said that it is a crucial operational arrangement for any type of intervention working directly with produce (rather than service provision). It can be hypothesized that this factor was excluded from the initial taxonomy, as it was developed with a focus on energy infrastructure, which does not necessarily involve direct distribution logistics focused on produce; rather it deals with the infrastructure necessary for the provision of a service. Third, market dynamics and conditions of peripheral industries are a key factor when assessing the market context. Particularly with regards to the pricing of any type of component required by LCUIs, the viability and ultimately the upscaling potential will be directly affected by this factor. Fourth, insurance also entails a clear factor in the market context, as the assessments of insurance companies, and their willingness to enter into agreements with initiators of LCUIs can directly affect the final form of the initiatives. Fifth, with regards to consumption culture, it can be said that this is a crucial element when it comes to the social-cultural context. By amending this cluster with this factor, the inherent agency of individuals can be highlighted with regards to consumption choices and resulting societal consumption patterns, which can directly affect the success of LCUIs. Sixth – closely related to the argumentation supporting the logistics factor – when planning for LCUIs that result in changes in the production method of produce specifically, it is essential to assess the quality change in the produce. This is categorized as a factor informing the social-cultural context, as the quality changes in the product are ultimately judged in light of the norms, values, and expectations of the end consumer. Finally, the factor regarding social- and power relationships highlights the fact that all initiatives aimed at decarbonizing cities are inherently political in nature, as they involve decisions resulting in the allocation of financial, social, as well as natural resources within cities and their communities.

7. Conclusions

This research set out to assess the potential for upscaling VF through gaining an in-depth understanding of the perspectives of experts working in this field, and ultimately aimed at exploring the role VF can- and should take in future cities from the perspective of sustainability and climate mitigation. This was done by asking the question*: (How) can vertical farming contribute to mitigating the climate impact of urban food systems?* In order to assess this contribution, and to understand how urban planning should accommodate and make use of developments in this field, a qualitative research design was chosen, which scoped the perspectives of a variety of experts, through 17 semi-structured key informant interviews. The MLP (Geels 2002, 2011) was applied to the wider analysis due to its explanatory power when it comes to processes and dynamics of socio-technical transitions in broad terms. Building on this, the upscaling framework (van Doren *et al.* 2018) was utilized as a practical operationalization of the MLP as it points toward a number of tangible factors, which can inform the upscaling of *niche* experiments, such as that of VF.

All in all, the growing body of literature discussing urban food systems allows for a contextualization of the problem at hand. In terms of theory, the Multi-Level Perspective (MLP) establishes the basis for understanding how *niche* sustainability experiments can challenge dominant *regime*s, and how this process is affected by broader exogenous factors. Nevertheless, as already mentioned, this framework has been criticized on multiple occasions, particularly for overlooking the social and political tensions which arise from transitions and, for this reason, the closely related framework of upscaling has been chosen in order to operationalize the MLP and cater to these shortcomings. By applying the upscaling framework to the case of VF more space is left for assessing the role of agency when evaluating a sociotechnical transition; second, conceiving of bottom-up processes is more possible, and finally explicitly addressing the emerging opportunities and barriers in the process of upscaling LCUIs due to the extensive taxonomy of contributing factors becomes possible. By analyzing opportunities and barriers the potential pathways can be better understood, and potential directions can be outlined for overcoming barriers and transforming them into enablers of action – as put forward by Burch (2010).

Three core findings emerged from applying the established theoretical frameworks to the socio-technical reality of VF. These can fittingly be viewed through the MLP framework developed by Geels (2002, 2011). First, in terms of *niche* developments, the integration of functions at the farm level is imperative to the viability and reliability of the farm. A five-fold classification of these integrative functions was developed including integration for marketability, environmental sustainability, the built context, education, and community engagement. This classification was not preconceived, as none of the consulted literature pointed toward the necessity to reinforce innovation and experimentation in the field of urban agriculture with further functions. However, it is sensible that technologically complex, and in terms of viability, uncertain innovations, require this type of support for success. Secondly, on the *regime* level, it can be said that VF should be conceived of as a potential supply-end intervention in what are larger, urban and regional food systems. This point is crucial, as it highlights that singular interventions aimed at mitigating the climate impact of cities are ill advised; given that they should be embedded in larger planned frameworks assessing urban and regional food systems. In light of the growing literature discussing the necessity to plan with food systems at the urban scale (Amsterdam Institute for Advanced

Metropolitan Studies (AMS) 2018; Forster and Escudero 2014; Cohen and Ilieva 2015) this finding is not of an unanticipated nature. This does, however, mean that contextual variables such as renewable energy availability and existing logistics networks need to be considered to adequately judge whether VF is an appropriate intervention in differing contexts. These considerations do, however, point toward the utility of assessing technological developments and singular interventions in the light of wider, systemic effects; as well as the necessity to guide and plan for these self-standing socio-technical experiments from the perspective of urban food systems.

Finally, with regards to *landscape* pressures, it can be said that the globalized dynamics of the neoliberal political economy have clear local implications, which affect VF in a dialectic relationship. This means that, on the one hand, the conditions of the political economy have set the stage for the emergence of capital- and technology-intensive food production methods, which could potentially also reduce the climate impact of cities; while on the other hand, the specific investments structure and resulting socio-political reality also further the inherent growth-oriented dynamics of the political economy, which has been traced to be one of the root causes necessitating climate interventions in cities, such as VF. Seeing the political philosophical roots of this finding, it was already hypothesized at the outset of the research that there is an interrelationship between the globalized neoliberal political economy, the environmental problems resulting from the core logic of this system, and the proposed technological solutions to these problems. Put simply, this finding points toward the risk apparent in treating environmental problems – the symptoms of a faulty political economic system – by introducing technologically intense interventions capable of providing only frivolous and superficial solutions, within the exact same political economic framing. Essentially, this finding calls for the reassessment of production relationships and their socio-political framing from the perspective of environmental problems and climate mitigation.

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