sustainability

MDPI

Article

Transformative Potential of Vertical Farming—An Urban Planning Investigation Using Multi-Level Perspective

Jost Buscher [1,*], Julija Bakunowitsch [1] and Kathrin Specht [2]

[1] Research Group Urban and Regional Planning, Department of Spatial Planning, TU Dortmund University, 44227 Dortmund, Germany; julija.bakunowitsch@tu-dortmund.de
[2] ILS—Research Institute for Regional and Urban Development, 44227 Dortmund, Germany; kathrin.specht@ils-forschung.de
* Correspondence: jost.buscher@tu-dortmund.de

Abstract: Due to different global trends, such as climate change and urbanization, challenges to the food supply in cities have become more permanent. As a new form of efficient and climate-resilient food production, vertical farming addresses these challenges but is not yet fully embedded in the context of urban planning. Thus, from the perspective of urban planning, this investigation aims to assess the potential of vertical farming in the context of large-scale transformation. Therefore, this paper uses the multi-level perspective. In this context, vertical farming is a so-called niche innovation at a lower level that forces establishment in the superordinate regime—here, urban planning. By using the strengths, weaknesses, opportunities, and threats (SWOTs) methodology, this paper presents the advantages and disadvantages of vertical farming, as well as its implications for urban planning. A final comparison of these aspects leads to six conditions paired with recommendations, which are considered necessary for the successful stabilization of this niche innovation.

Keywords: vertical farming; urban planning; urban sustainability; transformation research; multi-level perspective

Citation: Buscher, J.; Bakunowitsch, J.; Specht, K. Transformative Potential of Vertical Farming—An Urban Planning Investigation Using Multi-Level Perspective. *Sustainability* **2023**, *15*, 15861. https://doi.org/10.3390/su152215861

Academic Editor: George D. Bathrellos

Received: 13 October 2023
Revised: 8 November 2023
Accepted: 10 November 2023
Published: 11 November 2023

1. Introduction

Ongoing global population growth and overall rising affluence are inevitably leading to increased demand for food [1–3]. Since, according to forecasts, approximately 68% of the world's population will be concentrated in cities by the middle of this millennium, the demand for food is particularly increasing in cities [4]. Moreover, progressive climate change leads to the necessity for urban transformation. Such transformation requires cities to combine and intensify climate protection on the one hand and climate adaptation on the other hand. Both challenges occur prominently in the urban context and, therefore, address urban planning. The latter focuses on the development of sustainable cities and communities in line with Sustainable Development Goal (SDG) 11 of the 2030 Agenda, which also contributes to ending global hunger in line with SDG 2 [5]. In addition to urban contexts, the pressure to act around climate protection particularly affects the agricultural sector, as this sector is currently responsible for approximately a quarter of global greenhouse gas (GHG) emissions [6]. Climate-related developments are already leading to a worldwide decline in fertile arable land, which makes it difficult to ensure a secure food supply.

1.1. Vertical Farming and Urban Planning

For this reason, vertical farming, which is a concept for the high-yield cultivation of food in the vertical dimension in urban spaces, has emerged as an innovation. According to the original understanding, the goal of commercial surplus production is to be achieved through the efficient use of large spatial heights in an enclosed environment [7–9]. By using various technologies, such as hydroponics, aeroponics, or aquaponics, vertical farming

promises climate-independent land- and resource-efficient food production, higher nutrient content, and high profitability, as well as growing crops that are not suited to local conditions [10–12]. Thus, vertical farms can be classified as controlled-environment agriculture, building-integrated agriculture, and—provided no new land is used—zero-acreage farming [13–16].

Nevertheless, these efficiency advantages cannot yet be fully exploited, especially in view of the high energy consumption of vertical farming and limited crop types, which are often discussed in the literature [12,17–19]. The literature also indicates that vertical farming is accompanied by a further commodification of food and displacement effects in urban areas [6,20]. While the previous discussion on vertical farming, which focused on efficiency arguments, does not appear to be conducive to a broader assessment of potential, other dimensions of sustainability are considered more and more. Although the built environment of innovations such as vertical farming is rarely part of the relevant analyses, the perspective of urban planning has still not yet been strongly emphasized [21].

Moreover, vertical farms currently exist predominantly on a small scale and are spatially located mainly in America and East Asia [6,14]. However, the current need to address this concept in the European context or, in the present, study mainly the German context, arises from the fundamental contradiction between the need to produce increasingly more food on the one hand and the use of increasingly fewer climate-adapted and local resources on the other hand.

Since the last World Food Summit (2021) in New York, the importance of science, especially with regard to a sustainable transformation of food systems, has been emphasized [22]. In order to precisely approach these complex issues pertaining to a far-reaching process of social change, transformation research offers a suitable framework. While there are different approaches, it is generally recognized that global crises that threaten to transcend planetary boundaries can be addressed only through transformations as large-scale and ongoing emergent processes of change [23–28].

A heuristic approach in this context is the multi-level perspective, which is helpful for understanding complex dynamics in innovation research. Here, vertical farming can be categorized as a niche innovation and can be examined in the context of the regime level—urban planning—and the landscape level—climate change. For the following analyses, it is also useful to identify possible transformation pathways for vertical farming to become more permanent in the regime. To date, vertical farming has not been sufficiently studied as a possibly disruptive innovation in the course of transformation research for the urban context. Only Petrovics and Giezen (2021) have already classified vertical farming as a niche innovation using the multi-level perspective [6]. However, they focused on the food system, whereas this paper will subsequently examine urban planning.

Here, urban planning is understood as a primarily state-led task and as an interdisciplinary field that exerts a significant influence on the future development of cities. In the narrower legal sense, urban planning in Germany must prepare and regulate the use of land in a municipality. Due to the spatial concentration of people, economic power, resource consumption, and emissions in cities, cities play a key role with regard to the issue of sustainable development in the sense of the 2030 Agenda, and they represent a suitable context for analyzing the transformation potential of vertical farming [23,27,28]. The framework for sustainable development in Europe—the New Leipzig Charter 2020—also recognizes the transformative power of cities [29].

1.2. Research Gap and Objectives

As the spatial scales of cities and regions play only a minor role in today's food supply, the shift to global relationships and supply chains poses challenges, including for cities themselves [30]. Today, a glaring mismatch can be noted between the planning concerned with the food system and the claim of sustainable and integrated urban planning, although food supply still represents the fundamental provision of general interest [13,30]. Not only is this true for practice in urban planning offices, but it must also be criticized in the

fields of research, teaching, and politics [13,30,31]. In this context, it is often emphasized that the food system is a rural issue and that food supply falls within the competence not of local government but of the free market [30–32]. The topic is only slowly being taken up in urban planning discourse; since the 2000s, there have been signs that municipal planning is evolving with regard to the food system and recognizing corresponding sustainability potentials [20,33,34]. There are also recommendations in Germany to harness the transformative power of cities with regard to the food system [28].

On top of that, the spatial embedding of innovations—in this case, from the field of urban food production—is lacking in transformation research and in the application of the multi-level perspective [35]. For this reason, this paper places the innovation of vertical farming in the context of urban planning against the overarching backdrop of climate change. This embedding is intended to provide an exemplary and new contribution to the integration of food production in cities through the combination of theories from transformation research (multi-level perspective) and classic methods from urban planning (SWOT analysis). The added value, therefore, lies in a more holistic view of sustainable urban planning that also addresses an intersectoral way instead of limiting the research to individual economic or technological aspects [19,35,36].

In order to be able to assess the transformation potential of vertical farming, first, we (a) clarify the extent to which vertical farming can be classified as a niche innovation from the multi-level perspective, as well as its advantages and disadvantages for urban planning. Furthermore, we (b) clarify under which conditions vertical farming can be established as a niche innovation in the regime of urban planning. Finally, we (c) address the question of which recommendations for action should be implemented by urban planning to promote vertical farming.

2. Theoretical and Analytical Framework

2.1. Analytical Framework and Methods

The analytical framework (Figure 1) of this study focuses on a theoretical-conceptual examination to assess the transformation potential of vertical farming for urban planning in a comprehensible way by using transformation research (Section 2.2) as well as the multi-level perspective (Section 2.3). Due to the lack of practical examples in the German context, the chosen approach promises an early approach to the topic. For this purpose, a critical discussion of the results (Section 4) is indispensable.

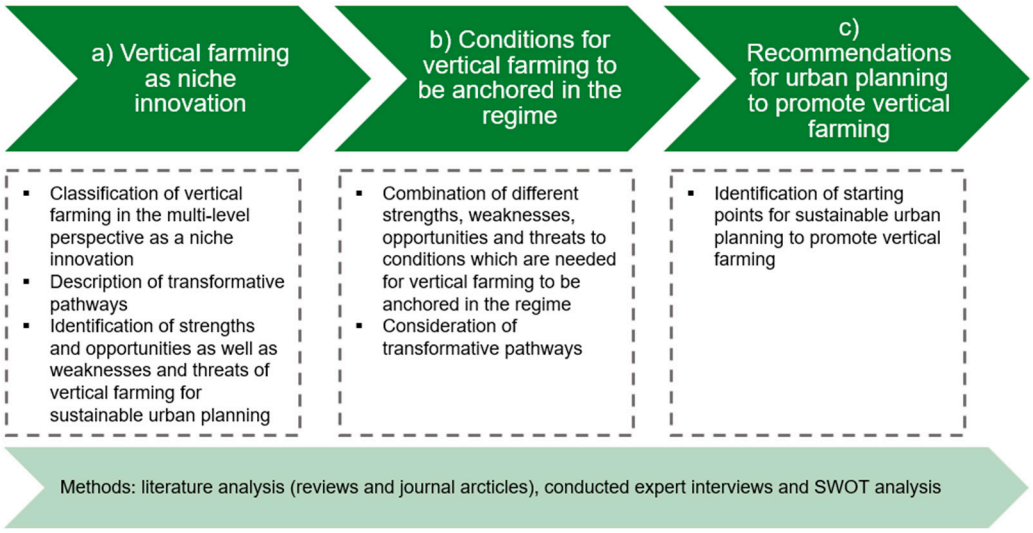

Figure 1. Analytical framework.

As a starting point, vertical farming was classified as a niche innovation. Based on the relevant reviews and other journal articles on the one hand and with reference to two expert interviews conducted with vertical farming companies on the other hand,

the advantages and disadvantages of vertical farming were identified. Then, using the strengths, weaknesses, opportunities, and threats (SWOTs) methodology, these advantages and disadvantages were first classified as strengths and weaknesses, which are factors that can be influenced, and as opportunities and threats, which are factors that cannot be influenced by urban planning [37–40]. In order to formulate the necessary conditions for the stabilization of vertical farming in the regime of urban planning, a linkage of the factors was made after this evaluation based on the method. In addition to the findings from the literature analysis, experiences from two expert interviews conducted with representatives of German urban planning authorities were considered. In the final step, key points on which urban planning can have an influence on supporting vertical farming companies were identified.

Thus, the chosen methodological approach of the present work focuses primarily on the scientific discussion and the theoretical embeddedness of vertical farming in the context of urban planning. Therefore, the less political, economic, or social discourse on this topic is examined. Due to the continuing gap in research between urban planning and the food system, predominantly, the transfer of work was essential to achieve results. Consequently, divergent assessments of sustainable urban planning in terms of the 2030 Agenda may be present in current practice related to this topic in planning departments.

Furthermore, the anticipatory character of the conditions for stabilization is necessarily associated with uncertainties. The degree to which the factors of vertical farming can be influenced can also be assessed differently, which makes it difficult to distinguish between the strengths and opportunities and between the weaknesses and threats [39,40]. Nevertheless, to address the area of competence of urban planning, recommendations for action in terms of the general conditions are ultimately formulated. In addition, individual factors are often kept general in SWOTs analysis [38]. However, given that this is a theoretical investigation of the niche status of vertical farming in Germany, it is suitable to identify more overarching points in the regime of urban planning.

2.2. Transformation Research

The concept of transformation goes back to Polanyi in 1944, who described profound social changes in the recent history of England [26]. Currently, however, the focus is less on historical developments and more on the anticipatory nature of transformation research [41]. Other characteristics of transformations as fundamental societal changes include the fact that such changes do not happen abruptly and can take decades [23,42]. Furthermore, transformations are characterized as dynamic changes with uncertainties, meaning that they do not occur linearly but emergently [4,23,41,43]. Moreover, transformations can bring a change in the socio-technical system, such as urban planning, and are also predominantly focused on the issue of sustainability [23]. Transformations can be analyzed more systematically through the differentiated view of the niche, regime, and landscape levels [26,44–47].

2.3. Multi-Level Perspective and Classification of Vertical Farming as a Niche Innovation

This three-level division takes up the multi-level perspective as a heuristic framework for understanding complex dynamics in innovation research and is suitable not only for analyzing systems but also for identifying transformation paths [26,44–46,48]. This way of looking at social, ecological, and economic innovation processes is applied not least in urban development [23,27,47–49].

The multi-level perspective states that innovations, such as vertical farming in this case, leave the niche level with the aim of stabilization in the regime precisely when a so-called "window of opportunity" opens under procedural conditions [44]. One precondition is that the landscape, which, here, is climate change, exerts pressure in the form of the need for climate adaptation on urban planning as a regime. In order to avoid exacerbating this over time, urban planning must address contributions to climate change mitigation. Another prerequisite includes internal tensions in the regime, which, here, is the increasing

need for greater engagement between urban planning and the food system for climate protection and climate adaptation reasons. To that end, urban planning must also assess the potential of the niche innovation of vertical farming. The third prerequisite is price and performance increases in niche innovations, which are considered fulfilled for vertical farming, especially in the future. Overall, the normative direction of transformation at the landscape and regime levels is toward sustainability. For vertical farming to become established in the regime, this innovation must first strive for economic efficiency (Figure 2).

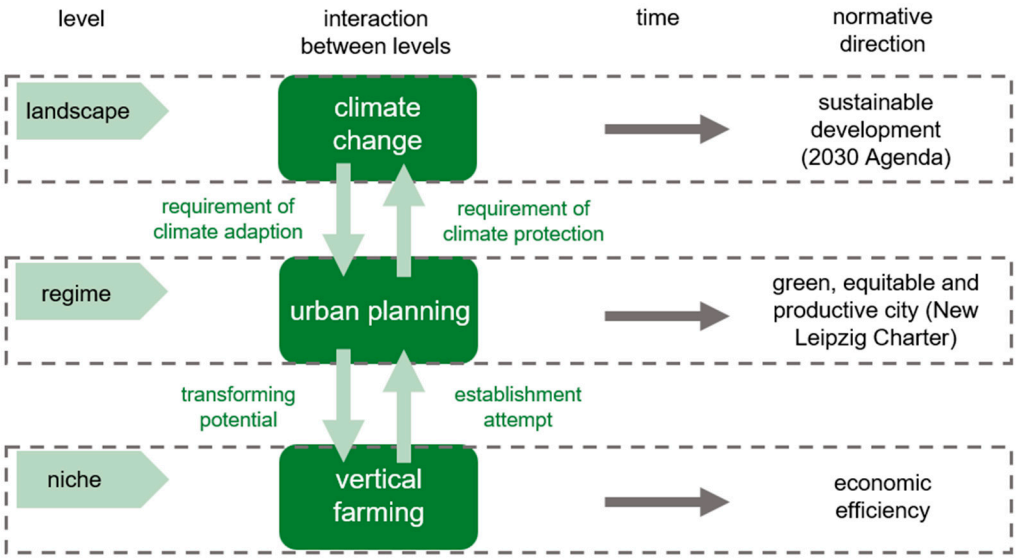

Figure 2. Vertical farming as a niche innovation from the multi-level perspective.

The superordinate level is the landscape, which, in this work, is climate change [47]. Climate change as a slowly but steadily progressing development on a global level cannot be considered in isolation from the other levels and is now leading, or will increasingly lead in the future, to clearly noticeable pressure to act in urban planning as a regime [26,44–47,49].

The regime level can be described as an interwoven network of different and diverse structures, and it has a co-evolutionary character due to the linkage of these elements [44,47]. Accordingly, regimes form a kind of dynamic stability; thus, only incremental developments take place based on an internal dynamic [44,45]. However, to satisfy societal needs, the regime has to adapt, e.g., due to pressure from changes at the landscape level [47,50]. Urban planning corresponds to the characteristics of a regime and must force rule-guided moderation for the future development of cities as complex social systems. Here, the interplay of material physical infrastructures or technologies as transformation objects on the one hand and immaterial modes of action of local actors as transformation subjects on the other hand must be considered [6,23,47]. So-called subsystems, such as transport and the economy, are, therefore, taken into account in the potential assessment of vertical farming and elaborated, albeit only implicitly.

As a third and lower level, the niche represents a limited application domain as well as a suitable and, from the regime, protected development space for innovations [26,45–48]. In terms of food system transformations, vertical farming is explicitly listed as an imaginable innovation and is currently developing as a regime largely independent of urban planning [51]. There is no guarantee that innovations will succeed. Thus, some may become established in the regime and even shape the overarching developments of the landscape in the long term, whereas others may fail [44,52].

However, if the processual conditions are fulfilled, there are several transformative pathways (Section 3.2). The first pathway (a) describes regime adaptation through repositioning, restructuring, or renewal through the acceptance of niche innovations [44–46,48,50,53]. Another pathway (b) envisions niche innovations intentionally diffusing into the regime (top-down), which may succeed, e.g., through reforming legislation, establishing infrastructures, or

regional alignment [44–46,48,50,53]. In contrast, in pathway (c), niche innovations can also diffuse unintentionally into the regime (bottom-up), e.g., through professionalization, the formation of communities, or the acquisition of recognition [44–46,48,50,53].

3. Results

3.1. Strengths, Weaknesses, Opportunities, and Threats of Vertical Farming for Urban Planning

For vertical farming, seven main strengths and two weaknesses that can be influenced as well as eight opportunities and four threats that cannot be influenced by urban planning are identified here (Tables 1–4).

Table 1. Strengths of vertical farming.

	Strengths
S1:	Reduction in shopping and transport traffic
S2:	More efficient use of urban heat
S3:	Vertical farming as a suitable reuse of brownfields and old building structures
S4:	Reduction in and recycling of organic waste
S5:	Contribution to urban economic growth
S6:	Vertical farming buildings as a flexible building block in urban planning
S7:	Vertical farming as part of an ecological building block for improving urban air and the microclimate

Table 2. Weaknesses of vertical farming.

	Weaknesses
W1:	Regulatory restrictions for vertical farms
W2:	Increased land pressure and competition

Table 3. Opportunities of vertical farming.

	Opportunities
O1:	Contribution to sustainable spatial development through efficient production methods
O2:	Contribution to water protection
O3:	Reduction in pesticides and fertilizers
O4:	Creation of jobs
O5:	Possibilities to control food production as a local market advantage
O6:	Nutrition education and food awareness creation
O7:	Contribution to urban food security and resilience
O8:	Healthier and more hygienic food production

Table 4. Threats of vertical farming.

	Threats
T1:	Increased urban energy demand
T2:	High initial investment and expensive operating costs for vertical farming companies
T3:	Selective supply due to limited farming methods
T4:	Acceptance problems of vertical farms and their products

3.1.1. Strengths as Influenceable Advantages of Vertical Farming for Urban Planning

An ecological interest in urban planning in vertical farming arises not only against the backdrop of reducing transport-related GHG emissions but also due to the avoidance of inner-city, traffic-related air pollutants. Since the location or accessibility of a shopping location influences the choice of transport mode, urban planning can promote environmentally friendly mobility through the targeted spatial location of vertical farms [30]. Urban planning is also able to design the spatial location of vertical farms in a way that enables benefits, such as the use of urban waste heat, and that can initiate or moderate such collaborations if necessary. Less for in-building and more for the development of citywide

closed-loop systems, urban planning is needed as a crossdisciplinary actor to help realize waste management cost savings [11,16]. Vertical farming comes into question during the desired inner development not only for brownfields but also in compact locations or in noise-intensive environments and competes here only to a limited extent with alternative land uses such as large-scale manufacturing or vulnerable housing [9,54]. Since unused built structures can also be utilized through vertical farming, the demolition of existing buildings and infrastructure and, subsequently, resource-intensive new construction can be avoided [55]. These reactivations of buildings can still trigger small-scale spillover effects, although a causal relationship remains open.

Furthermore, an argument in favor of vertical farming from an economic perspective of urban planning is that the reinvestment of tax revenues newly gained from vertical farming companies can be used, e.g., for the construction of parks or as incentives for further private investments [56]. In addition, the targeted siting of noise-protective vertical farm buildings can contribute to improved residential quality, especially in previously noisy residential locations, where, mostly, less privileged people live. Finally, such improvement also plays an important role in the health of the urban population, which is also improved by the plants of vertical farms, which clean the air, and by the ambient cooling effects of vertical farming buildings [7,9].

3.1.2. Weaknesses as Influenceable Disadvantages of Vertical Farming for Urban Planning

Stated regulatory limitations arise primarily from the fact that vertical farming cannot be classified into conventional land use categories [13,56]. Business operations can also be temporarily restricted by municipal regulations, e.g., regarding light pollution during nighttime hours [13]. In addition, vertical farming cannot be favored over other uses in principle. Despite these weaknesses, urban planning has the possibility to influence regulatory restrictions, as it is not least responsible for urban land use planning and building permits, and in its moderating function, can have regulatory restrictions negotiated between companies on the one hand and the urban population or local politics on the other hand.

Regarding the social aspects of urban development, urban planning must continue to provide socially equitable land use for the public good according to German building law. Urban planning can counter the additional land pressure or competition from vertical farming only in the sense of an integrated approach to ultimately achieve the best possible land use, in which the importance of vertical farming compared to other uses or other concerns must always be determined on a site-specific and individual basis [56].

3.1.3. Opportunities as Uninfluenceable Advantages of Vertical Farming for Urban Planning

Although the opportunities of vertical farming cannot be influenced by urban planning, they still offer potential for sustainable urban development. First, by saving agricultural land, the ecological enhancement of the urban environment can be triggered in cooperation with surrounding communities and can have a positive impact on the urban carbon footprint [8–10,57–59]. This would be a significant contribution to the frequently aspired urban climate neutrality.

Because of possible water shortages in Germany, urban planning should also have an interest in ensuring that no additional large quantities of valuable drinking water are demanded on an industrial scale. Vertical farming precisely promises this economical use in cities through hydroponic or aeroponic cultivation systems [8,9,60–62]. This leads to noticeable water savings in sources close to the surrounding area and, thus, contributes to improving the natural water cycle, and water availability around the city is also increased [63]. Furthermore, the circular thinking of urban wastewater means, on the one hand, low usage of resources through the recovery of materials and water in vertical farming itself [63,64]. On the other hand, this means saving money since capacities in wastewater treatment plants are used less [7,8,53,54] and, in contrast to conventional agriculture, no

long-term environmental costs are incurred due to the discharge of nitrate-contaminated wastewater into rivers or groundwater [8,9,19,57,63].

In addition, positive impacts on urban planning include new employment opportunities along the value chain [10,63], especially in commercial food production facilities, which can contribute to the attractiveness of neighborhoods [13,16]. Furthermore, the secondary impacts of new jobs on cities should not be neglected. Such jobs can grow the city population through immigration and increase the local gross value added, which can consequently lead to higher municipal revenues.

Socially, educational opportunities in vertical farming and raising awareness of local foods [9,13,16] can not only have long-term health benefits for urban populations but also generally increase interest in local-specific operations and processes. Increased civic engagement is conceivable not only in food institutions such as food banks but also in all areas of society.

Most of the opportunities above are already producing many urban health benefits, some of them intentionally. Urban planning also has a decidedly strong interest in a more resilient and healthier urban food system through vertical farming [7,9,65,66], as it pushes for holistic climate-adaptive and resilient urban development.

3.1.4. Threats as Influenceable Disadvantages of Vertical Farming for Urban Planning

The disadvantages of vertical farming listed as threats are particularly challenging due to the lack of influence by urban planning. From an environmental perspective, the first issue is the increased urban energy demand related to the high operational electricity use of vertical farms [10,11,17,67,68]. Since urban planning has no influence on the way electricity is generated in the grid, the business operations of vertical farms increasingly require electricity from fossil fuels, some of which are produced conventionally.

Moreover, there are no direct opportunities for urban planning to influence the necessary high initial costs [9,58] and expensive operating costs [10,16,56,63,69]. While there are certain opportunities for action in the urban land market, overall, the problem of high land and construction costs [9,13,58,69–71] falls beyond formal powers and is driven by overarching economic developments. Moreover, limited crop cultivation options [61,69,72–74] are an intracompany technical risk.

This also applies to acceptance problems of vertical farms as an urban land use [13] and their products [9,61,75]. Here, companies themselves are required to convince potential customers through advertising or education. Moreover, urban planning has no influence on the prices of the food sold.

In the overall comparison of strengths and weaknesses as well as opportunities and threats, it is evident that the positive factors of vertical farming, whether they can be influenced or not, predominate from the perspective of sustainable urban planning. However, since stabilization has not yet been achieved, the following section outlines the conditions in this regard.

3.2. Conditions for the Stabilization of Vertical Farming in the Regime of Urban Planning

The following six conditions are intended to take up the findings from the SWOT analysis and link them together in a meaningful way in accordance with the method (Figure 3). These conditions are not to be considered separately from each other; only in their entirety can they actually lead to the stabilization of vertical farming as a niche innovation in the urban planning regime. While there are certain interdependencies between them, the conditions are nevertheless not to be seen as being in chronological order or in order by priority.

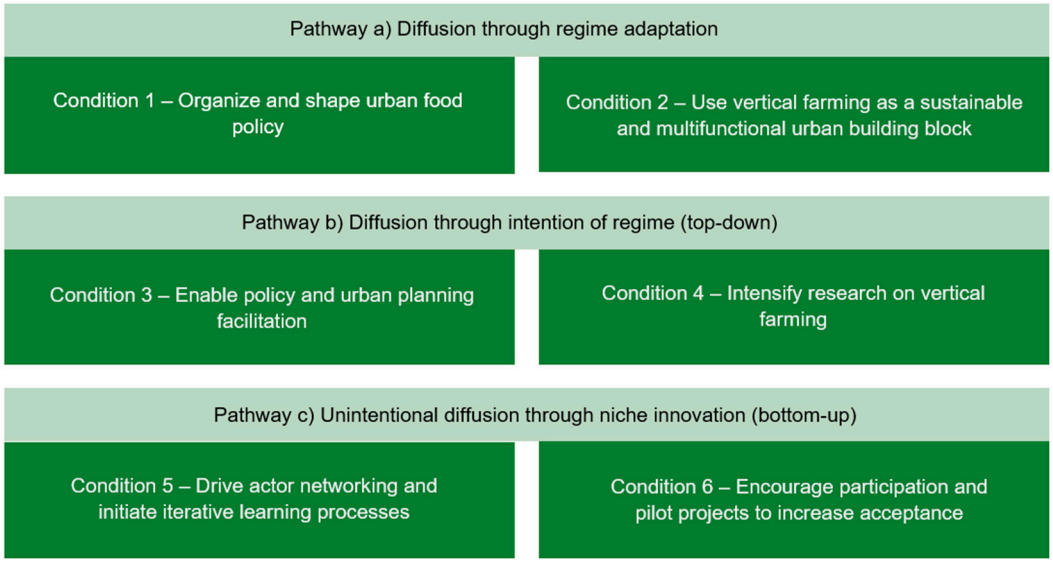

Figure 3. Pathways and conditions for the stabilization of vertical farming in the regime.

3.2.1. Condition 1—Organize and Shape Urban Food Policy

In order to incorporate vertical farming into urban development in a more targeted way, urban planning should address all the strengths of vertical farming mentioned above (see Table 1) to better exploit the opportunities for sustainable urban development through efficient production methods (O1) and healthier and more hygienic food production (O8). Therefore, a better understanding of urban food systems in both policy and urban planning is considered necessary. To that end, a two-step approach is considered necessary. Since urban planning has thus far lacked sufficient legal competencies and resources to initiate a holistic food policy in a municipality, political will is needed here. In addition to the 2030 Agenda, the starting point is a better understanding of the global framework in the food sector to exploit the possibility of anticipatory governance [41]. Ultimately, this involves following significant global norm-setting institutions, such as the Intergovernmental Panel on Climate Change (IPCC) or the Food and Agriculture Organization (FAO), as well as the Framework Convention on Climate Change or the United Nations Environment Program [2,41]. Based on these global developments, it is then necessary to draw conclusions for securing urban food locally and to recognize vertical farming as an opportunity for independent, healthy, and hygienic food production.

This further results in the opportunity to systematically incorporate the benefits of vertical farming into a sustainable urban transition and to ensure a more complete consideration in land use planning than has been the case to date. Doing so requires food to be recognized as a public concern. In addition, urban planning can be declared the co-ordinating actor in the administration for this issue, thus eliminating any jurisdictional problems and unclear administrative competencies and closing the existing gap with the food system. To that end, an even more integrated and strategically long-term type of planning, one that recognizes vertical farming as a possible use during a holistic consideration of urban agriculture or food production, is proposed [20].

3.2.2. Condition 2—Use Vertical Farming as a Sustainable and Multifunctional Urban Building Block

In contributing towards possible water savings (O_2) and reducing pesticides and fertilizers (O_3), vertical farming should be understood as a green or ecological and productive urban building block in the sense of the New Leipzig Charter (S7). Vertical farms can be used flexibly by urban planners (S6), and they can also reduce shopping and transport traffic (S1). This can be implemented through both horizontal and vertical use mixing. The latter means that in addition to vertical farming as the main use of a building, residential or

work opportunities are created, and synergistic effects are developed within a building and supplemented by educational opportunities [52]. The mix of uses can further contribute to shorter and lower-emission shopping trips.

Furthermore, it is important to design the buildings of vertical farms sustainably to obtain benefits for the urban microclimate. By greening buildings, local cooling effects can be achieved here in addition to CO_2 absorption [76,77]. In order to prevent vertical farming from becoming an additional large-scale consumer of urban energy, the use of renewable energy, even if occasionally suggested in the literature only for locations with favorable conditions, is almost inevitable and can lead to energy self-sufficiency for vertical farms [9,10,63,66].

In the case of new buildings, vertical farms should also exhibit sustainability throughout the life cycle of the real estate. To that end, bionic construction methods can contribute to energy and material conservation [63,66]. In addition to the functional benefits, regulations on aesthetics can be important to increase the aesthetic and intangible value of a building while obtaining benefits for the city's image [9,16,76].

As a result, however, vertical farming can become a sustainable urban building block primarily by saving land and resources in outdoor areas. Thus, for holistic climate protection reasons, there is an incentive for cities and agriculture to use food production using vertical farming with significantly increased land efficiency. What is desirable in the long term is not only the theoretical saving of land but also the practical return of built-up areas to nature.

3.2.3. Condition 3—Enable Policy and Urban Planning Facilitation

Given the regulatory restrictions for vertical farms (W1) and increased land use pressure (W2), regulatory facilitation on the part of policymakers and urban planners is still required for vertical farming to become more permanent and to reduce the high investment and operating costs (T2). This is facilitated not least by the fulfillment of the previous condition. First, a more widespread acceptance of vertical farming's contribution to land conservation would be necessary here. Therefore, a move away from the previous target for the reduction in land use to a more holistic approach would be beneficial. Accordingly, the calculated land savings of vertical farming compared to conventional agriculture should also be considered, e.g., in terms of financial compensation.

Furthermore, real estate is an indispensable prerequisite for the establishment of vertical farming. The usual internal development potentials in the form of reuse possibilities of fallow land and old building structures, as well as mixed-use, should be taken into account here, as should areas that are hardly usable for other purposes, such as disused air raid shelters, tunnels, and areas that become available due to social trends such as online retailing [11]. Due to the presumed continued high pressure on land and the limited opportunities in terms of quantity, instead of smaller inner-city sites, over the long term, land in suburban locations and at transport hubs will also have to be considered for larger vertical farms [56].

This heightened awareness of all urban land potential is the prerequisite for enabling uses on these sites. In this context, it is important to make the regulatory requirements for the construction and operation of vertical farms as low and as compatible as possible to minimally jeopardize the profitability of vertical farms. While urban planning, unlike policy, cannot provide financial support for vertical farming, it can still help reduce costs by providing well-prepared information, thus saving companies from having to carry out a long search for land.

3.2.4. Condition 4—Intensify Research on Vertical Farming

A deepening of research in this area is indispensable for vertical farming, as well as for most other niche innovations, to achieve continuous progress, which will contribute to increasing the strengths (see Table 1) and, at the same time, reducing all the risks mentioned above (see Table 4) [11]. First, when intensifying research regarding complex

food security issues and initiating a sustainability transition, it is important for research to abandon fragmentation and thinking in disciplinary silos [62,63,78]. Instead, food science should think long-term and conduct both systemic and interdisciplinary research, thereby enhancing credibility, relevance, and legitimacy, as well as the effectiveness of knowledge production [55,78]. Ultimately, one of the central concerns of research should be to continuously improve knowledge transfer, including to previous actors in agriculture, and to raise public awareness of sustainable transitions [56,62,78].

In addition, the substantive focus of research should be on the environmental friendliness and economic viability of existing and possibly new technologies. For this purpose, an increasing yield per unit area would be important to improve profitability in the long term [11], not only from a corporate perspective but would also continue to be important for promoting acceptance of research on circular food systems, which, e.g., reduces the reluctance to use raw materials from human waste as fertilizer, provided this is in line with legal hygiene regulations [79].

Furthermore, there is a need to rethink funding policy in the agricultural research sector, which mostly pushes only incremental solutions despite the approximately USD 56 billion invested annually worldwide [42,78]. Then, the mobilization of the necessary financial resources, which is seen as the most important condition for a transformation of the food system [42], seems possible.

3.2.5. Condition 5—Drive Actor Networking and Initiate Iterative Learning Processes

First, it can be helpful for the initially rather autonomous and dispersed companies of niche innovations, such as vertical farming, to interact with other actors [80]. Doing so allows, e.g., the reuse of urban waste heat (S2) as well as organic waste (S4), not only to reduce energy demand (T1) and costs (T2) but also to expand the previously limited supply (T3). This can be very important, especially in complex urban contexts, for generating knowledge and learning about the diverse, sometimes divergent, perspectives of stakeholders from different disciplinary fields through exchange [64,80]. It is desirable to consider stakeholders as broadly as possible since it is precisely this wide-ranging interaction that can lead to nonparticipating stakeholders being influenced [52]. Networking vertical farming with public or private actors in a city, such as municipal energy, water, and waste management, is important to achieve the corresponding efficiency and sufficiency effects on both sides in terms of resources and costs. Integrating vertical farming as a biorefinery into a holistic, sustainable urban material cycle also makes an important contribution to biological waste recycling and resilient urban ecology to mitigate climate change [66]. One approach is to develop an infrastructure for the collection and processing of local waste that is co-ordinated between the stakeholders involved and to introduce clean separation processes, e.g., organic waste that is harmless to humans can also be recycled locally to produce new food in vertical farms [11].

However, for the long-term success of this interdisciplinary networking of actors, continuous collaboration, which enables collective and iterative learning processes in the first place, is necessary. It is important to establish appropriate networks and initiate collaborations to make informal and formal communication, advance joint projects, and exchange resources and knowledge, e.g., for cultivation methods, as permanent as possible [64]. These network-like structures are referred to in the literature as protected spaces and sometimes as a "transition arena", and they can promote the scale and significance of small-scale innovations by attempting to incorporate their practices into local planning strategies, thereby enabling linkages into the existing regime [64,78,80,81].

3.2.6. Condition 6—Encourage Participation and Pilot Projects to Increase Acceptance

For vertical farming companies, niche innovation, and other technologies, it will be crucial to conduct persuasion and outreach efforts to mitigate acceptance problems (T4) [65]. First, it is important for companies to understand the local-specific contexts, needs, and culture, as well as the actors and user communities at the site [11]. Social acceptance

can be increased if the public, stakeholders, and policymakers are involved in the project development phase and are continuously informed or involved [20,76,78]. Consequently, regulatory facilitation can be better justified (W1), and awareness of the need for new land use (W2) can be created.

If possible, acceptance can be further expanded if such urban food production projects, in addition to the commercial dimension, consider environmental or social aspects [13,82]. For urban agriculture in general, the option of making projects accessible to citizens is often recommended [20,82]. Although doing so may be more difficult with vertical farms, also for hygienic reasons, an attempt should be made to provide insights to contribute to a higher appreciation of food and a stronger connection between production and consumption [20]. The employment of local residents is also conceivable, at least theoretically, to increase acceptance [20].

In order to illuminate participation and acceptance in terms of beyond only theory, vertical farming companies should, if possible, go ahead and implement examples in practice to be able to initiate an iterative process of improvement from this implementation by means of reflection and evaluation and to contribute to raising public awareness [80,81]. Moreover, in the case of successful implementation, political or urban planning facilitations can presumably be better justified on this basis.

3.3. Recommendations for Urban Planning

3.3.1. For Condition 1: Organize and Shape Urban Food Policy

The work follows the proposal for so-called urban food planning, which essentially means influencing the urban food system toward sustainable urban development in the sense of the well-being of the urban population [30,83]. The establishment of appropriate organizational structures, as well as additional public relations work, lends itself to this purpose [20,84]. It is necessary to consider vertical farming integrally as an urban land use and to be able to adjust it accordingly in consideration processes.

3.3.2. For Condition 2: Use Vertical Farming as a Sustainable and Multifunctional Urban Building Block

Urban planning can take up the suggestion that urban agriculture, in this case in the form of vertical farming, should not be seen as a competitor to residential use but, rather, should be planned as a supplement if the residential density is appropriate [20].

For a more sustainable design in terms of delivery, which will become more significant in the future, low-emission logistics concepts, which, e.g., only allow emission-free transport in a city via electric or hydrogen vehicles, should be developed in the long term.

Urban planning should also use municipal statute law or development plans to stipulate green roofs and facades under building law, demand the use of renewable energies, stipulate the lowest possible degree of sealing of the nonbuilt-up area (not only to counteract greater heat pollution but also to allow natural infiltration), and stipulate on-site rainwater drainage to increase the incentive to use rainwater in vertical farms themselves and, thus, relieve the burden on the urban sewer system.

The requirements for sustainability should be legally secure and proportionate, but at the same time, the approval processes should be completed quickly. This is also desirable from a business perspective, as the initial costs for vertical farms are high. Urban planning should also use guidelines, such as the "Sustainable Building Assessment System (BNB)", and specify recyclable materials. Apart from the mix of uses, however, the option of allowing vertical farming in such locations where urban planning identifies the need for noise control should be considered. Doing so can protect vulnerable uses such as residential areas partially or entirely from appropriate noise sources through vertical farm buildings.

3.3.3. For Condition 3: Enable Policy and Urban Planning Facilitation

In order to facilitate the search for the real estate availability of vertical farming companies, urban planning should provide information on land potential, such as vacant

or derelict sites, and vacancies, e.g., in the form of mapping, cadasters, or lists, free of charge and clearly arranged. Suitable plots of land could be strategically secured by the urban planning department, or the appropriate building rights could be created there. In general, urban planning should always consider the possibility of a municipal interim acquisition for all land developments with a view to municipal finances. In the case of contaminated brownfield sites, it is also important to obtain professional help, e.g., from appropriate state institutions.

3.3.4. For Condition 5: Drive Actor Networking and Initiate Iterative Learning Processes

When drawing up development plans or granting building permits for vertical farms, urban planning should examine the potential for the more efficient use of waste heat from the immediate surroundings and enter into a dialogue with vertical farming companies out of urban climate protection interests. Appropriate collection and processing infrastructure, including high food safety standards for inspection, should be established for local waste reuse [11].

3.3.5. For Condition 6: Encourage Participation and Pilot Projects to Increase Acceptance

Checking the acceptance of residents is also relevant for urban planning outside the legal requirements in this regard to avoid triggering negative reactions that could otherwise lead to time delays or protracted legal disputes [76]. In this context, companies also emphasize the importance of co-operation with urban planning to increase acceptance.

4. Discussion

Although vertical farming is still in development as a niche innovation, the advantages and disadvantages of urban planning can already be assessed. Some sustainability advantages can be influenced by urban planning in a targeted manner and can, thus, make it possible to better deal with resources, such as land, buildings, or urban waste heat. In addition, there are economic and social benefits, such as contributions to urban economic growth. These strengths of vertical farming are offset by weaknesses. Regulatory restrictions, as well as increasing land use pressure, are disadvantages for the establishment or operation of vertical farms, and these disadvantages can be mitigated by urban planning. Vertical farming also has numerous other positive characteristics that, although outside the sphere of influence of sustainable urban planning, should not be neglected. The main opportunity lies in the exploitation of the vertical dimension for food cultivation, which consequently results in far-reaching land savings that benefit nature and the environment. Other resource savings, such as the low use of water and the avoidance of pesticides and fertilizers, or at least their reuse or recycling in vertical farms, are also key ecological benefits that extend beyond urban areas. For cities themselves, vertical farming means not only the creation of new jobs but also the possibility of creating a new awareness of food. Furthermore, compared to conventional agriculture, vertical farms often produce more locally and independently as well as more healthily and more hygienically. However, there are also disadvantages that cannot be influenced by urban planning. Currently, vertical farming requires large amounts of energy for operation. For this reason, it is often stated that the use of renewable energy for indoor farms is a necessary prerequisite for sustainable food production [12]. In combination with high investment costs, which already start with the acquisition of land, the profitability of farms is at risk. In addition, thus far, only a small selection of foods can be produced, and there are acceptance problems with farms themselves and their products. It must also be noted that some of the aforementioned advantages can only be fully exploited in the future. The use of urban wastewater, e.g., is an option in principle, but a wide range of containments, such as pathogens, pharmaceuticals, and microplastics, need to be removed safely and in accordance with hygiene requirements. Nevertheless, this study shows that the advantages of vertical farming outweigh the disadvantages, especially in the ecological and health dimensions.

However, it is also important to differentiate between indoor and outdoor vertical farms, which means that the advantages and disadvantages mentioned differ. While indoor vertical farms are characterized by the controllability of the growing conditions and thus the contribution to food security, they require more energy than outdoor farms. The latter, in contrast, have various other challenges in cities. First, there is no control over environmental conditions such as light, water, or pest infestation. Second, vertical farms on the walls of buildings may look green and attractive during the growing season but might pose aesthetic problems in the cooler months of the year. On roofs, there is usually better access to the growing areas, and the environmental conditions can be at least partially influenced by light or wind protection, for example.

When looking at the literature and expert interviews evaluated, the discrepancy between urban planning and the food system described at the beginning is confirmed by the example of vertical farming. While primarily technological and economic factors and some ecological factors are discussed, the social (especially the urban) context is neglected. Despite global vicissitudes and imponderables, it is particularly surprising that a social and urban planning debate over vertical farming is not taking place, in contrast to similar innovations such as urban gardening.

Despite the ubiquity of sustainability and the increasing recognition of the need for a major transformation in response to climate change, potentially landmark and disruptive innovations, such as vertical farming, are being inadequately illuminated. Instead, funding dollars continue to be focused on incremental adjustments in the existing delocalized food system of conventional agriculture. Although initial well-known publications already mention the advantage of reduced land use with a corresponding possibility of opportunistic, sustainable land use, the discussion to date largely misses this central aspect [8]. Nonetheless, importantly, the potential implications for climate change are difficult to assess, even if vertical farming is perpetuated in urban planning.

Nevertheless, in contrast to the Asian and North American regions, whether the lack of vertical farms in Germany thus far is due to risks such as high costs and acceptance problems or to a lack of demand due to an apparently secure food system remains an open question. Instead of focusing on specific points and doing justice to the complexity of the topic, general conditions were, therefore, formulated first and foremost in the context of a necessary transformation. Accordingly, the further investigation of strategic documents and projects in the fields of sustainability, urban planning, the bioeconomy, and the circular economy, as well as agriculture at the European or national level, is also recommended. In addition, an even stronger examination in terms of building law of the topic, as well as the investigation of the idea of designing vertical farming for community use, would be promising.

Future research needs to remain in perpetuity due to the enormous development dynamics of vertical farming in terms of new cultivable crops for food, cosmetics, or pharmaceuticals, for energy production using algae or insects as a novel energy source, and ultimately with implications for the field of space travel [66,73]. In addition, research into nonfood crops on building walls could be expanded to better assess the impact on urban climate protection and small-scale climate adaptation. As already mentioned, it should be noted that the accessibility and, thus, the management of vertical gardens on walls is complex.

Although the results are primarily valid for Germany, the presented methodological approach can be used for future research. It may be helpful not to look at individual vertical farms in isolation from urban planning issues. Rather, by applying the multi-level perspective, a fundamental understanding of overarching developments with implications for the urban context can be gained. By identifying the strengths and weaknesses and opportunities and risks, e.g., through document analysis or expert interviews with relevant stakeholders, strategic conclusions can be drawn for the potential and establishment of vertical farms. Therefore, transferability requires an assessment of the spatial and local conditions. However, the prerequisites for corresponding research are that urban planning

has a real influence on the use of the land and that companies first show interest in vertical farming. Furthermore, the anticipatory nature of transformation research is necessarily associated with uncertainties, and an understanding of what is actually sustainable remains an ongoing process of negotiation.

5. Conclusions

This paper shows that an investigation using the multi-level perspective enables a broader view of the potential of vertical farming and brings in the previously missing perspective of urban planning to a greater extent. Accordingly, the "window of opportunity" or all process-related prerequisites for a transformation through vertical farming are fulfilled. The global changes of the 21st century, such as climate change on the landscape level, lead to the necessity of climate protection and climate adaptation on the regime level of urban planning. Consequently, to push the corresponding global transformation toward sustainability, disruptive changes in cities are needed. However, there is also a need for change due to internal tensions in urban planning, resulting not least from the misrecognized connection with food. In addition, research and networking trends are already leading to performance improvements in vertical farming.

Since vertical farming has not yet been established in Germany, six overarching conditions were formulated that adequately link the previously identified advantages and disadvantages. As a transformative path in the form of an adaptation of the regime, it is proposed to push the overdue closing of the gap between urban planning and the food system and to conceive of vertical farms as a sustainable and multifunctional urban building block. For this purpose, the establishment of urban food planning is proposed. On this basis, formal facilitation and the promotion of research on vertical farming as top-down strategies can support permanence. It is suggested that urban planning show land availability at a low threshold and actively influence it if needed. In contrast, it is necessary for vertical farming companies (in the sense of a bottom-up strategy) to achieve an increase in acceptance by networking with each other and interacting with urban stakeholders, engaging in iterative learning processes, and participating in and conducting pilot projects. At this point, urban planning should fulfill its moderating function and actively support these processes.

Finally, in the sense of a holistic view, it can be concluded from the literature that vertical farming has great potential to promote sustainable food production, especially in cities. While there is an inherent anticipatory nature to this potential assessment, there is little dispute about the evidence-based assessment that an inevitable transformation toward sustainability requires such innovations. If forward-looking efforts succeed in meeting the conditions and recommendations for the actions outlined above, food from vertical farms may become commonplace for urban populations. Nevertheless, vertical farming as a technological solution is not a panacea for all existing challenges [58]. Contrary to the occasional view that these complex challenges of the 21st century can be addressed only through various technological solutions, this paper concludes by pointing out that this requires organizing purposeful collaboration in society. Next, vertical farming promises to be an integral part of a green, equitable, and productive city in the sense of the New Leipzig Charter.

Author Contributions: Conceptualization, methodology, formal analysis, investigation, writing—original draft preparation, visualization, J.B. (Jost Buscher); writing—review and editing, supervision, J.B. (Julija Bakunowitsch) and K.S. All authors have read and agreed to the published version of the manuscript.

Funding: We acknowledge financial support by Deutsche Forschungsgemeinschaft and Technische Universität Dortmund/TU Dortmund University within funding program Open Access Costs. Moreover, Kathrin Specht is institutionally funded by the Research Institute for Regional and Urban Development gGmbH.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Alexandratos, N.; Bruinsma, J. *World Agriculture Towards 2030/2050: The 2012 Revision*; ESA Working Paper 12-03; Food and Agriculture Organization of the United Nations: Rome, Italy, 2012. Available online: https://www.fao.org/3/ap106e/ap106e.pdf (accessed on 16 March 2022).
2. Lajoie-O'Malley, A.; Bronson, K.; van der Burg, S.; Klerkx, L. The future(s) of digital agriculture and sustainable food systems: An analysis of high-level policy documents. *Ecosyst. Serv.* **2020**, *45*, 101183. [CrossRef]
3. Ramankutty, N.; Mehrabi, Z.; Waha, K.; Jarvis, L.; Kremen, C.; Herrero, M.; Rieseberg, L.H. Trends in Global Agricultural Land Use: Implications for Environmental Health and Food Security. *Annu. Rev. Plant Biol.* **2018**, *69*, 789–815. [CrossRef]
4. United Nations. *World Urbanization Prospects: The 2018 Revision*; Department of Economic and Social Affairs, Population Division: New York, NY, USA, 2019. Available online: https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf (accessed on 16 March 2022).
5. United Nations. *Transforming Our World: The 2030 Agenda for Sustainable Development—Resolution A/RES/70/1 Adopted by the General Assembly on 25 September 2015*; United Nations: Paris, France, 2015. Available online: https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/291/89/PDF/N1529189.pdf?OpenElement (accessed on 11 April 2023).
6. Petrovics, D.; Giezen, M. Planning for sustainable urban food systems: An analysis of the up-scaling potential of vertical farming. *J. Environ. Plan. Manag.* **2021**, *65*, 785–808. [CrossRef]
7. Banerjee, C.; Adenaeuer, L. Up, Up and Away! The Economics of Vertical Farming. *J. Agric. Stud.* **2014**, *2*, 40–60. [CrossRef]
8. Despommier, D. *The Vertical Farm*, 1st ed.; Thomas Dunne Books: New York, NY, USA, 2010.
9. Kalantari, F.; Tahir, O.M.; Joni, R.A.; Fatemi, E. Opportunities and Challenges in Sustainability of Vertical Farming: A Review. *J. Landsc. Ecol.* **2017**, *11*, 35–60. [CrossRef]
10. Engler, N.; Krarti, M. Review of energy efficiency in controlled environment agriculture. *Renew. Sustain. Energy Rev.* **2021**, *141*, 110786. [CrossRef]
11. O'Sullivan, C.A.; Bonnett, G.D.; McInterye, C.L.; Hochman, Z.; Wasson, A.P. Strategies to improve the productivity, product diversity and profitability of urban agriculture. *Agric. Syst.* **2019**, *174*, 133–144. [CrossRef]
12. Csordás, A.; Füzesi, I. The Impact of Technophobia on Vertical Farms. *Sustainability* **2023**, *15*, 7476. [CrossRef]
13. Benis, K.; Ferrão, P. Commercial farming within the urban built environment—Taking stock of an evolving field in northern countries. *Glob. Food Secur.* **2018**, *17*, 30–37. [CrossRef]
14. Butturini, M.; Marcelis, L.F.M. Vertical farming in Europe. In *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*, 2nd ed.; Kozai, T., Niu, G., Takagaki, M., Eds.; Academic Press: Cambridge, MA, USA, 2020; pp. 77–91. [CrossRef]
15. Ostuni, M.; Zaffi, L. Nurturing Cities: Pathways Towards a Circular Urban Agriculture. World Heritage and Design for Health. 2021. Available online: https://www.researchgate.net/profile/michele-dostuni-2/publication/353851009_nurturing_cities_pathways_towards_a_circular_urban_agriculture/links/611562711e95fe241aca3804/nurturing-cities-pathways-towards-a-circular-urban-agriculture.pdf (accessed on 7 May 2022).
16. Specht, K.; Siebert, R.; Hartmann, I.; Freisinger, U.B.; Sawicka, M.; Werner, A.; Thomaier, S.; Henckel, D.; Walk, H.; Dierich, A. Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agric. Hum. Values* **2014**, *31*, 33–51. [CrossRef]
17. Blom, T.; Jenkins, A.; Pulselli, R.M.; van den Dobbelsteen, A.A.J.F. The embodied carbon emissions of lettuce production in vertical farming, greenhouse horticulture, and open-field farming in the Netherlands. *J. Clean. Prod.* **2022**, *377*, 134443. [CrossRef]
18. Kobayashi, Y.; Kotilainen, T.; Carmona-García, G.; Leip, A.; Tuomisto, H.L. Vertical farming: A trade-off between land area need for crops and for renewable energy production. *J. Clean. Prod.* **2022**, *379*, 134507. [CrossRef]
19. Zhou, H.; Specht, K.; Kirby, C.K. Consumers' and Stakeholders' Acceptance of Indoor Agritecture in Shanghai (China). *Sustainability* **2022**, *14*, 2771. [CrossRef]
20. Horst, M.; McClintock, N.; Hoey, L. The Intersection of Planning, Urban Agriculture, and Food Justice: A Review of the Literature. *J. Am. Plan. Assoc.* **2017**, *83*, 277–295. [CrossRef]
21. Specht, K.; Zoll, F.; Schümann, H.; Bela, J.; Kachel, J.; Robischon, M. How Will We Eat and Produce in the Cities of the Future? From Edible Insects to Vertical Farming—A Study on the Perception and Acceptability of New Approaches. *Sustainability* **2019**, *11*, 4315. [CrossRef]
22. Braun, J.V.; Afsana, K.; Fresco, L.O.; Hassan, M. Science and Innovations for Food Systems Transformations and Summit Actions. 2021. Available online: https://sc-fss2021.org/wp-content/uploads/2021/09/ScGroup_Reader_UNFSS2021.pdf (accessed on 23 April 2022).

23. BBSR—Bundesinstitut für Bau-, Stadt- und Raumforschung (Federal Office for Building and Regional Planning). Vom Stadtumbau Zur Städtischen Transformationsstrategie (From Urban Redevelopment to Urban Transformation Strategy). Bonn. BBSR-Online-Publikation 09/2020. 2020. Available online: https://www.bbsr.bund.de/BBSR/DE/veroeffentlichungen/bbsr-online/2020/bbsr-online-09-2020-dl.pdf?__blob=publicationFile&v=2 (accessed on 25 January 2022).
24. Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F.S., III; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecol. Sci.* **2009**, *14*, 32. Available online: http://www.ecologyandsociety.org/vol14/iss2/art32/ (accessed on 24 May 2022). [CrossRef]
25. Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; de Vries, W.; de Wit, C.A.; et al. Planetary boundaries: Guiding human development on a changing plant. *Science* **2015**, *347*, 736–747. [CrossRef]
26. UBA—Umweltbundesamt (German Environment Agency). Transformationsforschung. Definitionen, Ansätze, Methoden. (Transformational Research. Definitions, Approaches, Methods.) Dessau-Roßlau. Texte 103/2017. 2017. Available online: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-11-08_texte_103-2017_transformationsforschung.pdf (accessed on 14 May 2022).
27. WBGU—Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change), Welt Im Wandel. Gesellschaftsvertrag Für Eine Große Transformation (World in Transition. Social Contract for a Great Transformation). 2. Aufl. Berlin. 2011. Available online: https://www.wbgu.de/fileadmin/user_upload/wbgu/publikationen/hauptgutachten/hg2011/pdf/wbgu_jg2011.pdf (accessed on 15 March 2022).
28. WBGU—Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change), 2016. Der Umzug der Menschheit. Die Transformative Kraft der Städte (Moving Humanity. The Transformative Power of Cities). Berlin. 2016. Available online: https://www.wbgu.de/fileadmin/user_upload/wbgu/publikationen/hauptgutachten/hg2016/pdf/wbgu_hg2016.pdf (accessed on 15 March 2022).
29. European Union. The New Leipzig Charta. The Transformative Power of Cities for the Common Good. Leipzig. 2020. Available online: https://futurium.ec.europa.eu/sites/default/files/2021-03/new_leipzig_charter_en.pdf (accessed on 11 April 2023).
30. Stierand, P. *Speiseräume: Die Ernährungswende Beginnt in der Stadt (Dining Room: The Nutrition Turnaround Begins in the City)*; Stierand: München, Germany, 2014.
31. Pothukuchi, K.; Kaufman, J.L. The Food System. *J. Am. Plan. Assoc.* **2000**, *66*, 113–124. [CrossRef]
32. Pothukuchi, K.; Kaufman, J.L. Placing the food system on the urban agenda: The role of municipal institutions in food systems planning. *Agric. Hum. Values* **1999**, *16*, 213–224. [CrossRef]
33. Cohen, N.; Reynolds, K. Urban Agriculture Policy Making in New York's "New Political Spaces". *J. Plan. Educ. Res.* **2014**, *34*, 221–234. [CrossRef]
34. Pothukuchi, K. Five Decades of Community Food Planning in Detroit. *J. Plan. Educ. Res.* **2015**, *35*, 419–434. [CrossRef]
35. Levin-Keitel, M.; Mölders, T.; Othengrafen, F.; Ibendorf, J. Sustainability Transitions and the Spatial Interface: Developing Conceptual Perspectives. *Sustainability* **2018**, *10*, 1880. [CrossRef]
36. Lin, B.B.; Philpott, S.M.; Jha, S. The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. *Basic Appl. Ecol.* **2015**, *16*, 189–201. [CrossRef]
37. Benzaghta, M.A.; Elwalda, A.; Mousa, M.M.; Erkan, I.; Rahman, M. SWOT analysis applications: An integrative literature review. *J. Glob. Bus. Insights* **2021**, *6*, 55–73. [CrossRef]
38. Comino, E.; Ferretti, V. Indicators-based spatial SWOT analysis: Supporting the strategic planning and management of complex territorial systems. *Ecol. Indic.* **2016**, *60*, 1104–1117. [CrossRef]
39. Kuster, J.; Bachmann, C.; Huber, E.; Hubmann, M.; Lippmann, R.; Schneider, P. *Handbuch Projektmanagement. Agil—Klassisch—Hybrid (Project Management Handbook. Agile—Classic—Hybrid)*, 5th ed.; Springer: Berlin/Heidelberg, Germany, 2022. [CrossRef]
40. Scholles, F. Bewertungsmethoden (Valuation Methods). In *Handbuch Theorien und Methoden der Raum-und Umweltplanung (Handbook of Theories and Methods of Spatial and Environmental Planning)*, 3rd ed.; Fürst, D., Scholles, F., Eds.; Rohn: Dortmund, Germany, 2008; pp. 403–532.
41. Muiderman, K.; Zurek, M.; Verwoort, J.; Gupta, A.; Hasnain, S.; Driessen, P. The anticipatory governance of sustainability transformations: Hybrid approaches and dominant perspectives. *Glob. Environ. Change* **2022**, *73*, 102452. [CrossRef]
42. Klerkx, L.; Rose, D. Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways? *Glob. Food Secur.* **2020**, *24*, 100347. [CrossRef]
43. EEA—European Energy Agency. In *Perspectives on Transitions to Sustainability*; EEA Report 15/2017; European Environment Agency: Luxembourg, 2017. Available online: https://www.eea.europa.eu/publications/perspectives-on-transitions-to-sustainability/file (accessed on 24 May 2022).
44. Geels, F.W. Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Res. Policy* **2002**, *31*, 1257–1274. [CrossRef]
45. Geels, F.W. Major system change through stepwise reconfiguration: A multi-level analysis of the transformation of American factory production (1850–1930). *Technol. Soc.* **2006**, *28*, 445–476. [CrossRef]
46. Geels, F.W.; Schot, J. Typology of sociotechnical transition pathways. *Res. Policy* **2007**, *36*, 399–417. [CrossRef]

47. UBA—Umweltbundesamt (German Environment Agency). Transformationsstrategien und Models of Change Für Nachhaltigen Gesellschaftlichen Wandel: Gesellschaftlicher Wandel als Mehrebenenansatz. (Transformation Strategies and Models of change for Sustainable Societal Change: Societal Change as a Multi-Level Approach.) Dessau-Roßlau. Texte 66/2015. 2015. Available online: https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_66_2015_gesellschaftlicher_wandel_als_mehrebenenansatz_3.pdf (accessed on 16 October 2021).
48. Schrape, J.F. Kurze Einführung in Die Multi-Level Perspective (Short Introduction to the Multi-Level Perspective). 2014. Available online: https://gedankenstrich.org/wp-content/uploads/2014/11/kurze-einf%c3%bchrung-in-die-multi-level-perspective.pdf (accessed on 1 November 2021).
49. Maassen, A. Heterogeneity of Lock-In and the Role of Strategic Technological Interventions in Urban Infrastructure Transformations. *Eur. Plan. Stud.* **2012**, *20*, 441–460. [CrossRef]
50. DeHaan, J.H.; Rotmans, J. Patterns in transitions: Understanding complex chains of change. *Technol. Forecast. Soc. Change* **2011**, *34*, 90–102. [CrossRef]
51. Sovacool, B.K.; Bazilian, M.; Griffith, R.; Kim, J.; Foley, A.; Rooney, D. Decarbonizing the food and beverages industry: A critical and systematic review of developments, sociotechnical systems and policy options. *Renew. Sustain. Energy Rev.* **2021**, *143*, 110856. [CrossRef]
52. Pigford, A.A.E.; Hickey, G.M.; Klerkx, L. Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions. *Agric. Syst.* **2018**, *164*, 116–121. [CrossRef]
53. Kemp, R.; Schot, J.; Hoogma, R. Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technol. Anal. Strateg. Manag.* **1998**, *10*, 175–198. [CrossRef]
54. UBA—Umweltbundesamt (German Environment Agency). Innenentwicklung in Städtischen Quartieren: Die Bedeutung von Umweltqualität, Gesundheit und Sozialverträglichkeit. (Interior Development in Urban Neighborhoods: The Importance of Environmental Quality, Health, and Social Compatibility). Dessau-Roßlau. Hintergrund 2019. 2019. Available online: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2020-01-13_hgp_innenentwicklung_umweltqualitaet_gesundheit_sozialvertraeglichkeit_final_bf.pdf (accessed on 13 July 2022).
55. McClements, D.J.; Barrangou, R.; Hill, C.; Kokini, J.L.; Lila, M.A.; Meyer, A.S.; Yu, L. Building a Resilient, Sustainable, and Healthier Food Supply Through Innovation and Technology. *Annu. Rev. Food Sci. Technol.* **2021**, *12*, 1–28. [CrossRef]
56. Carolan, M. Urban Farming Is Going High Tech. *J. Am. Plan. Assoc.* **2020**, *86*, 47–59. [CrossRef]
57. Germer, J.; Sauerborn, J.; Asch, F.; de Boer, J.; Schreiber, J.; Weber, G.; Müller, J. Skyfarming an ecological innovation to enhance global food security. *J. Verbraucherschutz Leb.* **2011**, *6*, 237–251. [CrossRef]
58. Kaur, G.; Chawla, P. All about Vertical Farming: A Review. *Turk. J. Comput. Math. Educ.* **2021**, *12*, 1–14. [CrossRef]
59. Mir, M.S.; Naikoo, N.B.; Kanth, R.H.; Bahar, F.A.; Bhat, M.A.; Nazir, A.; Mahdi, S.S.; Amin, Z.; Singh, L.; Raja, W.; et al. Vertical farming: The future of agriculture: A review. *Pharma Innov. J.* **2022**, *11*, 1175–1195. Available online: https://www.researchgate.net/profile/zakir-amin/publication/358749034_vertical_farming_the_future_of_agriculture_a_review/links/6213b0604be28e145ca7aab5/vertical-farming-the-future-of-agriculture-a-review.pdf (accessed on 3 May 2022).
60. Marvin, S.; Rutherford, J. Controlled environments: An urban research agenda on microclimatic enclosure. *Urban Stud.* **2018**, *55*, 1143–1162. [CrossRef]
61. Ragaveena, S.; Shirly, A.E.; Surendran, U. Smart controlled environment agriculture methods: A holistic review. *Rev. Environ. Sci. Biotechnol.* **2021**, *20*, 887–913. [CrossRef]
62. Sørensen, M.; Andersen-Ranberg, J.; Hankamer, B.; Møller, B.L. Circular biomanufacturing through harvesting solar energy and CO_2. *Trends Plant Sci.* **2022**, *27*, 655–673. [CrossRef]
63. Kalantari, F.; Tahir, O.M.; Lahijani, A.M.; Kalantari, S. A Review of Vertical Farming Technology: A Guide for Implementation of Building Integrated Agriculture in Cities. *Adv. Eng. Forum* **2017**, *24*, 76–91. [CrossRef]
64. Specht, K.; Zoll, F.; Siebert, R. Application and evaluation of a participatory "open innovation" approach (ROIR): The case of introducing zero-acreage farming in Berlin. *Landsc. Urban Plan.* **2016**, *151*, 45–54. [CrossRef]
65. Henry, R. Innovations in Agriculture and Food Supply in Response to the COVID-19 Pandemic. *Mol. Plant* **2020**, *13*, 1095–1097. [CrossRef] [PubMed]
66. Sreeharsha, R.V.; Mohan, S.V. Symbiotic integration of bioprocesses to design a self-sustainable life supporting ecosystem in a circular economy framework. *Bioresour. Technol.* **2021**, *326*, 124712. [CrossRef] [PubMed]
67. Graamans, L.; Baeza, E.; van den Dobbelsten, A.; Tsafaras, I.; Stanghellini, C. Plant factories versus greenhouses: Comparison of resource use efficiency. *Agric. Syst.* **2018**, *160*, 31–43. [CrossRef]
68. Mok, W.K.; Tan, Y.X.; Chen, W.N. Technology innovations for food security in Singapore: A case study of future food systems for an increasingly natural resource-scarce world. *Trends Food Sci. Technol.* **2020**, *102*, 155–168. [CrossRef] [PubMed]
69. Gentry, M. Local heat, local food: Integrating vertical hydroponic farming with district heating in Sweden. *Energy* **2019**, *174*, 191–197. [CrossRef]
70. Eigenbrod, C.; Gruda, N. Urban vegetable for food security in cities. A review. *Agron. Sustain. Dev.* **2015**, *35*, 483–498. [CrossRef]
71. Saxena, N.N. The Review on Techniques of Vertical Farming. *Int. J. Mod. Agric.* **2021**, *10*, 732–738. Available online: http://www.modern-journals.com/index.php/ijma/article/view/662 (accessed on 21 April 2022).
72. Benke, K.; Tomkins, B. Future food-production systems: Vertical farming and controlled-environment agriculture: Insights from design and management sciences and future directions. *Agric. Syst.* **2017**, *165*, 111–115. [CrossRef]

73. Hiwasa-Tanase, K.; Ezura, H. Molecular Breeding to Create Optimized Crops: From Genetic Manipulation to Potential Applications in Plant Factories. *Front. Plant Sci.* **2016**, *7*, 539. [CrossRef]
74. SharathKumar, M.; Heuvelink, E.; Marcelis, L.F.M. Vertical Farming: Moving from Genetic to Environmental Modification. *Trends Plant Sci.* **2020**, *8*, 724–727. [CrossRef]
75. Specht, K.; Sanyé-Mengual, E. Risks in urban rooftop agriculture: Assessing stakeholders' perceptions to ensure efficient policymaking. *Environ. Sci. Policy* **2017**, *69*, 13–21. [CrossRef]
76. Kosorić, V.; Huang, H.; Tablada, A.; Lau, S.K.; Tan, H.T.W. Survey on the social acceptance of the productive façade concept integrating photovoltaic and farming systems in high-rise public housing blocks in Singapore. *Renew. Sustain. Energy Rev.* **2019**, *111*, 197–214. [CrossRef]
77. Safikhani, T.; Abdullah, A.M.; Ossen, D.R.; Baharvand, M. A review of energy characteristic of vertical greenery systems. *Renew. Sustain. Energy Rev.* **2014**, *40*, 450–462. [CrossRef]
78. Dinesh, D.; Hegger, D.L.T.; Klerkx, L.; Verwoort, J.; Campbell, B.M.; Driessen, P.P.J. Enacting theories of change for food systems transformation under climate change. *Glob. Food Secur.* **2021**, *31*, 100583. [CrossRef]
79. Aschemann-Witzel, J.; Ares, G.; Thogersen, J.; Monteleone, E. A sense of sustainability? How sensory consumer science can contribute to sustainable development of the food sector. *Trends Food Sci. Technol.* **2019**, *90*, 180–185. [CrossRef]
80. Berthet, E.T.; Hickey, G.M.; Klerkx, L. Opening design and innovation processes in agriculture: Insights from design and management sciences and future directions. *Agric. Syst.* **2018**, *165*, 111–115. [CrossRef]
81. Loorbach, D.; Frantzeskaki, N.; Avelino, F. Sustainability Transitions Research: Transforming Science and Practice for Societal Change. *Annu. Rev. Environ. Resour.* **2017**, *42*, 599–626. [CrossRef]
82. Specht, K.; Weith, T.; Swoboda, K.; Siebert, R. Socially acceptable urban agriculture businesses. *Agron. Sustain. Dev.* **2016**, *36*, 17. [CrossRef]
83. Pothukuchi, K. Community Food Assessment: A First Step in Planning for Community Food Security. *J. Plan. Educ. Res.* **2004**, *4*, 356–377. [CrossRef]
84. Sonnino, R. Food system transformation: Urban perspectives. *Cities* **2023**, *134*, 104164. [CrossRef]