INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY
2023, VOL. 21, NO. 1, 2166230
https://doi.org/10.1080/14735903.2023.2166230

Routledge
Taylor & Francis Group

OPEN ACCESS Check for updates

Innovation systems for controlled-environment food production in urban contexts: a dynamic case study analysis of combined plant, fish and insect production in Berlin

Victoria Dietze and Peter H. Feindt

Humboldt-Universität zu Berlin, Thaer-Institute for Agricultural and Horticultural Sciences, Agricultural and Food Policy Group, Berlin, Germany

ABSTRACT

Producing enough healthy food for a globally growing urban population within planetary boundaries requires more resource-efficient and localized food production systems. Controlled-environmental food production systems (CEFPS) are a widely discussed new approach for sustainable food production in urban contexts. However, little research has addressed innovation processes of CEFPS in urban or rural areas. This paper aims to address this research gap by adapting an innovation system perspective, developing a conceptual framework for 'urban food production innovation systems' (UFoPrInS) and applying it to a paradigmatic case study in Berlin. Based on a content analysis of the relevant literature and 23 semi-structured expert interviews, we analyse (a) the main characteristics and (b) the key elements of the UFoPrInS and their relationships during different stages of the innovation process. The case results show that UFoPrInS faces various challenges related to possible structural failures that can occur in infrastructure, interactions, capabilities of actors and institutions. The current institutional framework at EU and national level was seen as the major barrier to innovations. To support new food production innovations, a comprehensive regulatory framework for CEFPS is needed that considers in an integrated approach the specifics of (1) the highly-intensive production processes, (2) the diverse types of products and (3) the urban location.

ARTICLE HISTORY
Received 16 May 2022
Accepted 4 January 2023

KEYWORDS
Urban food production systems; resource-efficient food production; sustainable food production; food regulation; structural failures; institutional framework; case study; semi-structured expert interviews; content analysis; innovation system perspective

Introduction

Providing enough healthy food for a growing world population (United Nations, 2019; World Bank Group, 2020) within planetary boundaries is a global challenge (FAO, 2019; OECD, 2015). At the same time, a world-wide trend towards urbanization (Nam & Pardo, 2011; Ojo et al., 2016) – the global number of urban residents is expected to increase by up to 85% by 2050 (OECD, 2015; World Bank Group, 2020) – will exacerbate competition for land as well as spatial separation of agricultural and urban areas, i.e. of food production and consumption (Eigenbrod & Gruda, 2015; Nellemann, 2009; Specht et al., 2019). In particular, in the evolving megacities (UN-Habitat, 2016) food supply chains which provide the local population with sufficient fresh, healthy and high-quality food products will likely become more complex (Schmutz et al., 2018) and more vulnerable to value chain disruptions as seen during the COVID-19 pandemic (Meuwissen et al., 2021). Furthermore, climate change and negative environmental impacts (e.g. loss of biodiversity and fertile soils, pollution of air, water and soils) from ecologically harmful farming practices will also reduce prospective food production (Eigenbrod & Gruda, 2015; Nellemann, 2009; Specht et al., 2019). Therefore, more resource-efficient and local food production systems

CONTACT Victoria Dietze Victoria.dietze@hu-berlin.de Department of Agricultural Economics, Humboldt University zu Berlin, 10115 Berlin, Germany

Supplemental data for this article can be accessed online at https://doi.org/10.1080/14735903.2023.2166230 are needed that help to reduce the negative environmental impacts of food production, to shorten food supply chains and to create a resilient supply of high-quality and nutritious food for a growing world population (FAO, 1989; Herrero et al., 2020; Willett et al., 2019).

One approach to address these complex issues is controlled-environmental food production systems (CEFPS), i.e. enclosed systems that protect food production from external environmental influences (e.g. seasons, climatic conditions) and enables fully controlled growing conditions (e.g. temperature, carbon dioxide, humidity, oxygen, light, nutrition) (Gómez et al., 2019; Rorabaugh, 2015) to optimize production efficiency, product quality and yields (Gómez et al., 2019). The interest in CEFPS has increased in recent years, in particular, as an option for food production in urban contexts (Broad, 2020; Despommier, 2010; Gómez et al., 2019). Different types of CEFPS have already been implemented in cities in Asia, Europe or the United States to enhance local food production (Despommier, 2013; Kozai et al., 2016).

CEFPS are more or less high-tech food production systems. While greenhouses fall under this category, various innovations such as vertical farming, container farming, hydroponics and aquaponics have created a high-tech portfolio of CEFPS (e.g. Despommier & Ellingsen, 2008; Gómez et al., 2019; Ingram, 2018; Orsini et al., 2013; Wezel et al., 2011). If located in urban areas, CEFPS constitute a different type of urban food production system than generally discussed as 'urban agriculture' or 'urban gardening', which refer to low-tech food production systems associated with social values, cooperative forms of organization and co-benefits for urban environments and social cohesion (Duzí et al., 2017; Grebitus et al., 2017). In contrast, CEFPS focus on resource-efficient and commercially viable food production (Gómez et al., 2019; Rorabaugh, 2015). Compared to the rich literature on 'urban agriculture' (e.g. Bannor et al., 2021; Di Fiore et al., 2021; Dielemann, 2019), little research has addressed innovation processes of CEFPS in either urban or rural areas. This is surprising, given the need to explore all available pathways towards sustainable food production (Pretty et al., 2010; van der Gaast et al., 2022).

To address this research gap, this paper aims to contribute to a better understanding of the innovation processes surrounding the development and implementation of CEFPS in urban settings. We adopt an innovation system perspective (Markatou & Alexandrou, 2015) to analyse the actors and elements involved in CEFPS, their mutual relationships and their interactions with the social, ecological and institutional context (Provė et al., 2016). Because prior concepts of innovation systems have not considered the analysis of urban CEFPS, we develop a conceptual framework referred to as 'urban food production innovation systems' (UFoPrInS). We use the CUBES Circle innovation in Berlin (CUBES Circle, n.d.) as a paradigmatic case study (Flyvbjerg, 2006) for evaluating an UFoPrInS. CUBES Circle aims to produce fish, plants and insects in a modular, container-based system with closed material and energy cycles. The technologically ambitious research has been funded by the German Federal Ministry of Education and Research under the research programme 'Agricultural systems of the future'. The CUBES Circle case allows to analyse and compare three overlapping controlled-environment food production innovation systems, namely for fish, plant and insect production, and the combined production system. Each of them is linked to different regulatory frameworks that might hinder and/or support the implementation of CEFPS in urban contexts. The case study therefore provides rich material for the purpose of developing the conceptual framework.

Apart from the technological development and implementation, establishing a CEFPS – like the CUBES Circle system – in urban areas also constitutes a technological innovation that requires the development of social and institutional contexts to overcome potential barriers to implementation. In particular, four barriers can be expected: (1) a possible lack of societal acceptance, e.g. towards the production of insects or combined fish and plant production in urban areas (De Wilt & Dobbelaar, 2005; Milicic et al., 2017; Specht et al., 2016), (2) cumbersome regulatory frameworks (overlapping regulations for zoning, commercial building operations, emissions, fish, plants and insect production, etc.) (COST Action, 2013; Curry et al., 2014; McEldowney, 2017), (3) general scepticism towards high-tech food production systems among European publics (De Wilt & Dobbelaar, 2005; Milicic et al., 2017; Specht et al., 2016) and (4) a general preference for 'natural' and 'traditional' food production in Germany and elsewhere (Specht et al., 2015; Specht et al., 2016). The social aspects of the innovation process are, of course, context-dependent and the technology development is shaped by social influences that vary across social contexts. Such context dependence must be reflected while developing the conceptual framework from the case.

In this paper, we adopt a dynamic perspective on innovation systems and distinguish between the conceptualization, development and implementation stage of innovation. This helps to analyse the shifts from a focus on technological to social aspects of the innovation process over time. The conceptualization stage includes the recognition of a problem and the emergence of an idea for an innovation that can contribute to solve the problem. One or more actors cooperate in order to conceptualize the innovation and to find funding opportunities for its development. The development stage starts after sufficient funding has been attracted, e.g. through grants or loans. Now, a group of actors works together to develop the innovation while considering the needs of potential users. This requires research and development (R&D) and collaboration of different types of actors. After successful development of the innovation, the ensuing implementation stage includes the embedding of the innovation in an existing or emerging market and in an established institutional framework. From this point onward, the innovation can be used by potential users. The success of the innovation is typically measured by the rate of adaption among potential users. Depending on the type of innovation, the duration of the implementation stage can differ greatly. Finally, during the diffusion stage, the innovation is communicated via different channels over a period of time and established in other social systems (Rogers, 1983). The diffusion stage will be not considered in this paper.

The innovation system concept is a useful approach to identify the different elements (actors, organizations, institutions) that contribute to the development and implementation of an innovation. Formal and informal institutions are crucial in this context because of their impact on the innovation process (Edquist, 1997; Edquist & Johnson, 1997). Using the CUBES Circle innovation and its prospective location in Berlin as a case, we address the following two research questions to characterize the UFoPrInS as an innovation system for a CEFPS:

(1) What are the main elements and relationships of an UFoPrInS during the conceptualization, development and implementation stages of the innovation process?
(2) How does the institutional framework enable or hinder the conceptualization, development and implementation of an CEFPS in urban contexts?

This study contributes to the analysis of innovation systems in the area of food production, with a particular view on urban settings, and identifies specific features of innovation systems for CEFPS. The development of the UFoPrInS concept aims to systematically capture the differences to non-food innovation systems or agricultural innovation systems in rural areas (Klerkx, van Mierlo, et al., 2012). This helps to better understand the preconditions for a successful establishment of CEFPS in urban areas. While the UFoPrInS concept has been developed with a specific view to CEFPS in urban settings, it can also be applied to other types of high-tech food production in urban areas. Whether the concept is also useful to understand urban gardening or urban agriculture projects without a predominant focus on production must be left for future discussions.

The paper proceeds as follows: Section 2 provides the theoretical and conceptual framework. The case study area, data collection and data analysis are explained in Section 3. Section 4 presents the results, followed by their discussion in Section 5. Section 6 contains overall conclusions and an outlook.

Conceptual framework: urban food production innovation systems

Dimensions and types of innovation systems

While the possible contribution of CEFPS to local food security has been widely discussed (Broad, 2020; Despommier, 2010; Gómez et al., 2019), the novelty of high-tech CEFPS implicates considerable uncertainty of their successful embedding into social, in particular, urban contexts and existing food trends. The success of CEFPS will therefore depend on the development of viable production processes and attractive products and the implementation under suitable context conditions at prospective locations (Cooke et al., 1997; Grebitus et al., 2020; Klerkx et al., 2010).

To analyse the development of CEFPS and their implementation in urban settings, we build on the concept of innovation systems – a heuristic approach (Lundvall, 1992) that has been developed for analysing structural elements and dynamics of innovation processes in a social context (Dielemann, 2019; Edquist, 1997; Markatou & Alexandrou, 2015; Putra & van der Knaap, 2018). The structural elements of an innovation system (actors, institutions, infrastructure, interaction) contribute to a common aim – the development and implementation of an innovation. Their interactions are characterized by the exchange of resources

(Coenen & Díaz López, 2009), with knowledge as a key factor for the formation of an innovation process (Freeman, 1987; Freeman, 1995; Nelson, 1993). During the innovation process, various actors are involved. They can join and leave the innovation process anytime (Putra & van der Knaap, 2018). In recent years, various types and contexts of innovation systems (e.g. national, regional, agricultural or urban) have been distinguished (Markatou & Alexandrou, 2015). Three of these concepts – agricultural innovation system (AIS), technical innovation system (TIS) and urban innovation system (UIS) – are potentially relevant for CEFPS.

The AIS concept focusses on the organization involved in technological, social and institutional innovations in the agricultural sector (Kilelu et al., 2013; Turner et al., 2016). It is usually applied at the national and sectoral level or to a specific technology (Pigford et al., 2018). AIS consist of networks of organizations, entrepreneurs and individuals who aim to develop new products, processes and organizational forms. Over time, AIS develop through a co-evolutionary process that is aligned with established institutions which influence interactions among the actors as well as the exchange of and access to knowledge (Chave et al., 2012; Eidt et al., 2020; Hall, 2005; Hall & Clark, 2010; Kilelu et al., 2013; Klerkx, van Mierlo, et al., 2012; Pigford et al., 2018). AIS analysis aims to understand the regulation of actors' interactions, the role of innovation policies and innovation-supporting structures (e.g. research and consulting) within the innovation process (Hall et al., 2003; Klerkx, Schut, et al., 2012).

TIS analysis focuses on the development, diffusion and utilization of new technologies. TIS consist of actors (e.g. firms, universities, civil societies or politicians), networks and institutions. The development of the technological innovations occurs through the entry of firms and other organizations, the creation of networks, the responses to institutional changes and the accumulation of knowledge. The innovation process is understood as a cumulative process that can take a long time and is characterized by high uncertainty about the technology under development and its acceptance, markets and regulatory frameworks. Furthermore, institutions are crucial for the development, diffusion and application of specific technologies (Bergek et al., 2008). In contrast to the AIS concept, the TIS concept does not include an a priori spatial and context boundary (Carlsson et al., 2002; Edquist, 2005). For a successful innovation, a TIS must fulfil seven functions: entrepreneurial activities; knowledge development; knowledge diffusion; guidance of the search; market formation; resources mobilization and creation of legitimacy (Hekkert et al., 2007).

In contrast to the AIS and TIS concepts, the UIS concept was developed to explain the development of institutional, political and technological innovations within the boundaries of a city and their contribution to economic growth of a nation (Markatou & Alexandrou, 2015). An UIS can be defined as a network that consists of a set of actors (e.g. firms, suppliers, start-ups, research institutes, investors, intermediaries or governmental agencies), networks, platforms and institutions with a shared purpose of developing and implementing one or more innovations in an urban context (Athey et al., 2007; Grossetti, 1999; Liu & Jiang, 2018; Sanyang et al., 2016; van Winden et al., 2014). Within an UIS, urban hubs and local links can be distinguished. Urban hubs (e.g. urban assets, urban markets) are needed to establish sectors and clusters and to develop large markets. Local links (e.g. urban networks, urban institutions) are required for the interlinkage of sectors and knowledge exchange (Athey et al., 2007). Especially, strong local links for innovations are needed that require high levels of knowledge (Markatou & Alexandrou, 2015). Urban areas that provide good conditions for UIS (e.g. well-developed communication and transport infrastructure, access to local and global markets, available workforces, high financial capital) are more likely to enable the development of an innovation (Athey et al., 2007; Markatou & Alexandrou, 2015). Particularly, urban capital and local actors support innovative activities and the innovation process (Markatou & Alexandrou, 2015).

Although the AIS, TIS und UIS approaches have identified similar elements that are needed for the success of an innovation, none of them explicitly focuses on urban food production. Prior studies on innovation systems have touched on innovations in urban food production (see e.g. Driscoll, 2017; Pfeiffer et al., 2015; Prain & de Zeeuw, 2007) but have not systematically linked these elements. We have therefore developed the UFoPrInS concept to address this research gap by identifying the relevant elements of food production innovations in urban contexts and their mutual relationships.

Urban food production innovation systems (UFoPrInS)

Conceptual frameworks are a useful tool for developing qualitative research when theoretical frameworks for a specific issue are not existing or not applicable (Ravitch & Carl, 2015). The UFoPrInS concept understands urban food production systems as a set of identifiable actors who are connected through different networks, institutions and relationships that are characterized by the exchange of various resources. The involved actors share an intention to establish a specific food production innovation in an urban area. The UFoPrInS concept builds on elements from the AIS, TIS and UIS concepts. Moreover, it emphasizes the role of institutions and the urban context within the innovation process. It is geared towards, but not limited to, applications with regard to CEFPS innovations.

Urban settings are usually characterized by complex social, ecological and institutional contexts (Prové et al., 2016). The ecological context comprises all abiotic (e.g. nutrient flows, climate) and biotic processes (e.g. dynamics of populations) (Di Fiore et al., 2021). The social context is shaped by individual and collective actors and their relationships. Their actions and behaviours are influenced by formal and informal institutions (Edquist & Johnson, 1997; Termeer et al., 2019). Conversely, the actors' behaviour and actions can also shape institutions over time (Giddens, 1984). Institutions represent the 'rules of the game' and can be understood as established social expectations (March & Olsen, 1989; North, 1990; Williamson, 2000). Formal institutions are binding rules, laws and regulations or legal requirements that are backed by specified sanctions. They regulate interactions and specify what is allowed or not (Coenen & Díaz López, 2009). In contrast, informal institutions are unwritten rules and expectations such as tacit norms, habits or customs (Bizer & Führ, 2014; Coenen & Díaz López, 2009; Cooke et al., 1997; Jacobsson & Bergek, 2011; Wenzelburger & Zohlnhöfer, 2014). Formal and informal institutions differ between nations, places, sectors or companies (Edquist & Johnson, 1997). The institutional framework can support or hinder an innovation process. In particular, it can decrease uncertainties that occur during the innovation process (Coenen & Díaz López, 2009; Edquist & Johnson, 1997; Liu & Jiang, 2018).

The UFoPrInS framework is visualized in Figure 1. At the centre is the innovation, here a CEFPS. The innovation is conceptualized, developed and implemented by networks of actors with direct or indirect relationships, which can be either formal or informal. Formal relationships are based on either long-term or short-term contracts among two or more parties who agree on compliance with specified behaviours for expected mutual benefit. Noncompliance with contractual conditions is linked to sanctions (Campbell & Harris, 1993; Sosik et al., 2005). In contrast, informal relationships among two or more actors can be based on collaboration in prior projects and/or similar values, life experiences or attitudes (Sosik et al., 2005) and can for example serve to exchange information and knowledge and to advance personal career goals (Sosik et al., 2005). Indirect relationships are connections between two or more actors that are not directly linked but through relations with other actors, e.g. through dedicated networks or organization (Saxena et al., 1990).

The relationships among actors within an UFoPrInS are characterized by the specific patterns of resource exchange. We differentiate between exchange of knowledge, services, material resources (e.g. technologies, hardware), financial resources and mutual access to networks. UFoPrInS are therefore characterized by a complex and dynamic structure, where actors can join and leave the innovation system over time. Besides the innovation actors in a narrow sense, the UFoPrInS framework emphasizes the role of local residents, in particular neighbours, whose acceptance is crucial for the success of food production innovations, in particular CEFPS, in urban contexts.

Methods and data

The case: CUBES Circle

Case studies are a research strategy for in-depth investigation of a social phenomenon. They consist of a detailed analysis of one or several cases that provide relevant representation and validity for a bigger scale and contribute to the development of knowledge (Flyvbjerg, 2006). Case studies usually apply multiple methods of data collection and analysis, e.g. interviews, archival research, surveys or observations (Creswell, 2009; Eisenhardt, 1989; Yin, 2017). Furthermore, case studies contain narrative elements that explain the complexity and contradictions of real life (Eisenhardt, 1989; Flyvbjerg, 2006; Yin, 2017).

Our selected case is the CUBES Circle innovation (CUBES Circle, n.d.), an example of a complex CEFPS under development, which aims to produce food at sealed or uncultivated urban locations that are otherwise not suited for food production. The CUBES Circle

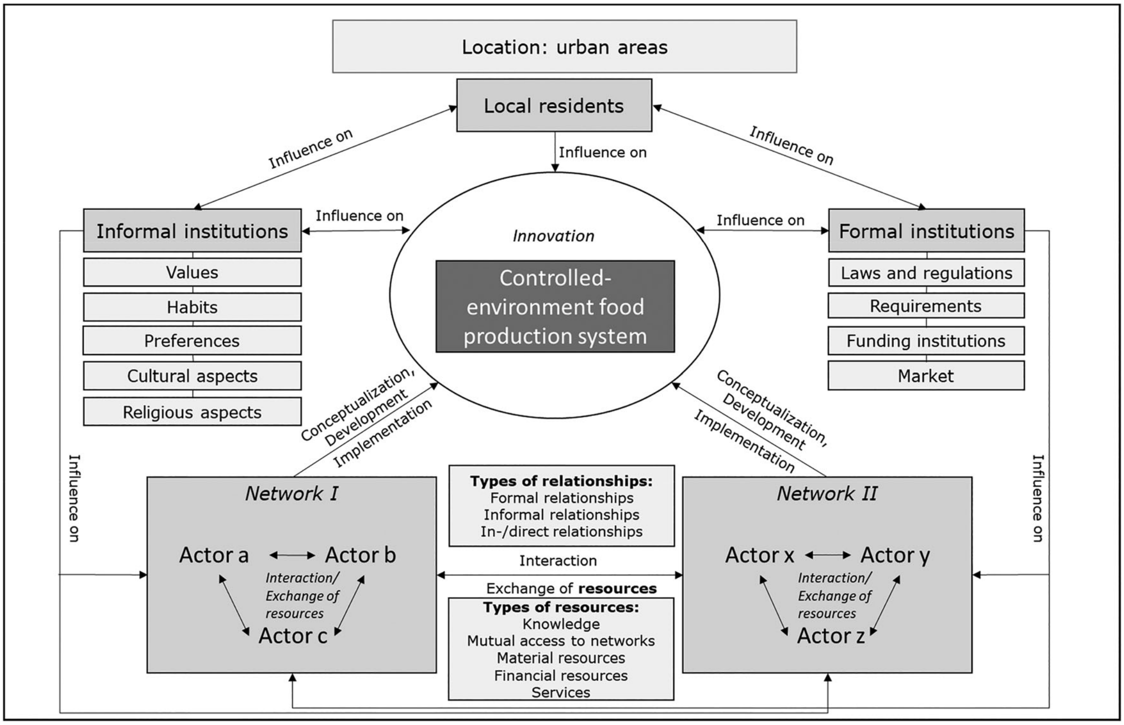

Figure 1. Conceptual framework for the analysis of an urban food production innovation system (UFoPrInS).
Source: Authors' visualization.

concept involves the modular and flexible combination of container elements in which either plants, fish or insects are produced. The ambition of the CUBES Circle innovation is to create a system with internally closed energy and material cycles that can be linked to its urban environment. The interlinkages between plants, fish and insect production are highly complex and fulfil various functions to create a circular system. In particular, fish water and nutrients from a fish CUBE are induced into a plant CUBE, based on real-time nutrient analysis, while transpired water from a plant CUBE is led back into a fish CUBE. The fish is fed back with insect-based feed from an insect CUBE. Vice versa, the sediments from a fish CUBE and the harvest residues from a plant CUBE are used as insect food. The carbon dioxide emitted during the production of insects and fish is induced into a plant CUBE for enhanced photosynthesis. Activated-carbon filters prevent odour nuisance by cleaning gaseous emissions from insect CUBEs. Nevertheless, the CUBES Circle system still needs various energy and material inputs (e.g. supplemental feed additive water, energy, additional nutrients) for delivering the expected outputs (e.g. oils, proteins, harvest). The CUBES Circle concept requires a number of parallel innovations in the areas of horticultural greenhouse production (e.g. tomatoes, strawberries), aquaponics (e.g. Tilapia fish) and insect production (e.g. black soldier flies) (CUBES Circle, n.d.) alongside innovative control technologies.

For our research, we selected Berlin as the case study because it represents the pilot location of the CUBES Circle innovation. Implementation of the pilot is planned at the agricultural campus of Humboldt Universität zu Berlin in Dahlem, which is surrounded by residential areas. Counting 3.6 million inhabitants (Berlin.de, 2019), Berlin is by far Germany's biggest city (Statista, 2021). Its ethnically diverse population is forecast to reach 3.9 million inhabitants by 2030 (Senatsverwaltung für Stadtentwicklung und Wohnen, n.d.). Berlin is also a science hub with three big universities and 42 different research institutes (Berlin.de, 2019). Niche markets for urban food production systems have already been established. Examples for commercial urban food production systems include Dachfarm Berlin, Vita City Berlin, IBZ-Dachfarm (http://www.dachfarmberlin.com/), roof water farm (http://www.roofwaterfarm.com/), infarm (https://www.infarm.com/) and ECF Farm Berlin (https://www.ecf-farm.de/).

By signing the Milan Convention's 'Urban Food Policy Pact' in October 2015, Berlin committed to implement a comprehensive, long-term and equitable food policy. The governing coalition (coalition period: 2017–2021 and 2021–2023) agreed in its coalition treaty to support the development of a sustainable, regionally oriented food strategy for Berlin to address major challenges such as the reduction of food waste, strengthening regional food supply chains and the extensive use of the economic and ecological potential of recycling to reduce resource consumption. To reach these aims, an action plan with objectives, concrete measures and recommendations was adopted by representatives of civil society organizations, the food sector, science, policy and administration in December 2018 (SenJustVA, n.d.). The establishment of the Berlin Food Policy Council (n.d.) indicates lively interest by civil society organizations in food-related topics.

Data collection and analysis

Research for this paper combined a qualitative content analysis of scientific and grey literature and semi-structured expert interviews. The content analysis of scientific and grey literature aimed to identify relevant formal and informal institutions at European, national (Germany) and local level (Berlin) that might influence the conceptualization, development and implementation of CEFPS. Here, we applied a systematic review procedure (the PRISMA statement) that includes a search strategy, screening, extraction of records and the report of the results. Such a literature review is appropriate for providing an overview of research in a specific field (Snyder, 2019). Using a deductive content analysis, we analysed the publications with regard to our research question.

Literature was searched by using the search string: (*'urban food production'* OR *'controlled-environmental food production'* OR *'aquaponics'* OR *'vertical farming' OR 'insect feed' OR 'insect food' OR 'container farming'*) AND (*'institutional framework'* OR *'informal institutions'* OR *'formal institutions'* OR *'acceptance' OR 'cultural aspects' OR 'habits' OR 'laws' OR 'regulations' OR 'EU-policy'* OR *'German policy')* in the database Scopus. Scopus is one of the largest and most widely recognized databases of abstracts and citations for academic research (Baas et al., 2020). We chose Scopus as the database because it includes journals with an international and regional academic focus. Furthermore, data can be more easily extracted compared to other databases such as Google Scholar (Hackfort, 2021).

The first search was conducted on 05.08.2020 and limited to publications that appeared between January 2012 and July 2020. In total, 72 publications were identified via Scopus. To update the sample, a second search was conducted on 02.12.2021. By using the same search string, we focussed on literature that had been published between July 2020 and November 2021. This search resulted in 30 more publications (see Appendix A). By manual screening of title, abstract and keywords, publications were selected that were identified as relevant for our analysis and for answering our research questions, namely with an explicit focus on the institutional framework for urban food production. In this connection, publications were removed that focussed on natural sciences or on case studies outside of the EU. This reduced the text corpus to 27 publications (18 from the first and 9 from the second search). Subsequently, we read these publications and excluded those that did not contain explicit statements about the institutional framework for high-tech food production systems (e.g. CEFPS, aquaponics, vertical farming or container farming) in urban areas. This reduced the text corpus to 15 publications (nine from the first and six from the second search). Following the snowball principle, we added publications and grey literature recommended by colleagues or interview partners. The final sample of 48 publications was analysed with a deductive coding strategy, using codes that were derived from the research focus. The analysis of the final sample considered formal and informal institutions related to urban food production systems as well as social acceptance toward these types of food production systems. To identify relevant actors within the innovation process we used the project proposal and the homepage of the CUBES Circle project.

Semi-structured expert interviews were conducted for supplementing the results of the literature and document analysis. The expert interviews focussed on identifying and analysing institutions, actors and their relationships that are relevant for the development and implementation of the CUBES Circle innovation.

Experts were selected by purposive sampling (Meuser & Nagel, 1997; Rapley, 2014), based on their position and competencies in the innovation process, their interest in the implementation and utilization of the CUBES Circle innovation and their capability to influence the innovation process. Interview partners fell into three groups:

- Members of the project team: The consortium of the CUBES Circle project, which is involved in the development of the CUBES Circle innovation and has an interest in its implementation.
- External partners: Practical partners and actors from the scientific advisory council of the CUBES Circle project, who have an interest in the implementation and adoption of the CUBES Circle system.
- Institutional environment: Actors from relevant institutions and organizations which provide the framework for the development, implementation and adoption of the CUBES Circle innovation.

Further relevant experts were identified through snowball sampling during the interviews (Rapley, 2014). To reflect different degrees of involvement in the innovation process, three different semi-structured interview guidelines were developed. The interview guideline for the first group focussed on relevant actors and institutions in the development and implementation stage of the CUBES Circle innovation. Interview guidelines for the two other groups concentrated on institutions and actors in the implementation stage of the CUBES Circle innovation. Open questions in the interview guidelines referred to institutions, actors and their functions during the innovation process, whereas closed questions addressed preferred impacts of actors or institutions on the development and implementation of the CUBES Circle innovation, using five-point Likert scales.

Overall, we conducted 23 expert interviews via video conference software Zoom between October 2020 and March 2021 (nine interviews with members of the project team, 10 interviews with external partners and four interviews with experts from the institutional environment). Following Grounded Theory (Baur & Blasius, 2014), sampling was closed when theoretical saturation was reached. On average, interviews lasted 90 min with project members and 60 min with the other groups. All interviews were recorded, manually transcribed and analysed according to qualitative content analysis guidelines (Gläser & Laudel, 2008). For coding, we developed a combined deductive and inductive category system, with most deductive categories derived from the literature analysis and additional codes added inductively, based on insights gained during the interviews and their analysis (Bortz & Döring, 2015). The coding scheme was repeatedly discussed between the authors and revised when necessary. The closed questions were analysed via descriptive statistics and overview tables. They did not aim at representativeness but as anchors to assess interviewees' positions. All quotes from the interviews in the results section were translated by the authors from German to English.

Results

This section presents the findings on the composition and characteristics of the UFoPrInS for the CUBES Circle innovation during the conceptualization, development and implementation stage. At the time of the interviews, the CUBES Circle innovation was at an early development stage, which is therefore often referred to as the present stage. In contrast, the conceptualization stage denotes the past and the implementation stage a prospective future of the innovation process. Due to the novelty of the innovation as a CEFPS, statements by the interviewees about the kinds of actors and institutions that might become relevant or should be considered during the implementation stage are mostly based on assumptions and expectations.

Conceptualization stage

According to the project proposal, the actors that were involved in conceptualizing the CEFPS innovation fall into three categories: knowledge institutions (e.g. universities, technical colleges and research institutes), private sector (e.g. production, industry and consultancy) and value chain actors (e.g. retailer). These actors knew each other from prior projects and their relationships were based on existing networks. The innovation concept pursued a highly interdisciplinary approach, involving researchers from a broad range of specialized knowledge areas (Ulrichs et al., 2017).

The research proposal and the website of the project explained that research was divided into nine subprojects with specific objectives during the innovation process (see Appendix B). The involved actor groups were meant to contribute complementary resources and competencies to develop the innovation. The conceptualization of the innovation was mainly based on the combination of existing knowledge of the involved actors, mostly gained from prior research projects, making knowledge a crucial resource during the conceptualization stage (Ulrichs et al., 2017; CUBES Circle, n.d.).

The most important formal institutions during the conceptualization stage were, apart from the formal elements of the involved organizations, funding institutions since financial resources were needed for the development of the innovation. The research consortium was formed in response to a call by the German Federal Ministry of Research and Education, titled 'Agricultural systems of the future', which invited research proposals to develop innovative solutions to overcome major challenges facing the food sector. The requirements and volume of the research programme guided the conceptualization of the innovation (BMBF, 2022; CUBES Circle, n.d.).

Development stage

The results of the expert interviews show that a variety of *actors* are involved in the development stage. They fall into seven different categories: the project partners, private sector (e.g. technological and industrial entrepreneurs), knowledge institutes, value chain actors (e.g. retailers, consumers), the project's scientific advisory council, civil society organizations, the broader public (e.g. media) and political actors. Project partners, private sector and knowledge institutes were mentioned most frequently as relevant for the development stage. The interviewees attributed the greatest influence during the development stage to the project partners, followed by private sector, knowledge institutes, value chain actors, public actors and political actors (moderate influence). The influence of the scientific advisory board and civil society organizations was seen as rather low. The actor constellations in the development stage are characterized by a high degree of interdisciplinarity with different knowledge areas and competencies contributing. The majority of the interviewees saw the project leader as the central actor because he was looking for new project partners and is responsible for public relations:

> *'[…] project management, we coordinate what we do and it is also this networking character […]' (Interview 04: 53f.)*

The interviews identified various important *functions* of the innovation system during the development stage. In particular, the development of hardware, software and various partial innovations, the collection and provision of data, experimentation, the creation of knowledge and consultancy (see Appendix C). To enable the development of the innovation, project partners contributed patents from prior research projects (see e.g. Kloas et al., 2008; ZINEG, 2014).

According to the interviewees, the crucial *resource* during this innovation stage is knowledge that was created by experimentation. Knowledge is also the primary resource that is exchanged among the actor groups. The relationships between the actor groups were described by the interviewees as mostly informal at this stage. Additionally, formal, indirect and other types of relationships (e.g. dependencies) are present but were seen as being of minor importance. Less mentioned but also important for the development of the innovation is the exchange of material and financial resources, services and the mutual access to networks (see Appendix C).

While the interviewees attributed only medium to low influence on the development of the innovation to *informal institutions*, several of them were mentioned as requiring consideration: values, preferences, cultural aspects, habits and religious aspects. Values encompass for example a vegan or vegetarian lifestyle but also a preference for 'naturalness'. The latter could inhibit the success of the innovation, given its highly artificial production environment which for example contradicts principles of organic agriculture:

> *'[…] then we have to consider that there are quite a few people whom we have to convince that what we are doing is sustainable […] because there are just many who think that such technical systems do not correspond to nature. This is not a natural production, which we make, but an artificial hemisphere, in which we produce here and nevertheless we must show outward that it makes sense, in the sense of a future agriculture' (Interview 01: 150-155)*

Preferences include e.g. customers' demand for food products or their expectations about urban food production systems. Cultural aspects mostly referred to perceived critical attitudes of potential customers towards food production within an artificial environment. Habits involve the year-around availability of food in homogenous high quality.

According to the interviews, laws and regulations were seen as the most relevant *formal institutions* for the development stage. Interviewees explicitly mentioned the German Food and Feed Code, Animal Welfare Act, Federal Building Code, Federal Regional Planning Act, Federal Law on Nature

Protection, Patent Act, Federal Immission Control Act, Federal Nature Conservation Act, Plant Protection Act and Genetic Engineering Act. Although some of these laws and regulations will only become relevant during the implementation stage, they already need to be considered at the development stage. Other important formal institutions with a big influence on the development stage are funding institutions, statutory requirements and insurance.

The results from the literature review supplement the finding from the interviews, in particular, that CEFPS are confronted with a complex and incoherent regulatory framework (see Appendix D for an overview). Urban food production receives little consideration by European, national and local legislation (Curry et al., 2014). Generally, the European Regulation (No 305/2011) for the marketing of construction products is implemented by the building law in Germany. All construction products have to conform with this European Regulation. The German building law contains also technical standards that have to be considered when building an urban food production facility. However, there is neither a common legal framework (Joly et al., 2015; Milicic et al., 2017; Reinhardt et al., 2019) nor a clear permit procedure for urban CEFPS such as aquaponics and hydroponics (König et al., 2018). Different aspects of aquaponic and hydroponic systems (e.g. food security, hygiene, pest control, slaughter and animal welfare) are covered by different laws at national, local and EU level (Cammies et al., 2021; Hoevenaars et al., 2018; Joly et al., 2015; König et al., 2018; Reinhardt et al., 2019) with partly contradictory requirements (König et al., 2018). Urban food production systems that use a circular system are not subject to the regulations of the Waste Water Ordinance. The multiple uses of water within the facility are not regulated by the German Water Law if there is a central wastewater treatment. German fertilizer law is not applicable if the fish waste is used within the facility as plant fertilizer (DüngG, 2009). The German Plant Protection Law prescribes that natural solutions shall be used for pest control before pesticides are applied (Reinhardt et al., 2019).

Implementation stage

The results of the expert interviews with all three groups indicated that the implementation stage would be characterized by a higher variety of involved actors which can be categorized into ten groups: private sector (e.g. building companies, technology firms), value chain actors (e.g. retailers, consumers), civil society organizations, administrative actors, project partners, knowledge institutes, political actors, public sector (e.g. schools, kindergarten) as well as local residents and veterinarians. Private sector and value chain actors were expected by the interviewees to be most relevant because they will be responsible for building and operating the CEFPS:

> *'[…] you have a product that needs to be sold and we need someone to sell it, that's the supermarket chains and generally those who are supposed to sell it have to offer it first, so we need a platform' (Interview 18: 77ff.)*

According to the interviews administrative and political actors will become more relevant in the implementation phase:

> *'If they are not really behind it then I think you have no chance of success. […] If they are convinced that it could be gonna help to supply affordable and acceptable food for urban consumers in a more environmentally friendly way, they can help so much. They can organize meetings, they can lobby out of consumer groups. They could give you subsidies' (Interview 16: 103-107).*

According to the interviewees, the extended actor constellation will have important *functions* during this innovation phase, in particular, design, building, operating, optimization, commercialization, processing, selling of the products, giving permissions, R&D, provision of a legal framework and financial support of the innovation (see Appendix E).

In relation to the interviews, the expected primary *resource* will be knowledge that will be exchanged among the actor groups. Informal relationships are expected to prevail. However, formal relationships will become more important at the implementation stage. Further important resources are expected to be services, mutual access to networks, financial and material resources.

A new challenge at the implementation stage will be the *acceptance* of the CEFPS innovation by consumers and by local residents in urban areas. According to the interviews, eventual adoption of the innovation will likely depend on several factors: transparency and design of the innovation, location, production of competitive products, willingness of consumers to pay for these products and involvement of partners and networks who diffuse the idea of the innovation. Acceptance of this innovation type will be influenced by informal institutions. Interviewees expected values, preferences, cultural and religious aspects to be relevant at the implementation stage. Potentially relevant values include personal attitudes towards animal welfare, vegetarian or vegan lifestyles or environmental awareness. Preferences include costumers' predilection for and associations to food products but also aesthetic aspects and acceptance of food production in urban areas. Cultural challenges could arise from lacking acceptance of insects as food and scepticism towards food production in artificial, 'unnatural' systems.

Whether religious aspects, e.g. faith-related rejection of specific animal products, would affect the innovation, is unclear. Interviewees had different views how strongly each informal institution would influence the prospective implementation of the innovation. A rather big influence during the implementation stage was attributed to cultural aspects, followed by preferences (moderate influence), values (rather low influence) and religious aspects (low influence). Interviewees from all groups saw awareness of current sustainability challenges (e.g. feeding an increasing world population, climate change or expansion of urban areas) and increasing societal demand for sustainable, healthy and fresh food as catalysts for the implementation and as precondition for a successful adoption of the innovation. One interviewee suggested to link the prospective production sites with shopping experiences, e.g. producing food in front of a supermarket. This would create trust in the production system.

The assessments from the expert interviews regarding acceptance of this CEFPS innovation resonate with the results of the literature review. High-tech food production systems such as aquaponics, hydroponics, vertical farming or agroparks are commonly less accepted by consumers and the public (De Wilt & Dobbelaar, 2005; Di Fiore et al., 2021; Milicic et al., 2017; Specht et al., 2016; Specht et al., 2019). Main reasons for refusal of CEFPS are lack of awareness about these production types (Jürkenbeck et al., 2019; Milicic et al., 2017; Specht et al., 2016), negative affective attitudes (e.g. towards the combination of fish and plant production, loud noises, polluted air and water resources through fertilizers) (Grebitus et al., 2020; Milicic et al., 2017), negative perception of aspects of animal welfare (Honkanen et al., 2006; Milicic et al., 2017; Specht et al., 2019; Zander & Hamm, 2010) and personal attitudes (e.g. vegan or vegetarian lifestyle) (Collins et al., 2019; Milicic et al., 2017).

Against the background of increasing demand for healthy, safe, nutritious, fresh and sustainable food (Grebitus et al., 2017; Ruggeri et al., 2016), the literature emphasizes that most consumers in Germany have a 'traditional' vision of good agriculture and food production. The majority prefers agricultural products that are 'natural', produced with traditional production processes and not in 'artificial' production systems (Specht et al., 2015; Specht et al., 2016; Specht et al., 2019). Several studies have shown that respondents are more sceptical about urban animal production (e.g. meat, milk, cheese, fish or eggs) than urban plant production (De Wilt & Dobbelaar, 2005; Specht et al., 2015; Specht et al., 2016; Specht et al., 2019). Perception of insect production is generally ambivalent. In many countries, consumption of insects and algae is quite common, whereas in Western societies insect consumption would require a change of dietary patterns (Dagevos, 2021; Elorinne et al., 2019; Hartmann & Siegrist, 2017; House, 2016; Iannuzzi et al., 2019; Kauppi et al., 2019; Kornher et al., 2019; Mancini et al., 2019; Onwezen et al., 2019; Poortvliet et al., 2019; Rumpold & Langen, 2019; Sidali et al., 2018; Sogari et al., 2019; van der Weele et al., 2019; Verbeke, 2015). Nevertheless, younger people were found more open to eat insects compared to the older generation (Naranjo-Guevara et al., 2021; Orsi et al., 2019; Verbeke, 2015). Moreover, utilization of insects as feedstuff is assessed as a less risky alternative for Western markets with relatively low legal requirements on the production procedure, whether in urban or rural food production systems (Oroian et al., 2015; Stamer, 2015).

Formal institutions featured highly in the expert interviews when the prospective implementation of the CUBES Circle innovation was considered. According to the interviews, laws and regulations, statutory requirements, market, funding institutions and insurance were all attributed a large influence at the implementation stage. Laws and regulations that were explicitly mentioned by the interviewees are Animal Welfare Act, German Food and Feed Code, Federal Building Code, Federal Regional Planning Act, Federal Nature Conservation Act, Labour Protection Law, Federal Immission Control Act, Consumer Protection Law, Federal Water Act, Patent Act, Waste Water Directive, Levy Act, Common Agricultural Policy (CAP), Federal Emission Control Law and Federal Land Utilization Ordinance. Moreover, local regulations were summarily added in this context.

The literature review showed that the implementation of CEFPS in urban contexts faces a complex regulatory framework (see Appendix D). The local level is responsible for various overlapping permission procedures, in particular the building permission, permission for water quality and discharge, emission protection and finally the operational license (Reinhardt et al., 2019). In addition, the operation of an urban CEFPS has to conform with planning, building and water regulations as well as specific regulations for animal, fish and plant production, depending on the products (König et al., 2018; Reinhardt et al., 2019). The Planning Act applies to the preparation of a land plot for utilization based on land use and development plans (§1 Building Law). Planning permissions for aquaponic facilities depend on the nature and location of the farm (Cammies et al., 2021). However, aquaponic facilities are regarded as 'too agricultural' for urban areas for considering them in the German Planning Acts (König et al., 2018; Reinhardt et al., 2019) or the federal state planning of Berlin (Specht et al., 2015). Relevant EU policies for aquaponics include the EU Animal Welfare Strategy, Food and Nutrition Policy and Environmental Policy.

Surprisingly, the Common Agricultural Policy (CAP) was mentioned in the interviews as relevant legislation for urban CEFPS, while the publications in the literature review came to a different conclusion. Although targets are set in the CAP and Common Fisheries Policy (CFP) to improve the sustainability and competitiveness of aquaculture and agriculture (Massot, 2020), there are no initiatives to include novel forms of food production into agricultural policy (Curry et al., 2014; McEldowney, 2017). Notably, market orders at European level cover agricultural products, independently of their origin. However, not all products are covered by market orders. The income support of the CAP is confined to agricultural producers. Aquaponics and similar systems are not considered as 'agricultural' and can therefore not receive payments reserved for 'farmers'. At the same time, due to their locations, urban CEFPS are excluded from most of the rural development programmes of the second pillar (COST Action, 2013; Curry et al., 2014).

Aquaponic as a newly emerging field must compete with already established horticultural practices, infrastructure and support (Cammies et al., 2021). The CAP and the CFP both affect aquaponic facilities (Cammies et al., 2021; Hoevenaars et al., 2018). However, there are no specific regulations provided for aquaponic within the CFP (COST Action, 2013; Curry et al., 2014; McEldowney, 2017; Milicic et al., 2017). The CAP is responsible for regulating the hydroponic part of an aquaponic facility. Here, fewer regulations are relevant compared to aquaculture. Main regulations for hydroponic production involve planning permission and food safety (Cammies et al., 2021). Furthermore, EU fishery funds are primarily distributed to maritime and traditional freshwater aquaculture rather than to aquaponics (König et al., 2018).

A further problem is the labelling of products from urban CEFPS. The fish and plant products from e.g. aquaponic systems cannot be certified with the ecolabel of the EU because the organic certification for plant production prescribes that nourishing of plants shall occur primarily through the soil ecosystem. As a consequence, hydroponic cultivation does not qualify for organic certification. Even though fish waste is used as a natural fertilizer within an aquaponic system, EU organic certification does not permit its utilization (Cammies et al., 2021; Fruscella et al., 2021; Kledal et al., 2019; Milicic et al., 2017; Reinhardt et al., 2019). Furthermore, the fish products within an aquaponic system cannot be considered for organic certification because the use of Recirculating Aquaculture Systems (RAS) is prohibited. In contrast, the Aquaculture Stewardship Council (ASC) allows the use of recirculating systems of farmed fish (Cammies et al., 2021; Fruscella et al., 2021). While the EU assists mainly research projects to develop aquaponics, financial measures for supporting the sector in commercial development are lacking (Hoevenaars et al., 2018).

According to the literature analysis, the legal framework for insect production has progressed in recent years. Since January 2015, whole insects and their parts are explicitly mentioned in the EU regulation (No. 2015/2283) on novel food (Lähteenmäki-Uutela et al., 2018; Reinhardt et al., 2019; Sidali et al., 2018; van der Weele et al., 2019). Moreover, the use of insects and insect protein as fish feed has been legalized in the Food and Feed Code (Lähteenmäki-Uutela et al., 2018; Reinhardt et al., 2019), conditional on a safety assessment authorized by the European Food Safety Authority (EFSA) (Lähteenmäki-Uutela et al., 2021). Noticeable, authorization is restricted to seven insect species, including black soldier fly (Lähteenmäki-Uutela et al., 2018). The specific hygiene rules for insect foods are stipulated in the Regulation (EC) No. 853/2004 (Lähteenmäki-Uutela et al., 2021).

From the case study to the UFoPrInS concept

Relevance of the UFoPrInS concept

The development and implementation of an innovation requires not only technical changes but also changes in social dimensions such as user practices, regulations, processes, organizations, networks, actors' behaviour or their relationship to each other (Cooke et al., 1997; Geels, 2002; Klerkx et al., 2010). It is never certain whether novel innovations such as CEFPS in urban settings will be accepted, what adaptations they will require and how they will be embedded into the institutional environment. The innovation system concept is useful to analyse the interplay of actors, institutions, relationships and structures during an innovation process (Dielemann, 2019; Edquist, 1997; Markatou & Alexandrou, 2015; Putra & van der Knaap, 2018). We have suggested to introduce the concept 'urban food production innovation system' (UFoPrInS) to understand the specific challenges of CEFPS innovations in urban contexts.

Figure 2 represents the findings for the CUBES Circle innovation system for the different innovation stages. To start with, this innovation aims to establish a high-tech food production system. Strongly advanced by the creation of new knowledge and driven by research institutes, it can be regarded as a radical innovation due to its scientific basis, the complex innovation process and the intended new way of producing food (van Winden et al., 2014). If successful, the CUBES Circle system would constitute a CEFPS that does not qualify as an agricultural system as for example defined in CAP regulations. The case therefore differs significantly from the agricultural innovations typically discussed in the AIS literature.

At the same time, the case does not fit the typical characteristics of an urban innovation system as discussed in the UIS literature. The key actors during the conceptualization and development stage are researchers and knowledge institutes with selected private and value chain actors, connected through mostly informal networks. Relationships with urban society and economy are negligible in the conceptualization stage and limited in the development stage (see Figure 2). However, eventual implementation at urban locations is an essential part of the innovation concept and its value proposition. During the prospective implementation stage, the innovation system would therefore need to develop intensive relations with urban society for acceptance and support and with the urban economy for commercial success. Furthermore, the implementation concept requires adaptation of the innovation to the specific institutional framework at the urban location, which implies specific challenges due to regulations that aim to manage interactions between production activities and other uses and users of the city under conditions of high spatial density. In this regard, CUBES Circle differs from food production innovations aimed at no specific or at rural locations, making the 'urban' component of the UFoPrInS concept an essential and distinctive feature of this case.

Given its technological focus, CUBES Circle could be considered as a case of a TIS. However, establishing a typically rural activity at urban locations is essential to the value proposition. Such an explicitly spatial component is not included in the TIS concept, even less so as the defining characteristic of innovation. The case study also shows that the intended urban location creates specific implementation challenges which are likely to shape the development of the innovation in response to issues of trust and acceptance among a heterogenous urban population, city-specific institutional and regulatory requirements and an urban/rural divide in the funding environment. The UFoPrInS concept emphasizes a thorough analysis of these particularities.

Challenges faced by UFoPrInS

Since the characteristics of the CUBES Circle case support the relevance of the UFoPrInS concept, we now discuss which specific challenges for UFoPrInS can be derived from the case study.

The success of innovation generally requires that all involved actors share a common vision. Missing or wrong interaction could hinder a successful implementation. Innovation systems fail if structural components are weak (Bergek et al., 2008). Structural failures can occur in infrastructure (related to actors), interaction (related to networks), capabilities of the actors, or institutions (Klein Woolthuis et al., 2005). We discuss these four dimensions in turn.

First, CEFPS at urban locations can benefit from available *infrastructures*. In the case study, the availability of an advanced research infrastructure was decisive for the location of most development stage activities in the metropolitan area of Berlin. More

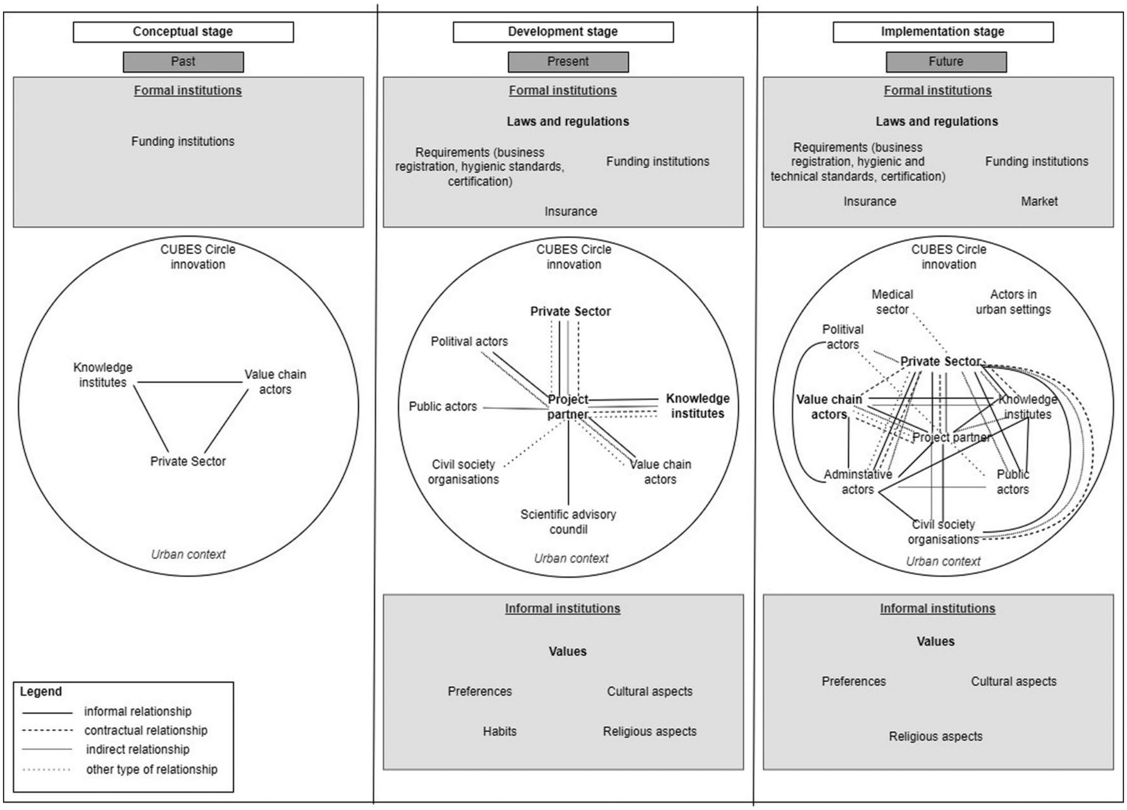

Figure 2. The urban food production innovation system during the different innovation stages.
Source: Authors' visualization, 2022.

generally, available infrastructures are likely a factor in attracting food innovations to urban areas. Due to the relatively high costs of space and the lack of open ecological systems in cities that would be suitable for food production, urban food production innovations are likely to entail CEFPS, which in turn require a sophisticated and reliable infrastructure.

Second, urban locations might facilitate network *interactions* that are necessary for CEFPS innovations. In the case study, the number and variety of involved actors increased from the conceptualization to the development and the implementation stage (see Figure 2). Our results show that actors connect and disconnect with new people or resources and ideas over time in a continuous process of interactions and changes (van der Gaast et al., 2022). Notably, network interactions in the case study were not limited to one location. The development of a real-time data exchange infrastructure across remote locations was a key element of the innovation. This suggests to conceptualize the urbanity dimension of the UFoPrInS not merely in physical terms but with reference to discussions about cities as nodes in networks (Sassen, 2013). In general, CEFPS innovations will move to urban locations if they can benefit from location-specific advantages generally ascribed to UIS, thereby creating a UFoPrInS. This might entail access to networks of developers, to markets, or to other elements of an innovation ecosystem as well as greater collaboration between entrepreneurs, policy actors and knowledge institutes, as these will foster the development and implementation of sustainable food innovations through policy support (van der Gaast et al., 2022). Due to the internet, it is now easier to create more decentralized and smaller forms of cooperation and networks that reduce dependency on larger organizations and allow entrepreneurs to acquire essential knowledge (Knickel et al., 2017).

Third, *capabilities* of the actors are activated through the exchange of resources. In the case study, knowledge was the most important resource during the conceptualization and development stages. It was mostly exchanged through informal relationships, facilitated by trust built through previous projects and long-standing relations. The implementation stage was expected to require a broader range of resources. This is likely true for CEFPS more generally. To the degree that necessary resources can be more easily leveraged in urban contexts, where more heterogenous populations and organizations are in close proximity than in rural areas, more UFoPrInS are likely to emerge. However, availability of space and natural resources are limiting factors.

Fourth, CEFPS generally face a complex, partially contradictory *institutional environment*. The case study points to specific institutional challenges for UFoPrInS that can lead to structural failure. A common regulatory framework or permission procedure for CEFPS does not exist (Joly et al., 2015; Milicic et al., 2017; Reinhardt et al., 2019). Aquaponics, plant and insect production are covered by different regulations. Their combination in order to close material cycles therefore increases both technological and institutional complexity. Regulatory complexity can be further exacerbated at urban locations where legal exemptions for agricultural holdings in planning law and other legislation are unlikely to apply. However, the growing demand for local, sustainable and healthy food and the potential of urban CEFPS to contribute to meeting these demands requires a change of land use and planning policy that increasingly consider novel types of food production (Knight & Riggs, 2010). In the EU, urban CEFPS have no access to funding under the CAP since they are not considered as 'agriculture' and fall outside the spatial scope of rural development funding (Joly et al., 2015; Reinhardt et al., 2019). UFoPrInS therefore depend on other funding instruments, in particular from R&D programmes and venture capital, and must make up the lack of state support in comparison to CAP-supported competitors.

Finally, acceptance of CEFPS in urban locations depends on informal institutions such as values, preferences and trust. The case study indicates that these can become inhibiting factors since food production in urban locations and in controlled environments challenges prevailing conceptions of urban and rural space, naturalness and sustainability. An important task for UFoPrInS is therefore the promotion of food production within urban settings and their various benefits (e.g. healthy food, job provision) (Knight & Riggs, 2010), the early involvement of relevant stakeholder groups (e.g. consumers or actors in urban settings) and the anticipation of their preferences, values and needs through public debates or surveys during the development process. Trust-building is essential (de Vries et al., 2019), with measures to enhance visibility and transparency, e.g. branding and development of a labelling system (Reinhardt et al., 2019). As the case study indicates, while many of the formal and informal institutions become relevant at the implementation stage, they already need to be considered during the development stage of a UFoPrInS.

Conclusions

Resource-efficient and sustainable food production systems are needed in order to provide sufficient and high-quality food products to a growing urban population. CEFPS in urban locations are widely discussed as an option to enhance local food production in a resilient and sustainable way. However, such solutions require technical, organizational and social innovations. This study therefore aimed to contribute to the understanding of innovation systems for controlled-environment food production in urban areas. Adopting an innovation system perspective, we developed the UFoPrInS concept to emphasize the specific characteristics and challenges of CEFPS innovations in urban settings. We suggest that the UFoPrInS concept can also be applied to other types of high-tech food production systems that could be implemented in urban areas. Further research is needed to determine whether this concept could also be usefully applied to low-tech food production systems such as urban agriculture or gardening projects or extending to peri-urban areas as possible locations for CEFPS.

To study the usefulness of the UFoPrInS concept, we used the CUBES Circle innovation as an exemplary case study, deploying a combination of literature and document analysis and semi-structured expert interviews. We analysed the elements involved in this innovation process, their mutual relationships and their interactions with the social and institutional environment during three different innovation stages – conceptualization, development and implementation. The analysis showed that the CUBES Circle innovation has several specific characteristics that distinguish it from the innovations usually discussed in the AIS, UIS and TIS literatures, justifying the UFoPrInS concept.

Based on the case study, we conclude that UFoPrInS have complex and dynamic characteristics. We can derive several expectations for future case studies: First, the number and variety of involved actors increases and mutual relationships are becoming more complex over time. Second, while the conceptual and development stages are dominated by research institutes, private sector and value chain actors are becoming dominant in the implementation stage. Third, knowledge is a crucial resource in all innovation stages and mostly exchanged through informal relations of trust.

On this basis, we were able to identify specific challenges to UFoPrInS in the areas of infrastructure, interactions and networks, capabilities and resource exchange, and formal and informal institutions. Formal and informal institutions were identified as major barriers to innovation. Support for new types of food production systems, in particular CEFPS, would require a comprehensive regulatory framework that considers in an integrated approach the specifics of (1) the highly-intensive production processes, (2) the diverse types of products and (3) the urban location. Furthermore, innovations must be aligned with values, perceptions and preferences of the broader public, making measures to enhance transparency and trust-building essential elements of the innovation process.

The challenges according to the infrastructure, interactions and networks, capabilities and resource exchange, and formal and informal institutions of the UFoPrInS could guide future research. Areas of particular interest are how infrastructures, networks, capabilities and resources might attract food innovations to urban contexts; perceptions and acceptance of CEFPS in urban contexts among neighbours, residents, key actors in business, policy and administration, and urban publics; and the role of implementation of CEFPS at urban locations for their value proposition. Further research is also needed to better understand the processes and dynamics through which UFoPrInS fulfil the functions needed for a successful innovation process as identified in TIS analyses. Application of the UFoPrInS concept to more cases would help to address the main limitations of this study: its reliance on one case study and the affiliation of the authors with the consortium under study (which at the same time enabled access). Whether peri-urban areas are more suitable locations for CEFPS than urban areas due to more available land, less restrictive regulations or other support programmes requires further analysis of the innovation system. However, the ambition of this paper was as much conceptual as empirical: to contribute to a better understanding of the preconditions for the establishment of CEFPS in urban areas and thereby to facilitate better solutions for resilient urban food systems.

Acknowledgment

The authors are grateful to the members of the CUBES Circle consortium, the scientific advisory council and to all interviewees for participating in the interviews.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The work was supported by the German Federal Ministry for Education and Research (BMBF) [grant number 031B0733A]. The article processing charge was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 491192747 and the Open Access Publication Fund of Humboldt-Universität zu Berlin. The funding sources had no influence on contents or submission of the paper.

Data availability statement

Data used in this research is available upon reasonable request from the corresponding author.

References

Athey, G., Glossop, C., Harrison, B., Nathan, M., & Webber, C. (2007). *Innovation and the city. How innovation has developed in five city-regions*. NESTA.

Baas, J., Schotten, M., Plume, A., Côté, G., & Karimi, R. (2020). Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. *Quantitative Science Studies*, *1*, 377–386. https://doi.org/10.1162/qss_a_00019

Bannor, R. K., Sharma, M., & Oppong-Kyeremeh, H. (2021). Extent of urban agriculture and food security: Evidence from Ghana and India. *International Journal of Social Economics*, *48*(3), 437–455. https://doi.org/10.1108/IJSE-08-2020-0519

Baur, N., & Blasius, J. (2014). Methoden der empirischen Sozialforschung. Ein Überblick. In N. Baur, & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (pp. 41–62). Springer VS.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, *37*(3), 407–429. https://doi.org/10.1016/j.respol.2007.12.003

Berlin.de. (2019). *Berlin im Überblick*. Zahlen und Fakten. Retrieved July 7, 2021, from https://www.berlin.de/berlin-im-ueberblick/zahlen-und-fakten/

Berlin Food Policy Council. (n.d.). *The Berlin Food Policy Council*. Retrieved July 7, 2021, from https://ernaehrungsrat-berlin.de/the-berlin-food-policy-council/

Bizer, K., & Führ, M. (2014). *Praktisches Vorgehen in der interdisziplinären Institutionenanalyse. Ein Kompaktleitfaden*. sofia-Diskussionsbeiträge. https://www.sofia-darmstadt.de/fileadmin/Dokumente/Sonstige/Delta-Analyse/Kompakte_Stufenheuristik_2022-01-12_mf.pdf

BMBF. (2022). *Agricultural systems of the future*. Retrieved March 10, 20221, from https://www.agrarsysteme-der-zukunft.de/en/home

Bortz, J., & Döring, N. (2015). *Forschungsmethoden und -evaluation. Für Human- und Sozialwissenschaftler* (4th ed.). Springer.

Broad, G. M. (2020). Know your indoor farmer: Square roots, techno-local food, and transparency as publicity. *American Behavioral Scientist*, *64*(11), 1588–1606. https://doi.org/10.1177/0002764220945349

Cammies, C., Mytton, D., & Crichton, R. (2021). Exploring economic and legal barriers to commercial aquaponics in the EU through the lens of the UK and policy proposals to address them. *Aquaculture International*, *29*(3), 1245–1263. https://doi.org/10.1007/s10499-021-00690-w

Campbell, D., & Harris, D. (1993). Flexibility in long-term contractual relationships: The role of co-operation. *Journal of Law and Society*, *20*(2), 166–191. https://doi.org/10.2307/1410166

Carlsson, B., Jacobsson, S., Holmén, M., & Rickne, A. (2002). Innovation systems: Analytical and methodological issues. *Research Policy*, *31*(2), 233–245. https://doi.org/10.1016/S0048-7333(01)00138-X

Chave, M., Ozier-Lafontaine, H., & Noël, Y. (2012). Towards agricultural innovation systems: Designing an operational interface. *Outlook on Agriculture*, *41*(2), 81–86. https://doi.org/10.5367/oa.2012.0090

Coenen, L., & Díaz López, F. J. (2009). *Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities*. Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE), Lund University. Paper no. 2009/12.

Collins, C. M., Vaskou, P., & Kountouris, Y. (2019). Insect food products in the western world: Assessing the potential of a new 'green' market. *Annals of the Entomological Society of America*, *112*(6), 518–528. https://doi.org/10.1093/aesa/saz015

Cooke, P., Gomez Uranga, M., & Etxebarria, G. (1997). Regional innovation systems: Institutional and organisational dimensions. *Research Policy*, *26*(4-5), 475–491. https://doi.org/10.1016/S0048-7333(97)00025-5

COST Action. (2013). *COST-Aktion zur urbanen Landwirtschaft "Urban Agriculture Europe"*. Erklärung von Barcelona zur urbanen Landwirtschaft und der Gemeinsamen Agrarpolitik. Retrieved December 10, 2019, from http://www.urban-agriculture-europe.org/files/130624_barcelona_declaration_on_urban_agriculture.pdf

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Sage Publications.

CUBES Circle. (n.d.). *CUBES Circle - Future Food Production*. Retrieved June 18, 2020, from https://www.cubescircle.de/

Curry, N., Reed, M., Maye, D., & Kirwan, J. (2014). Urban agriculture and the policies of the European union: The need for renewal. *Spanish Journal of Rural Development*, *5*(1), 91–106. https://doi.org/10.5261/2014.ESP1.08

Dagevos, H. (2021). A literature review of consumer research on edible insects: Recent evidence and new vistas from 2019 studies. *Journal of Insects as Food and Feed*, *7*(3), 249–259. https://doi.org/10.3920/JIFF2020.0052

Despommier, D. (2010). *Vertical farm: Feeding the world in the 21st century*. Macmillan US.

Despommier, D. (2013). Farming up the city: The rise of urban vertical farms. *Trends in Biotechnology*, *31*(7), 388–389. https://doi.org/10.1016/j.tibtech.2013.03.008

Despommier, D., & Ellingsen, E. (2008). *The vertical farm: The skyscraper as vehicle for a sustainable urban agriculture*. CTBUH 8th World Congress.

de Vries, J. R., van der Zee, E., Beunen, R., Kat, R., & Feindt, P. H. (2019). Trusting the people and the system. The influence of institutional design on interpersonal and institutional trust in collective action for agri-environmental management. *Sustainability*, *11*(24), Article 7022. https://doi.org/10.3390/su11247022

De Wilt, J., & Dobbelaar, T. (2005). *Agroparks: The concept, the response, the practice*. Innovation Network.

Dielemann, H. (2019). Innovation system approach for urban agriculture: Case study of Mexico city. In M. Farooq, & M. Pisante (Eds.), *Innovations in sustainable agriculture* (pp. 79–104). Springer.

Di Fiore, G., Specht, K., & Zanasi, C. (2021). Assessing motivations and perceptions of stakeholders in urban agriculture: A review and analytical framework. *International Journal of Urban Sustainable Development*, *13*(2), 351–367. https://doi.org/10.1080/19463138.2021.1904247

Driscoll, L. (2017). *Urban farms: bringing innovations in agriculture and food security to the city*. Policy Brief, Berkeley Food Institute.

DüngG. (2009). Düngegesetz vom 9. Januar 2009 (BGBl. I S. 54, 136), das zuletzt durch Artikel 96 des Gesetzes vom 10. August 2021 (BGBl. I S. 3436) geändert worden ist. Retrieved November 1, 2022, from https://www.gesetze-im-internet.de/d_ngg/BJNR005400009.html

Duzí, B., Frantál, B., & Simon Rojo, M. (2017). The geography of urban agriculture: New trends and challenges. *Moravian Geographical Reports*, *25*(3), 130–138. https://doi.org/10.1515/mgr-2017-0012

Edquist, C. (1997). Systems of innovation approaches – their emergence and characteristics. In C. Edquist (Ed.), *Systems of innovation technologies, institutions and organizations* (pp. 1–35). Routledge; Taylor & Francis Group.

Edquist, C. (2005). Systems of innovation: Perspectives and challenges. In D. C. Mowery, & J. Fagerberg (Eds.), *Oxford Handbook of Innovation* (pp. 181–208). Oxford University Press.

Edquist, C., & Johnson, B. (1997). Institutions and organizations in systems of innovation. In C. Edquist (Ed.), *Systems of innovation technologies, institutions and organizations* (pp. 41–63). Routledge.

Eidt, C. M., Pant, L. P., & Hickey, G. M. (2020). Platform, participation, and power: How dominant and minority stakeholders

shape agricultural innovation. *Sustainability*, *12*(461), 1–21. http://doi.org/10.3390/su12020461
Eigenbrod, C., & Gruda, N. (2015). Urban vegetable for food security in cities. A review. *Agronomy for Sustainable Development*, *35*(2), 483–498. https://doi.org/10.1007/s13593-014-0273-y
Eisenhardt, K. M. (1989). Building theories from case study research. *The Academy of Management Review*, *14*(4), 532–550. https://doi.org/10.2307/258557
Elorinne, A.-L., Niva, M., Vartiainen, O., & Väisänen, P. (2019). Insect consumption attitudes among vegans, non-vegan vegetarians, and omnivores. *Nutrients*, *11*(2), 292–305. https://doi.org/10.3390/nu11020292
FAO. (1989). *Sustainable Development and Natural Resources Management*. Twenty-Fifth Conference, Paper C 89/2, Rome.
FAO. (2019). *FAO framework for the urban food agenda. Leveraging sub-national and local government action to ensure sustainable food systems and improved nutrition*. Retrieved October 10, 2021, from https://www.fao.org/publications/card/en/c/CA3143EN/
Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, *12*(2), 219–245. https://doi.org/10.1177/1077800405284363
Freeman, C. (1987). *Technology policy and economic performance: Lessons from Japan*. Pinter.
Freeman, C. (1995). The national system of innovation in historical perspective. *Cambridge Journal of Economics*, *19*, 5–24. https://www.jstor.org/stable/23599563
Fruscella, L., Kotzen, B., & Milliken, S. (2021). Organic aquaponics in the European Union: Towards sustainable farming practices in the framework of the new EU regulation. *Reviews in Aquaculture*, *13*(3), 1661–1682. https://doi.org/10.1111/raq.12539
Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8
Giddens, A. T. (1984). *The constitution of society. Outline of the theory of structuration*. Polity Press.
Gläser, J., & Laudel, G. (2008). *Experteninterview und qualitative Inhaltsanalyse als Instrument rekonstruierender Untersuchungen* (3rd ed.). VS Verlag für Sozialwissenschaften.
Gómez, C., Currey, C. J., Dickson, R. W., Kim, H.-J., Hernández, R., Sabeh, N. C., Raudales, R. E., Brumfield, R. G., Laury-Shaw, A., Wilke, A. K., Lopez, R. G., & Burnett, S. E. (2019). Controlled environment food production for urban agriculture. *HortScience*, *54*(9), 1448–1458. https://doi.org/10.21273/HORTSCI14073-19
Grebitus, C., Chenarides, L., Muenich, R., & Mahalow, A. (2020). Consumers' perception of urban farming—An exploratory study. *Frontiers in Sustainable Food Systems*, *4*, Article 79. https://doi.org/10.3389/fsufs.2020.00079
Grebitus, C., Printezis, I., & Printezis, A. (2017). Relationship between consumer behavior and success of urban agriculture. *Ecological Economics*, *136*, 189–200. https://doi.org/10.1016/j.ecolecon.2017.02.010
Grossetti, M. (1999). *The genesis of two urban innovation systems in France: Grenoble and Toulouse*. Regional Innovation Systems, Sep 1999, San Sebastian, Spain. halshs-00477337.
Hackfort, S. (2021). Patterns of inequalities in digital agriculture: A systematic literature review. *Sustainability*, *13*(22), 12345. https://doi.org/10.3390/su132212345
Hall, A. (2005). Capacity development for agricultural biotechnology in developing countries: An innovation systems view of what it is and how to develop it. *Journal of International Development*, *17*(5), 611–630. https://doi.org/10.1002/jid.1227
Hall, A., & Clark, N. (2010). What do complex adaptive systems look like and what are the implications for innovation policy? *Journal of International Development*, *22*(3), 308–324. https://doi.org/10.1002/jid.1690
Hall, A., Sulaiman, R., Clark, N., & Yoganand, B. (2003). From measuring impact to learning institutional lessons: An innovation systems perspective on improving the management of international agricultural research. *Agricultural Systems*, *78*(2), 213–241. https://doi.org/10.1016/S0308-521X(03)00127-6
Hartmann, C., & Siegrist, M. (2017). Insects as food: Perception and acceptance. Findings from current research. *Ernährungs Umschau*, *64*, 44–50.
Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change*, *74*(4), 413–432. https://doi.org/10.1016/j.techfore.2006.03.002
Herrero, M., Thornton, P. K., Mason-D'Croz, D., Palmer, J., Benton, T. G., Bodirsky, B. L., Bogard, J. R., Hall, A., Lee, B., Nyborg, K., Pradhan, P., Bonnett, G. D., Bryan, B. A., Campbell, B. M., Christensen, S., Clark, M., Cook, M. T., de Boer, I. J. M., Downs, C., … West, P. C. (2020). Innovation can accelerate the transition towards a sustainable food system. *Nature Food*, *1*(5), 266–272. https://doi.org/10.1038/s43016-020-0074-1
Hoevenaars, K., Junge, R., Bardocz, T., & Leskovec, M. (2018). EU policies: New opportunities for aquaponics. *Ecocycles*, *4*(1), 10–15. https://doi.org/10.19040/ecocycles.v4i1.87
Honkanen, P., Verplanken, B., & Olsen, S. O. (2006). Ethical values and motives driving organic food choice. *Journal of Consumer Behaviour*, *5*(5), 420–430. https://doi.org/10.1002/cb.190
House, J. (2016). Consumer acceptance of insect-based foods in the Netherlands: Academic and commercial implications. *Appetite*, *107*, 47–58. https://doi.org/10.1016/j.appet.2016.07.023
Iannuzzi, E., Sisto, R., & Nigro, C. (2019). The willingness to consume insect-based food: An empirical research on Italian consumers. *Agricultural Economics*, *65*, 454–462. https://doi.org/10.17221/87/2019
Ingram, J. (2018). Agricultural transition: Niche and regime knowledge systems' boundary dynamics. *Environmental Innovation and Societal Transitions*, *26*, 117–135. https://doi.org/10.1016/j.eist.2017.05.001
Jacobsson, S., & Bergek, A. (2011). Innovation system analyses and sustainability transitions: Contributions and suggestions for research. *Environmental Innovation and Societal Transitions*, *1*(1), 41–57. https://doi.org/10.1016/j.eist.2011.04.006
Joly, A., Junge, R., & Bardocz, R. (2015). Aquaponics business in Europe: Some legal obstacles and solutions. *Ecocycles*, *1*(2), 3–5. https://doi.org/10.19040/ecocycles.v1i2.30
Jürkenbeck, K., Heumann, A., & Spiller, A. (2019). Sustainability matters: Consumer acceptance of different vertical farming systems. *Sustainability*, *11*, Article 4052. https://doi.org/10.3390/su11154052

Kauppi, S.-M., Pettersen, I. N., & Boks, C. (2019). Consumer acceptance of edible insects and design interventions as adoption strategy. *International Journal of Food Design*, *4*(1), 39–62. https://doi.org/10.1386/ijfd.4.1.39_1

Kilelu, C. W., Klerkx, L., & Leeuwis, C. (2013). Unravelling the role of innovation platforms in supporting co-evolution of innovation: Contributions and tensions in a smallholder dairy development programme. *Agricultural Systems*, *118*, 65–77. https://doi.org/10.1016/j.agsy.2013.03.003

Kledal, P. R., König, B., & Maulic, D. (2019). Aquaponics: The ugly duckling in organic regulation. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics food production systems* (pp. 487–500). SpringerOpen.

Klein Woolthuis, R., Lankhuizen, M., & Gilsing, V. (2005). A system failure framework for innovation policy design. *Technovation*, *25*(6), 609–619. https://doi.org/10.1016/j.technovation.2003.11.002

Klerkx, L., Aarts, N., & Leeuwis, C. (2010). Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment. *Agricultural Systems*, *103*(6), 390–400. https://doi.org/10.1016/j.agsy.2010.03.012

Klerkx, L., Schut, M., Leeuwis, C., & Kilelu, C. W. (2012). Advances in knowledge brokering in the agricultural sector: Towards innovation system facilitation. *IDS Bulletin*, *43*(5), 53–60. https://doi.org/10.1111/j.1759-5436.2012.00363.x

Klerkx, L., van Mierlo, B., & Leeuwis, C. (2012). Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In I. Darnhofer, D. Gibbon, & B. Dedieu (Eds.), *Farming systems research into the 21st century: The new dynamic* (pp. 457–484). Springer Science + Business.

Kloas, W., Rennert, B., van Ballegooy, C., & Drews, M. (2008). *Aquaponic system for vegetable and fish production*. US Patent and Trademark Office Publications no. US20110131880 A1. Retrieved March 10, 2015, from www.google.com/patents/US20110131880

Knickel, K., Ashkenazy, A., Calvão, T., Parrot, C., & Parrot, N. (2017). Agricultural modernization and sustainable agriculture: Contradictions and complementarities. *International Journal of Agricultural Sustainability*, *15*(5), 575–592. https://doi.org/10.1080/14735903.2017.1373464

Knight, L., & Riggs, W. (2010). Nourishing urbanism: A case for a new urban paradigm. *International Journal of Agricultural Sustainability*, *8*(1-2), 116–126. https://doi.org/10.3763/ijas.2009.0478

König, B., Janker, J., Reinhardt, T., Villarroel, M., & Junge, R. (2018). Analysis of aquaponics as an emerging technological innovation system. *Journal of Cleaner Production*, *180*, 232–243. https://doi.org/10.1016/j.jclepro.2018.01.037

Kornher, L., Schellhorn, M., & Vetter, S. (2019). Disgusting or innovative – consumer willingness to pay for insect based burger patties in Germany. *Sustainability*, *11*(7), Article 1878. https://doi.org/10.3390/su11071878

Kozai, T., Fang, W., Chun, C., Yang, Q., Tong, Y., Cheng, R., Kubota, C., & Lu, C. (2016). PFAL business and R&D in the world: Current status and perspectives. In T. Kozai, G. Niu, & M. Takagaki (Eds.), *Plant factory: An indoor vertical farming system for efficient quality food production* (pp. 1448–1458). Academic Press.

Lähteenmäki-Uutela, A., Hénault-Ethier, L., Marimuthu, S. B., Talibov, S., Allen, R. N., Nemane, V., Vandenberg, G. W., & Józefiak, D. (2018). The impact of the insect regulatory system on the insect marketing system. *Journal of Insects as Food and Feed*, *4*(3), 187–198. https://doi.org/10.3920/JIFF2017.0073

Lähteenmäki-Uutela, A., Marimuthu, S. B., & Meijer, N. (2021). Regulations on insects as food and feed: A global comparison. *Journal of Insects as Food and Feed*, *7*(5), 849–856. https://doi.org/10.3920/JIFF2020.0066

Liu, B., & Jiang, M. (2018). *Research on the elements and structure of urban innovation system*. International Conference on Frontier Computing. FC 2018: Frontier Computing (pp. 1194–1199).

Lundvall, B-Å. (1992). *National systems of innovation: Towards a theory of innovation and interactive learning*. Pinter.

Mancini, S., Sogari, G., Menozzi, D., Nuvoloni, R., Torracca, B., Moruzzo, R., & Paci, G. (2019). Factors predicting the intention of eating an insect-based product. *Foods*, *8*(7), Article 270. https://doi.org/10.3390/foods8070270

March, J. G., & Olsen, J. P. (1989). *Rediscovering institutions. The organizational basis of politics*. Free Press.

Markatou, M., & Alexandrou, E. (2015). Urban system of innovation: Main agents and main factors of success. *Social and Behavioral Sciences*, *195*, 240–250. https://doi.org/10.1016/j.sbspro.2015.06.355

Massot, A. (2020). *The common agricultural policy (CAP) and the treaty*. Fact Sheets on the European Union. Retrieved May 12, 2020, from https://www.europarl.europa.eu/ftu/pdf/en/FTU_3.2.1.pdf

McEldowney, J. (2017). *Urbane Landwirtschaft in Europa*. Modelle, Herausforderungen und Strategien. EPRS. Wissenschaftlicher Dienst des Europäischen Parlaments. Retrieved August 13, 2020, from https://www.europarl.europa.eu/RegData/etudes/IDAN/2017/614641/EPRS_IDA(2017)614641_DE.pdf

Meuser, M., & Nagel, U. (1997). Das ExpertInneninterview – Wissenssoziologische Voraussetzungen und methodische Durchführung. In B. Friebertshäuser, & A. Prengel (Eds.), *Handbuch Qualitative Forschungsmethoden in der Erziehungswissenschaft* (pp. 481–491). Beltz Juventa.

Meuwissen, M. P. M., Feindt, P. H., Slijper, T., Spiegel, A., Finger, R., de Mey, Y., Paas, W., Termeer, K. J. A. M., Poortvliet, P. M., Peneva, M., Urquhart, J., Vigani, M., Black, J. E., Nicholas-Davies, P., Maye, D., Appel, F., Heinrich, F., Balmann, A., Bijttebier, J., … Reidsma, P. (2021). Impact of Covid-19 on farming systems in Europe through the lens of resilience thinking. *Agricultural Systems*, *191*, Article 103152. https://doi.org/10.1016/j.agsy.2021.103152

Milicic, V., Thorarinsdottir, R., Santos, M., & Hancic, M. (2017). Commercial aquaponics approaching the European market: To consumers' perceptions of aquaponics products in Europe. *Water*, *9*(80), 80. https://doi.org/10.3390/w9020080

Nam, T., & Pardo, T. A. (2011, June 12–15). *Conceptualizing smart city with dimensions of technology, people, and institutions*. Paper presented at the 12th Annual International Conference on Digital Government Research.

Naranjo-Guevara, N., Fanter, M., Conconi, A. M., & Floto-Stammen, S. (2021). Consumer acceptance among Dutch and German students of insects in feed and food. *Food Science & Nutrition*, *9*(1), 414–428. https://doi.org/10.1002/fsn3.2006

Nellemann, C. (2009). *The environmental food crisis: The environment's role in averting future food crises*. UNEP. Retrieved November 23, 2021, from https://www.grida.no/publications/154

Nelson, R. R. (1993). *National innovation systems: A comparative analysis*. Oxford University Press.

North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge University Press.

OECD. (2015). *Das Jahrhundert der Metropolen. Eine Analyse der Ursachen und Konsequenzen von Urbanisierung*. Zusammenfassung. Retrieved September 9, 2019, from https://www.oecd.org/cfe/regional-policy/Metropolitan-Century-Policy-Highlights-German.pdf

Ojo, A., Dzhusupova, Z., & Curry, E. (2016). Exploring the nature of the smart cities research landscape. In J. R. Gil-Garcia, T. A. Pardo, & T. Nam (Eds.), *Smarter as the new urban agenda: A comprehensive view of the 21st century city* (pp. 23–47). Springer International Publishing.

Onwezen, M. C., Van den Puttelaar, V. J., Verain, M. C. D., & Veldkamp, T. (2019). Consumer acceptance of insects as food and feed: The relevance of affective factors. *Food Quality and Preference*, *77*, 51–63. https://doi.org/10.1016/j.foodqual.2019.04.011

Oroian, C. F., Safirescu, C. O., Harun, R., Chiciudean, G. O., Arion, F. H., Muresan, I. C., & Bordeanu, B. M. (2015). Consumers' attitudes towards organic products and sustainable development: A case study of Romania. *Sustainability*, *9*(9), Article 1559. http://doi.org/10.3390/su9091559.

Orsi, L., Voege, L. L., & Stranieri, S. (2019). Eating edible insects as sustainable food? Exploring the determinants of consumer acceptance in Germany. *Food Research International*, *125*, Article 108573. https://doi.org/10.1016/j.foodres.2019.108573

Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: A review. *Agronomy for Sustainable Development*, *33*(4), 695–720. https://doi.org/10.1007/s13593-013-0143-z

Pfeiffer, A., Sillva, E., & Colquhoun, J. (2015). Innovation in urban agricultural practices: Responding to diverse production environments. *Renewable Agriculture and Food Systems*, *30*(1), 79–91. https://doi.org/10.1017/S1742170513000537

Pigford, A.-A. E., Hickey, G. M., & Klerkx, L. (2018). Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions. *Agricultural Systems*, *164*, 116–121. https://doi.org/10.1016/j.agsy.2018.04.007

Poortvliet, P. M., Van der Pas, L., Mulder, B. C., & Fogliano, V. (2019). Healthy, but disgusting: An investigation into consumers' willingness to try insect meat. *Journal of Economic Entomology*, *112*(3), 1005–1010. https://doi.org/10.1093/jee/toz043

Prain, G., & de Zeeuw, H. (2007, December). Enhancing technical, organisational and institutional innovation in urban agriculture. *Urban Agriculture Magazine 19*, The RUAF Foundation.

Pretty, J., Sutherland, W. J., Ashby, J., Auburn, J., Baulcombe, D., Bell, M., Bentley, J., Bickersteth, S., Brown, K., Burke, J., Campbell, H., Chen, K., Crowley, E., Crute, I., Dobbelaere, D., Edwards-Jones, G., Funes-Monzote, F., Charles, H., Godfray, J., … Pilgrim, S. (2010). The top 100 questions of importance to the future of global agriculture. *International Journal of Agricultural Sustainability*, *8*(4), 219–236. https://doi.org/10.3763/ijas.2010.0534

Prové, C., Dessein, J., & de Krom, M. (2016). Taking context into account in urban agriculture governance: Case studies of Warsaw (Poland) and Ghent (Belgium). *Land Use Policy*, *56*, 16–26. https://doi.org/10.1016/j.landusepol.2016.04.025

Putra, Z. D. W., & van der Knaap, W. G. M. (2018). Urban innovation system and the role of an open web based platform: The case of Amsterdam smart city. *Journal of Regional and City Planning*, *29*(3), 234–249. https://doi.org/10.5614/jrcp.2018.29.3.4

Rapley, T. (2014). Sampling strategies in qualitative research. In U. Flick (Ed.), *The SAGE handbook of qualitative data analysis* (pp. 49–63). SAGE.

Ravitch, S. M., & Carl, N. M. (2015). *Qualitative research: Bridging the conceptual, theoretical, and methodological*. SAGE Publications.

Reinhardt, T., Hoevenaars, K., & Joyce, A. (2019). Regulatory frameworks for aquaponics in the European Union. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics food production systems. Combined aquaculture and hydroponic production technologies for the future* (pp. 501–522). Springer Open.

Rogers, E. (1983). *The diffusion of innovations* (3rd ed.). The Free Press.

Rorabaugh, P. A. (2015). *Intro to hydroponics and CEA*. University of Arizona Controlled Environment Agriculture Center. Retrieved November 23, 2021, from https://ceac.arizona.edu/resources/intro-hydroponics-cea

Ruggeri, G., Mazzochi, C., & Corsi, S. (2016). Urban gardeners' motivations in a metropolitan city: The case of Milan. *Sustainability*, *8*, Article 1099. http://doi.org/10.3390/su8111099

Rumpold, B. A., & Langen, N. (2019). Potential of enhancing consumer acceptance of edible insects via information. *Journal of Insects as Food and Feed*, *5*(1), 45–53. https://doi.org/10.3920/JIFF2018.0041

Sanyang, S., Jean-Baptiste, S., Julienne Kuiseu, T., Coulibaly, N., & Konaté, L. (2016). A paradigm shift in African agricultural research for development: The role of innovation platforms. *International Journal of Agricultural Sustainability*, *14*(2), 187–213. https://doi.org/10.1080/14735903.2015.1070065

Sassen, S. (2013). *The global city*. Princeton University Press.

Saxena, J. P., Sushil, & Prem, V. (1990). Impact of indirect relationships in classification of variables-a MICMAC analysis for energy conservation. *Systems Research*, *7*(4), 245–253. https://doi.org/10.1002/sres.3850070404

Schmutz, U., Kneafsey, M., Sarrouy, K., Doernberg, A., & Zasada, I. (2018). Sustainability impact assessments of different urban short food supply chains: Examples from London, UK. *Renewable Agriculture and Food Systems*, *33*(6), 518–529. https://doi.org/10.1017/S1742170517000564

Senatsverwaltung für Stadtentwicklung und Wohnen. (n.d.). Bevölkerungsprognose für Berlin und die Bezirke 2018–2030. Ergebnisse der Bevölkerungsprognose. Retrieved November 23, 2021, from https://www.stadtentwicklung.berlin.de/planen/bevoelkerungsprognose/de/ergebnisse/index.shtml

SenJustVA. (n.d.). *Die Stadt isst fair! Die Berliner Ernährungsstrategie*. Senatsverwaltung für Justiz, Verbraucherschutz und Antidiskriminierung. Retrieved May 10, 2021, from https://www.berlin.de/ernaehrungsstrategie/strategie/

Sidali, K. L., Pizzo, S., Garrido-Pérez, E. I., & Schamel, G. (2018). Between food delicacies and food taboos: A structural equation model to assess Western students' acceptance of Amazonian insect food. *Food Research International*, *115*, 83–89. http://doi.org/10.1016/j.foodres.2018.07.027.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sogari, G., Lui, A., & Li, J. (2019). Understanding edible insects as food in Western and Eastern societies. In D. Bogueva, D. Marinova, T. Raphaely, & K. Schmidinger (Eds.), *Environment, health, and business opportunities in the new meat alternatives market* (pp. 166–181). IGI Global.

Sosik, J. J., Lee, D., & Bouquillon, E. A. (2005). Context and mentoring: Examining formal and informal relationships in high tech firms and K-12 schools. *Journal of Leadership and Organizational Studies*, *12*(2), 94–108. https://doi.org/10.1177/107179190501200208

Specht, K., Siebert, R., & Thomaier, S. (2015). Perception and acceptance of agricultural production in and on urban buildings (ZFarming): A qualitative study from Berlin, Germany. *Agriculture and Human Values*, *33*(4), 1–17. http://doi.org/10.1007/s10460-015-9658-z

Specht, K., Weith, T., Swoboda, K., & Siebert, R. (2016). Socially acceptable urban agriculture businesses. *Agronomy for Sustainable Development*, *36*(17), 1–14. https://doi.org/10.1007/s13593-016-0355-0

Specht, K., Zoll, F., Schümann, H., Bela, J., Kachel, J., & Robischon, M. (2019). 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*, *11*(4315), 1–22. https://doi.org/ 10.3390/su11164315

Stamer, A. (2015). Insect proteins – a new source for animal feed. *EMBO Reports*, *16*(6), 676–680. https://doi.org/10.15252/embr.201540528

Statista. (2021). *Einwohnerzahl der größten Städte in Deutschland am 31*. Dezember 2019. Retrieved July 14, 2021, from https://de.statista.com/statistik/daten/studie/1353/umfrage/einwohnerzahlen-der-grossstaedte-deutschlands/

Termeer, C. J. A. M., Feindt, P. H., Karpouzoglou, T., Poppe, K. J., Hofstede, G. J., Kramer, K., Ge, L., Mathijs, E., & Meuwissen, M. P. M. (2019). Institutions and the resilience of biobased production systems: The historical case of livestock intensification in the Netherlands. *Ecology and Society*, *24*(4), Article 15. https://doi.org/10.5751/ES-11206-240415

Turner, J. A., Klerkx, L., Rijswijk, K., Williams, T., & Barnard, T. (2016). Systemic problems affecting co-innovation in the New Zealand agricultural innovation system: Identification of blocking mechanisms and underlying institutional logics. *Journal of Life Sciences*, *76*, 99–112. https://doi.org/10.1016/j.njas.2015.12.001

Ulrichs, C., Schmidt, U., Geilfus, C.-M., Feindt, P., Grimm, B., Onasch, L., Kloas, W., Kühne, S., Streif, S., Herrmann, C., Mempel, H., Katz, H., & Simon, D. (2017). *CUBES circle*. Future Food Production.

UN-Habitat. (2016). *Urbanization and development: emerging futures*. World cities report 2016. Retrieved November 23, 2021, from https://unhabitat.org/sites/default/files/download-manager-files/WCR-2016-WEB.pdf

United Nations. (2019). *World population prospects 2019: Highlights*. Retrieved March 18, 2020, from https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf

van der Gaast, K., van Leeuwen, E., & Wertheim-Heck, S. (2022). Food systems in transition: Conceptualizing sustainable food entrepreneurship. *International Journal of Agricultural Sustainability*, *20*(5), 705–721. https://doi.org/10.1080/14735903.2021.1969163

van der Weele, C., Feindt, P., van der Goot, A. J., van Mierlo, B., & van Boekel, M. (2019). Meat alternatives: An integrative comparison. *Trends in Food Science & Technology*, *88*, 505–512. https://doi.org/10.1016/j.tifs.2019.04.018

van Winden, W., Braun, E., Orgaar, A., & Witte, J.-J. (2014). *Urban innovation systems. What makes them thick? Regional Studies Association. The global forum for city and regional research, development and policy*. Routledge.

Verbeke, W. (2015). Profiling consumers who are ready to adopt insects as a meat substitute in aWestern society. *Food Quality and Preference*, *39*, 147–155. https://doi.org/10.1016/j.foodqual.2014.07.008

Wenzelburger, G., & Zohlnhöfer, R. (2014). Institutionen und Public Policies. In K. Schubert, & N. C. Bandelow (Eds.), *Lehrbuch der Politikfeldanalyse* (pp. 311–340). De Gruyter Oldenbourg.

Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., & David, C. (2011). Agroecology as a science, a movement and a practice. *Sustainable Agriculture*, *29*(4), 503–515. https://doi.org/10.1051/agro/2009004

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., De Vries, W., Sibanda, L. M., … Murray, C. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, *393*(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Williamson, O. E. (2000). The new institutional economics: Taking stock, looking ahead. *Journal of Economic Literature*, *38*(3), 595–613. https://doi.org/10.1257/jel.38.3.595

World Bank Group. (2020). *Population estimates and projections*. Retrieved November 23, 2021, from https://databank.worldbank.org/source/population-estimates-and-projections

Yin, R. K. (2017). *Case study research and applications: Design and methods*. SAGE Publications.

Zander, K., & Hamm, U. (2010). Consumer preferences for additional ethical attributes of organic food. *Food Quality and Preference*, *21*(5), 495–503. https://doi.org/10.1016/j.foodqual.2010.01.006

ZINEG. (2014). ZukunfInitiative NiedrigEnergieGewächhaus. Ein Verbundvorhaben gefördert vom Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit sowie der Landwirtschaftlichen Rentenbank unter Federführung des Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz mit Unterstützung der Bundesanstalt für Landwirtschaft und Ernährung. Retrieved April 20, 2021, from http://zineg.net/