frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 27 September 2022
DOI 10.3389/fsufs.2022.913412

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OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Social Movements, Institutions and Governance, a section of the journal Frontiers in Sustainable Food Systems

RECEIVED 05 April 2022
ACCEPTED 09 September 2022
PUBLISHED 27 September 2022

CITATION
Klebl F, Walthall B and Vicente-Vicente JL (2022) Planning for sustainable food communities: An optimal spatial allocation study of food hubs considering the 15-min city concept—The case of *LebensMittelPunkte* in Berlin. *Front. Sustain. Food Syst.* 6:913412. doi: 10.3389/fsufs.2022.913412

Planning for sustainable food communities: An optimal spatial allocation study of food hubs considering the 15-min city concept—The case of *LebensMittelPunkte* in Berlin

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Food hubs (FHs) providing neighbourhoods with regional food from agroecological production are a promising concept for a sustainable food system transformation. However, their operationalization and scaling are still unclear. We developed a methodological approach that, for the first time, scales out FHs to an entire city (Berlin) based on a 15-min walking distance and socio-culturally oriented sub-districts as underlying spatial units. We considered the population density and the distance to organic groceries, public transportation and between FHs to estimate their most suitable locations. The results reveal an optimal allocation of 231 FHs covering 91% of the city's populated areas in a radius lower than 1 km and almost the entire city within a 1.5 km radius. We found this approach to be a meaningful way to plan the inner-city allocation of FHs from an integrative perspective and to adopt urban policies by considering the local specificities of each neighbourhood. The scaling out of agroecology-based regional FHs in Berlin allows for the creation of a sustainable city-region food system that increases the resilience of the metropolitan food environment. We generally propose a participative and integrative approach in order to realise this process.

KEYWORDS

walkability, sustainable city, living lab, regional food system, urban-rural, urban agroecology, urban planning, spatial suitability

Introduction

There is a global trend of population to concentrate in cities (United Nations Department of Economic Social Affairs, 2019), which are experiencing a permanent expansion process (Angel et al., 2011), thus, questioning their sustainability (Ferrara et al., 2014; Zitti et al., 2015). Consequently, the population of rural areas is generally decreasing, accompanied by an increase in the abandonment of agricultural land and concentration of land ownership (Weissteiner et al., 2011; Estel et al., 2015; van der Zanden et al., 2017; Bunkus and Theesfeld, 2018; Palšová et al., 2021). On the other hand, there is a growing debate on the sustainability of the globalised food system due to its contribution to climate change or the loss of biodiversity (Benton et al., 2021; Crippa et al., 2021; Ricciardi et al., 2021), as well as on its vulnerability to severe disruptions and shocks (Puma et al., 2015; Puma, 2019; FAO, 2021).

Several interventions addressing the sustainability of the agricultural system, such as technological innovations or changes in agricultural management practises, have been proposed by the scientific community (e.g., Pretty, 2018). However, they are mainly incremental; they focus on reforming specific aspects of the food system, but they do not address the fundamental characteristics of the system (Wezel et al., 2020). In response to this, there is a growing proportion of the scientists, NGOs and citizens proposing the adoption of integrative and more radical approaches to transform the agri-food system as the way to overcome structural causes and impacts of food production and consumption (Carlson and Chappell, 2015; Gliessman, 2016; FAO, 2018; HLPE, 2019; Webb et al., 2020; Argumedo et al., 2021; Calo et al., 2021; Carter et al., 2021; Dengerink et al., 2021; Jonas, 2021; Leeuwis et al., 2021; Ruben et al., 2021; Singh et al., 2021; McGreevy et al., 2022). This has also been mirrored in policies taking new directions, such as the Farm to Fork Strategy of the European Union (European Commission, 2020).

In this context, the integration of food networks, urban planning and sustainability is emerging as an effective approach. While the role of food networks has been described regarding their contribution to urban-rural linkages (Sonnino and Marsden, 2006; Opitz et al., 2017, 2019; Dansero and Pettenati, 2018), an inner-city perspective bringing the distribution of regionally produced food into the focus remains conceptually, evidence-based and largely under-investigated. As far as we know, socio-spatial aspects have not yet been investigated from an urban food network planning perspective.

However, some concepts to make cities more resilient and sustainable have been implemented in the last few years. One of them is the 15-min city (Moreno et al., 2021), in which a neighbourhood is planned such that all basic facilities can be reached within a walking time of 15 min or less. This "chrono-urbanism" approach (also see Weng et al., 2019; Capasso Da Silva et al., 2020) is based on the assumption that the quality of life in urban areas is inversely proportional to the amount of time invested in transportation. The 15-min city was initially developed for Paris ("*La Ville du ¼ d'Heure*") (Moreno, 2016) and addresses four different dimensions: (1) density, (2) proximity, (3) diversity and (4) digitalization. In other words, the city should have an optimal density allowing for sustainability, be quickly and easily accessible, offer a diverse set of products and services, as well as cultural interactions in order to have more liveable neighbourhoods. It should further provide mechanisms to ensure inclusivity, participation and access through digitalization, particularly in a post-pandemic city (Moreno et al., 2021).

When applying the 15-min city concept solely to food, the density and proximity dimensions are fully applicable. However, assessing the sustainability and resilience of the food system requires a consideration of the entire supply chain and, therefore, the 15-min city concept has to be expanded in order to cover the urban-rural interactions and the re-regionalization of the food system (i.e., a foodshed approach) (Zasada et al., 2019; Vicente-Vicente et al., 2021a,b). One possibility to address the two first dimensions of the 15-min city and the re-regionalization of the food system are food hubs (FHs) or "*LebensMittelPunkte*" (LMP) in German. Although there is no common definition of regional FHs, they can be understood as "innovative organisational arrangements capable of bridging structural holes in the agri-food markets between small producers and the consumers" (Berti and Mulligan, 2016), which have been tested empirically under real conditions in different contexts (e.g., Quaranta et al., 2019; Aramendi et al., 2020; Winarno et al., 2020).

The concept of LMP is becoming increasingly relevant throughout Germany, and some prototypes have been implemented recently. The prototype at "*Das Baumhaus*" (https://www.baumhausberlin.de/) in Berlin, for instance, has inspired many other initiatives to set up FHs throughout the city region (see https://lebensmittelpunkte-berlin.de/). One of the main activities in "*Das Baumhaus*" is the weekly delivery of food from different community-supported agriculture farms located in the surrounding area of the city (Vicente-Vicente et al., n.d.). These farms provide diverse regional products that are cultivated following agroecology principles and, therefore, improve the sustainability and resilience of the food system. Furthermore, FHs are not just a point of food distribution, but also a space in which citizens of the neighbourhood can meet and organise different activities around the topic of food, such as collective cooking and workshops. Hence, they are usually rooted into the neighbourhood. The fact that LMP are among the priorities of the new government (SPD Berlin, 2021) indicates that the concept of FHs has not only been supported by practitioners but also by Berlin's federal state government.

One major challenge in establishing a city-wide network of FHs is their integration within urban planning (e.g., selecting most suitable administrative units) and the regional food production, so as to contribute to the sustainability and resilience of the city-region food system. The majority of the existing literature on FHs is theoretical and descriptive (Horst et al., 2011; Fischer et al., 2015; Berti and Mulligan, 2016; Rose, 2017; Prost, 2019; Driessen, 2021; Sgroi and Marino, 2022) or focused on assessing specific case studies (Stroink and Nelson, 2013; Cleveland et al., 2014; Quaranta et al., 2019; Conner et al., 2020; Canal Vieira et al., 2021). Therefore, there is no common understanding on how to scale out FHs, or in other words, how to study their optimal spatial allocation in a given space according to a set of criteria. In order to enhance the sustainability and resilience of the food system and simultaneously to operationalize the scaling out of the FHs, we combine them with the 15-min city concept.

The overall goal of this study is to assess the scaling out of the existing FHs in Berlin to the city's entire metropolitan area while considering the 15-min city concept. Accordingly, we developed a methodological approach that allows us to (1) estimate the number of FHs required in Berlin and (2) assess their optimal spatial allocation. We also discuss the implications of the results for current policies in Berlin and give recommendations for policymakers regarding the implementation of FHs.

Materials and methods

Study design

In line with West and Schill (2022, p. 11), we perceive methodological approaches and methods not as neutral technical tools but as performative in the sense "that methods actively participate in the realities they describe". Therefore, it is important to be aware of the influence methods can have on the type of knowledge, discourses and practises being generated. Accordingly, we chose a participatory and community-centred approach that applies "simple, easy-to-use, and understandable models and methods" (Klosterman, 2013; p. 161) to adequately address local specifies with and for the public. As Klosterman (2013) argue, simple models and methods can help to reduce top-down planning approaches and knowledge imbalances between stakeholders while creating accessible information and enabling affected communities to be part of the planning and decision-making process. In this way, local communities are not passive receivers of food planning and policy making but rather active co-creators in shaping their food systems and a fundamental part or putting food sovereignty from a theoretical concept into practise. Against this background, we involved key actors who were part of planning and implementing the FH in developing a straightforward and replicable methodological approach.

Study area

The study is applied to the city of Berlin at a block level with an average size of 2.5 ha as the spatial resolution. Blocks with an average population density of <10 inhabitants per hectare (i.e., industrial areas, embassies, forests, etc.) and some special areas, such as large business areas, hospitals or prisons, were excluded. The reason for this is that the study is focused on people's everyday lives and, thus, on areas of the city where people live.

We refer to the so-called "*Lebensweltlich orientierte Räume*" (LOR or Eng. life-world-oriented spaces), which are sub-districts that share socio-economic, cultural, demographic and infrastructural characteristics (Senatsverwaltung für Stadtentwicklung, Bauen und Wohnen, n.d.), in approaches 2, 3b and 3c (Figure 1). More precisely, the focus lies on the district level (i.e., "*Bezirksregionen*") as one of three spatial resolutions available, which consists of 143 sections each with about an average of 25,000 inhabitants. These are defined by the Berlin government based on similar structures of buildings, the formation of milieus or spatial obstacles, such as major streets and natural barriers, for monitoring the social city development (Amt für Statistik Berlin-Brandenburg, 2019, 2021). By referring to the spatial units of LOR, the study generates not only accessible, but also compatible information for local policy and planning processes.

Estimation of quantity and distance

The aim of the first approach (1 in Figure 1) is to potentially provide the entire population of Berlin with a FH within a 15-min walking distance, while distributing the FHs efficiently throughout the city. Assuming an average walking speed of 4 km/h, the time was translated into a maximum walking distance of 1 km. In contrast to Weng et al. (2019), we did not differentiate between the walking time children, adults and seniors because the outcome desired was a rough estimation rather than an exact calculation. We further decided on the Euclidean distance and not on the path distance, and traffic lights and other obstacles were also not considered because this would have resulted in asymmetric and irregular spatial patterns. Another reason for this decision is to reduce complexity in order to keep the threshold for its' practical implementation low. Instead, we decided to minimise the first order error (i.e., a location is wrongly calculated to be within a walking distance of 15 min) to the cost of the second order error (i.e., a location is assumed to be beyond the 15 min walking distance but is indeed not) by adjusting the circumradius to 900 m. Furthermore, an excessive overlap was avoided by choosing hexagons instead of circular buffers. Random samples were tested for the accuracy in terms of the real walking times.

The central purpose of Approach 2 (Figure 1) is to allocate at least one FH to every LOR while simultaneously providing most of the inhabited area with a FH within 1 km, which equates to 15–18 min walking time, and nearly the entire area within a radius of 1.5 km. As a first step, the block features of each LOR were dissolved and the blocks' outer perimeters were calculated. In the case where the perimeters covered more than 500 ha, they were divided into subdivisions to end up within an average radius of no more than 1.5 km. We subsequently determined the centroids of these areas and, where necessary, shifted them into built areas. The centroids were then slightly manually adjusted to

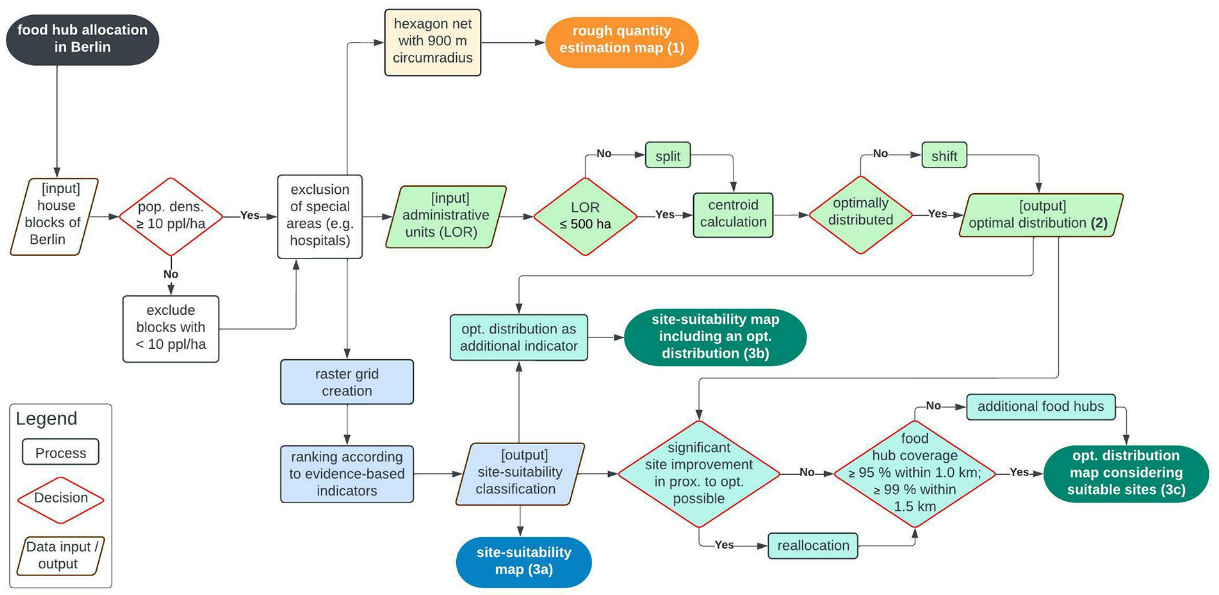

FIGURE 1
Workflow and interrelationship of the different approaches. The approaches 1 and 2 aim at estimating the number of food hubs (FHs), whereas Approach 3 considers the spatial site-suitability for implementing FHs. The overall number of FHs required for Berlin was initially estimated following the 15-min city (1), an allocation to the LOR (1b) and a combination of both outcomes (2). The site-suitability for implementing FHs in Berlin considering several indicators (3a) was assessed simultaneously. The results of 2 were then combined in two different ways: the first is to integrate the distance to the locations of 2 as an additional indicator (3b), and the other is to reallocate the FHs (3c).

optimise the distance between the centroids. These final points are referred to as the optimum.

Site-suitability assessment

Set of indicators

In order to have a sound set of spatial eligibility criteria, we consulted experts who are involved in the political agenda setting, planning and realisation of FHs in Berlin. These experts included the Food Policy Council Berlin, as a key promoter of the FH idea, the organisers of the LMP prototype "*Das Baumhaus*" Berlin, representatives from the federal state government and experts of the innovation action project FoodSHIFT 2030 (https://foodshift2030.eu/). All stakeholders were approached with suggestions of influencing factors (i.e., truck accessibility, population density, distance to public transportation, organic grocery density, average rent index, location in pedestrian zones) and were asked to rank their importance on a scale between 1 and 10 and/or to propose alternative factors.

Most of the suggested variables were perceived to be relevant. Public transportation stops, which include bus stops, train and underground railway stations, play an essential role for the reachability of FHs in Berlin and were chosen to be relevant within a radius of 500 m. The population density indicates where many people can be reached within a short distance, but it is also critical to avoid neglecting remote areas. The distance to the closest organic grocery was used to identify areas with a weak supply of organic food. Supermarkets that partly provide organic food were excluded because their business models are far from a FH. The variables selected were given a rank of 7 out of 10, with the exception of the distance to the organic groceries (rank 3) (Table 1). The remaining variables were either perceived as not relevant by the stakeholders (i.e., accessibility for trucks) or excluded due to a lack of sufficient data (i.e., the availability of ground-floor spaces, rank 8) or a distortion of results (i.e., the proximity to pedestrian zones, rank 8).

Factor weighting

The site-suitability is determined for each pixel using raster layers with a resolution of 10 m. The suitability scores are normalised to the range 0 to 1. The suitability of a pixel s_p is calculated using a weighted average, as given in Equation 1:

$$s_p = \frac{\sum \left(f_i q_i^p\right)}{\sum f_i} \quad (1)$$

where f_i is the factor (i.e., the rank) of the respective indicator and q_i^p the indicator's quality specified for each pixel. The quality scores q are obtained as follows. For

TABLE 1 Label, name and rank given by the stakeholders involved (except for dist_opt), maximum distance (when applied), data sources and reference year of the indicators for assessing the site-suitability of the food hubs in Berlin.

Label	Indicator	Rank	Max dist. (m)	Data sources	Ref. year
pop_dens	Population density	7	–	(Amt für Statistik Berlin-Brandenburg, 2019)	2019
pub_transp	Distance to public transportation	7	500	OpenStreetMap	2021
org_groc	Distance to organic groceries	3	1000	OpenStreetMap; berlin.de; veganberlin.com; maps.google.com	2021
dist_opt	*Distance from the optimum*	*7*	*750*	Own calculation; LOR: (Amt für Statistik Berlin-Brandenburg, 2021)	2021

TABLE 2 Overview of the results the approaches described in Figure 1.

Approach	1	2	3a	3b	3c
Concepts and data basis	15-min city	LOR, 15-min city	stakeholder consolidation	LOR, 15-min city, stakeholder consolidation	LOR, 15-min city, stakeholder consolidation
Number of food hubs	332	203	–	–	231
% of area covered within 1 km radius	99.9	85.6	–	–	90.6
% covered within 1.5 km radius	100	99.8	–	–	99.8
Site-suitability assessment	–	–	x	x	x
Large-scale assessment	x	x	–	x	x
Result	Figure 2A	Figure 2B	Figure 3A	Figure 3B	Figure 3C

Three quantitative results are given: the number of food hubs, percentage of area covered by food hubs within a radius of 1 km and percentage covered within 1.5 km. It is also listed for which scenarios the site-suitability and the large-scale assessment (i.e., allocation throughout the entire city) were considered. The graphic results are shown in the respective figures.

org_groc and pop_dens, q equals the normalised pixel value (i.e., $v/v_{\max}$), which means the greater the distance to organic groceries and the higher the population density, the higher the value. By contrast, the closer a pixel is located to public transportation stops and the optimum, the higher the quality, which is expressed by the equation $q = 1 - v/v_{\max}$. The value of $v_{\max}$ is defined by the maximal distance of relevance (Table 1). All quality scores are clipped to the range 0 to 1. This means, for instance, that a distance to public transportation stops of 500 m or more is revalued to zero.

Adaptation and reallocation

The locations identified in the Approach 2 were adapted towards the site-suitability (3c in Figure 1). The FHs within the respective LOR were manually shifted whenever a significant improvement of site-suitability could be achieved within the proximity of the optimum. In a second step, the area covered by the FH within a radius of 1 and 1.5 km, respectively, was calculated and the FHs were readjusted while retaining a similar value of site-suitability. We repeated this step iteratively and added new FHs where considerable gaps emerged until a new optimum was reached.

Software and data management

The spatial assessment was developed by using the geographic information system software QGIS Version 3.20.2 (QGIS Development Team, 2021). For processing the spatial data, the Universal Transverse Mercator projection (zone 33 N) based on the European Terrestrial Reference System 1989 (EPSG 25833) was applied. Data on population density and LOR were obtained from the official statistics of Berlin-Brandenburg (Amt für Statistik Berlin-Brandenburg, 2019, 2021). Data on public transportation was gained from OpenStreetMap (Geofabrik, 2020), whereas we combined the OpenStreetMap with the available data on organic groceries in Berlin from different sources (Table 1).

Results

Quantity and distribution of food hubs

The spatial calculation reveals that a full supply of Berlin's populated areas with FHs within a maximum walking distance of 15 min would require a total of 332 sites (Figure 3A, Table 2). However, this number is hypothetical because whether the FHs in the centre of the hexagons are located within a suitable area is not considered.

The second estimation of FHs is derived from the LOR (Figure 2B). The number of FHs within the LOR varies between one and five depending on the extent and distribution of populated areas in the respective LOR. There are a total of 203 potential FHs allocated to the 143 LOR. In contrast to the previous approach, all FHs are located within potentially feasible areas. Although this example lacks a full implementation of the 15-min city concept, most of the area includes a FH within a walking time of 15–20 min (Table 2).

Site-suitability for implementing FHs

The maps of Figure 3 illustrate the site-suitability and potential sites for implementing FHs for two site samples located in the districts of Neukölln, on the left, and Marzahn-Hellersdorf, on the right (results for the whole city are shown in the Supplementary material). Results [a] represent the suitability regarding the population density, and the distance to public transportation stops and the closest organic grocery for each raster pixel (3a in Figure 1).

Consequently, the distribution throughout the city is not considered here. The normalised values reach a maximum of 0.8, which indicates the most suitable sites of the city.

Integrating the distance to the optimum as an additional indicator into results [a] leads to a substantial clustering of the site-suitability around the optimum [b]. Nevertheless, the suitability in the vicinity of the optimum is still differentiable due to the rank chosen and maximum distance of the variable (Table 1).

In the results [c], the locations generated from the optimal distribution are shifted to more suitable areas by an average of 338 m, as indicated by white arrows. The city-wide coverage with FHs and the 15-min walking time are incorporated here and roughly illustrated by black circles with a radius of 1 km around the new sites. In order to fulfil this task, additional FHs were added where necessary, ending up in 231 potential FHs with a mean distance of 2.65 km. Almost the entire populated area (99.8%) is situated within a distance of <1.5 km to the next FH, and 90.6% are covered by a 1 km radius, which is a significant increase compared to the previous approach (Table 2). Areas that are not within the 1 km threshold are characterised by a low population density, which means that an even higher share of the population is provided with a FH nearby.

Discussion

A full coverage of Berlin with FHs within a 15-min walking time is based on an equitable allocation of FHs. First section focuses on how to operationalize this concept in the city of Berlin considering socio-spatial aspects that shape their allocation. It also includes the reallocation of FHs by integrating the variables selected and their prioritisation to the previous analysis is discussed. Secondly, we discuss the agroecology-based regional FHs and their implications in terms of sustainability and resilience in a 15-min city, whereas the implications of the scaling out of the FHs for the city of Berlin are evaluated in the third section. Finally, we specify the limitations of the study and the caveats when applying this approach to other case studies.

Envisioning the *LebensMittelPunkte* in a 15-min Berlin

Operationalizing the 15-min city in Berlin (approaches 1 and 2)

Although the direct application of the 15-min city concept to urban planning might provide a first idea on the number of FHs, which is 332 (Figure 2A), it has to be adapted regarding the city's specificities. We found the LOR to be suitable for combining the 15-min distance with the specific socio-spatial conditions of the different areas of Berlin (Figure 2B). The LOR are the administrative units commonly used by the administration of Berlin for implementing plans and programmes or monitoring the social city development. Their size is variable and depends on the characteristics of the area. Sparsely populated areas, for instance, are usually enveloped by larger LOR. Thus, we observed that some LOR exceed the area covered by the 15-min distance around the centre, wherefore these areas were split and the number of potential FHs within the 143 LOR amounts to 203 (Figure 2B).

Berlin differs from many other European cities in terms of its spatial arrangement and, therefore, urban planning. The heritage of the city's past, for example, the division of Berlin, shapes the urban landscape substantially so that large industrial, abandoned or green areas, such as the former Berlin Tempelhof Airport, are frequently found in between neighbourhoods (Duda, 2007). Due to these distribution patterns, some FHs are beyond the 15-min walking distance.

Spatial reallocation of the food hubs based on the suitability map (approach 3)

The previous allocation is based on the integration of the 15-min walking distance into the LOR distribution, but does not consider the variables selected (i.e., population density, organic groceries, distance to public transportation) and their prioritisation at a small-scale, which is the block level here (Figure 3A). The site-suitability assessment is more reliable when considering real-life conditions but, in turn, does not include information on the location of the other FHs. Thus, different highly suitable areas

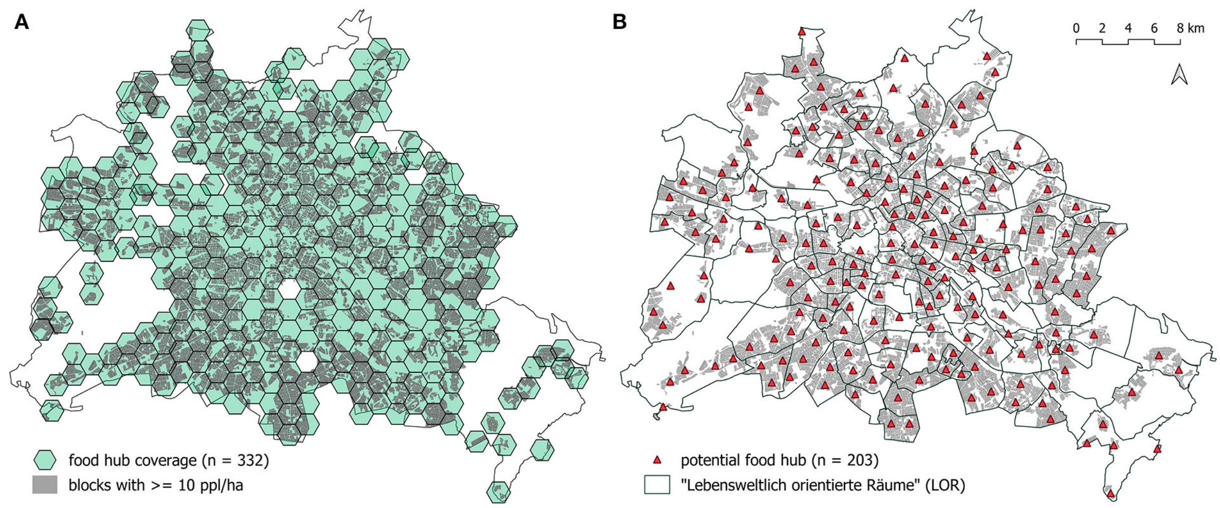

FIGURE 2
The allocation of FHs in Berlin based on **(A)** the 15-min city concept and **(B)** the LOR.

belonging to two different LOR might be located close to each other. To overcome this issue, the fourth variable (i.e., distance to the locations resulting from the optimal allocation) was incorporated into the assessment (Figure 3B). Consequently, the site-suitability is highlighted around the optimum determined previously, which ensures a minimum distance between the FHs (note the changes from Figures 3A,B).

The outcome of the second option to combine the small-scale site-suitability analysis with an efficient large-scale allocation across the city is a new optimum of 231 FHs (Figure 3C). It is more concrete than the first one and suited for scaling up the urban planning to district level at least. This allocation is further characterised by a higher equality among different areas resulting from a more efficient distribution and relatively close implementation of the 15-min city concept.

To the best of our knowledge, this is the first study in which the 15-min city concept is operationalized at a city level. Although the concept has been proposed and developed for the city of Paris (Ville de Paris, 2021), it is still a theoretical approach that was applied to some neighbourhoods but without an explicit urban planning proposal for the whole city. In the case of Berlin, only a few small initiatives in specific districts, such as the "*Begegnungszonen*" (i.e., encounter zones), have been implemented so far. They are only focused on designing streets in such a way that users of all means of transport can meet on equal terms in public streets and eventually improve the experience for pedestrians (Senatsverwaltung für Umwelt, Mobilitäat, Verbraucher und Klimaschutz, n.d.).

Agroecology-based regional food hubs in a polycentric, just, sustainable and resilient 15-min city

In this study, we adapted the 15-min city concept to an urban food system. We do not perceive the concept as a dogmatic approach to create completely autonomous neighbourhoods rather than a strategy to create a polycentric city with balanced independencies and interconnectedness between different centres (Kloosterman and Musterd, 2001; Ostrom, 2010; Carlisle and Gruby, 2017; Xu et al., 2020). Thus, a polycentric 15-min city allows the reconsideration of the unequal distribution of food products and services (King, 2004) and can "enhance innovation, learning, adaptation, trustworthiness, levels of cooperation of participants, and the achievement of more effective, equitable, and sustainable outcomes" (Ostrom, 2010).

The diverse site-specific conditions of neighbourhoods revealed by the LOR in combination with the prioritisation of variables justified the deviation from the strict 15-min walking distance when allocating the FHs. In order to counterbalance these inequalities, distances between FHs vary depending on the socio-spatial conditions. The distance is, for instance, about 0.7 km in the most densely populated areas, whereas it increases to values up to 3.7 km in sparsely populated areas, typically in between green or industrial zones. This fact is reflected in the spatial accumulation of FHs, as illustrated in the heat map (Figure 4). Despite these different FH concentrations across the city, the results show that the vast majority of the area is covered by a FH radius of 1 km, and almost the entire area by a FH radius of 1.5 km (Table 2).

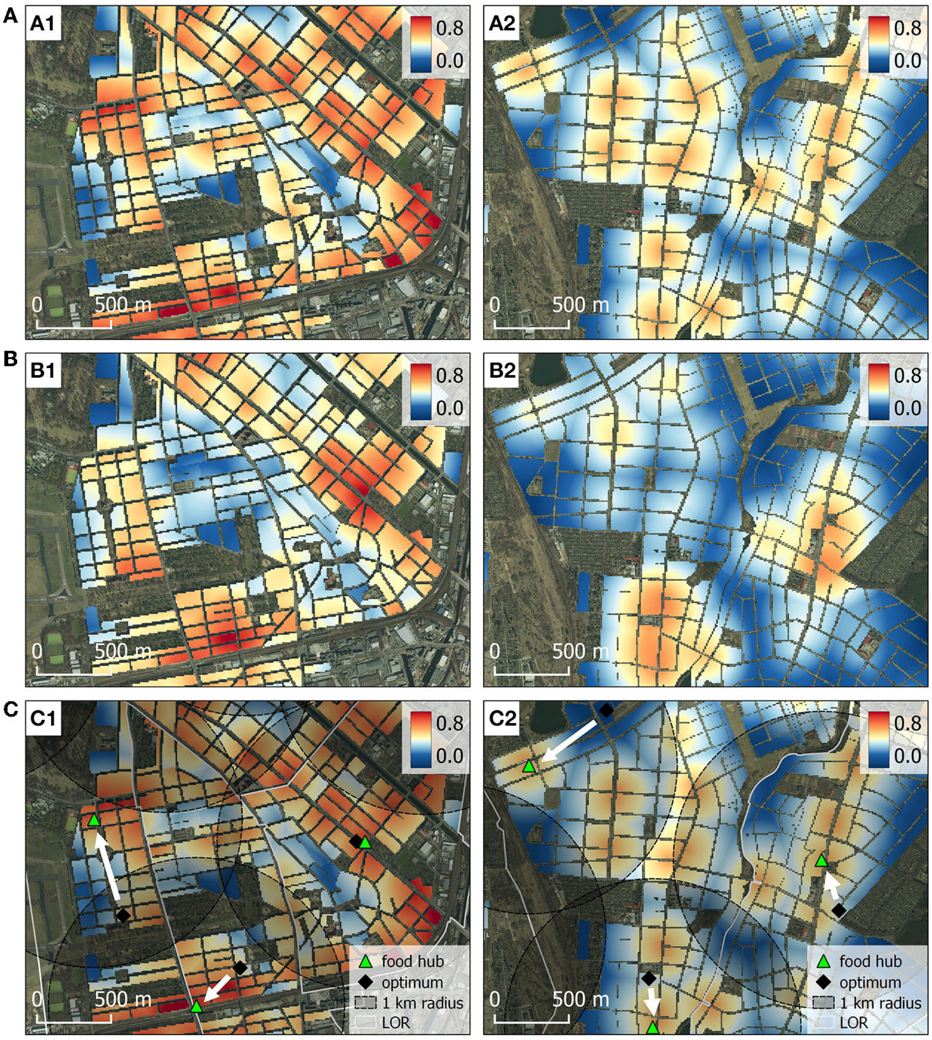

FIGURE 3
Site-suitability for implementing FHs in two contrasting areas of Berlin (left: Neukölln, right: Mahrzahn-Hellersdorf). **(A)** Site-suitability without considering an optimal distribution, **(B)** site-suitability considering an optimal distribution and **(C)** reallocation of the optimum. The satellite image is provided by © MapTiler and © OpenStreetMap contributors.

The FHs would be situated at accessible points to public transportation in a real-life scenario, and eventually would be part of an alternative food network (AFN). They would, thus, relate to a whole alternative food system that combines accessibility, relative short distances between households and FHs and an agroecological food production, therefore improving the sustainability of the food system and promoting the cultural survival, economic development, social justice and healthy diets in the region (Hinrichs and Lyson, 2007; Berti and Mulligan, 2016; Canal Vieira et al., 2021; Driessen, 2021; Sgroi and Marino, 2022).

The FHs are not only a theoretical concept but have become reality in several districts of Berlin. The existing FH prototype is connected to different community-supported agriculture farms that follow the principles of agroecology (Vicente-Vicente et al., n.d.) and, hence, contributes to the creation of an agroecology-based local agri-food system (ALAS) (González De Molina and Lopez-Garcia, 2021; López-García and González de Molina, 2021). The ALAS have already been tested empirically. For instance, López-García and González de Molina (2020) studied them in the context of urban agroecology in 13 Spanish cities belonging to the Spanish *Red de Ciudades por la Agroecología* (Network of Cities for Agroecology), where nine of them involved the participation of food hubs. Furthermore, agroecology in short food-supply chains and AFNs has been widely implemented in the Global South, for instance by creating farmers' markets (Otekunrin et al., 2019), as well as throughout cooperation systems and farmers and peasant

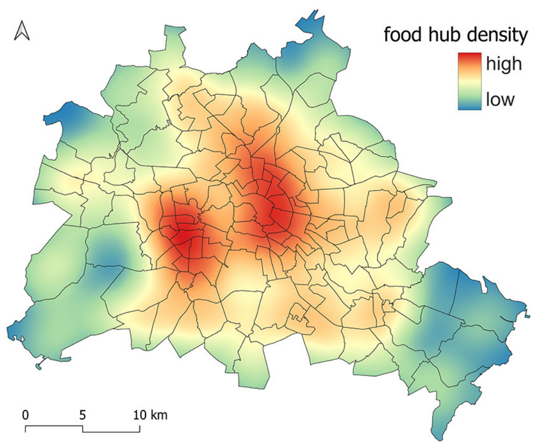

FIGURE 4
Heat map indicating the spatial accumulation of food hubs in Berlin.

movements (Mier y Terán Giménez Cacho et al., 2018). It is also in the Global South, particularly in Latin America, where the agroecological territorialisation has been studied in the frame of achieving food sovereignty (Giraldo and McCune, 2019). Although in our case we are still far from achieving food sovereignty, linking urban agroecology to agricultural production would be the first link to re-connect urban and rural contexts through AFNs (López-García and González de Molina, 2020; Tornaghi and Dehaene, 2020). Therefore, the scaling out of the agroecology-based regional FHs to the entire city would foster the articulation of an ALAS, "linking territories and actors within the city-region food system" (López-García and González de Molina, 2020), which has been proposed as a resilient model to overcome the complexity of the system and increasingly achieve sustainable food systems (Vaarst et al., 2018; Quaranta et al., 2019; Bén, 2020; Blay-Palmer et al., 2021) based on the principles of sufficiency, regeneration, distribution, commons and care (McGreevy et al., 2022).

Realising the scaling out of the *LebensMittelPunkte* in Berlin

There are currently 16 initiatives within Berlin aiming to establish a new FH, and the number is rising rapidly. While some initiatives, such as the FH prototype "*Das Baumhaus*" or the "*Haus der Statistik*" (https://hausderstatistik.org/), are, according to our results, located at suitable sites, others are still on the search. In the latter case, the results of this study can provide valuable input for selecting a potential site. This ought to take place in the form of a dialogue in which practitioners, planners and policymakers refer to the same study as a common ground. A common reference point allows an inclusion of different actors and a more coherent approach towards establishing FHs across the city. Moreover, in the case where an initiative wants to apply for funding for a FH, the allocation assessment could provide evidence for agreeing on a suitable location.

The spatial allocation assessment is one relevant piece of a puzzle towards a sound FH implementation plan. However, the state of Berlin does not have any integrative policy strategy considering food, urban planning and environmental sustainability yet. Currently, there are some sectoral strategies, such as the Berlin Food Strategy or the Urban Landscape Strategy (Senatsverwaltung für Stadtentwicklung und Umwelt, 2017; Senatsverwaltung für Umwelt, Mobilitäat, Verbraucher und Klimaschutz, n.d.), but these efforts alone will not be sufficient to address the complexity of current sustainability issues. By contrast, the city of Bristol (UK), for instance, has embarked on this endeavour by developing a "One City Plan". The latter brings together a number of city-wide strategies and covers themes such as environment, housing and community, health, economy, culture and transportation, among others (Bristol Once City, 2021).

The implementation of FHs across the city of Berlin is one ambition defined in the 2021 coalition treaty of the current Berlin government (SPD Berlin, 2021). The treaty reads: "by establishing at least one '*LebensMittelPunkt*' in every Berlin district, where possible in existing infrastructures, the coalition promotes neighbourly community and enables access to good, healthy and regional food, regardless of budget". Whereas integrating principles of equal access and spatial justice by establishing FHs across the city is a clear objective, the decision on where to allocate the FHs is still vague. In this context, the suitability maps can support the decision-making process. A combination of the results and an assessment of public infrastructures (such as libraries, schools and community centres) at a district level could, for instance, provide a selected number of suitable locations. In addition, the installation of a FH network requires a supporting infrastructure (e.g., depots for food storage) and should be implemented together with other basic facilities defining a "proximity city" (Ville de Paris, 2021).

Limitations of the study and application of the methodology to other cities

There are some caveats that should receive attention when interpreting the results of the case study. Some areas that are not residential spaces might be suitable for implementing a FH but are not included. This is due to insufficient data that allows for a sound differentiation between suitable and unsuitable public and commercial sites. Nevertheless, their values can be estimated by using the values of the neighbouring blocks in the site-suitability map because only sites surrounded by populated areas are relevant. Moreover, we are aware that one important variable might be the direct access from the street (i.e., street front and ground level). However, we could not include this in the assessment due to a lack of data. Thus, the site-suitability maps have to be combined with direct real observations.

There are also issues that are important when applying this methodology to other case studies. The variables and spatial units selected might differ due to the unique socio-economic conditions. Furthermore, data availability is an important constraint when selecting the variables and, therefore, has a potentially significant effect on the reliability of the study. Although a manual reallocation of the FHs is *per se* of limited transferability, it has been proved to be much more accurate than an automated distribution because it allows a better adaptation to the real conditions. This process has to be developed by a stakeholder consolidation process identifying sites that are meaningful to the community. Therefore, we do not claim to provide a methodological or conceptual blueprint for allocating FHs. Instead, we propose a procedure to approach a solution that is appropriate for a real-life implementation.

Conclusions

The present study is, to the best of our knowledge, the first one assessing an optimal allocation of FHs within cities, thus, becoming an instrument for regional food system transformation towards sustainability. This is also the first study applying a methodology that operationalizes the 15-min city in a comprehensive way and, therefore, one which can be applied to other cities. We estimated a potential optimal number of 231 FHs for the city of Berlin based on socio-spatial units and a set of variables with different levels of prioritisation. As a result, citizens in more than 90% of the populated area of Berlin would be supplied with a FH at a maximum distance of 1 km, which equals a walking distance of 15–18 min. Moreover, the optimal spatial allocation maps provide valuable inputs for selecting the most suitable areas at the neighbourhood level, while simultaneously avoiding overlaps with surrounding FHs.

We envision the scaling out of the FHs to the whole city not as a set of independent 'food islands' but as components of a polycentric city with a balanced level of autonomy and interconnectedness. This model would facilitate a food system transformation by the creation of a more sustainable city-region food system. However, the state of Berlin does not, as yet, have an integrated sustainability strategy. We call for a systemic approach in policy-making in order to implement a net of agroecology-based regional FHs covering the entire city, which should be reachable in walkable distances. In order to achieve this, a multi-actor participative approach including practitioners, planners and policymakers should be adopted not only at the city level but also between Berlin and the state of Brandenburg, where the majority of the food would be produced. In this regard, future efforts may focus on the implications of the agroecology-based regional FHs at the agricultural landscape level in order to move towards an agroecology-based, territorialised agri-food system.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

FK: methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft, writing—review and editing, and visualisation. JV-V: conceptualisation, resources, writing—original draft, writing—review and editing, and supervision. BW: investigation, resources, writing—original draft, and writing—review and editing. All authors contributed to the article and approved the submitted version.

Funding

This research was partially funded by institutional funds from Leibniz Centre for Agricultural Landscape Research (ZALF) e.V. and by the research project FoodSHIFT 2030 of the European Union's Horizon 2020 Research and Innovation Programme under grant agreement number 862716.

Acknowledgments

We warmly thank Dr. Annette Piorr for the fruitful discussions and her overall support, as well as Jannes Münchmeyer for verifying the calculation and underlying equations. We also thank the reviewers for their suggestions, which were highly valuable to improve the manuscript. Furthermore, this study would not have been possible without the valuable collaboration with our partners Karen Wohlert from *Das Baumhaus*, Lisa Haarhoff from the Food Policy Council Berlin and Toni Karge from the Berlin Senate Department for Environment, Mobility, Consumer and Climate Protection.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.913412/full#supplementary-material

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