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Choosing modelling approaches for participatory food governance in city-regions. Comprehensive guidelines for a system-perspective selection

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ABSTRACT

As centres of consumption, knowledge and services under some political and administrative control, cities are acknowledged as strategic food governance transition nodes. Increasing stakeholder coordination and participation, however, means identifying pathways for transformative change and accelerating uptake of innovative and participatory modes of governance. We argue that modelling approaches, by helping to meet the three preconditions for participatory governance (relationship-building, shared understanding and experimentation) offer valuable input and can help establish ad hoc institutional space for redesigning food system governance. Based on a selective literature review, we define four key dimensions to consider when modelling for participatory food governance in city-regions: stakeholders' involvement, process phases, capacity for joint action and use of a multi-sectoral and multi-scale approach. The state-of-the-art review presented in this paper focuses on seven modelling approaches that can meaningfully support stakeholder participation in food system transitioning processes, considering the specific context, objectives and available resources. The strengths and limitations of combined modelling approaches are illustrated and critically reviewed, using a concrete example from the Berlin city-region. This highlights the relevant contribution that modelling can make to creating new spaces for participatory food governance.

1. Introduction

Today, approximately 55% of the world's population live in urban areas, a proportion expected to increase to 68% by 2050 (UN, 2019). Food security and nutrition are currently negatively and significantly affected by the vulnerable globalised agri-food system and climate change (IPCC, 2019, 2022; FAO, 2021; FAO et al., 2022), prompting communities to look for sustainable transformative solutions (FAO and INRAE, 2020). These include strengthening links between rural and urban areas in order to create sustainable city-region food systems (FAO, 2017). As hubs of consumption and innovation, cities play an important role in transitioning food systems (Cohen and Ilieva, 2015; Forster and Escudero, 2014) and urban governments have emerged as spaces for re-designing food system governance (Deakin et al., 2019; Rossi and Brunori, 2015; Sonnino, 2019). Overall, food system governance can be understood as the practices, mechanisms and processes that structure the interactions between people and their food system (Clancy, 2014; Termeer et al., 2018). In this sense, participatory food governance can then be broadly understood as the establishment of practices, mechanism and processes, involving a wider public and diverse stakeholder at multiple sites, that facilitate active engagement and deliberation aimed at making and implementing food policy decisions (Fanzo and Davis, 2021; Huttunen et al., 2022; Sonnino, 2019). It involves institutions and organisations, ways of making decisions and organising collective action. The mechanisms include informal rules, laws and policy regulations, conventional governance structures (e.g. local authorities, but also national governments), food strategies, food partnerships, as well as language itself (Andrée et al., 2019; Hospes and Brons, 2016; Sonnino, 2019). The range of actors can be quite broad, including governments, NGOs, producers, retailers, small businesses, citizens, informal associations and researchers (Donkers, 2013; Koc et al., 2008). Approaches to conceptualising food system governance are manifold, and have been

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described as integrative (Blay-Palmer et al., 2018; Lang and Barling, 2012; Rossi and Brunori, 2015), systemic (Sonnino et al., 2019; Termeer et al., 2018), reflexive (Clancy, 2014; Sonnino et al., 2014; Moragues-Faus et al., 2017) and/or adaptive (Fridman and Lenters, 2013), to mention only a few.

Common to these different approaches are new institutional arrangements aimed at getting civil society, private stakeholders and local governments together to experiment with new and flexible forms of food governance that are more inclusive, collaborative, socially-oriented and context-linked (Sonnino and Beynon, 2015; Rossi and Brunori, 2015). Participatory food governance approaches are acknowledged to yield several benefits and synergies, such as improving the legitimacy, accountability and equity of food policies (Moragues-Faus and Morgan, 2015; Rossi and Brunori, 2015; Sonnino and Beynon, 2015; van de Griend et al., 2019). Further, more technical approaches to food-growing have led to models of farm production and natural resources management being increasingly linked to governance structures (see, for instance, Jones et al., 2016). Similarly, food system governance modelling has increasingly been linked to climate change modelling (Steiner et al., 2020); it has been included in adaptation and mitigation strategies and policies addressing climate change impacts on more vulnerable producers and consumers (Vermeulen et al., 2012).

Although public participation in food governance is obviously beneficial, this is often prevented by rigid bureaucratic structures, lack of the skills required for participation and power imbalances that make it difficult for vulnerable or affected groups to actively influence policy-making (Duncan and Claeys, 2018; Hospes and Brons, 2016; Moragues-Faus et al., 2017; Prost, 2019; Rossi and Brunori, 2015). What is needed is methods of dealing with tensions between elite and bottom-up or civic perspectives and of integrating public concerns into formal policy-making (Huttunen et al., 2022; Moragues-Faus and Morgan, 2015). Huttunen et al. (2022) call for wider deliberative systems and processes to involve diverse stakeholders and to establish connections between multiple sites and activities in participatory food governance. Nevertheless, a general top-down approach prevails due to the complexity of both real-world phenomena and the policy process (Zasada et al., 2017).

Assuming that fostering participation does not simply involve downscaling policies from higher levels or upscaling governance innovations from niche level, we argue that modelling approaches can make a key contribution. In particular, modelling approaches can facilitate multi-stakeholder processes, deliberation and decision-making by providing a temporary, ad hoc platform for knowledge-sharing and dialogue between different stakeholder interests and needs. This would be particularly valuable when institutional designs do not (yet) provide for relationship-building, shared understanding and experimenting with new governance arrangements. We illustrate how modelling approaches can enhance participatory food system governance with a practical example from Berlin (Section 6).

We are, however, aware that modelling approaches do not automatically lead to increased participation in food governance per se. Cautious and reflexive application is needed, as well as an overview of the modelling tools, methods and processes that can contribute to city-region participatory food governance. Here, therefore, we address the following questions: Which modelling approaches best facilitate participatory food governance? When and why is their use appropriate? What criteria should be used to select a suitable modelling approach? Our comprehensive guidelines for choosing a model or a combination of models to contribute to participatory food governance in city-regions are based on key factors and operational principles, and we provide a good-practice example of a promising strategy.

2. Material and methods

2.1. Literature assessment

We assessed the literature with a twofold aim: 1) to conceptualise modelling approaches through the lens of participatory food governance (Sections 3) and 2) to find modelling approaches that could enhance participatory food governance of the city-region food systems (Section 4). Contributions published between 2002 and 2020 were found by screening scientific bibliographic databases and using snowballing methodology (i.e. following up cross-referrals within scientific and grey literatures through key words) (see Appendix A for key words). The literature selection was based on two criteria: 1) the authors' expert judgement concerning well-established modelling frameworks and their suitability for participatory processes; 2) the application of these models to food systems, focusing on operational dimensions (i.e. modelling context, objectives and available resources like time, money, knowledge and technical tools).

We took a multi-step analytical approach. First, we identified from the literature review four relevant dimensions (stakeholders' involvement, process phases, capacity for joint action and multi-sectoral and multi-scale approach) which we argue must be considered when modelling for participatory governance in city-region food systems (Section 3). Second, we selected seven outstanding modelling approaches used or potentially usable in participatory food governance. Taking the operational dimensions as relevant criteria, and informed by our own experience in developing modelling and participatory approaches, we classified the modelling approaches according to their design and implementation: qualitative, quantitative and mixed-methods (Section 4). Third, we identified their strengths and shortcomings through a qualitative assessment of each study's findings, considering the four dimensions relevant to participatory governance (Section 5).

2.2. Case study

The city-region of Berlin in Germany serves as a case study in Section 6 to illustrate and discuss the use of some of the modelling approaches found and analysed theoretically in the previous sections. This case is particularly interesting because Berlin is currently making the transition from minimal action on food governance, initiated in 2015, towards increasingly participatory deliberation and collaborative action (Hoffmann, 2019). This latter development was initiated by a bottom-up process involving both quantitative and qualitative modelling approaches. The case is also particularly appropriate because three out of the six authors (Annette Piorr, José-Luis Vicente-Vicente and Beatrice Walthall) are located in Berlin and have actively participated in the governance process through their different scientific roles and in a number of forms. For instance, as co-authors of foodshed modelling studies (Zasada et al., 2017, 2019; Vicente-Vicente et al., 2021a, 2021b; Mouléry et al., 2022), as co-organisers and keynote speakers in civic-driven events and meetings (Regioweek 2018, Action Conference 2019) and as workshop co-organisers of participatory modelling activities (Walthall et al., 2022a).

3. Identifying modelling features relevant to participatory food governance

A distinctive aim of participatory food governance is to move beyond passive information-providing and towards active engagement, facilitating synergistic relationships that can deliver policy outputs (Doherty et al., 2020; Moragues-Faus and Morgan, 2015). This is realised through co-creating knowledge, sharing responsibilities and resources, or providing space for different arguments, reflection and deliberation (Huttunen et al., 2022). Participatory governance practices include forums, lay-expert involvement, or citizen science (Krick, 2022) deployed in food initiatives and networks (Prost, 2019; Scharf et al., 2019), food strategies (Hospes and Brons, 2016; Sonnino, 2019, Moragues-Faus et al., 2013), multi-stakeholder platforms, or citizen food assemblies (Doherty et al., 2020).

Based on Voinov and Bousquet (Voinov and Bousquet, 2010), we define modelling as the activity of describing a system or a process, which implies defining its spatial, social and ecological boundaries and main components, in order to understand how the system functions and to assess the (enabling and constraining) factors impacting it. Modelling can be used in a participatory process, allowing participants "to co-formulate a problem and use modelling to describe the problem, to identify, develop and test the solutions, and to inform the decision-making and actions of the group" (Voinov et al., 2018: 233). We argue that modelling approaches help to meet the pre-conditions for participatory governance (Section 3.1), and we identify relevant dimensions to consider when modelling for participatory food governance in city-regions (Section 3.2).

3.1. Pre-conditions for participatory governance

i. Building relationships: participatory food governance builds on relationships between different actors and sectors, through collaborative action (e.g. agricultural practices, research, spatial planning and policy-making – horizontal axis) and across governance levels (from local to global - vertical axis) (Blay-Palmer et al., 2018; Lang and Barling, 2012; Rossi and Brunori, 2015; Termeer et al., 2018; Clancy, 2014; Sonnino et al., 2014). Through self- and social questioning (reflexivity), people engage within the food governance arena (Moragues-Faus et al., 2017). Modelling approaches that assess sustainable city-region food system management help to build relationships and democratise the process. As a resource management tool, they assist stakeholders in addressing questions such as: Who should speak? What is the issue at stake? What solutions are proposed? This makes them a novel way to approach challenges and propose solutions from a civic-driven perspective.
ii. Shared understanding: being reflexive or becoming knowledgeable about food systems helps communities to recognise tensions and contradictions and to deal with them in a respectful way, thereby building a shared view (Clancy, 2014; Hassanein, 2008). In fact, lack of cross-scale, multi-level and enabling food participatory governance may correlate with substantial knowledge gaps on the various food system stages that connect production with consumption (i.e. the "missing middle", Sonnino et al., 2019). Modelling approaches can highlight the complex interactions of city-region food systems and the connections between different levels and dimensions.
iii. Experimentation: By experimenting with different visions, political options and scenarios, modelling approaches can provide the knowledge to create futures that are new to participants and to foster the concrete action required to achieve them, which in turn can support policy development (Voinov and Bousquet, 2010).

3.2. Relevant dimensions to be considered when modelling for participatory food governance in city-regions

i. Stakeholders' involvement: the degree of participation by "active citizens" (Fung and Wright, 2003), which includes ordinary people affected by the tangible problems addressed (e.g. grassroots operators, field operatives), officials close to them and narrowly trained experts. Stakeholders' involvement can range from pure information to occasional collaboration (e.g. stakeholders help describe the current dynamics, enabling the analyst to set the modelling assumptions and empirical rules) or even to co-construction (e.g. stakeholders participate in designing and simulating various scenarios) (Voinov and Bousquet, 2010).
ii. Process phases: how modelling methods are linked to the phases and objectives of participatory food governance for which they are mainly used, and whether they can be extended to additional phases. Based on Halbe et al. (2020), we identify 5 process phases: i) integrated knowledge production and problem definition, ii) stakeholder analysis and selection, iii) participatory visioning and goal formulation, iv) interactive strategy development that anticipates long-term systemic effects and v) simulated implementation of experimental actions.
iii. Capacity for joint action: the resources and skills developed by involved citizens through the modelling approach, empowering them to jointly build the "social capital" needed for deeper participation in the governmental process (Fischer, 2012; Fung and Wright, 2003; Gaventa, 2002). Capacity applies either to the generation of new, shared knowledge (e.g. understanding a system and its dynamics under various conditions) or to the development of practical skills (e.g. communication, dealing with policy discussion, etc.) (Emerson et al., 2012).
iv. Multi-sectoral and multi-scale approach: related to systems thinking, how far the modelling approach reveals the connections and loops between government (e.g. municipal steering committee, civil servants), civil society (e.g. residents/commuters/newcomers) and private (e.g. food shop managers, cooperative food production services) **sectors** (**horizontal axis**) and the multiple jurisdictional and spatial **scales** (e.g. district, municipal, inter-municipal; -**vertical axis**) of the food system, and how far it supports the integration of the horizontal and vertical governance axes. Most models consider both axes, as they are not mutually exclusive. This constitutes modelling approaches' biggest contribution to participatory governance: filling the gap in "traditional" participatory governance approaches which focus on the horizontal expansion of views and interests (Rossi and Brunori, 2015). In other words, the multi-sectoral and multi-scale approach makes it possible "to identify the socio-ecological and political reconfigurations that are really needed, across places and scales, to meet the challenges of systemic food change" (Sonnino et al., 2019: 6).(Table 1)

Given that local food production is a central building block of regional food strategies, we also suggest that city-region food governance needs to consider agricultural system innovation and even landscape and land-use innovation. Accordingly, the spatial dimension should be integrated into any information and decision support system, for instance through spatial-sensitive modelling approaches.

Table 1
Relevant dimensions and their functions to be considered when modelling for participatory governance in city-region food systems.

Goal	Dimension	Functions[a]
Participatory food governance in city-regions	stakeholders' involvement	information cooperation co-construction
	process phases	I. definition II. analysis III. goal IV. strategy V. implementation
	capacity for joint action	knowledge skills
	multisectoral and multiscale approach	horizontal vertical

[a] The functions of the dimensions (Table 1) are not intended as a ranking or a gradient, but should be viewed simply as individual characteristics.

4. Modelling approaches enhancing participatory food governance of city-region food systems

Seven modelling approaches derived from our literature review are presented, with their objectives, methodology, strengths and shortcomings. These are classified into three categories: a) future participatory qualitative approaches; b) quantitative approaches integrating expert knowledge; and c) iterative approaches involving stakeholders and using mixed methods. Examples of their application are provided. Section 6 further explores the usefulness of some of the selected approaches through an illustrative case in Berlin.

4.1. Future participatory qualitative approaches

Qualitative analysis methods have been used to obtain data from qualitative stakeholder statements, enabling the identification of a complex set of drivers and success factors behind food practices in cities (Krikser et al., 2019; Opitz et al., 2019).

4.1.1. Visioning

Objective. The visioning approach seeks to articulate the image that a group of citizens and decision-makers have of a desired future in a common time horizon of usually 30 or 50 years (O'Brien and Meadows, 2001; D'Hondt, 2012). It has proven useful for stimulating creative thinking, eliciting local knowledge and encouraging system thinking to tackle complex and challenging problems (Kok et al., 2011; Schmitt Olabisi et al., 2010).

Methodology. A visioning process encompasses various methods, including stakeholder workshops or semi-structured visioning interviews. It usually follows five steps to development of a collective image: i) analysis of the current situation, ii) assessment of the external environment, iii) formulation of a desired future, iv) connection of the future to the present state and v) testing of the vision (O'Brien and Meadows, 2001: 498). While online collaborative platforms (such as MURAL or MIRO) can be used, computer software is not required.

Strengths and shortcomings. The visioning approach has a relatively low threshold for application compared to other modelling approaches (e.g. Foodshed Modelling). While some methodological knowledge is required, the training time is relatively short. One challenge is comparing and evaluating desired futures, as visions often derive from qualitative and imaginative language and thus may not match quantitative information on future scenarios (Schmitt Olabisi et al., 2010: 2688).

Example: In food system studies, the visioning approach guided a comprehensive foresight process for alternative food networks (AFN) within the research project FuFuCo (2015–2017) (Warnke et al., 2018).

4.1.2. Backcasting

Objective. Participatory backcasting involves normative scenario analysis aimed at developing desirable future-present pathways (Robinson, 2003). Backcasting is often used to understand contextual vulnerabilities and to define shared strategies.

Methodology. A series of steps lead to an action plan, starting with a desired future as a vantage point and moving backwards to the present by looking back at how the desired future might have been achieved (Kok et al., 2011; Faldi and Macchi, 2017). Backcasting can take place through interviews, stakeholder workshops, or focus groups.

Strengths and shortcomings. As in the visioning approach, the methodological threshold is relatively low. Moderate expert knowledge is required but can be gained through short training. Since the method allows for imaginary or utopian ideas, innovative approaches can emerge, pointing to possible pathways that might not have been visible from conventional viewpoints based on present conditions or dynamics. (Robinson, 2003; Faldi and Macchi, 2017).

Example: The backcasting method was applied within the Food-SHIFT2030 project, in which participants from 9 different European city-regions co-developed a vision towards "good food governance" during a 3.5-hour workshop (Walthall et al., 2022b).

4.2. Quantitative approaches integrating expert knowledge

4.2.1. Foodshed modelling (FM)

Objective. Foodshed modelling approaches focus on quantitatively assessing an area's capacity to supply food meeting the population's specific consumption pattern so as to achieve a certain level of self-sufficiency in all food commodities (Zasada et al., 2019; Vicente-Vicente et al., 2021b) or in a specific commodity (Vicente-Vicente et al., 2021a; Mouléry et al., 2022).

Methodology. Foodshed modelling approaches require expert knowledge to manage spatial databases (GIS).

Strengths and shortcomings. Despite potential limitations due to lack of available data or suitability of local agro-ecological conditions for producing locally consumed food (Schreiber et al., 2021), the foodshed approach can usefully inform policies (Bala, 2014).

Example: It can be used to simulate the foodshed under different diet scenarios (Zasada et al., 2019), the impact of energy crops on local food self-sufficiency (Tavakoli-Hashjini et al., 2020), or links between local food production and climate change (Kriewald et al., 2019).

4.2.2. Structural equation modelling (SEM)

Objective. Structural models aim to analyse the relationships between unobserved variables that often reflect concepts or willingness (i.e. latent variables, like the willingness to consume local food) and observed variables (i.e. manifest variables, like the producer's location and the consumer's income) that may drive or explain the former.

Methodology. Manifest variables can be measured from available databases (e.g. census), specific publications (e.g. geographical measurements) and surveys.

Strengths and shortcomings. SEM requires expert knowledge to hypothesise the relationships between the variables and to code them in modelling computations. Both processes usually employ participatory methods and can take several months. However, structural models produce easily readable graphs and diagrams.

Example: SEM can be used to inform policy-making. Szakos et al. (2020) highlight behavioural patterns that explain household food waste, supporting waste mitigation policy. From a local food supply assessment perspective, Boussougou Boussougou et al. (2021) identify spatial units of periurban farmland that might enable short city-oriented marketing chains to be developed. However, few studies have used SEM to model relationships between stakeholders' behaviours and management institutions (Calancie et al., 2018).

4.3. Systems thinking iterative approaches involving stakeholders and using mixed methods

Systems thinking has long been used to understand complex food systems and simulate them over time (Armendáriz et al., 2015).

4.3.1. System dynamics modelling (SD)

Objective. System Dynamics (SD) models provide insights into the causal relationships in complex systems and represent dominant feedback processes (both reinforcing and balancing) over time by means of causal loop diagrams and similar visual tools.

Methodology. SD methodology requires expert knowledge and computational modelling skills. It has been widely applied to basic issues related to food systems, such as resource availability, energy, food and population.

Strengths and shortcomings. Causal loop diagrams can be collaboratively developed through a process called Group Model Building (GMB), an engaging, iterative process that actively involves decision-makers, community partners and modellers (Hovmand et al., 2012).

Example: SD was applied to map the water-energy-food nexus (Purwanto et al., 2019) or to pinpoint actions for improving healthy food access in a low-income urban environment (Mui et al., 2019). SD was also used to assess the effects of biofuel production on food security and land competition (Martínez-Jaramillo et al., 2019), to manage supply chains and food systems (Georgiadis et al., 2005) and to evaluate policy aiming at sustainable agri-food systems (Armendáriz et al., 2016).

4.3.2. The companion modelling approach (CM)

Objective. Companion Modelling (CM) is an outstanding participatory approach that involves a combination of agent-based models and role-playing games.

Methodology. Based on iterative interactions between landscape stakeholders' representatives, scientific experts and modellers, the model evolves with the participatory process, which can take anywhere from a few months to a few years (Étienne, 2014).

Strengths and shortcomings. Simulations of landscapes' spatial organisation resulting from environmental and social interactions are used to compare, discuss and derive scenarios with local stakeholders. Thus, the model serves as an intermediary object raising awareness of different points of view and their consequences in terms of action supporting collective decision-making.

Example: CM has been successfully implemented since the mid-1990 s worldwide, mainly to enhance multi-stakeholder integrated management of natural resources (for example, reconciling farming practices with landscape and biodiversity conservation in France - Moreau et al., 2019 - or within a development project in the Philippines - Campo et al., 2010). Agent-based models have been used to analyse specific food supply and distribution systems (Utomo et al., 2018), to assess community food security (Dobbie et al., 2018) and to evaluate policies in the agro-food sector (Gagliardi et al., 2014), but not yet to manage city-region food systems (Berthet et al., 2016).

4.3.3. Fuzzy cognitive mapping (FCM)

Objective. Fuzzy Cognitive Maps (FCM) are fuzzy-graph structures for representing causal reasoning (Kosko, 1986) and modelling and simulating complex systems (Özesmi and Özesmi, 2004). FCMs consist of concept nodes (i.e. factors used to describe the main behavioural characteristics: actions, values or events) and weights (i.e. strength of connections representing casual connections among nodes).

Methodology. The model is usually formalised through a participatory process that takes a few months. Fundamental to FCM are stakeholders' and experts' knowledge and experience. They determine which elements of FCM will affect one another and whether positively or negatively, establishing specific rules for how events are impacted. Causality is represented as a fuzzy relation on causal concepts.

Strengths and shortcomings. FCM is particularly useful as a communication and learning tool for bridging the gap between narrative storylines and quantitative models (van Vliet et al., 2010).

Example: Recently documented applications of FCM to food issues include analysis of sustainable food consumption models (Morone et al., 2019), multi-scale food system sustainability (Halbe and Adamowski, 2019), the energy-water-food nexus (Ziv et al., 2018) and monitoring of food security programmes (Aliyev et al., 2017). FCM has also been used to assess public-goods governance in agriculture landscapes (Targetti et al., 2019), the authors providing an overview of the system of relations between stakeholders (highlighting social mechanisms that prevail over governance mechanisms like power or market relations).

5. Choosing an appropriate modelling approach to enhance participatory food governance

In this section we recall the features of modelling approaches suggested in Section 3 to assess the strengths and shortcomings of the modelling approaches reviewed in Section 4. General operational factors (context, objectives and available resources) are linked to the four dimensions identified as relevant to fostering participatory food governance (stakeholders' involvement, process phases, capacity for joint action and multi-sectoral and multi-scale approach).

5.1. General operational factors

We examine methodological challenges and strengths based on three operational factors:

i. **Modelling context:** Key to model selection is the specific context of application and the issues to be addressed (Basco-Carrera et al., 2017; Voinov et al., 2018). While simple issues might be addressed with a visioning or backcasting approach, complex issues require more input on system dynamics and behaviour, as provided by an approach like SD. Another consideration is whether the issue is narrowly defined or involves a high degree of uncertainty. Since food systems are complex and adaptive, resource users and managers need to continuously test and develop new knowledge and understanding to cope with change and uncertainty (Thompson and Scoones, 2009). The choice of a model may depend on whether there are issues like power relations within food governance (Visioning, Backcasting), on willingness to change food behaviour (SEM) or on a city-region's degree of self-sufficiency (FSM).
ii. **Modelling objective:** The specific purpose of the modelling also influences choice (Basco-Carrera et al., 2017; Voinov et al., 2018). Is the goal to co-develop common understanding, build trust, identify shared values or even formulate strategic actions? While qualitative modelling approaches are better suited to building trust and developing shared understanding, more advanced quantitative models might provide better input to decision-making on strategic actions (Voinov et al., 2018). Combining several modelling approaches to address multiple objectives may be a fruitful strategy, as discussed in greater detail in Sections 5.2 and 6.
iii. **Available resources:** A final consideration is available resources, including time, money, people, knowledge and skills, data, technical tools and software platforms (Basco-Carrera et al., 2017; Voinov et al., 2018). While space constraints preclude discussing all resources, we consider the key temporal, knowledge and technical factors.

- *Time constraints*: When only limited time is available (e.g. for knowledge development), modelling approaches requiring lengthy data collection (e.g. FSM) are unsuitable. Moreover, time constraints hinder in-depth longer-term impact assessment on the participatory action post-process (Mangnus et al., 2019). Potential advantages would include time-tracking and temporal monitoring of the modelling approach by feeding back information from the participants, especially by means of digital games. This makes interactive formats (e.g. visualisation games) a good choice to enhance participation and stakeholders' commitment.
- *Experience and knowledge*: Model requirements range widely, from limited expert knowledge (Backcasting) to extensive expert knowledge (FSM, SEM or FCM). Those requiring expert knowledge may not be easily transferable or appropriate as a functional tool enabling participatory governance (McIntosh et al., 2008). Often underestimated, moreover, are the knowledge and communication differences between citizens and decision-makers on the one hand and modellers (academia, think tanks, consultants) on the other. To improve the available skill set, we recommend building a team with different knowledge backgrounds.
- *Technical aspects:* Generally, qualitative modelling approaches require less technical equipment (e.g. (online) whiteboards, recording devices for interviews), while quantitative models have more complex technical requirements ranging from harmonising data sets to modelling software platforms. This is linked to the knowledge dimension, since expert knowledge and extensive technical skills are obviously required to manage the data analysis via software platforms (e.g. GIS software).

5.2. *Key dimensions within participatory food governance*

Fig. 1 graphically depicts each modelling approach's most prominent functions, also summarised in Table 2. Each modelling approach is represented in a circle divided into the four dimensions outlined in Section 3, with their functions in coloured segments. Brighter colours mark the outstanding strengths of each modelling approach; approaches can be combined throughout the participatory governance process to separately address each phase according to expected outcomes. Nevertheless, since not all are compatible, we provide a general guide to selecting and combining these approaches.

Table 2
Outstanding functions of the modelling approaches on the key dimensions to consider when modelling for participatory governance of city-region food systems.

	Stakeholder involvement [information, cooperation, co-construction]	Process Phase [I, II, III, IV, V]	Capacity for joint action [knowledge, skills]	Multi-sectoral and multi-scale approach [horizontal, vertical]
Qualitative approaches				
Visioning	co-construction	II, III	skills	horizontal
Backcasting	co-construction	II, IV	knowledge	horizontal
Quantitative approaches				
Foodshed modelling	information	I	knowledge	horizontal
Structural models	information	II	knowledge	vertical
Mixed-methods approaches				
System Dynamics	cooperation	I, III	knowledge	vertical
Companion Modelling	co-construction	IV, V	skills	horizontal
Fuzzy Cognitive Mapping	cooperation	I, V	knowledge	horizontal

On stakeholders' involvement (information, cooperation, co-construction), qualitative approaches stand out by co-constructing the modelling process with active citizens, while quantitative approaches tend solely to inform stakeholders. Mixed-methods approaches tend mainly to foster occasional cooperation with key informants, particularly to describe and set the dynamics of the system. Different process phases (numbered I, II, III, IV, V in Table 1, from problem definition to simulated implementation of experimental actions) may require different approaches. Phase I (problem definition) is best addressed by

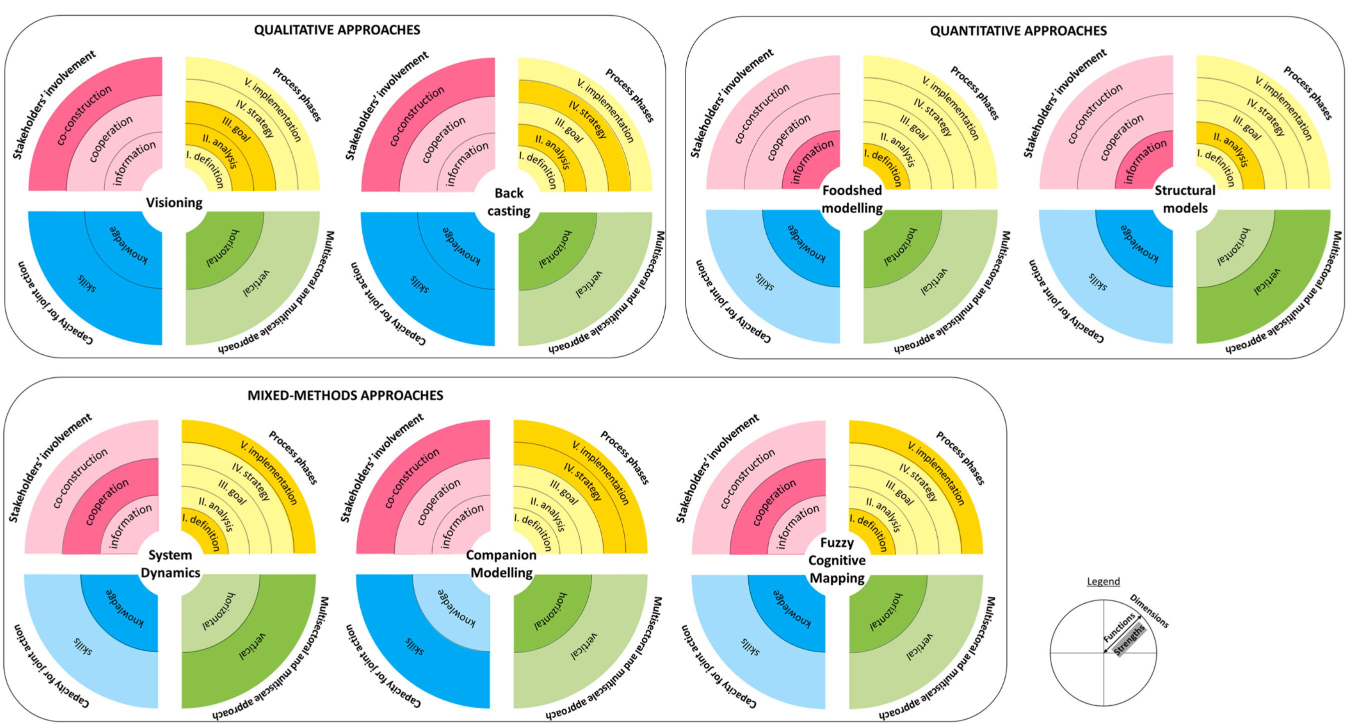

Fig. 1. Performance of the seven modelling approaches according to a conceptual framework identifying four key dimensions involved in participatory food governance at city-regions: stakeholders' involvement, process phases, capacity for joint action and relational approach.

FM, SD and FCM, the latter two also best addressing phase V (simulated implementation). However, phase II (stakeholder analysis) is meaningfully depicted by SM, Visioning and Backcasting. Visioning also seems the most appropriate approach to phase III (goal formulation), while Backcasting seems best for phase IV (strategy development). Finally, CM is the best choice for simultaneously addressing phases IV and V, actively involving stakeholders.

On capacity for joint action, most of the analysed modelling approaches contribute to the generation of knowledge rather than to the development of practical skills, except for Visioning and CM, which specifically stimulate creative thinking and collective decision-making. Six out of the seven modelling approaches prove their value for co-producing knowledge and becoming more reflective (BC, FM, SEM, SD, FCM). Their stakeholder participation makes them easily adaptable to include diverse knowledge sets and social values and to support an audience-specific learning-by-doing approach, useful when examining the trade-offs and synergies involved in different outcomes under alternative food system management scenarios (Voinov and Bousquet, 2010; Voinov et al., 2016). Finally, on the multisectoral and multiscale approach and governance axes (horizontal, vertical), Visioning, Backcasting, FM, CM and FCM mainly reveal the connections between the different sectors (horizontal axis), whereas SM and SD excel at showing the loops between scales (vertical axis).

6. Combining complementary modelling approaches to support participatory food governance in the Berlin city-region

In this section, we illustrate how complementary modelling approaches can help to get diverse stakeholders involved in the participatory food governance process. Depending on context, objectives and on available resources, we argue that one or a combination of the above modelling approaches is particularly appropriate. We present a concrete example from Berlin, where qualitative and quantitative modelling approaches were used in bottom-up initiatives to deliberate on and facilitate active regionalisation of a city-region food system (i.e. increasing the proportion of regionally-grown food consumed in the city).

Historically, very little regional food has been supplied to Berlin from surrounding areas, despite the region's considerable food production. This is largely exported, due to a lack of functioning and/or economically viable distribution models linking Berlin with its surrounding region. Berlin was the first German city to initiate a Food Policy Council (BFPC) in 2015 and put food issues back on the urban policy agenda (the previous urban food mandate and administration vanished after reunification in 1989). Within the last 7 years, the BFPC has created public spaces for participation and democratisation of food governance at the city-region level, leading in 2022 to a commitment to a regional food strategy linking Berlin and the surrounding region of Brandenburg (i.e. the Berlin city-region). Modelling approaches were used to support the regional supply change (see Fig. 2).

In the early stages of the food governance process in 2015, the BFPC focused on identifying food system issues and building up knowledge

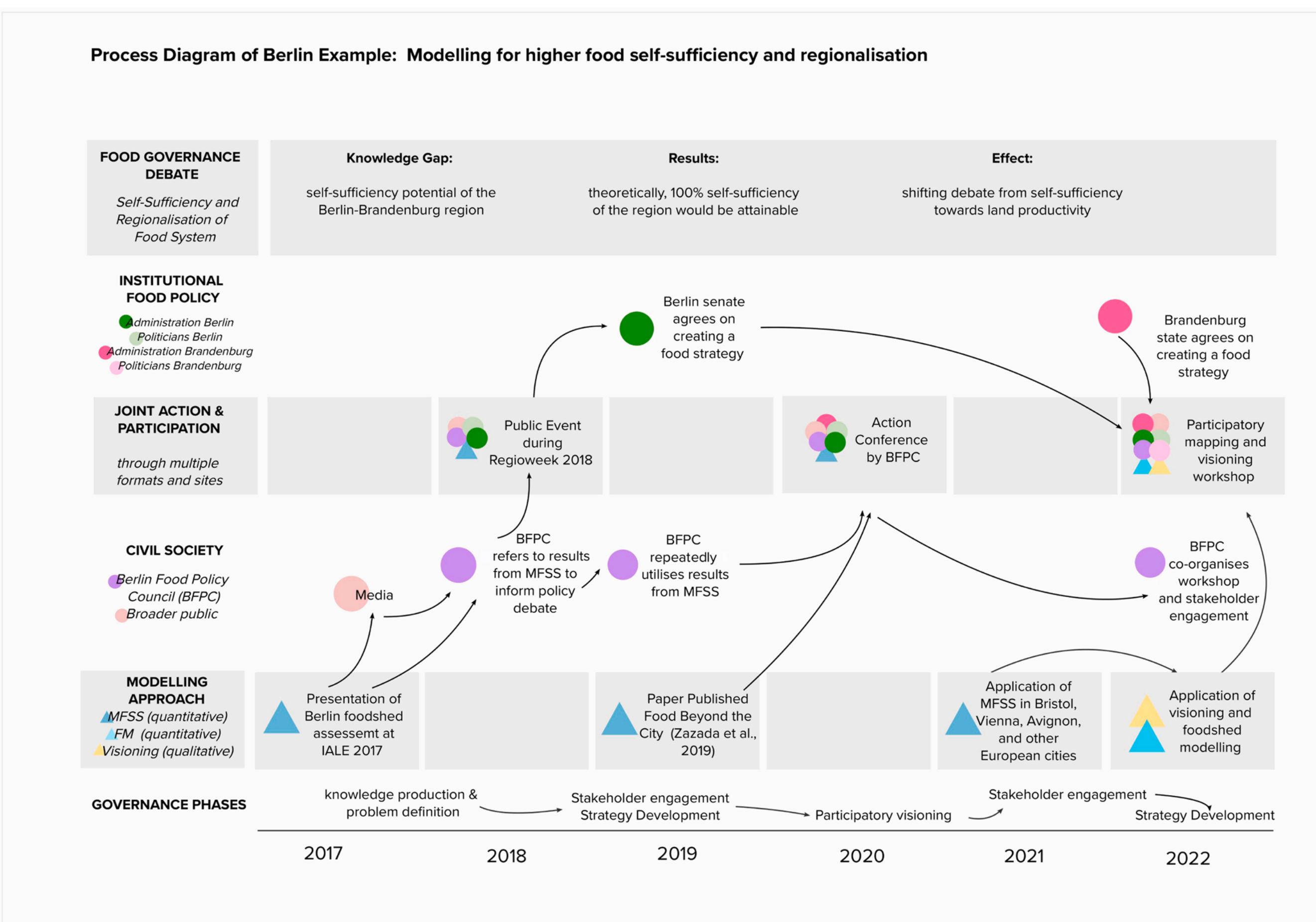

Fig. 2. Process diagram of the Berlin city-region example illustrating the role of modelling approaches and key stakeholders in enhancing participatory food governance.
Source: own illustration inspired by https://www.koopwohl.de/umwelt-2/.

related to the city-region food system. A key issue was the city's degree of self-sufficiency, yet public knowledge, e.g. on the amount of locally sourced food, was very scarce (House of Representatives, Berlin, 2016). Momentum was built up in 2017 with the presentation of the results of a foodshed modelling approach applied to the Berlin city-region, namely the Metropolitan Foodshed and Self-Sufficiency Scenarios (MFSS) (Zasada et al., 2019). The model was spatial-specific and focused on quantitatively assessing the metropolitan capacity to satisfy the population's specific consumption pattern. It addressed questions raised by the BFPC, such as *How self-sufficient could the Berlin city-region become? Could the city-region feed itself? What production systems and dietary patterns foster the greatest potential food self-sufficiency?* Given the available farming area and the population of the Berlin city-region, 100% self-sufficiency was found to be attainable. For the first time, a quantitative balance was graphically shown in a spatial context.

The scientific evidence supported a deliberative process regarding food supply, no longer considered as regulated by the market but seen as a political issue. While the modelling approach was not participatory in itself, the results sparked high interest among media and government at different scales: the BFPC (local and regional scale), the federal parliament (national scale) and the European parliament. For instance, the BFPC repeatedly used the MFSS results to communicate about political claims and actions for improving the regionalised food systems (e.g. a public event at Regioweek 2018, panel discussions, evaluation reports on public procurement). To incorporate the private sector perspective, additional stakeholders such as farmers and caterers were invited to discuss the potential and implications of collective ordering schemes or pricing policies when regionalising food supply chains. A milestone was reached in 2019, when the city senate agreed to develop a food strategy for Berlin, demonstrating a political will for active involvement. Furthermore, the high interest led to MFSS being applied to other cities, such as Vienna and Bristol (Vicente-Vicente et al., 2021b), or Avignon (Mouléry et al., 2022; Vicente-Vicente et al., 2021a), where these results informed discussion on the status quo, current food policies and ways to increase food self-sufficiency.

In 2020, the BFPC organised an action conference to co-construct visions, political demands and concrete actions for a food system transformation. The results from the foodshed model were used to reframe the food governance debate, shifting the focus from level of food self-sufficiency towards farmland productivity. New questions jointly addressed different food system sectors (production, land planning, distribution, consumption): *How can higher levels of regional food supply be achieved? Where should different (food) crops be allocated? How should land be chosen and used for regional food production? How can food supply and demand patterns be modified and what are sustainable diets?*

This focus on different stakeholders' perspectives and the emerging issues meant that a solely quantitative model was no longer sufficient. Instead, a combination of qualitative and spatial-sensitive approaches was needed. Participatory visioning was chosen, with complementary quantitative foodshed modelling (FM) as a follow-up. Two participatory actions were developed by the BFPC in collaboration with a group of researchers. First, an online survey was co-constructed and conducted in 2022 to capture the stakeholders' vision of the future production of Brandenburg-region food for consumption in Berlin. Stakeholders were identified and selected through a collaborative process based on network knowledge, face-to-face discussion with lay experts and recommendations by network partners. Participants represented multiple food system sectors (production, catering, retail, processing, consumption), at policy and government scales (Berlin and Brandenburg), civil society organisations and research. The survey results provided the researchers a basis for developing various scenarios on regional production and consumption patterns (e.g. plant-based, vegetarian, or meat diets), which were assessed by foodshed modelling. Second, a participatory visioning mapping workshop was organised with the same stakeholders to provide a space for interactive co-design of land-use scenarios. In particular, the workshop helped to explore the impacts of different diets on land-use options by allocating specific crops to different soil profiles (Walthall et al., 2022a). The crop sites were allocated using MapTable hardware (Wascher et al., 2010: 27) and adjusted according to the previously developed scenarios. By giving a voice to private and public stakeholders, this enabled a more nuanced picture of the dynamics and power-relations shaping the regional food system to emerge. Yet it also added ambiguity to the process by revealing that there is not just one way to approach governance of a city-region food system, but many, and raising questions like how to adapt land use and according to what criteria. The workshop helped to explore and discuss various land-use strategies and to frame common narratives and visions for co-creating more resilient and regionalised food systems (Walthall et al., 2022a). This led to identifying a potential set of actions in different policy fields, which fed into the process of developing a regional food strategy starting in late 2022.

The combined quantitative and qualitative modelling approaches helped the BFPC define the problem, experiment with different options and formulate goals. Moreover, the approaches helped to involve different stakeholders, develop relationships and networks and ensure the sharing of knowledge. In short, social learning among diverse stakeholders was facilitated and strategies and actions involving different sectors at local and regional scales became easier to coordinate.

Further steps could be envisaged using additional modelling approaches. For instance, a Fuzzy Cognitive Mapping (FCM) approach would make the cause-effect pathways clear and highlight particular impacts and motivations, addressing the questions "Who/why/to what degree/based on what rationales?". A Structural Model could be used to analyse stakeholders' motivations (Who will go for the reserved land?) and to reveal the drivers of stakeholders' behaviours (Under what conditions?). Furthermore, a Companion Modelling approach (CM) could be employed to support collective decision-making on a strategy targeting long-term systemic effects (What interventions are needed? How can preferred stakeholders, like young farmers, be supported? What is the best way to manage land competition?). The CM approach would also be useful to simulate the implementation of experimental actions (e.g. setting up a budget for incentives). In addition, an FCM approach could be reapplied in cooperation with the original stakeholders to consider how to rearrange framework conditions.

Finally, whatever models are chosen, we recommend the presence of both governmental and non-governmental stakeholders so as to create realistic avenues for joint action on policy-making and implementation. However, the balance of power between stakeholders must be monitored to avoid political exclusion and inequality, if the aim is truly to provide opportunities for participatory governance (Coulsona and Sonnino, 2019).

7. Conclusion. The role of modelling approaches in enhancing participatory food governance in city-regions

Cities are becoming strategic transition nodes that can exploit the policy vacuum created by the absence of comprehensive, coherent and integrated national and supra-national food policies (Sonnino et al., 2019). Food policy regionalisation, perceived as contrasting with "one-size-fits-all" approaches (OECD et al., 2016), is being promoted by a range of institutional initiatives. Driven by civil society, state and market institutions (with differing histories, interests and power) approach food governance with varying combinations of territorial priorities and with uneven awareness of food security concerns such as community and food access (Hinrichs, 2013). Filling these gaps with participatory and democratic modes of governance, however, is not a linear nor a neutral process (Coulson and Sonnino, 2019; Sonnino et al., 2019). On the contrary, as the Berlin case study shows, it is complex, ambiguous and experimental (Walthall et al., 2022a). Any modelling approach to food policy regionalisation must account for conflicting interests, in particular the frequent opposition between the private sector and the public interest. For instance, land owners' interest often lies in seeking urban rents through the developable land market, in opposition to attempts to protect peri-urban agricultural areas.

The main objective of this study was to investigate how modelling can support such participatory food governance initiatives. We extracted from the literature the relevant pre-conditions for participatory governance and matched them with the key process dimensions and functions addressed by specific modelling approaches. This yielded comprehensive guidelines for targeted choice of modelling approach in city-regions, depending on the particular participatory food governance phase or function: the paper's main novel contribution. To support the decision-making process, we developed a graphic summary of key dimensions and functions to be considered within participatory governance and indicating what each model could contribute (Fig. 1). All the modelling approaches presented in this paper provide, in their own ways, useful input to build more deliberative spaces for participatory food governance. Applied on an ad-hoc basis, they can facilitate social learning, enhance relationships among diverse stakeholders and foster convergence of public and private sectors' interests and actions. The contribution that modelling experts can make is to critically inform all stakeholders regarding the advantages and disadvantages of the different modelling approaches.

Further aims of the study concerned the appropriateness and conditions of use of the comprehensive modelling framework to select and combine suitable approaches. We hoped to foster system-perspective selection, considering the choice of modelling approach for a particular city-region as a tailored decision-making process based not only on modelling experts' knowledge but on broad collaboration and deliberation. For instance, in the case of Berlin, the up-take of foodshed modelling, visioning and back casting was facilitated by the close collaboration between the civic-driven BFPC and research. In other cases, different resources, skills, needs and interests might lead to selecting a different model and approach. For example, where questions around improved food access prevail, governmental action and planning departments could apply system dynamics modelling. Either way, as testing grounds for participatory governance, the actions surrounding modelling provide insights into the necessary conditions for long-term food governance change, such as a transition towards systemic, reflexive and collective approaches.

This paper argues that modelling approaches open space for active engagement, deliberation and effective participation in decision-making processes within food governance. It also stresses that the design of the modelling methodological framework must reflect the specific city-region's conditions and focus on the actions taken or forecasted by the stakeholders to collaboratively build the social capital needed for meaningful and sustainable participation. Participatory food governance in city-regions does not simply mean downscaling policies from higher levels. Different tools, skills and operational practices are required to reveal connections within and between the multiple sectors and scales of the food system. We agree with Voinov et al. (2016) that, in food system governance, no single form of participatory modelling can be recommended for universal application.

Achieving the Great Food Transformation as defined by the EAT-Lancet Commission (Willett et al., 2019) requires not only innovation or seed initiatives (Bennett et al., 2016) but also governance conditions that allow participatory and collaborative approaches to flourish, such as balanced power relations, trust and commitment. While it would be too much to claim that modelling approaches can guarantee participatory food governance and reconfigure societies, they can certainly support the development of alternative forms of political thinking and public action. Our example from the Berlin city-region illustrates how modelling approaches can be used to gain a more nuanced picture of dynamics and power relations, reframe food governance discourse, and suggest leverage points to facilitate regionalisation of city-region food systems. In Berlin and elsewhere, further research on the added value from each approach will reveal the potential of cross-administrative collaboration. On the policy side, a major challenge is to shape a common policy arena that can foster a form of inclusive governance for a central city and its peri-urban surroundings (i.e. the city-region) on the basis of their functional interrelationships (Piorr et al., 2018).

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CRediT authorship contribution statement

Esther Sanz Sanz: Conceptualisation, Methodology, Investigation, Formal Analysis, Visualisation, Writing – original draft, Writing – review & editing; **Beatrice Walthall:** Conceptualisation, Methodology, Investigation, Formal Analysis, Visualisation, Writing – original draft, Writing – review & editing; **Claude Napoléone**: Conceptualisation, Methodology, Investigation, Writing – review & editing; **José-Luis Vicente-Vicente**: Methodology, Investigation, Writing – reviewing & editing, Visualisation; **Leonith Hinojosa**: Investigation, Writing – review & editing; **Annette Piorr**: Conceptualisation, Methodology, Investigation, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Appendix A

source	key words	number of papers
Web of Science	"food", "participatory", "governance", "modelling"	80
	"food", "modelling", "city-regions"	42
	"food", "modelling", "visioning", "participatory"	26
	"food", "modelling", "backcasting"	11
	"foodshed", "modelling"	27
	"food-system", "structural equation model"	47
	"food-system", "system-dynamics", "modelling"	55
	"food", "participatory", "Agent-Based Modelling"	8
	"food", "fuzzy", "cognitive", "maps"	79

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