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A cybernetic participatory approach for policy system of systems mapping: Case study of inclusive economies

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ABSTRACT

Traditional participatory systems modelling demands synchronous time from many experts and face-to-face interaction. This is not always feasible (e.g., during a pandemic) and can restrict which participants can be included. There are additional limitations in the effectiveness of physical paper-based modelling when handling large complex systems with numerous variables and links between them. The key challenge facing practitioners is then how can we retain the benefits of traditional participatory modelling whilst exploiting the advantages of new technologies? This paper contributes to development of an original systematic methodology inspired by Cybernetic principles. The proposed method, referred to as 5X – standing for Expose, Explore, Exploit, Explain, and Expand – offers a fully virtual co-produced environment for iterative cycles of stakeholder engagement and feedback before, during and after workshops, leading to developing more confidence in systems mapping, and promoting knowledge across policy areas. A primary application of the proposed method in a real policy setting illustrates its capability to generate a shared policy understanding of a complex inclusive economy system, where there is conflicting or dispersed knowledge about system structure, refine this understanding through online feedback channels and dynamic visualisations, and transfer this understanding to wider policy and academic partners.

1. Introduction

Participatory systems modelling (PSM) (Voinov & Bousquet, 2010) has become an increasingly popular approach for building a common understanding of complex (socioeconomic) problems. It offers a co-produced and co-learning environment in which multiple parties (with different perceptions, priorities, and levels of expertise) work jointly to gain an improved understanding of system boundaries, what drives the system in each policy area, how they are connected to the decisions of other areas, and how the system behaves under alternative conditions (Reed, 2008; Voinov et al., 2016). Such collective knowledge can then be used for coordinating actions across the organisation (Klimoski & Mohammed, 1994; Király et al., 2016) and predicting what might go wrong during a policy

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implementation process (Van Der Meer et al., 2005). At a more individual level, joint thinking on a given topic can lead to an increase in confidence and quality of decisions (Voinov & Bousquet, 2010; Kingston, 2007) for example through identifying points of synergies and conflicts in views (Gray et al., 2018), and greater feeling of ownership (Moser & Ekstrom, 2011).

Inclusive Economies (IncEc) are an example of a complex policy system in which PSM could prove useful. *IncEc* are economies that pursue fairer outcomes within their design, through the inclusion of more people (RSA, 2017), and seek to reduce inequalities whilst also achieving economic growth (Hill O'Connor et al., 2023). From a systems perspective, *IncEc* is a contested term (Lee, 2018) which involves a dynamic and heterogeneous group of people and technologies interacting across different policy areas – such as work and employment, economy, education, health and wellbeing, and transport. Such systems are typically managerially and operationally independent with a separate set of priorities and strategies and varying degree of exogenous impact (Andersson & Törnberg, 2018), so may possess unplanned emergent behaviour.

Policymakers typically make decisions based on their perception of a given situation but due to sectoral silos they only have detailed insight into their own area of the whole system. Whilst there is often not a direct policy link between the decisions that are made within each of these areas, in practice the decisions taken in one area (e.g., employment-related) have consequences that relate to other areas (e.g., economy) (Hassannezhad et al., 2021). Achieving such a whole-system understanding would therefore become important in making well-balanced policy decisions and achieving alliances across multiple policy areas.

Traditional methods of PSM (Voinov & Bousquet, 2010; Voinov et al., 2018) bring together groups of people in a fixed place and time, using analogue technologies such as flip charts, sticky notes, and marker pens. Despite undeniable capability in encouraging interactivity and exchanging information, constraints on both synchronous and face-to-face availability may make traditional PSM less inclusive and limit participation to those who are geographically close (Wilkerson et al., 2020). In recent years, advancements in information and communication technologies has encouraged academics and practitioners to investigate alternative methods of participation in systems modelling through the exploitation of digital technologies (Voinov et al., 2016). Digital technologies can have positive implications for *distributed* systems where people are located remotely from one another, but also for modelling *large complex* systems with many stakeholders, many factors, and numerous links amongst them. Digitalization is also an effective solution when physical meetings is not desirable or feasible (e.g., global pandemic; environmental sustainability) (Kingston, 2007).

However, successful implementation of a fully digitalised PSM process is quite a challenge, which requires a different (or adapted) set of requirements (compared to the traditional processes), and there is still very little knowledge on what makes implementation of such a process successful. This study was designed to address policy partners' desire to develop a common 'whole-system' understanding of the complex system of *IncEc* across different groups of stakeholders and policy sectors in Greater Manchester Combined Authority (GMCA) , a body created to formalise a long-standing commitment to policy coordination across several local authorities. The study was influenced by disruptions of the planned work caused by the Covid-19 pandemic and took place under the highly restrictive UK lockdown conditions in March 2020 which demanded the deployment of a fully digitalised systems mapping and analysis process.

This paper describes an innovative way of implementing PSM process in a fully virtual setting –expanding the scope beyond solely running online workshops with stakeholders. With strong focus on the *iterative* construction of knowledge about the system based on 'ongoing learning', we place the emphasis on the mechanism by which 'observers' (i.e., policymakers and topic experts) construct models of the systems with which they interact (in line with the notion of 'Cybernetic' (Steinbruner, 2003)) and present the implementation of a systematic methodology referred to 5X. The proposed method offers a dynamic and iterative co-learning environment for **Ex**posing the problem complexity, **Ex**ploring the system structure, **Ex**ploiting stakeholders' understanding of the system, **Ex**plaining the findings, and **Ex**panding its application. It is built upon the previous work in PSM (in particular, fuzzy cognitive mapping (FCM) (Özesmi & Özesmi, 2004)) whilst inspired by Cybernetic foundations (Steinbruner, 2003; von Foerster, 2003), and incorporates analytical concepts from Engineering Systems Design (Jarratt et al., 2011) to address the requirements of fully digitalised PSM process.

The proposed method offers an iterative co-learning environment to enable real-time population of the map from (in-workshop) group discussions or (post-workshop) individual interrogation (see Section 4.4 for details) that is tied up with an underlying computational learning algorithm to understand the indirect propagation effects of changes across different policy areas. The algorithm would enhance the current practice of typical network analysis in analysing system maps (Barbrook-Johnson & Penn, 2021); existing techniques typically focus on centrality metrics (such as the number of inward or outward links) and does not provide sufficient transparency on myriad of ways that two system components in different policy areas (with no direct link) can influence each other. In *IncEc*, this can nevertheless be seen as a substantial property of the system.

In addition, 5X offers new heuristics for enhancing the efficiency of online mapping workshops (through online data (or feedback) collection and a prioritisation scheme) before the workshop, and for amalgamating multiple cognitive maps (obtained from parallel workshopping groups) after the workshop. The aim is to (1) strengthen stakeholders' recognition of the system by combining (in-workshop) joint thinking with (post-workshop) individual interrogation, appraisal, and 'circular feedback' (Fischer & Herr, 2019) to make a better representation of reality; and (2) develop the capacity for 'live continuous support' beyond the scope of the participatory workshops (across various policy areas and academic disciplines) – as well as reconciling the map to the other related policy areas.

The rest of paper is organized as follows. Section 2 explains the study context and motivations, followed by discussing the theoretical foundation of participatory systems mapping in Section 3. Section 4 presents the proposed 5X methodology, as applied within GMCA. Section 5 discusses insights and reflections on its implementation.

2. Study context and motivation

The SIPHER consortium (Meier et al., 2019) is working closely with a number of policy partners who work at local, regional and national scales of the UK governance. As part of the SIPHER consortium research, *IncEc* was identified by all policy partners as a key area of interest and a desire to use participatory modelling to support the development of *IncEc* policies.

Interpretation of the term *IncEc* varies (see Hill O'Connor et al., 2023 for full discussion) however in the context of this study – GMCA (GMCA, 2019), it refers to the idea that everyone should have the opportunity to contribute to, and benefit from the economy. In practice, this includes good employment (i.e., secure and paid at a living wage), the means to access employment (i.e., transport links), and the opportunity to benefit through improved services and increased quality of life (GMCA, 2019). A key challenge here stems from the fact that *IncEc* goals can only be achieved through well-aligned strategies across different policy areas, where each acts as a complex system with a separate set of priorities and strategies and varying degree of interdependencies (Lupton et al., 2019). Defining the exact boundaries of such a system with multiple (sometimes conflicting) interests and identifying improvement opportunities can hence be quite problematic.

Informed by the analysis of interviews with eight GMCA officers (Hill O'Connor et al., 2023) to explore their work on *IncEc*, it was evident that there was a need for a way to understand the interplay of multiple policies across the system. Interviewees did not use a consistent definition of *IncEc* and, in some cases, used different language to describe the work they were doing. Nevertheless, there was agreement about the desired outcomes of policy (namely, addressing inequalities) and the need to identify practical ways to deliver these. The different perceptions and dispersed knowledge of the *IncEc* policy agenda necessitated the need for a PSM approach in order to allow space for discussion and the development of a shared understanding of the system more widely – in terms of what types of strategies drives the system (referred to as 'factor' in this paper), their expected objectives (referred to as 'outcome' in this paper), and their interactions.

Developing an understanding of the system in this way will inform academic partners on how policymakers collectively perceive the *IncEc* system and the factors within it, thus making sure that the scope and boundaries of the resultant quantitative (simulation) models are fitted to the problem. Within the context of GMCA, it can enable the development of a common understanding of the system and policy discussions to shape future decision-making from a more holistic view. Therefore, it is important that the outcome of this process provide 'live continuous support' (over the cloud) to support collaborative activities, as new evidence emerge and more people (from public, private, and third sector organisations) engage in the mapping process.

3. Background

3.1. Participatory systems modelling

PSM is the generic term for engaging stakeholders (anyone inside or outside the policy system who has an interest (a 'stake') in a particular policy issue) in the modelling process. The process has long been used for exploration and communication of complex phenomena, especially in cases where there are multiple (conflicting) interests and may require contradictory interventions, with numerous applications in socio-ecological contexts such as environment (Reed, 2008), water (Mehryar et al., 2017), energy (Jetter & Schweinfort, 2011), and smart cities (Firmansyah et al., 2019).

Successful design and delivery of PSM requires finding the right compromise between several interrelated dimensions. Gray et al. (2018) classify them as purpose (the why), process (the how), partnership (the who), and product (the what). Consequently, despite similarity in the logic, each PSM exercise can be seen as a unique process with important decisions to be made at different stages; for instance about the selection of methods to be used, the choice of inputs and outputs of the process, the inclusion and exclusion criteria for participants (i.e., balancing technical granularity and inclusive participation (Nabavi et al., 2017)), and how participants should interact with each other and with the map.

When the problem situation is messy and unclear, conceptual modelling techniques (such as Fuzzy Cognitive Mapping (FCM) (Penn et al., 2013), Causal-Loop Diagrams (Goodier et al., 2010), and Rich Pictures (Bell et al., 2016)) may help to specify the boundaries and bring shared understanding to how the system works. If the purpose is solely to develop a common ground upon stakeholders' knowledge, then this may be sufficient. Alternatively, subject to the availability of quantitative data, representation of causal relationships in such methods can be the key input for constructing mathematical and simulation models, most commonly Agent-based

Table 1
Input attributes of systems mapping workshop and their color-coding in the mapping.

Component-related attributes		Connection-related attributes	
Class	Priority (purple node) Strategy (green node) Outcome (blue node)	Strength	Strong (thick grey arrow) Moderate (medium grey arrow) Weak (thin grey arrow)
Importance	Essential (red node) Very important (yellow node) Important (green node)	Confidence (no change in colour)	Sure Not-sure Not-defined
Source (no change in colour)	Policy documents Individual policy interviews Workshop discussions	Directionality	Positive (A+ leads to B+; green arrow) Negative (A+ leads to B-; red arrow) Bi-directional (complicated; blue arrow)

modelling (Mehryar et al., 2019), System Dynamics (Biglari et al., 2022), Discrete-event simulation (Freebairn et al., 2019) and Bayesian belief networks (Xue et al., 2017) models.

In this study, FCM is the preferred choice for developing a whole-system map of *IncEc* based on group of experts' knowledge. That is chiefly because it is relatively quick and easy to populate and parameterize from varied sources of qualitative knowledge (Singer et al., 2017) with flexibility in representation (as more components are added to the system) (van Vliet et al., 2010), modest time investment, and a degree of transparency to non-technical experts (Voinov et al., 2018, Table 1). They might be most suited for data-poor and multi-interest situations (Jetter & Kok, 2014) where there is not sufficient explicit knowledge and empirical data about the system to develop quantitative simulation models (Voinov et al., 2018, Table 2). In addition, comparing to other conceptual mapping techniques, FCM allows more resolution on the nature of links (Papageorgiou & Salmeron, 2013) which can be used to quantify and analyse structural dynamics of the system (e.g., using network metrics) across individual or groups of participants (Özesmi & Özesmi, 2004). The next sub-section outlines the FCM, as the main method for PSM in this study, and discuss some of the available web-based FCM tools.

3.2. Fuzzy cognitive mapping

FCM is a class of Signed Fuzzy Weighted graphs (Papageorgiou & Salmeron, 2013), and typically include feedback loops (reflecting circular patterns of causation) consisting of nodes (indicating descriptive components) and directed edges (indicating cause-effect relations) between them. It offers a systematic and intuitive approach to combine the experiences and expertise of individuals (with various qualitative knowledge) with the data obtained from policy document analyses (Mehryar et al., 2017). While FCM is a static model that cannot reflect temporal and spatial dynamics (Papageorgiou, 2012), its semi-quantitative representation of cause-effect relationships – typically delineated in form of low, medium, and high – allows the model to simulate 'what-if' scenarios to understand the impact of different policy options. In this sense, FCM is a dynamic modelling tool whose further iterations (e.g., through simulation experiments) can eventually provide a better resolution of the system structure (van Vliet et al., 2010) – thus making it a suitable option to be combined with computational change propagation algorithm (described in Section 4.3) in this study.

There are several software tools (both open-source and commercial) available for modelling and analysis of FCMs (Felix et al., 2019). Examples include Mental Modeler (Singer et al., 2017), OCAM (Online Cognitive Automatic Mapper) (Kireev et al., 2018), FCM Expert (Nápoles et al., 2018), Cofluences (Giabbanelli et al., 2019), FCMWizard (Papageorgiou et al., 2020), and the commercial Kumu. Amongst them, Mental Modeler and Kumu both have been widely used in research and allow web-based collaborative modelling and (limited) network analysis. However, compared to the former, Kumu shows better functionality for modelling large complex maps and flexibility to organise data and edit maps. The ability to display causal pathways, make comments and for individuals to use and maintain the map post-workshop meant that Kumu was the preferred option in this present study.

3.3. Digitalizing participatory modelling processes

Utilising the power of digital technologies in PSM is not a new research agenda and there is an extensive body of literature focusing, for example, on the use of GIS technology within public participation (referred to as *Active Citizenship*) (Burnett, 2020) or computer games primarily for a functional purpose rather than pure entertainment (referred to as *Serious Games*) (Taillandier et al., 2019). However, as cyber-enabled participatory approaches are moving beyond one-way data collection from members of the public and becoming more routine in policy discussions (Voinov et al., 2016), there are important emerging questions about the conceptual, procedural, and technological design of workshops in order to ensure effective stakeholder participation (Gray et al., 2018), effective facilitation of participatory workshops, and the exchange of information over the cloud, with the follow-up access to the resultant model and underlying data (Giabbanelli & Baniukiewicz, 2018).

Facilitating a web-based discussion is very different from the physical workshops and requires an adapted set of scripts and supporting tools, to ensure that all participants are getting an equal opportunity to express their opinions, encourage mutual learning, and

Table 2
Summary of network metrics for four elicited FCMs (out of four groups) and their unified map.

Criteria	Group A	Group B	Group C	Group D	Unified Map
Number of nodes	59	59	59	59	89
Number of links	187	108	68	128	337
Number of links with resolution *	37	11	34	64	194
Fuzziness of the map * *	0.20	0.10	0.50	0.50	0.58
Density of the map	0.11	0.06	0.04	0.07	0.41
Top in-degree component	O3	O18	O3	O3	O3
Top out-degree component	S9	S11	S23	S9	S9
Number of transmitters	8	18	32	33	2
Number of receivers	22	26	24	22	2

*Links with resolution refers to the links with quality information, the ones for which participants identified the 'connection-related attributes': Strength, Directionality, and Confidence. There are many links in the map that, due to time constraints, participants of the workshop could not get back to them and discussing the 'connection-related attributes' further.

* * Fuzziness of the map refers to the fraction of the number of links with resolution over the total number of links that identified in group.

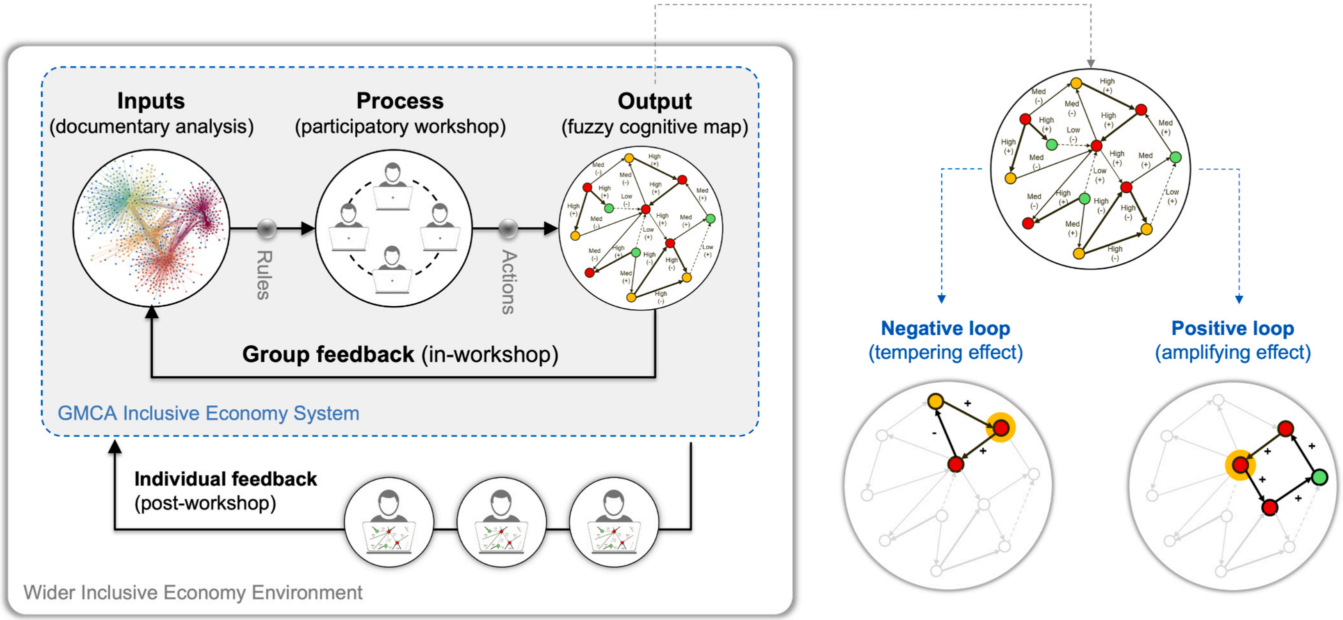

Fig. 1. Cybernetic view of participatory systems modelling.

that all information is properly captured within the systems map with minimum bias (Voinov et al., 2016). Further, the nature of the role depends on a number of factors for instance whether the model is developed in real-time during the workshop or after the workshop (Rieder et al., 2021), by participants (collaborating on a virtual whiteboard) or by a modelling team (or a mixture), and whether the same person acts in the role of facilitator and modeller (Wilkerson et al., 2020). Such requirements determine the selection of the tools to be used in the process. For example, some collaborative platforms (such as Miro and Google Jamboard) provide advanced functionality for improving engagement and exchanging ideas but may underperform in organising large amount of data (necessary for complex systems such as *IncEc)* into interactive causal maps (with detailed information on the links) – especially within the limited timeframe of online workshops.

In addition, whilst there has been a little attention in previous studies to the initial consultation with prospective participants on workshop content design (MacDonald, 2020), in complex system of *IncEc*, we found it a useful mechanism (which saved time at the start of the session) to use online data collection tools in goal-setting, and could begin the workshop with areas that participants proactively recognized as more important. Notwithstanding that there has been some limitations reported on the post-workshop analytical capabilities of the online tools, model validation, and future use of the constructed map (Voinov et al., 2018; Wilkerson et al., 2020).

3.4. Cybernetic principles for participatory systems modelling

From Cybernetic standpoint, *IncEc* in GMCA is a learning policy system (Fig. 1), with characteristics of growth and change, whose structure and behaviour are defined by the ways in which system components are interconnected and exchange information (Steinbruner, 2003; McLoughlin & Webster, 1970). In organisational (policy) settings, this would be problematic since the role and influence of people who are making decisions will influence their recognition of system structure and knowledge of which would be tacit and highly subjective in a participatory process.

The notion of Cybernetic, in the context of this study, refers to the mechanism by which ‘observers’ (i.e., policymakers and topic experts) construct models of the systems with which they interact, with focus on the iterative construction of knowledge about the system based on learning. When applying to the PSM process, the concept can have several implications in principle, by:

Focusing on the whole-system rather than parts, by highlighting the role of (cross-sectoral) interfaces between system components and causal *pathways* in the ‘perceived’ system as a means to understand what should be changed in the system to influence outcomes in desirable ways (Sedlacko et al., 2014; Meadows, 2008). This is crucial in distributed systems like *IncEc* where local knowledge plays a vital role in capturing a whole-system understanding.

Focusing on implicit (or tacit) knowledge about the system. The new science of Cybernetic (also called Second-Order Cybernetic (Cadwallader, 1959)) places the emphasis on how ‘observers’ (i.e., policymakers and experts in our case) construct models of the systems with which they interact. This could be a crucial challenge in PSM as the information included in the system being ‘modelled’ (output in Fig. 1) depends on the nature of information in the system being ‘perceived’ by workshop participants (and stakeholders) between which there may or may not be alignment. Such a progressive refinement in the proposed method provides the potential for developing a living map beyond the workshop, leading to improved individual perceptions of the system.

Focusing on circular causality between system components. The essence of control mechanism in such interconnected systems is identifying an acceptable compromise between *positive* and *negative* feedback processes (Edwards, 1992; Dubberly & Pangaro, 2015;

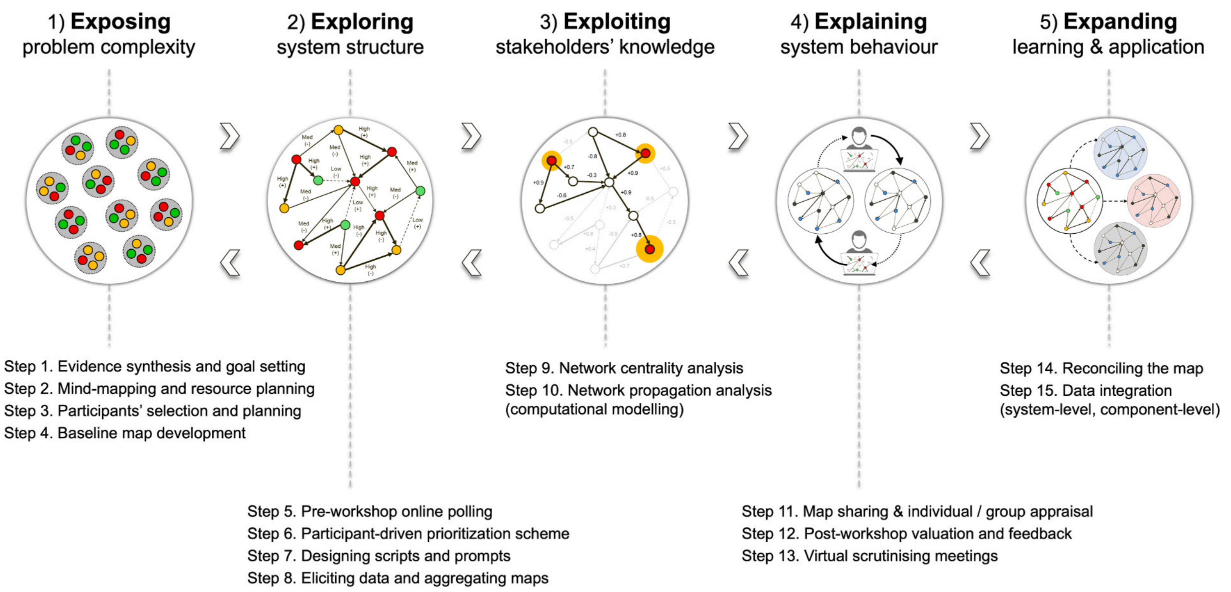

Fig. 2. Overview of the proposed 5X methodology.

Oliver & Montgomery, 2001). *Negative* feedbacks tend to dampen changes while *Positive* feedback results in propagating changes with 'knock-on' (or amplifying) effect on the whole system (Fig. 1) – since 'effect' of a change can be 'cause' for new changes and so on (McLoughlin & Webster, 1970). Knowledge of such change propagations can enable decision-makers to think proactively and turn intended positive feedback into negative or vice-versa, so directing unintended consequences towards something manageable where they have the control to either accept or mitigate it (Hassannezhad et al., 2019); this has not previously been applied into systems mapping practices.

In this study, we suggest that full digitalisation of the PSM process, that is by taking a *systems approach* and nurtured by incorporating structural mapping methods (capable of handling implicit knowledge and causal influence) and computational systems analysis methods (capable of quantifying the knock-on effect of change propagations) can provide the capacity to develop and implement a Cybernetic-inspired participatory process – through *5X*. The next section presents the proposed systematic methodology.

4. The proposed 5X method

This section describes the step-by-step implementation of the 5X method in the context of the GMCA *IncEc* system, as illustrated in Fig. 2 – showing the main stages, objectives, and methods being used. The proposed framework expands the paradigm from traditional PSM methods (focusing on the physical paper-based workshops) to enable stakeholders to fully (and virtually) engage in the process during pre-workshop design (aligning the mapping purposes with stakeholders' needs), in-workshop elicitation (identifying system drivers and their pathways), and post-workshop evaluation and feedback (identifying gaps and change priorities). We named the method as '5X' since it offers a dynamic and iterative co-learning environment for **Ex**posing the problem complexity, **Ex**ploring the system structure, **Ex**ploiting stakeholders' understanding of the system, **Ex**plaining the findings, and **Ex**panding its application.

Despite following the same logic with the majority of traditional PSM processes presented in the literature (Voinov & Bousquet, 2010; Voinov et al., 2016), 5X offers a number of fundamental technical advancements in terms of scoping the problem, engaging stakeholders throughout the process, eliciting data from stakeholders, aggregating multiple individual maps that are developed in parallel, analysing and refining the outcome maps, promoting individual (and group) feedback from a distributed group of stakeholders, and using the map in both research and practice. In addition to being amongst the first fully virtual mapping processes reported in academia, it presents one of the very few attempts on developing a whole-system map of *IncEc* in complex policy settings – lessons from which are important to many academics and policy organizations in the UK and internationally. At the time of writing this paper, the proposed methodology has been run successfully with different sets of stakeholders in different UK jurisdictions.

4.1. Stage 1. Exposing problem complexity

Stage 1 is concerned with broadening our general knowledge of the problem (in terms of purpose, scope, boundaries) and translating this understanding into a set of requirements for the mapping process. Such understanding is used to design a more effective process and making up an effective team of stakeholders. In doing this, the core development team (a group of six people from both academic and policy partners) recognized a set of principles that should be taken into consideration in advance:

- Principle 1. Balancing an adequate representation of the breadth of the system against the depth of granularity of information required by the heterogeneous users of the map.
- Principle 2. Balancing the complexity of the system (perceived reality) with the complexity of its abstraction model (systems map).
- Principle 3. Purposeful selection of workshop participants, considering the inclusivity and balancing the diversity, breadth, and depth of knowledge.
- Principle 4. Balancing the quality of developing a detailed map against the development cost (i.e., policy and academic partners' resource commitment).

4.1.1. Step 1: evidence synthesis and goal setting

The collated evidence obtained from policy document analysis and discussions within the core development team highlighted the *multi-interest* and *complex* nature of the context, i.e., understanding the factors influencing successful delivery of *IncEc* very much depends on who you are talking to (i.e., their role, experiences, and aspirations). Furthermore, there is not a single 'right' level of granularity from which a whole-system problem can be mapped and analysed. The primary study guided the core team to set the key goal as understanding improvement levers and change priorities in the system, based on stakeholders' knowledge. The specific objectives are:

- *Building a model informed by collated evidence*: identifying, mapping, and articulating the key performance indicators and the likely causal pathways between them.
- *Building consensus for policy decision-making*: consolidating knowledge and creating a shared representation of reality by expressing beliefs.
- *Building trust in the model and its outputs*: Engaging participants actively in the modelling process, increasing confidence in understanding, using, and appraising the model. This will eventually enable academic partners (in SIPHER consortium) understand how policy partners perceive the system, thus helping them to develop simulation models (out of the systems map) that are more relevant and trusted.

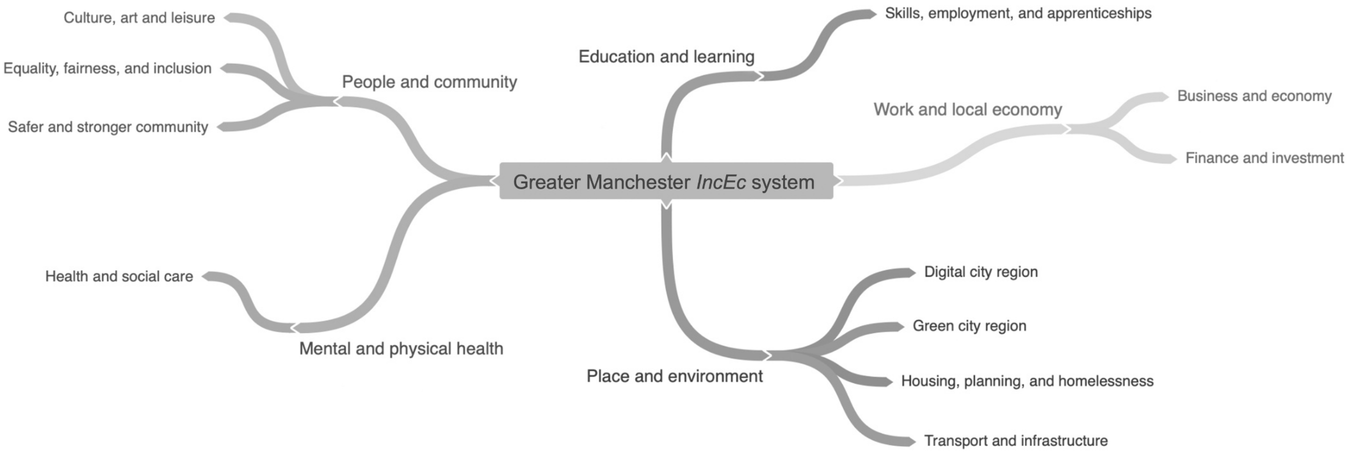

Fig. 3. The *IncEc* mind map developed for scoping.

4.1.2. Step 2: mind-mapping the scope and resource planning

IncEc involves multiple domains, with many drivers, and stakeholders involved in decision-making. In order to be feasible and manageable in an online setting, it is therefore vital to narrow the scope of the modelling without compromising the quality of outcome map – thus getting a sufficient resolution of the system to understand key drivers and underlying causal pathways. By taking a Systems Thinking approach, the core development team developed an online mind map (illustrated in Fig. 3) to get an impression of the boundaries of the *IncEc* system in GMCA – in terms of the key policy areas that should be included into the whole system map. This information directs the core team to identify the right settings, in terms of the time and resource required for the workshops – in line with the aforementioned principles.

4.1.3. Step 3: participants' selection and workshop planning

For the workshop, we needed a combination of people with a good knowledge of the whole system (i.e., somebody working at the intersection of a range of policy areas) and other attendees with more specific deeper expertise in one or two area(s). Further consideration made with policy partners on finding the right balance between getting most relevant individuals (to the scope of the workshop), their resource and time commitments, and their expectations.

Key activities taken by core team at this step include agreeing an invitation list, deciding on the number of groups (four, in the first workshop), assigning participants for breakout discussions (between three and four, per group), identifying roles and responsibilities, choosing the right set of facilitators (one facilitator from policy partner per group, supported by a senior academic advisors), and preparing them for real-time population of the map (acting as the modeller in the workshops) by creating a guide, script, and prompts for each workshop session. The output of the first stage is a detailed workshop plan with an agreed list of participants and facilitators, and a baseline map – acting as the starting point of conversations in the workshop.

4.1.4. Step 4: baseline map development

In developing the baseline map, the overarching GMCA strategy plan (GMCA, 2017) was used as the reference point, since all selected participants were familiar with it – and it sets out the key priorities for GMCA over the next five years. The document was the result of a participatory process per se, based on a range of digital (e.g., use of social media) and face-to-face engagement over a period of 12 months. It is the third version of the strategy plan that builds on the work that has been undertaken since the initial version in 2009.

Developing the baseline map was an iterative process involving academic and policy partners; it started with 58 components extracted from strategy plan (across five policy areas) and 349 components (across eight domains) from related policy documents; this was informed by the information derived from individual interviews with policy officers (a different group of people - as compared to workshop attendees), which resulted in a further 19 components, to conceptualize the baseline map. The map contains a list of 59 priorities, strategies, and outcomes in GMCA (with no connections between them) which acts as the reference point in designing the pre-workshop online poll and starting point of conversation in the workshop. Whilst this was seen to be a more engaging process as compared to starting from scratch, we would suggest keeping it as simple (and familiar to participants) as possible, i.e., the strategy plan in our case, to encourage contributions during the workshop.

4.2. Stage 2. Exploring system structure

Stage 2 is about making sure that all the important variables of the *IncEc* system and the perceived causal relationships between them are elicited from the participatory process. Causal relations may contain various forms and levels of information, typically capturing in some way that an increase or decrease in one variable causes an increase or decrease in another (Carvalho, 2013). Broadly speaking, these relations can be represented in the form of linguistics (e.g., "low", "medium", "high") or probability values (within the interval of [0,1]) or even a mathematical function, subject to the availability of reliable empirical data.

A prominent challenge in developing FCMs in this study is that the *IncEc* system comprises numerous concepts (i.e., nodes in FCM)

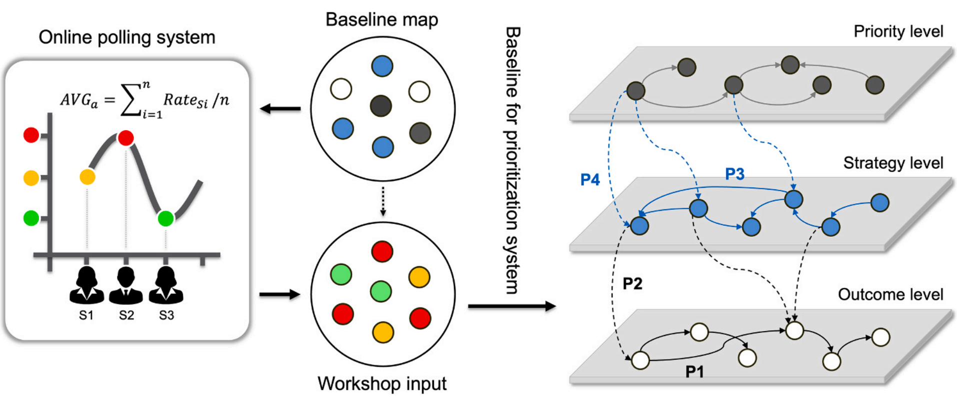

Fig. 4. The proposed online polling and participant-driven prioritization scheme.

that relate to different policy areas and can infer different meanings, of which the majority can be recognized as 'important' to a certain extent. Capturing all these important nodes by groups of policymakers and reaching consensus is highly challenging, given the very limited time available in an online workshop. Therefore, we propose an approach to collate individual views by pre-workshop consultation with the confirmed participants, through designing an *online polling system*. This subsequently leads us to the development of a *participant-driven prioritization scheme* to effectively manage activities during the workshop sessions (towards focusing more on causal pathways).

4.2.1. Step 5: pre-workshop online polling

The GMCA strategic plan describes a set of 10 interdependent so-called *Priorities* for the period of 2019–2024 (GMCA, 2017). Each priority in the document is associated with a range of *Strategies* that drives the system to achieve a set of (overlapping) *Outcomes*. The primary discussions with key policy partners showed that the importance of these components would potentially be different for different policy areas (Fig. 4, left-hand side). For example, 'GMCA Strategy' may be an essential strategy for business and economy sub-systems but may be less important for education and health. Besides, participants' limited understanding of the importance of drivers and outcomes in other policy areas may affect their engagement in the workshop as well as the resulting map.

In response to this heterogeneity, we extracted the information from the GMCA strategic plan and the baseline map into a set of questions, aiming to understand the relative (collective) importance of system drivers based on a five-point Likert scale, ranging from "Not important at all" to "Modest importance", "Important", "Very important", and "Essential". A live polling system was designed and implemented in Slido software and communicated with the confirmed participants (together with an information pack) a few days before the workshop. This sort of pre-workshop engagement enables each participant to think globally (in terms of what drives the *IncEc* system in other policy areas) and share their views with other participants (everyone attending the workshop and not necessarily the people in the same group). The feedback enables the development team to design the workshop sessions effectively by focusing on the areas identified by participants as 'most important' or there was an agreed concern. For example, the following points have been identified by some participants as the example of biggest emerging challenges in the short-term facing GMCA *IncEc*:

- "Lack of a shared vision for *IncEc* prevents integration across policy areas";
- "Lack of prioritization given to sustainable growth is resulting in negative outcomes for many vulnerable people, and will require a significant internal and external response";
- "Climate emergency and particularly addressing clean air ambitions"; and,
- "Automation, ageing society, clean growth, and future of mobility are examples of wide-ranging inequalities that could make us less equal (government's grand challenges)".

Accordingly, participants collectively identified "a thriving and productive economy" as one of the GMCA priorities by far which would be most affected by the emerging challenges. This sort of primary feedback guided us to flag this priority in the workshop so that participants can provide further resolution on its underlying strategies and affected outcomes.

4.2.2. Step 6: participant-driven prioritization scheme

Traditionally, participatory workshops are organized for a full day (or sometimes two consecutive days). When engaging senior policymakers, it would be very difficult to bring a representative group together for more than few hours of a single day – even with a long notice period. During the first UK lockdown (in March 2020), when this study was undertaking, the situation was even more problematic as most of policy officers have been very busy with the emerging Covid-related challenges.

To run an effective workshop while taking this limited availability and the complexity of *IncEc* into consideration, the core development team supported by further consultation from GMCA use the result of online poll to propose a *prioritization scheme* to start the workshop session with areas that participants previously recognized as more important. Obviously, rather than setting out rules, the scheme is meant to be a guidance which enables participants to collectively discuss the concepts in the workshop sessions and add resolution or remove the concept from the map. It would only be applicable if we can get an acceptable rate of response from workshop participants in advance (60% in our case), otherwise it can limit the participatory potential of the exercise. Assuming the *IncEc* system as a multi-layer network of Priorities, Strategies, and Outcomes (Fig. 4, right-hand side), a set of four levels of priority identified by key policy partners to guide workshop discussions, respectively:

- P1: identifying key outcomes and the mutual links (interactions) between them;
- P2: identifying the impact of strategies on outcomes;
- P3: identifying key strategies and the mutual links between them; and,
- P4: identifying the mutual links between priorities and strategies.

Within each priority level, we use the aggregated response from the online poll and progressively discuss the 'Essential' components and then 'Very important' and 'Important' components, respectively. These components are distinguished by color-coding in the interactive mapping platform in Fig. 6.

The advantage of a prioritization scheme is that, within a limited timeframe, it ensures the outcome map will minimally represent all important phenomena – captured collectively by participants – that matter to key stakeholders in GMCA. A disadvantage is that the collective importance of components may not necessarily be aligned with the individual view of some participants, perhaps affecting their degree of engagement in the workshop. However, when communicating the outcome map for individual appraisal (in Stage 4), there will be sufficient breadth for participants to reflect on their views in a considered manner.

4.2.3. Step 7: designing scripts and prompts

In traditional physical workshops, the facilitator role principally involves taking care of mutual learning and active engagement to help foster a collaborative environment (Voinov et al., 2018). In virtual settings, however, the role of coaching and facilitation becomes more complex as more efforts are required to ensure interactivity in the breakout sessions and effective coordination between coach and facilitators is vital in dealing with any unpredictable circumstances (e.g., with technology disruptions, potential loss of discussion data). In our case, in three (out of four) groups, facilitators were also the 'mappers' who interacted with the online mapping tool during the breakout sessions so that the participants could see the population of the system map in real-time. In the fourth group, as a pilot study, we used two facilitators in the group, one taking care of group discussion and the other, as the 'mapper'.

The importance of real-time population of the map (performed by the facilitation team, accessible to everyone in the online group) should not be underestimated as it enabled the participants to fully concentrate on the content, discussing important phenomena, adding data, revisiting and refining the map, identifying the gaps, and learn from each other – thus making the workshop sessions as effective as possible. On the flipside, it can take the facilitators' task more complex as they have to run the discussion and interact with the online mapping platform concurrently. Therefore, aligned with the literature (Hovmand, 2014) and subject to availability of resource, we found it more effective to use two facilitators per group, one for interacting with and translating data into the map (the 'mapper') and the other for facilitating the discussion, plus a coach (the lead author in this study) with a floating role across groups to take care of technical (digital) matters, data protection, inquiries, and making sure all working groups are running smoothly and objectives are met.

To support facilitators in running workshop sessions effectively, a range of scripts and prompts were designed (similar for all groups) and reflected into the mapping platform, including for example details about the purpose of each session, questions to promote the conversation, and building blocks of the systems map. Furthermore, a mock workshop was delivered by coach, and a training session managed with the core development team and facilitators to make sure they feel confident in interacting with the tool and that they have a clear understanding of the workshop process, in terms of input attributes (information needs to be obtained at each session), expected output (the FCM model), and the prioritization scheme. The input attributes visualized in the baseline map in form of color-coded nodes and links, as per shown in Table 1.

4.2.4. Step 8: eliciting data and aggregating multiple maps

During the workshop sessions, 15 policy representatives (including three amongst the core team), with different policy backgrounds and levels of experience, were organised into four groups in such a way that each group represented the full boundary of *IncEc* across seven policy areas. Each group, supported by a facilitator, was given an identical set of tasks to add resolution to the concepts and identify causal links and flow of change – using the same baseline map. The output of our participatory workshop was four FCM models (obtained from four parallel groups, see Table 2 for details) with each allowing free text qualifiers around components; these provides extra piece of information on each component which could be used during the aggregation process. These elicited maps need to be aggregated into a unified map for learning and analysis.

The literature usually treats it by condensing the maps either qualitatively (e.g., by combining the concepts and nested into the upper level (Mehryar et al., 2017)) or quantitatively (e.g., by applying the concept of near-decomposability (Iwasaki & Simon, 1994)). In either way, aggregation is a mean of simplification that results into losing information. In this study, we introduce a set of metrics for aggregating multiple maps which preserves all the details about components and links into the amalgamated map. Central to the proposed metrics is examining the input attributes of links that each group added to their local map during the workshop, and quantifying the consensus on the nodes and links, by understanding:

- *Contribution* (*Contr*) of a link: how many groups agreed there is a link between a pair of components? For example of a given link between Component a and Component b, $Contribution_{ab} = \{BC\}$ determines that two groups of B and C (out of four groups) identified this link in the workshop breakout sessions.
- *Collective Importance* (*CIm*) of a link: quantifies the rate of Contribution of a link, based on the total number of groups with the assumption that all groups are equally valid with the same weight. In the given example above, if $Contribution_{ab} = \{BC\} \rightarrow CIm_{AB} = 2/4 = 0.5$).
- *Collective strength* (*CSr*) of a link: represents the proportional probabilistic strength that the Contributed groups assigned to a link (in terms of strong, moderate, or weak). The popular *Weighted Geometric Mean* method is applied for this purpose, by following (1), where k refers to the number of Contributed groups (maximum $m = 4$ here) and λ_k shows the weight of each group if they differ. In the above example, $\lambda_2 = 0.5$, as two groups out of four are contributed to this link with equal weights.

$$CSr_{ab}^{(c)} = \prod_{k=1}^{m} \left(Strength_{ab}^{(k)} \right)^{\lambda_k} \tag{1}$$

The above formula does not support negative numbers, so for aggregating multiple probabilistic values with the range of $[-1, +1]$ in the FCMs, we would suggest applying a normalization algorithm such as Feature Scaling (Hassannezhad et al., 2021) to restrict the values between [0,1].

- *Collective Confidence* (*CC*) of a link: is a proportional value showing how many groups were sure that there was a link between components. This is a probabilistic function of Contribution (representing how many groups discussed a link in their session) and

Confidence (representing if those groups were Sure about the link – its direction and strength). Therefore, the Least Confident scenario is when there is only one (or two) group that identified the link and that group is not *sure* in it ($CC = 0.1$ in Fig. 5); the Most Confident scenario is when all four groups agree that there is a link and all are *sure* in it ($CC = 1.0$ in Fig. 5). Out of 194 links (with resolution, see Table 2) identified in our participatory workshop, Fig. 5 right-hand bar shows the number of links that falls into each category of *CC*.

The output of this stage, illustrated in Fig. 6, is an amalgamated map; it shows not only the *collective view* of stakeholders (in terms of how various groups of people think about the same concept differently), also the *agreed (critical) view* of stakeholders which helps to identify the synergies and conflicting views between groups. The interactive visualisation in the map allows the user to develop a customised version of the whole-system, for example by filtering down to only visualize the *Most Confident* view ($CC \geq 0.8$) – a more confident version of the map in that at least three (out of four) groups felt 'Sure' about a link.

4.3. Stage 3. Exploiting stakeholders' understanding

The amalgamated FCM model represents the collective thinking of participants, which can be subject to a range of analysis and a baseline for interrogation, calibration, and gaining insights. The literature of PSM typically moves this forward by applying a range of basic network metrics to measure the influence of system components in a network based on their centrality (such as in-degree, out-degree, and betweenness) (Newman, 2003). Despite their simplicity of use, such metrics only looks at the direct links between system components and cannot take into account the complexity of causal pathways (and their combined effects) across the network – which is fundamental in studying *IncEc* system of systems.

More advanced quantitative methods such Bayesian Belief Network and Neural Networks seem promising but the main challenge with these methods is that they are computationally expensive for large complex systems such as the *IncEc* map with 89 nodes and 327 links between them. So, the number of incoming links for some nodes should be reduced as the complexity makes running the quantitative analysis problematic. Moreover, Bayesian networks require precise information about probabilistic relationships between nodes (which is not available at this early stage of modelling) and that they cannot accommodate feedback loops (which is central in this study), so they should be removed from the map. Besides, Neural Networks are black-box models and hence, lacking the transparency of generating knowledge and the ability to explain causal pathways.

Therefore, inspired by techniques that have been used in handling complex engineering systems, in this study, we complement the network centrality metrics by incorporating the concept of *Network Propagation Analysis* (Hassannezhad et al., 2021) to quantify the 'knock-on' effect of change propagations (resulting from feedback loops in the map).

4.3.1. Step 9: network centrality analysis

Applying such metrics to the aggregated FCM model suggest the most influential drivers of *IncEc* in GMCA as, illustrated in Fig. 7: Local industrial strategy (S_9), Spatial framework (S_{11}) and, Work and skills strategy (S_{23}); the most influenced outcomes of those strategies are: Improved economic growth (O_3), Increased sustained employment (O_{18}) and Reduced economic inequality (O_{23}).

When defining the prioritization system, a forwarding flow of information was assumed from Priorities to Strategies and from Strategies to Outcomes. Therefore, it is not surprising that most of Strategies in Fig. 7 are found to have a higher level of 'activity' and Outcomes with more 'passivity' in the network. By looking at the backward flow (feedback loops), we found the following outcomes

Group 1	Group 2	Group 3	Group 4	Contribution	Collective Importance	**Collective Confidence**	
sure	sure	sure	sure	4	CI = 1.00	**1.00**	4
sure	sure	sure	unsure	4	CI = 1.00	**0.90**	4
sure	sure	sure		3	CI = 0.75	**0.80**	10
sure	sure	unsure	unsure	4	CI = 1.00	**0.70**	
sure	sure	unsure		3	CI = 0.75	**0.60**	21
sure	sure			2	CI = 0.50	**0.50**	4
sure	unsure	unsure	unsure	3 or 4	0.75 <= CI <= 1.00	**0.40**	55
sure	unsure			1 or 2	0.25 <= CI <=0.50	**0.30**	54
unsure	unsure	unsure	unsure	3 or 4	0.75 <= CI <= 1.00	**0.20**	11
Unsure	unsure			1 or 2	0.25 <= CI <= 0.5	**0.10**	31

Fig. 5. Computing the Collective Confidence in 5X (left-hand side) and their frequency in the mapping workshop (right-hand side).

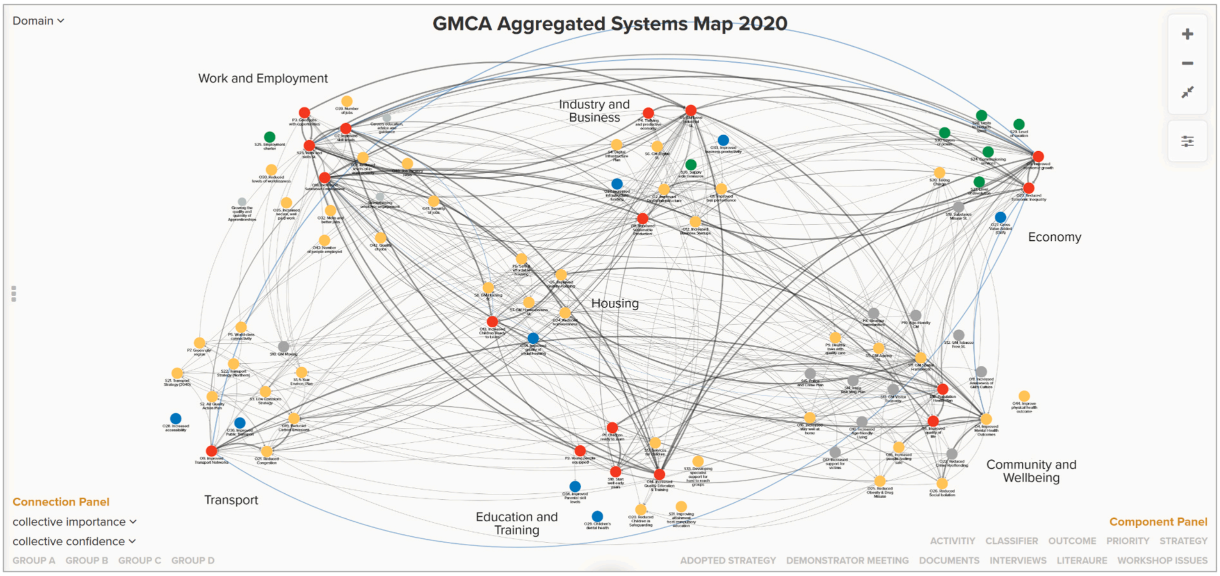

Fig. 6. The amalgamated map showing the collective view of participatory workshop across seven *IncEc* domains. Control panel: enabling user to customize the view based on system domain (top-left); Collective Importance, Collective Confidence of links, and Contribution of groups (bottom-left); and Class of components and their source (bottom-right). Color-coding: Red (essential), Yellow (very important), Grey (important), Green (strategy, regardless of importance), and Blue (outcome, regardless of importance).

with largest impact on Priorities: Good jobs with opportunities (P_3), Thriving and productive economy (P_4), and Healthy lives with quality care (P_9).

The network analysis also specifies the GMCA Moving strategy (P_{10}) and Increased age-friendly living strategy (O_{10}) as *transmitters* of systems change (with positive out-degree and zero in-degree) and the Increased support for victims (O_{17}) and Reduced children in safeguarding (O_{20}) as *receivers* of change (with positive in-degree and zero out-degree). In both cases, it would be beneficial to understand the rationale for transmitters and receivers, i.e., it is possibly due to time limitation in the workshop.

4.3.2. Step 10: network propagation analysis

To compute the cascading effects across *IncEc* system, we use the Change Prediction Method (CPM) (Clarkson et al., 2004) algorithm implemented in the *Cambridge Advanced Modeller* (Barzegar et al., 2018), where the algorithm uses the information about *Collective Confidence* (representing the likelihood of propagating a change) and *Collective Strength* (as the impact of propagation) to produce the measure of whole-system *risk*. The main outcome of CPM would be a risk portfolio plot showing different types of change propagation behaviour. According to the results (Fig. 8A), the components S_{23}, S_9, and S_{16} are found as *multipliers* (bottom-right quadrant) with high influence on the rest of system but hardly affected by them. The top-left quadrant shows the components O_{23} (Reducing economic inequality), O_3 (Improved economic growth), and O_{18} (Increased sustainable employment) as *absorbers*; they have a small effect on the rest of system but have a high risk of being influenced by changes to other components. At a more detailed level, the risk plot (Fig. 8B) shows that a change in for instance Work and skills strategy (S_{23}) have the largest systemic effect on Reducing economic inequality (O_{23}) and Improved economic growth (O_3) respectively, and on O_7, O_{14} and O_{18} at a lower level.

Understanding the cascading effects of system components would be particularly valuable when there seems not to be a direct dependency between components. For example, although the aggregated FCM model shows no direct effect from Improved sustainable production (O_8) to Reducing economic inequality (O_{23}), our computational propagation path analysis (based on three propagation steps) reveals that there are four different ways this could happen in practice, through their interfacing components O_3 (Improved economic growth), O_4 (Improved mental health outcomes), S_{16} (Population health plan), and O_{18} (Increased sustainable employment):

1) $O_8 \rightarrow O_{18} \rightarrow O_4 \rightarrow O_{23}$
2) $O_8 \rightarrow O_{18} \rightarrow O_3 \rightarrow O_{23}$
3) $O_8 \rightarrow O_{18} \rightarrow S_{16} \rightarrow O_{23}$ and,
4) $O_8 \rightarrow O_3 \rightarrow O_{18} \rightarrow O_{23}$.

The information obtained from applying network centrality and propagation analyses can be embedded into the interactive mapping platform to support the user with a dynamic visualization of most influential components in the system. A color-coding scheme is designed for this purpose, such as the one illustrated in Fig. 9, in that size of components indicates their importance from a network perspective (e.g., based on risk of change propagation, or in-degree, out-degree, and betweenness in multiple views), colour of components indicates their importance from participants' perspective (essential in Red, very important in Yellow, and

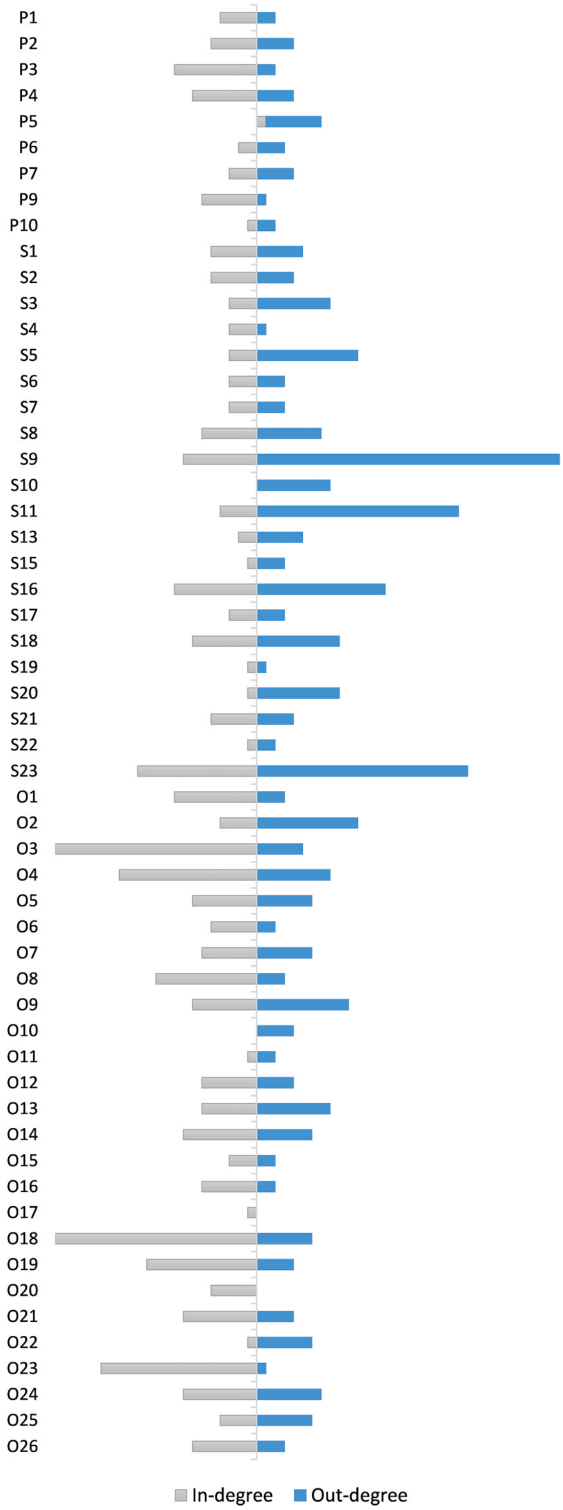

Fig. 7. Applying degree centrality analysis to the aggregated FCM model.

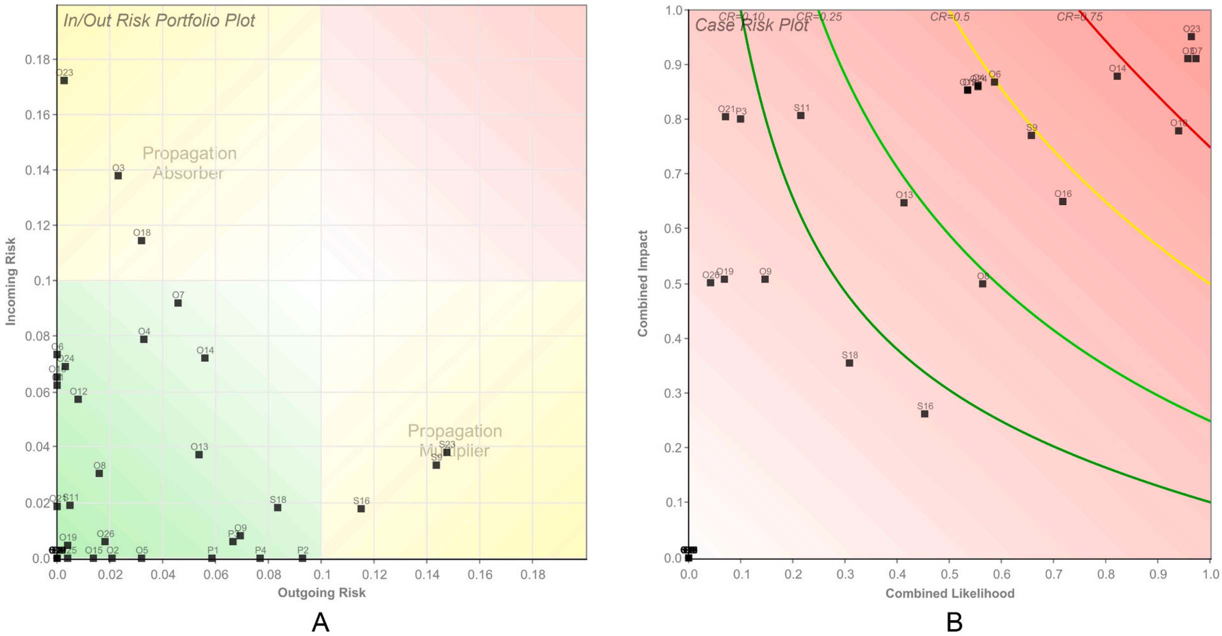

Fig. 8. Applying network propagation analysis to the aggregated FCM model: (A) the Risk portfolio lot, (B) Compound risk plot for S_{23}.

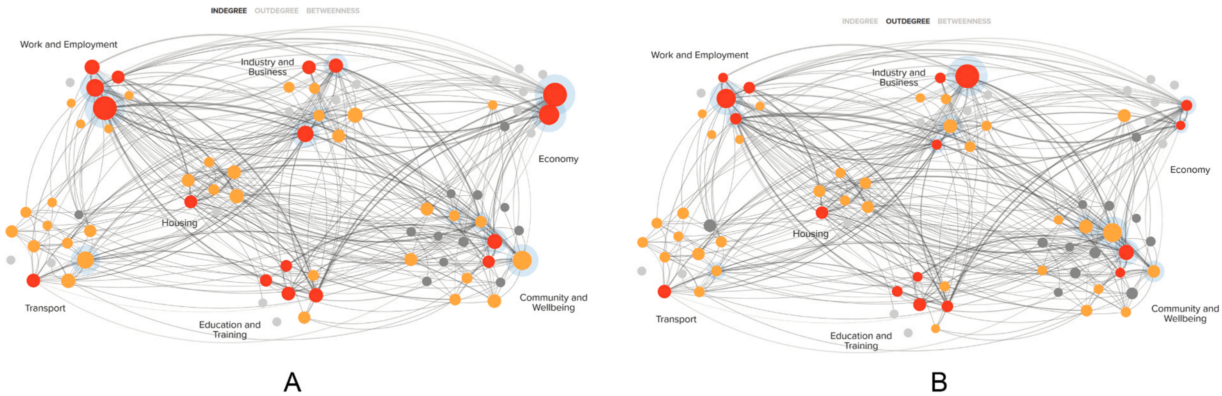

Fig. 9. Dynamic visualization of *IncEc* map: example of (A) In-degree and (B) Out-degree views.

important in Grey), and thickness of links show their importance (in terms of Collective Strength and Compound Risk of propagation).

4.4. Stage 4. Explaining system behaviour

The objective of this stage is to find effective ways for communicating and evaluating the product of the participatory process (e.g., the map, learnings and findings extracted from maps) with stakeholders (sometimes beyond the boundary of workshop participants). After the first round of workshopping, a map will usually need to go through a verification and evaluation process. The literature typically moves this forward by arranging following-up meetings and further iterations of workshopping, where the core development team works with the same or a different group of stakeholders to for instance verify previous findings, filling the gaps, and working around limited business narratives.

Accepting this view, in policy systems mapping, we discuss that there are situations in which there is limited availability of policy experts, or there are multiple (conflicting) interests relating to different policy areas, i.e., it is quite likely that every policymaker would come up in the following-up workshop with numerous narratives deemed equally important. Furthermore, in situations where it is not possible to conduct a second round of workshops with the same set of participants, there is a risk of repetition, due to differing perceptions and aspirations, without finding resolutions.

4.4.1. Step 11: online map sharing and individual appraisal

Drawing on the literature gap, in this study, we developed an online collaborative environment (equipped by analytical capabilities) to enable stakeholders to individually interact, interrogate, and scrutinise the map against their individual expectations – before planning a follow-up workshop. At the first instance, interrogation was performed by key policy stakeholders in GMCA and three *IncEc* topic experts in SIPHER Consortium. The focus of this stage is twofold: (1) extending the implications of the systems map conceived by GMCA policy partners to other audiences (e.g., other policy partners, academic partners) of the model (not necessarily participants of the workshop) and understanding their needs. There might be different interests for example in the process, in outcome map, in quantitative aggregation method, or in qualitative social learnings; (2) designing an effective way to communicate system behaviour and getting feedback.

4.4.2. Step 12: post-workshop valuation and feedback

Feedback was sought in two parts in the process. Initially, right at the end of workshop, participants were asked to share their quick view on different aspects of the process, including communication, pre-workshop polls, facilitation, and overall mapping process. Where 88% believed communication has been good or excellent, and 89% found the facilitation as excellent. In particular, they "enjoyed being able to consider existing strategies in a different way" and found it a "useful exercise on how online tools can be used for mapping workshops; interesting to see the emerging population of the map in real-time". Whilst 63% of participants found the pre-workshop poll a useful exercise, there were some concerns that "responses from the poll were partial (with 60% contribution) and unrepresentative of the wider group". Overall, 89% of participants found this mapping exercise a good or excellent process.

By development of the aggregate map (Stage 3), a *post-workshop information package* prepared and communicated with participants of the workshop together with an individual (and secured) access to the online mapping platform and the access code to online polling system to share their reflections on the initial findings. Use of digital technologies, reflected in our interactive *IncEc* map, provides the potential for two-way communication and iterative refinement of the map – before any further attempt. The outcome will then determine the necessity and properties of the next iteration of workshopping: should we go back to Stage 1 (discussing about new purposes, granularity, and scope), or to Stage 3 (making clarifications on learnings).

We believe this complementary approach – group model building and individual map testing – enables stakeholders to identify what is missing or should be modified in the model, while overcoming some of the limitations facing the individual-level verification of FCM models in the literature (Mehryar et al., 2017). The feedback we received at this stage suggested the need for a further iteration of the workshop yet with a narrower focus on specific policy areas to flesh out the *missing details* in the first round and understand the *activity underpinning key strategies*. As the result, by going back to Stage 1 (Fig. 2), we planned and delivered a series of three workshops for the period of November 2020 to March 2021 (with the initial workshop was run in March 2020), 90 min in duration, and with groups of 5–8 topic experts in thematic policy areas: Economy and Business (workshop 1), Work and skills (workshop 2), and Health and social care (workshop 3). The process resulted into an additional set of 100 nodes (including an activity layer with 70 nodes) and 272 links between them.

4.4.3. Step 13: virtual scrutinising meetings

In multi-partner projects such as the SIPHER consortium, policy partners are not the only stakeholders of systems map, and our academic partners will be using it as input to build up dynamic simulation-based models of *IncEc*. Therefore, careful consideration of multiple stakeholders' needs is required to ensure ongoing engagement while enhancing the utility of systems map. Through arranging a series of virtual scrutinising meetings, our maps were scrutinized not only by different workstrands in SIPHER (to understand how this feeds their modelling attempts) but also by external community panels comprised of people who had lived experience of the relationship between income, work, and poor health.

4.5. Stage 5. Expanding application and learning

As mentioned earlier in Section 2, the SIPHER consortium is working closely with three policy partners who represent local, regional and national scales of the UK policy government (Meier et al., 2019). While each partner is working on its own priorities and strategies to develop whole-system mapping of *IncEc* system, running the first systems mapping workshop with all three partners shows some degree of overlap in their boundaries and practices. This raises prospects about the extent to which the learnings from applying the current mapping process can be expanded to be used in future systems mapping practices with other partners – for example by using GMCA *IncEc* map to inform their initial analysis and identifying requirements of a policy workshop.

4.5.1. Step 14: reconciling the map

In the first instance, both methodological and technological capabilities that were primarily developed for this study have consequently been used in additional systems mapping processes with two other policy partners. Altogether, the data from three FCM models were collated to build an integrated 'mega-map' of the UK *IncEc* system with more than 700 nodes and 1200 links between them. At the time writing this paper, this integrated map, containing detailed information on drivers of *IncEc*, their outcomes, and their underlying links, has been used as a reference point in all systems mapping activities (or other consortium activities such as the WS4 model structure). while being used by academic partners to inform evidence gaps in broader areas of *IncEc* in the scientific literature – thus adding to the credibility of proposed mapping process and its outcome maps.

4.5.2. Step 15: system- and component-level data integration

Beyond that, complex policy systems such as *IncEc* involve many concepts from a range of interconnected policy areas including environment and transport, education and employment, and health and wellbeing. We believe expansion can also happen at the domain-level (i.e., focusing on a particular policy area) and existing information be used in mental modelling of other policy areas (such as health and wellbeing). This can lead to a major contribution to the scientific literature of participatory mapping – where there is currently a gap (Voinov et al., 2018) to develop a scalable (and reproducible) mapping system that promotes knowledge and learning and reconcile the map to other policy areas.

5. Reflections on the implementation

The design and delivery of a fully virtual systems mapping process required a co-production process with policy partners. This was undertaken over a period of ten months (starting in Oct 2019), with the first three months spent on interviews, and then the implementation of each stage respectively at month five (exposing complexity), six (exploring structure), eight (exploiting understanding), eight-ten (explaining behaviour) and ten-onwards (expanding application).

This study brought both methodological and implementation novelty to the field by pushing the boundaries of *IncEc* participatory modelling practice to online settings with considerations of theoretical enrichment by focusing on the way that data are elicited, aggregated, analysed, and refined in short- and longer-terms. Based on the feedback acquired from our participants, facilitators, and reflection from the core development team, we would highlight the following learning points:

5.1. Scoping and participation

The definition and scope of our focus policy system, *IncEc*, changes significantly when looking at a local, regional, or national scale, and is understood differently within and between organizations. In this study, we used a document (GMCA strategic plan) that was well understood across the organization as a starting point of the process. This was partly driven by the need to have a shared definition and understanding of the term and partly driven by the policy partners' needs and role within the workshop design process. The use of this document was well perceived mainly because we ran the exercise with the stakeholders inside the policy institution; it is not entirely clear how well it could be used in other settings or mixed settings (e.g., due to concerns with effective facilitation of unequal power or information dynamics in an online environment).

Perhaps unsurprisingly, this produced a map that was very focused on contemporary policy development in the organisation with transparency on some specific levers of policy actions and their intended consequences. However, like any other mapping exercise, if certain types of stakeholders experience digital exclusion, then their perspectives will not be captured into the map. This could arguably be an acute concern for topics like *IncEc* that impact on disadvantaged communities. We dealt with this concern through scrutinising the map by community panels (with lived experiences), which could be a minimum requirement for such topic areas.

5.2. Pre-workshop engagement

There was limited availability of participants to attend the workshop and it was felt by the organisers that a full day spent in an online workshop would be draining. Therefore, in order to use the workshop time more efficiently we designed an online poll in order to prioritise the focus of the workshops. Whilst it was helpful to get an impression of what policy officials think about such a broad topic of *IncEc* (i.e., key system variables) in advance of the workshop, the output of online poll was found to be unrepresentative of the wider group of stakeholders. More importantly, the use of prioritization to reduce the time resources needed for the workshop can be seen as the potential limitation of the process which may constrain the workshop process or bias the workshop outcomes. However, the lack of such prioritization scheme (in an inherently contested topic of *IncEc*) could have increased the risk of obtaining a (potentially large) scattered map which is more difficult to use without topic expert distillation.

5.3. In-workshop facilitation and engagement

Encouraging interactivity in virtual settings can be even more challenging than face-to-face meetings – it is harder to read body language and the flow of conversation is more easily disrupted. It is therefore important to have very clear instructions and prompts for each facilitator, and to pick the right set of tools to support the workshop activities. The feedback from facilitation team also suggests allowing more time to practice with the mapping software, together with running a mock workshop and training sessions, and perhaps a glossary of the common terms. This exercise reaffirms that human facilitation is still an important part of the 5X process, and our approach inherits the strengths and weaknesses of traditional PSM in this regard, i.e., the effectiveness of the workshop is strongly influenced by the effectiveness of the facilitation. Nevertheless, we found the pilot use of using two facilitators quite promising, one to guide the discussion and the other as the 'mapper'.

To encourage engagement between participants, we built smaller and more diverse groups (20 people including 12 policy officials classified in four working groups) with support from a senior academic advisor (with significant knowledge about *IncEc*) and a trained facilitator. Albeit engaging a diverse group with technology is a challenge per se (Wilkerson et al., 2020), seeing the population of such a complex map in real-time found to be one of things that participants liked most about the workshop (according to post-workshop poll), which encouraged interactivity and flow of conversation and enabled participants to see the big picture in real-time. A lot of off-line mapping processes manage nowadays to publish the resulting map online; this requires lots of efforts from modelers after the workshop – yet with an existing gap between the population (of the map) and dissemination (Wilkerson et al., 2020; Freebairn et al., 2019). This would suggest the need for a proper evaluation (i.e., follow up interviews with the policy organisations) to understand the effectiveness of approaches.

5.4. Aggregation and analysis

Aggregation happens at two stages in the proposed method. During the pre-workshop aggregation, responses from polls were collated to obtain an average importance of system components in the baseline map. After the workshop, the proposed heuristic of aggregating group maps provided a systematic way of identifying areas in the map that participants felt more confident about them, also areas with a better contribution (of different groups), as well as controversial areas where participants raised concerns – while minimizing information loss.

Applying network analytics to the aggregated map could provide useful insights on structural dynamics of the *IncEc* system, acting as a common ground in future discussions with policy partners. However, whilst the software being used in this study provides powerful visualization and flexible data population, it only offers limited analytical capabilities which does not allow for running complex simulation models. Whilst it was suitable for the purpose of this study, it had limited functionality in answering to specific policy scenarios such as what would be the effect on population health and health inequalities of ensuring that all employers paid the real living wage?

Nevertheless, incorporating computational (change propagation) analysis into online PSM opens up new opportunities towards developing Cybernetic-enabled system maps which enable not only population of the map but also the computational analysis to be done in real-time so that it can feed back immediately into the workshop. This is a non-trivial exercise which requires more work in this multi-disciplinary area, such as developing computational capabilities, new tools (such as the primary work on cloud-based computational analysis tool presented in Hassannezhad et al., 2022) , and the right set of skills.

5.5. Evaluation

Central to the evaluation process in this study has been the need to understand *what is a good enough representation*? And how much detail is required by the policy organization to understand how the system functions? At this stage, while it was generally accepted that the proposed process could successfully develop a common ground for such a complex system of *IncEc*, important concerns arose about the tension between granularity of information (required by different user groups) and generality of its use (across the consortium and policy partners). For example, participants “found the discussion of the strength, directionality of influences, and causality quite interesting” but also suggested to allocate “more time to review and revise the initial maps from across the groups” – either during or after the workshop. With regards to the efficacy of the proposed method, the authors note that it was not possible to run a parallel traditional PSM given the Covid-19 restrictions in place at the time of the research, as such there is no direct comparison to be made to show 5X’s comparative level of efficacy – but this may be a route for further research. It would also be useful for further work to study the alignment between evidence that come from policy workshops with relevant evidence in scientific literature, potentially to verify the findings and fulfilling the gaps based on scientific evidence.

5.6. Concluding remarks

5X is a move towards digitalization of modelling with continuous stakeholder engagement, with the goal to develop better more comprehensive systems maps and to enhance their utility by providing the opportunity for a wider range of stakeholders to be involved. Through initial implementation applied to the contested and broad topic of *IncEc* – and under challenging circumstances of Covid-19 lockdown, the proposed method showed a range of potential as an alternative way of running typical mapping exercise which makes an important contribution to the accessibility of mapping processes.

Successful implementation of a fully virtual PSM process within policymaking would be a resource intense process and complex to design. Consequently, documented cases of fully virtual PSM in policymaking is rare. As there is an increase in use of online platforms and tools, this paper makes a valuable contribution to our knowledge of the strengths and limitations of a virtual approach to systems mapping.

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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

The datasets generated and analysed during the current study are not publicly available as they contain confidential information. Requests for regulated access may be directed to the SIPHER Consortium.

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