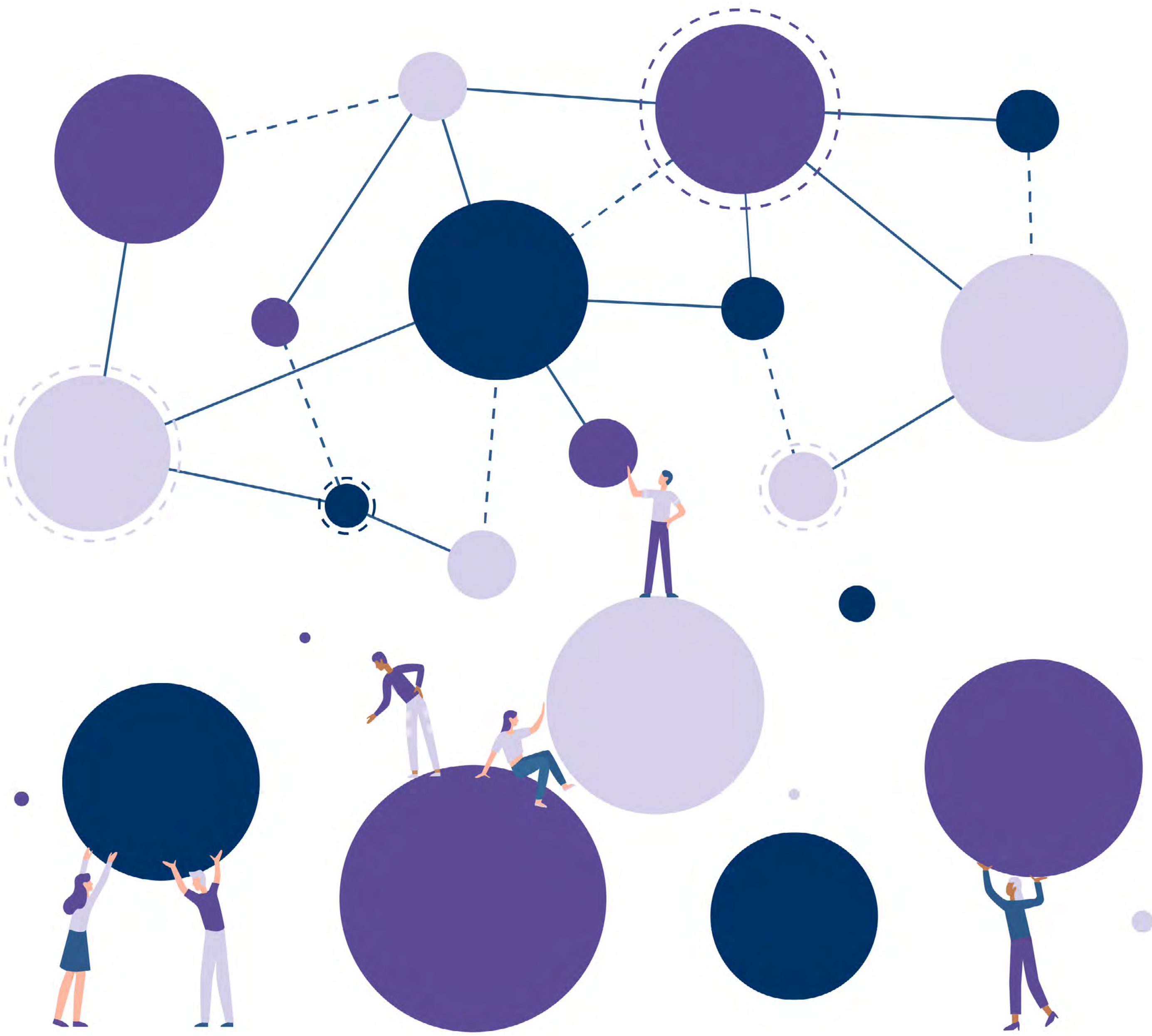
Participatory systems mapping for population health research, policy and practice

Guidance on method choice and design



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Abbreviations

BBN	Bayesian belief networks
CECAN PSM	Centre for the Evaluation of Complexity Across the Nexus - Participatory Systems Mapping
CLD	Causal loop diagram
FCM	Fuzzy cognitive mapping
GMB	Group model building
SD	Systems dynamics
S&F	Stock and flow diagrams
ToC	Theory of Change
UK	United Kingdom
USA	United States of America

Executive summary

What is participatory systems mapping?

Participatory systems mapping engages stakeholders with varied knowledge and perspectives in creating a visual representation of a complex system. Its purpose is to explore, and document perceived causal relations between elements in the system. This guidance focuses on six causal systems mapping methods: systems-based theory of change maps; causal loop diagrams; CECAN participatory systems mapping; fuzzy cognitive maps; systems dynamics models; and Bayesian belief networks.

What is the purpose of this guidance?

This guidance includes a Framework that aids the choice and design of participatory systems mapping approaches for population health research, policy and practice. It offers insights on different systems mapping approaches, by comparing them and highlighting their applications in the population health domain. This guidance also includes case studies, signposting to further reading and resources, and recommendations on enhancing stakeholder involvement in systems mapping.

Who is this guidance for?

This guidance is designed for anyone interested in using participatory systems mapping, regardless of prior knowledge or experience. It primarily responds to calls to support the growing demand for systems mapping (and systems-informed approaches more broadly) in population health research, policy and practice. This guidance can however also be applied to other disciplines.

How was it developed?

The guidance was created by an interdisciplinary research team through an iterative, rigorous five-stage process that included a scoping review, key informant interviews, and a consultation exercise with subject experts.

What is the 'Participatory Systems Design Framework' included in this guidance?

The Design Framework supports users to choose between different methods and enhance the design of participatory systems mapping projects. Specifically, it encourages users to consider: 1) the added value of adopting a participatory approach to systems mapping; 2) the differences between methods, including their relative advantages and disadvantages; and 3) the feasibility of using particular methods for a given purpose. An editable version of the Framework is available to download as a supplementary file.

How will this guidance support future use of these methods?

Participatory systems mapping is an exciting and evolving field. This guidance clarifies and defines the use of these methods in population health research, policy and practice, to encourage more thoughtful and purposeful project design, implementation, and reporting. The guidance also identifies several aspects for future research and development: methodological advancements; advocating for and strengthening participatory approaches; strengthening reporting; understanding and demonstrating the use of maps; and developing skills for the design and use of these methods.

1. Introduction

1.1 Purpose, scope and audience

What is the purpose of this guidance?

The purpose of this guidance is to inform the choice and design of participatory systems mapping approaches in population health research, policy and practice. Systems mapping is the creation of a visual representation of a system to provide an explicit understanding of a complex system. This guidance looks specifically at participatory causal systems mapping. It does not include: (i) non-participatory approaches; or (ii) soft systems approaches that aim to develop non-causal illustrations of a system.

The guidance provides:

- ✓ insight into the range of methods
- ✓ key considerations when comparing different methods
- ✓ an overview of how these methods have typically been used in population health research, policy and practice
- ✓ a Participatory Systems Mapping Design Framework to support the design of projects in population health research, policy and practice
- ✓ insight into how to strengthen meaningful involvement of stakeholders
- ✓ example case studies from population health research, policy and practice, as well as related areas
- ✓ key messages and recommendations to support the use of participatory systems mapping methods

This document should be read in conjunction with other detailed guidance on each specific method; suggested references are included throughout.

Who is this guidance for?

This guidance is relevant for anyone interested in using a participatory approach to systems mapping. It is suitable for readers with or without prior knowledge.

The focus of the guidance is on the application of participatory systems mapping in population health but may be relevant for use elsewhere (e.g. economics, environmental sciences, sociology, etc.). The guidance responds to the increased interest in systems mapping methods in population health research, policy and practice. This has been driven by an increased recognition of the complexity inherent in many population health challenges (see Box 1) and the need for systems-informed policy and research [1].

Box 1. How the concept of complexity is being used in population health research, policy and practice

The concept of complexity is increasingly used in population health research, policy and practice to characterise:

- Population health challenges with many interconnected determinants across different domains
- Interventions and programmes designed to address these challenges
- The contexts in which these interventions and programmes take place
- The consequences of these interventions

Intervention development and implementation are common but not inevitable endpoints of participatory systems mapping activities. Population health researchers are interested in how these four complexity-related concepts interact.

For further reading see: [1-4]

Which systems mapping methods are included?

Systems mapping has many definitions and meanings. This guidance focuses on causal systems mapping methods. In brief, we consider systems mapping as the creation of visual representations of complex systems, their constituent parts, and the causal relations between these parts (see page 15 for a more detailed explanation). The following six methods are included in this guidance:

1. Systems-based theory of change (ToC) maps
2. Causal loop diagrams (CLD)
3. The CECAN participatory system mapping (PSM) method
4. Fuzzy cognitive maps (FCM)
5. Systems dynamics (SD) models[1]
6. Bayesian belief networks (BBN)

This is not an exhaustive list; other methods may be considered as causal systems mapping (see Appendix A).

What is a participatory approach to systems mapping?

Systems mapping is participatory when a range of stakeholders take part in the process. They either hold knowledge that is important for understanding a system or bring different perspectives on it. The number of stakeholders involved, as well as the timing and extent of their involvement, depends on the context of each systems mapping project and its resources. See Sections 2 and 3 for more details.

1 Systems dynamics modelling often includes creating two forms of system maps: CLDs and stock and flow diagrams (S&F)

How was the guidance developed?

The guidance was developed by an interdisciplinary research team. The process comprised five stages and used a range of methods: desk-based research, primary data collection and a consultation process (Figure 1). Full details about each of the research stages are provided in Appendix B.

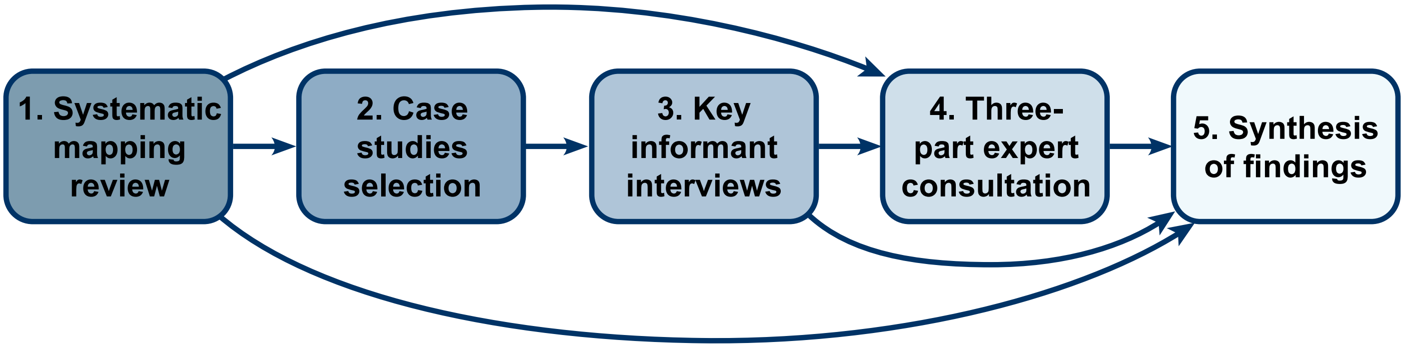


Figure 1. The five stages of guidance development

1.2. Structure of guidance document

This guidance is structured as follows:

Section 2: introduction to systems thinking.

Section 3: overview of systems mapping and participatory approaches. Introduction to the six participatory systems mapping methods.

Section 4: introduction to the Participatory Systems Mapping Design Framework: a tool to navigate the choice of method and design of a participatory systems mapping project. A downloadable and editable template of the Framework is available as Supplementary file 1.

Section 5: summary of the findings of a systematic scoping review on how participatory systems mapping methods have been used in population health.

Section 6: overview of 10 international case studies that highlight examples of best practice and key features of different participatory systems mapping methods. Full case studies are available in Appendix C.

Section 7: concluding remarks with a summary of the benefits, challenges, and opportunities of using participatory systems mapping approaches in the population health domain.

References

Supplementary file:

- Editable version of the Participatory Systems Mapping Design Framework ([Supplementary file 1](#))

Appendices:

- List of other participatory systems mapping methods (Appendix A)
- Methods used for guidance development (Appendix B)
- 10 case studies (Appendix C)
- Glossary of terms (Appendix D)
- List of useful resources on participatory systems mapping methods (Appendix E)
- Examples of systems mapping software packages (Appendix F)

2. Systems thinking – introduction and overview

This section provides a brief introduction to systems thinking, and its role in understanding and addressing complexity in population health research, policy and practice. The following questions are discussed:

- What is a system?
- What is a complex system?
- What is systems thinking and why use it?

2.1 What is a system?

A system is defined by a set of factors and/or actors (e.g. a behaviour, people, or organisations) that interact with one another. While the boundaries that delineate a system can be drawn in different ways, systems may be broadly categorised as simple, complicated, or complex. This guidance focuses on methods that facilitate consideration of complex systems; the other types are:

- Simple – these systems are understood easily. They have a minimal set of sub-systems, and there are clear cause and effect relations between the function of the system's parts and the outcome. If individual parts of the system are changed, the likely effect is predictable and reproducible [5]. A bicycle can be used as an example of a simple system. It has many component parts, and no single part operates the bicycle alone. It can only be ridden when all the parts work together. Its function is fully predictable.
- Complicated – these systems are defined as complicated in terms of their scale (e.g. the number of component parts or difficulty of a problem they influence) and the degree to which specialist expertise and coordination is required to understand the system and influence change. They typically contain sub-systems that interact in a definite and predictable pattern [5]. A space rocket is as an example of a complicated system. Compared to a bicycle, it has many more component parts, which typically require specialist expertise to understand and operate. Nevertheless, if operating correctly, the component parts of a space rocket lead to a predictable outcome.

2.2 What is a complex system?

Complex systems are defined by several attributes, including:

1. Change over time – complex systems are dynamic; they change and develop their behaviour over time. This is because they interact with their environment and other systems, allowing information, people, or materials to be exchanged [6]
2. Emergence – the properties and behaviours of the system cannot be predicted from analysing its individual components [7], and it is therefore said to be greater than the sum of its parts [1]. For example, the unequal distribution of health across a population is an emergent property of the interactions between employment, environment, food, housing, and other systems that influence population health
3. Feedback – a change in a system may either reinforce or suppress further change. For example, if fewer people commute by car, then the number of people cycling to work may increase. This may increase the appeal of active commuting and lead to further reductions in car journeys and more active travel [8]. This is an example of a reinforcing feedback loop

4. Non-linearity – this means that the outcome, or effect of an input on the system, is not proportional to that input [6]. For example, the effect of a new public health programme to reduce smoking may initially be slow but at some point, smoking prevalence will rapidly decline, before slowing again or even increasing
5. Adaptation – elements or people within the system can learn and evolve to exhibit new ways of behaving in response to interventions, or other changes in the system [6]. For example, in response to a new UK tax imposed on manufacturers and importers of high-sugar drinks (the Soft Drinks Industry Levy), some of the additional costs to businesses were passed on to consumers, but not always on targeted drinks (note, adaptation is not a feature of all complex systems) [9]

Readers interested in finding out more about types of systems and their implications for decision-making in practice may find the Cynefin Framework helpful [10]. More detail about the properties of complex systems is provided by Barbrook-Johnson et al., 2020 [11].

2.3 What is systems thinking?

Systems thinking is about seeing the 'bigger picture.' The term is used to describe a range of methods, theories, and concepts that are applied to make sense of systems and are particularly helpful when addressing complex systems [2]. See Peters (2014) for a summary of the key approaches [12]. These may include a range of simple thought tasks (e.g. to consider how one's area of interest affects, or is affected by, the bigger picture), qualitative methods (e.g. soft systems methods) and quantitative approaches (e.g. simulation). Here are six ways systems-thinking can be applied to population health research [2, 12-14]:

- Exploring causal pathways
- Understanding the contextual influences on problems of interest
- Understanding the structure and boundaries of systems
- Examining the relations between actors (e.g. people or organisations) and the wider system
- Determining places to intervene in a system for population health benefit
- Hypothesising the impacts of interventions as events in complex systems

2.4 Why use systems thinking?

In addition to helping people understand and explore complex systems, systems thinking has numerous beneficial applications. This includes understanding and evaluating the context surrounding interventions, or developing whole system perspectives that support systemic change [15]. Jebb et al. 2021 [3] argued that applications of systems thinking may be considered as a continuum, ranging from low to high degree of systems thinking. In particular, the following applications have relevance to the systems mapping methods presented in this guidance:

- Identifying people, institutions, structures and actions (behaviours) that collectively influence population health problems
- Mapping the interactions and relations between system elements (including target populations)
- Collaborating with stakeholders to harness multiple perspectives in understanding problems, contexts and solutions
- Using maps and models to identify potential points for intervention, as well as unintended consequences and adaptive responses that may enhance or inhibit interventions

- Developing computer models or simulations to quantify relations and to explore dynamic system behaviour, and the potential impact of interventions over time
- Building complex dynamic computer models that include adaptive responses and feedback loops and are grounded in evidence-based models of how people and communities behave

Potential outcomes from systems-thinking

1. Identifying systems problems

Systems problems are the consequences of multiple interactions within the overall system. Problems that emerge in one part of the system tend not to remain localised, rather their impact has a cascading effect that propagates changes across the system. In this way, specific observable issues are likely to be both cause and effect of wider systemic problems [3, 16].

2. Identifying ways to address systems problems

Addressing systems problems requires a big-picture perspective, which acknowledges how influences on health at various levels (including individual, social, and environmental factors) interact with each other. Systems thinking enables the identification of leverage points for intervention through, for example: (i) increasing recognition of patterns and repetition associated with problems; (ii) identifying feedback loops that are (un)helpful for creating the intended change in the system (see glossary, Appendix D); (iii) exploring where resources are being taken up by individual parts of a system at the expense of the wider system; or (iv) identifying key sinks (i.e. factors that do not influence anything else) and drivers (i.e. factors that influence a problem, but are not influenced by it) in the system [3, 17].

3. Turning 'mental models' into explicit ones

People hold a range of assumptions and ideas about what systems look like. These 'mental models' include views about their constituent parts, what sits within and outside the system boundaries, and how the system behaves. Systems thinking encourages the conversion of these 'mental models' into explicit models through a range of different visual, quantitative, or qualitative techniques (including, but not limited to, participatory systems mapping). This enables people to reconcile different implicit models (people's perspectives/'mental models'), and better understand a system's constituent parts, boundaries, and interactions. It also enables people to understand how different activities or changes in one part of the system may affect other parts, sometimes in unexpected ways [7].

4. Broadening perspectives

In the absence of systems thinking, a narrower focus on the relations between inputs and outcomes is taken. This is often a linear, sequential process, for example as used in causal analysis or in logic model-based planning of interventions. While effect modifiers and contextual factors may be considered within this narrower approach, systems thinking facilitates the conceptualisation of causal relations within a wider understanding of the system, and of interventions as disruptive interruptions in systems. This broader way of thinking fundamentally challenges how research questions are prioritised, away from identifying linear causal relations and effective interventions, toward understanding how systems function, and identifying what might contribute to system change, under what circumstances, and why [12, 18].

5. Gaining alternative perspectives

Systems thinking approaches typically draw insight from a range of stakeholders, enabling the identification of differences in understanding and facilitating the creation of a collective understanding of a system, including of how different individuals, populations, organisations, and sectors relate to one another. For example, gaining alternative perspectives enables stakeholders with expertise and agency at one level (e.g. national policymakers) to gain insights into the perspectives of those working at other levels (e.g. those with lived experience or community organisers). Crucially, a systems thinking approach enables identification of, and contribution from, actors who uniquely hold knowledge specific to different parts of a system [2, 13].

6. Creating a platform for learning

Systems thinking has the potential to generate tools and a language to better understand and address population health challenges at local, national, and global levels through enhanced synergy and coherence across different activities and processes [13, 14, 19].

3. Participatory systems mapping methods – introduction and overview

This section of the guidance introduces participatory systems mapping methods, covering the following aspects:

What are system maps?

- How have systems mapping methods developed over time?
- What are the purposes and benefits of systems mapping?
- Why use participatory approaches to systems mapping?
- What are the key features of different causal systems mapping methods?

3.1 What are system maps?

System maps are visual representations of systems. They are used to illustrate the different elements in a system, the relations and interactions between these elements, and processes that occur as a result of these relations and interactions (e.g. feedback loops, or sometimes trends over time – see glossary in Appendix D). This guidance relates specifically to a subset of methods: participatory systems mapping to represent causal relations.

It is important to highlight that the term map is often used synonymously with the word model. Barbrook-Johnson and Penn (2022) provide a more in-depth discussion and show that most types of system maps share three core components (see Figure 2 for an illustrative example) [20]:

- **Elements** (also referred to as nodes, entities or factors): These are the constituent parts of the system and are usually depicted as boxes or bubbles.
- **Connections** (also referred to as edges, relations, links or arcs): These show the direction, and sometimes strength, of relations between elements. They are commonly drawn as lines or arrows. Often, system maps include a polarity mark (e.g. '+' or '-') for each causal connection, which distinguishes whether the relation between elements is positive or negative. See Section 3.4.1.2. for further information.
- **Networks**: These are the collective set of elements and connections that represent the system, or part of a system. These illustrate the structure and how the multiple elements interconnect.

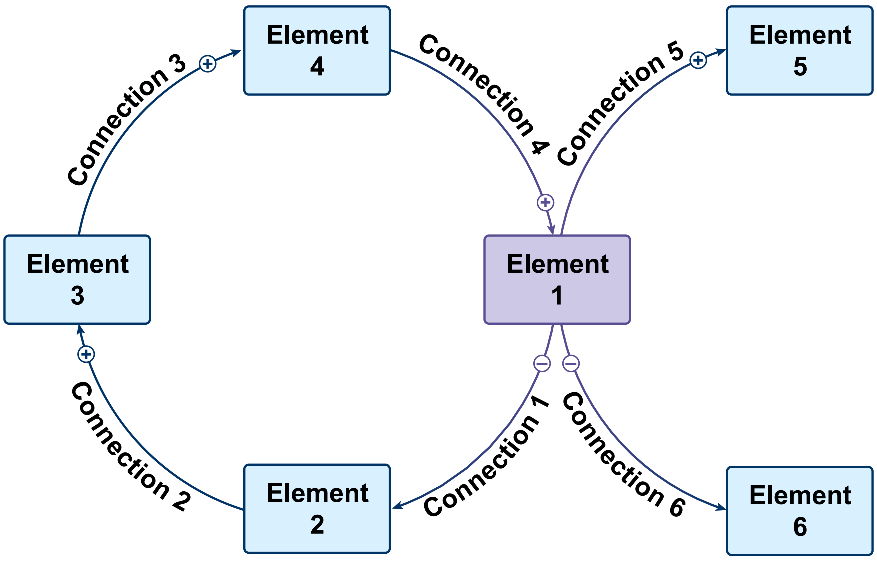


Figure 2. Schematic illustration of the core components of a system map

3.2 What are the purposes and benefits of system maps?

System maps can be used as both thinking and communication tools [17, 20], in order to:

- **Understand or describe what a system looks like, by making ‘mental models’ explicit:** Systems mapping enables users to consider the elements and connections within a system of interest through a formal process. This allows people to better understand how the characteristics of systems (see Section 2.1) influence outcomes, by creating a visual representation of these complex arrangements and processes. The process of systems mapping can be enhanced through participatory approaches (see section 3.3), which encourage people to share their views of the system (their ‘mental models’) and discuss their differences, to elicit, present and communicate a shared understanding of what the system looks like - and how it operates - in an explicit form [3, 17, 21].
- **Bring information together:** Systems mapping can facilitate the collection and assimilation of diverse types of knowledge, information and evidence on a topic of interest, which includes but also extends beyond the knowledge of participants involved in the process. These may be used at various stages of the mapping process but come together to create an understanding of the system that would otherwise remain partial, or potentially, unknowable [20].
- **Explore possible causality:** The types of system maps discussed in this guidance provide a starting point for users to consider the causal processes (often referred to as mechanisms) that underpin the relations between elements in a system and how it can be held in equilibrium through reinforcing or balancing feedback loops [21-23]. Systems mapping methods enable the visual exploration of a system’s hypothesised structures, causal relations and change in these over time [20].
- **Consider influence and intervention:** Systems mapping can help users identify possible leverage points for intervention to improve system outcomes. A leverage point is the part of a system where a shift in one or more elements can produce substantial changes across the system, even if the initial alteration is relatively small. However, there is no ‘gold standard’ method of identifying leverage points; various qualitative or statistical methods are used [24, 25]. Often this involves examining feedback loops to identify possible levers that may be more likely to lead to sustainable, self-reinforcing change. Alternative techniques include network analysis or using the expert knowledge of key stakeholders. Systems mapping can also help people consider how a system can change over time, and what the range of consequences could be. It can also support understanding the possible barriers to intervention and decision-making, to mitigate unintended consequences or potential system adaptations. Furthermore, users can reflect on what data may be necessary to monitor or evaluate interventions [3, 17, 21].
- **Build simulations:** A system map typically shows a hypothesised conceptual model of a system at a given point in time. However, sometimes, systems mapping is used as an important early step in creating models to predict how a system or an outcome of interest may change over time, typically because of a proposed intervention. For example, causal loop diagrams are often used in the development of simulations and other computer-based models, such as systems dynamics models [20]. Both causal loop diagrams and systems dynamics models are introduced in Section 3.4.

- **Involve stakeholders:** Involving stakeholders to develop maps can help build a common understanding and vision of a system. Using participatory approaches supports understanding of the multi-sectoral nature of population health issues. It can strengthen partnership working, determine whether interventions are likely to be acceptable or feasible, and understand issues that matter to all stakeholders beyond the focal population health problem. The mapping process can also serve as an intervention itself, as participants gain novel insights into their system and other people's differing perspectives on it, build relations with each other, learn to appreciate complexity, and consider leverage points for systems change [3, 17, 21].

3.3 Why use participatory approaches to systems mapping?

A participatory approach to systems mapping means actively involving a range of stakeholders external to the core team at one or more stages of the mapping process. These stakeholders may hold diverse, yet relevant, perspectives about the system. Alternatively, they may have important knowledge about different parts of the system and in their role, they may have potential to meaningfully influence it. Participants in systems mapping should ideally represent a range *of 'people or organisations with an interest in the problem and its (re-)solution'* (p.2) [26].

Participatory approaches in population health are increasingly required by those funding and commissioning research and intervention design (for example, through patient and public involvement (PPI), as well as engaging with policymakers or other professionals) [27]. Although not widespread, efforts have been made to increase participation of stakeholders in complexity and systems approaches to population health problems [28].

While many systems mapping methods can be used without the participation of stakeholders, all can be designed to include a participatory approach. The involvement of stakeholders may range from a low to a high degree across the map building process. Certain methods have participatory design at their core (e.g. CECAN PSM, see Section 3.4.1.3). In population health research, participatory approaches to systems mapping have been most common in projects using causal loop diagrams and systems dynamic modelling. More detail about the use of participatory approaches across different methods is provided in the summary findings from a scoping review (see Section 5).

Key reasons for using a participatory approach include [20, 29]:

- To harness participants' domain-specific expertise for map development
- To capture stakeholders' 'mental models'
- To identify congruent, convergent and divergent views
- To encourage social learning between participants about diversity in views
- To foster joint problem framing to ensure the map is focused on priority questions
- To promote trust and acceptance of stakeholders in the system map
- To produce context-specific solutions
- To increase the likely success and buy-in of interventions and programmes

3.3.1 Who should be involved and how to ensure meaningful participation

The discussions taking place during the participatory systems mapping process are key to understanding the system being studied. The number and diversity of stakeholders to involve depends on the context of each project and its resources. It is rarely possible to involve all stakeholders, and therefore decisions must be made about whose perspectives are critical to understanding the system and its parts, whilst ensuring a range of views.

Involving people with lived experience of the system or problem of interest in the mapping process is key to ensuring the views of the people with direct knowledge of the issue are included (e.g. someone living with diabetes). Studies increasingly include these experts-by-experience in their mapping. See case studies 1 and 9 (Section 6 or Appendix C) for interesting examples.

Across all systems mapping methods, there are several considerations for ensuring meaningful involvement of stakeholders. In particular, the experts who were consulted in the development of this guidance recommended the following:

- Clearly communicate the purpose of stakeholder involvement in mapping activities
- Ensure the chosen process and content is accessible to all stakeholders (including language, format, etc.)
- Start by setting clear research questions and boundaries around the system under consideration (see glossary, and case studies 4 and 6)
- Ensure the system is well-defined, or consider focusing on a sub-system
- Accept that the process will involve trade-offs due to competing interests and agendas of the various stakeholders. However, some tension or conflict can be productive, provided there are clear rules for involvement that support positive group dynamics and a safe space for discussion
- Invest in skilled facilitation to help manage problematic power dynamics
- Provide regular feedback to stakeholders between systems mapping activities to maintain engagement with the process

The Participatory Systems Mapping Design Framework (Section 4) supports users of this guidance to assess the relevance of different mapping approaches to their work and explains how to design and plan for participation. Stakeholders can take part in map building using various approaches (e.g. group model building, interviews, focus groups, surveys), and this may differ at each stage of the process. Case studies 1, 8 and 9 (Section 6 or Appendix C) provide useful examples of highly participatory systems mapping projects.

Box 2. Five considerations in choosing a participatory approach

- *Who defines the problem or system under consideration?* Which group(s) will have a say in defining the problem? Will it be the stakeholder group, the project team, other external groups such as funding institutions or a combination of these?
- *How structured will the process be?* This can range from an iterative and open process to a more formalised structure.
- *What types of map(s) will be developed to ensure stakeholders can take part in the process?* The complexity of the map (number of factors, wording used) will influence the extent to which stakeholders feel able to engage.
- *Will the process begin with a blank page/board or a pre-existing map?*
- *How involved will stakeholders be in determining the analysis needed?*

Adapted from Vennix et al. (1996) [30].

3.4 What are the key features of different systems mapping methods?

Understanding and use of system maps has developed extensively since the emergence of systems dynamics modelling in the 1950s. However, the historical roots can be traced much further. Figure 3 provides a timeline of key developments in systems mapping methods included in this guidance.

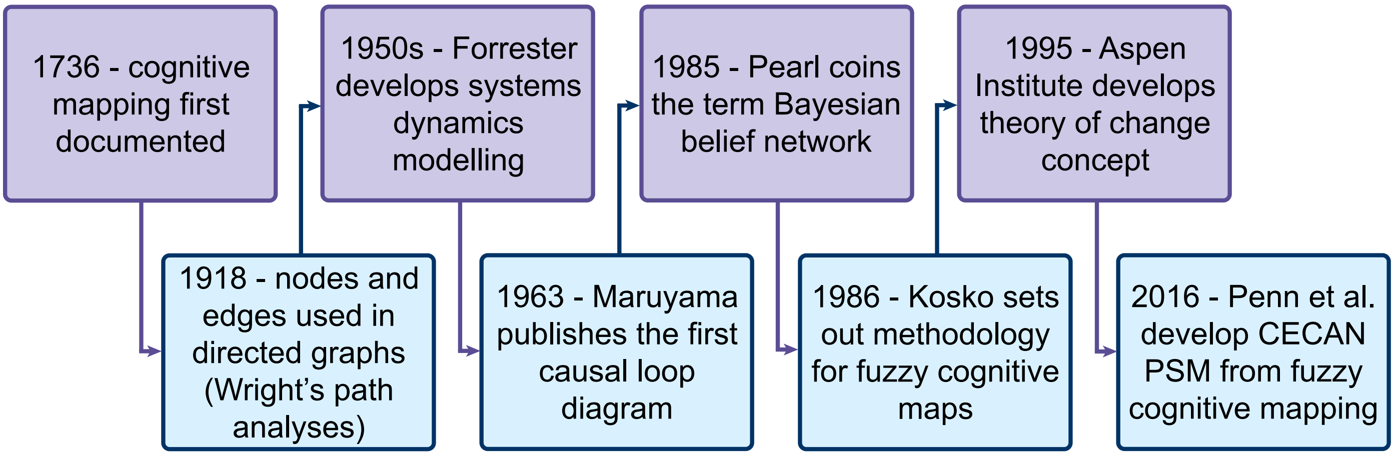


Figure 3. Timeline of key methodological developments in causal systems mapping

The following are a few key facts on the development of these methods:

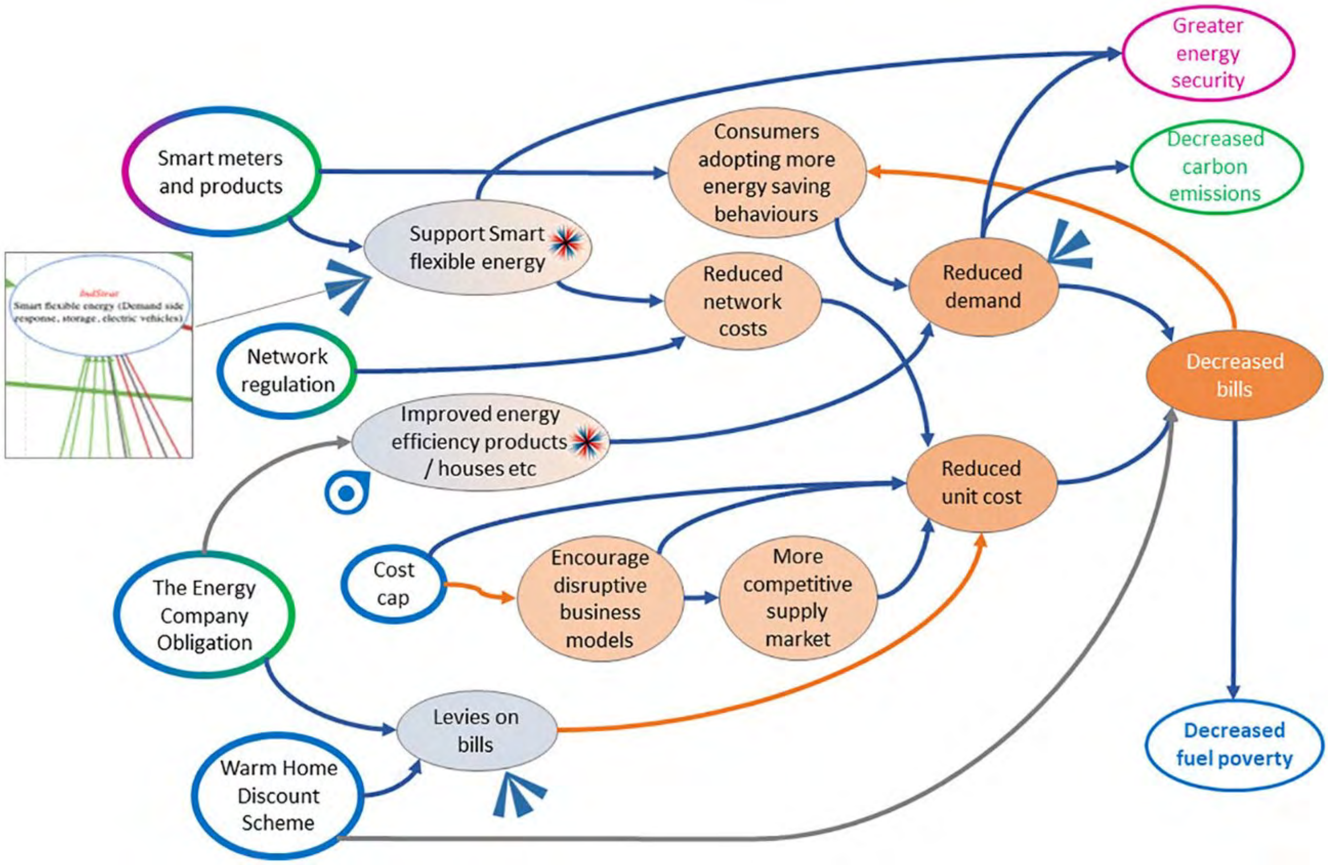
- Causal loop diagrams were first used in, and have since become entwined with, systems dynamics in 1968, primarily to communicate model designs
- Pearl and Neapolitan developed Bayesian belief networks from Pearl's earlier work on graph theory, which often included Bayesian statistics
- Fuzzy cognitive mapping was adapted from Axelrod's work on cognitive mapping. Participatory approaches and applications of the method have grown significantly since about 2000
- Systems-based theory of change mapping is a more recent development in the theory of change field, and grew in response to models often being linear and narrow in focus
- CECAN PSM was designed to overcome issues of sensitivity to researcher assumptions in the analysis of fuzzy cognitive maps, and emphasise the view of stakeholder input more by using subjective network analysis

The following sections provide a brief description of selected systems mapping methods, all of which can be used in a participatory way. Each description is accompanied by an illustration of a published system map to enable visual comparison of methods.

More qualitative methods are shown first, followed by more quantitative methods. Within these groups, methods are ordered from the conceptually simplest through to more challenging approaches.

3.4.1 Qualitative systems mapping methods

3.4.1.1 Systems based Theory of Change (ToC) maps



[View original systems-based Theory of Change diagram]

Figure 4. Example of a systems-based Theory of Change diagram on the energy trilemma system. Source: [31]

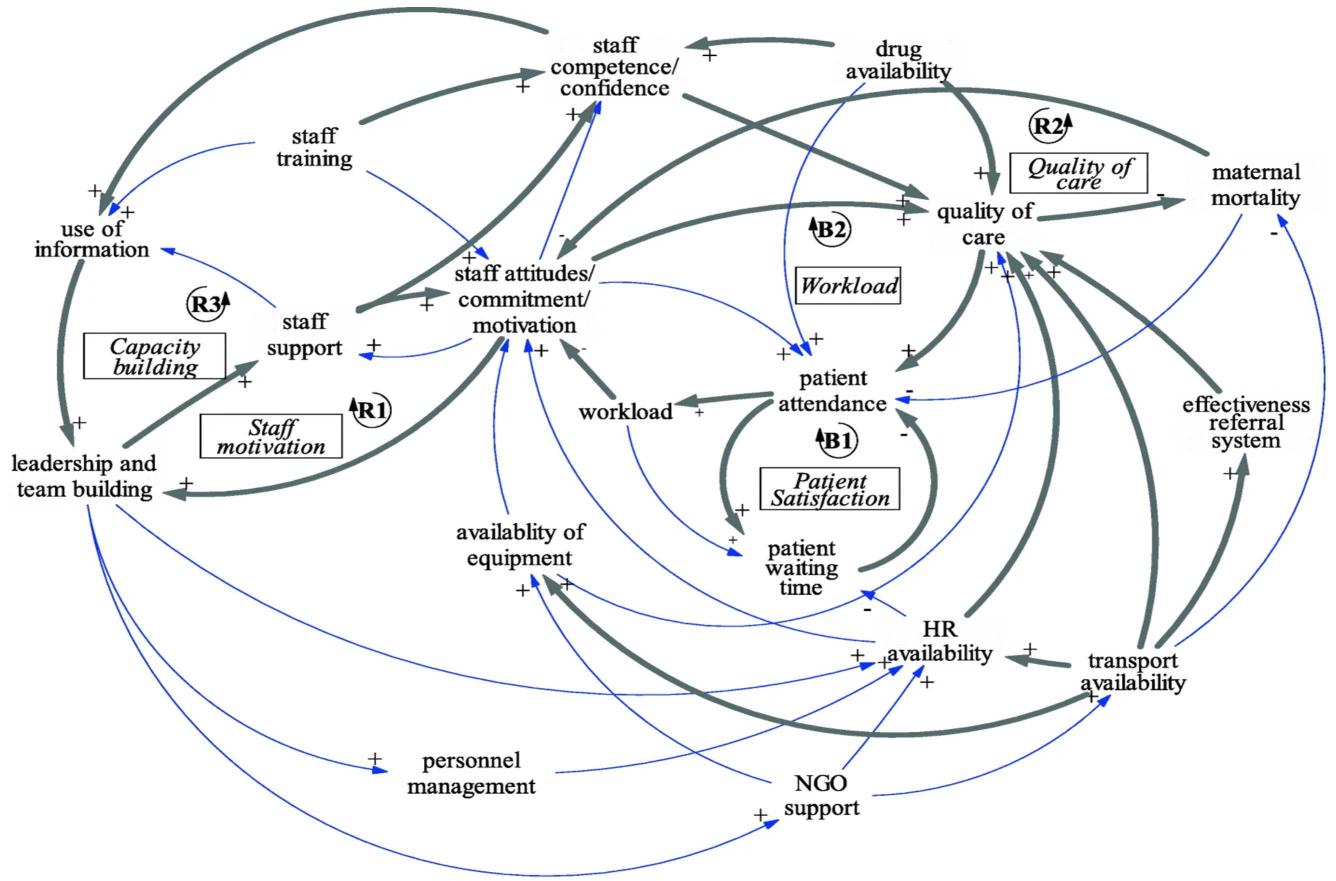
Systems-based ToC mapping is an emerging method that is designed to overcome challenges of established ToC models (e.g. typically linear models). Theory of change is an approach to *'framing, structuring, and implementing the design and evaluation of interventions'* (p.33) [20]. It is a means to develop and communicate how and why key aspects of a programme or intervention are expected to influence the intended aims and outcomes being sought in a particular context. The ToC field is diverse[2]; this guidance focuses on systems-based ToC.

Systems-based ToC mapping removes the need to assume linear, acyclic change by establishing the complex causal arrangement of factors between points of intervention and outcomes. Different systems mapping methods, such as those included in this guidance, can be used as the starting point for developing a systems-based ToC map [31]. It tends to be less formal and is developed to fit research needs. Many different forms of ToC diagrams exist, and some are more systems-focused than others. Core to all maps, however, are inputs, activities, outputs and outcomes; systems-based ToC maps rarely include feedback loops.

The method lends itself to policy and evaluation-focused questions [32], but is generally intended to explain the logic or theory of any intervention at the point of design or evaluation. Often, these incorporate the framework of logic models to map the inputs, activities, outputs, outcomes and impacts of an intervention, as well as key assumptions. This approach is distinct from, but related to, methods such as programme theory development, logic mapping, logic modelling, results chaining, or outcome mapping [15, 20].

2 See: The Centre for Theory of Change

3.4.1.2 Causal loop diagrams (CLD)



View original causal loop diagram

Figure 5. Example causal loop diagram. Source: [33] – see case study 6

Causal loop diagrams provide a qualitative picture of a system's structure. One of their purposes is to identify feedback loops, which can help explain how systems behave, and in turn how these behaviours lead to particular outcomes associated with problems of interest. These maps comprise a series of theorised causal relations between elements in the system; the elements are expressed as factors that may increase or decrease. The relations may be expressed as either positive (sometimes called 'same direction' – see Figure 6) or negative (sometimes called 'opposite direction' – see Figure 7). Positive relations signify that an increase in one element leads to an increase in an element to which it is connected; alternatively, a decrease in one element leads to a decrease in an element to which it is connected. Negative relations signify that causal influences between elements are opposite; an increase in an element leads to a decrease in another, or alternatively a decrease leads to an increase.

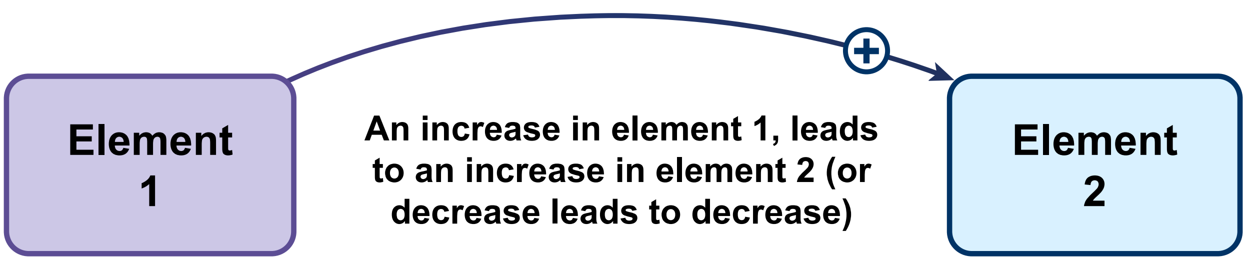


Figure 6. Example of a positive connection in a CLD (change in the same direction)

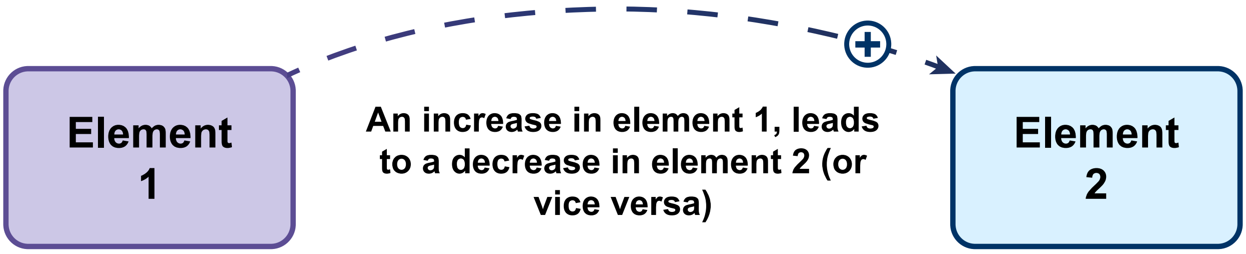


Figure 7. Example of a negative connection in a CLD (change in the opposite direction)

The relations in a CLD connect multiple system elements in dynamic and circular ways [34]. The resultant feedback loops (see glossary – Appendix D) may have a reinforcing or balancing effect (i.e. a change in system behaviour is reinvested in further change, or alternatively further change is resisted, and the *status quo* perpetuated). In the loops below (taken from the above example CLD), the loop on the left (B2) is balancing and the loop on the right (R2) is reinforcing.

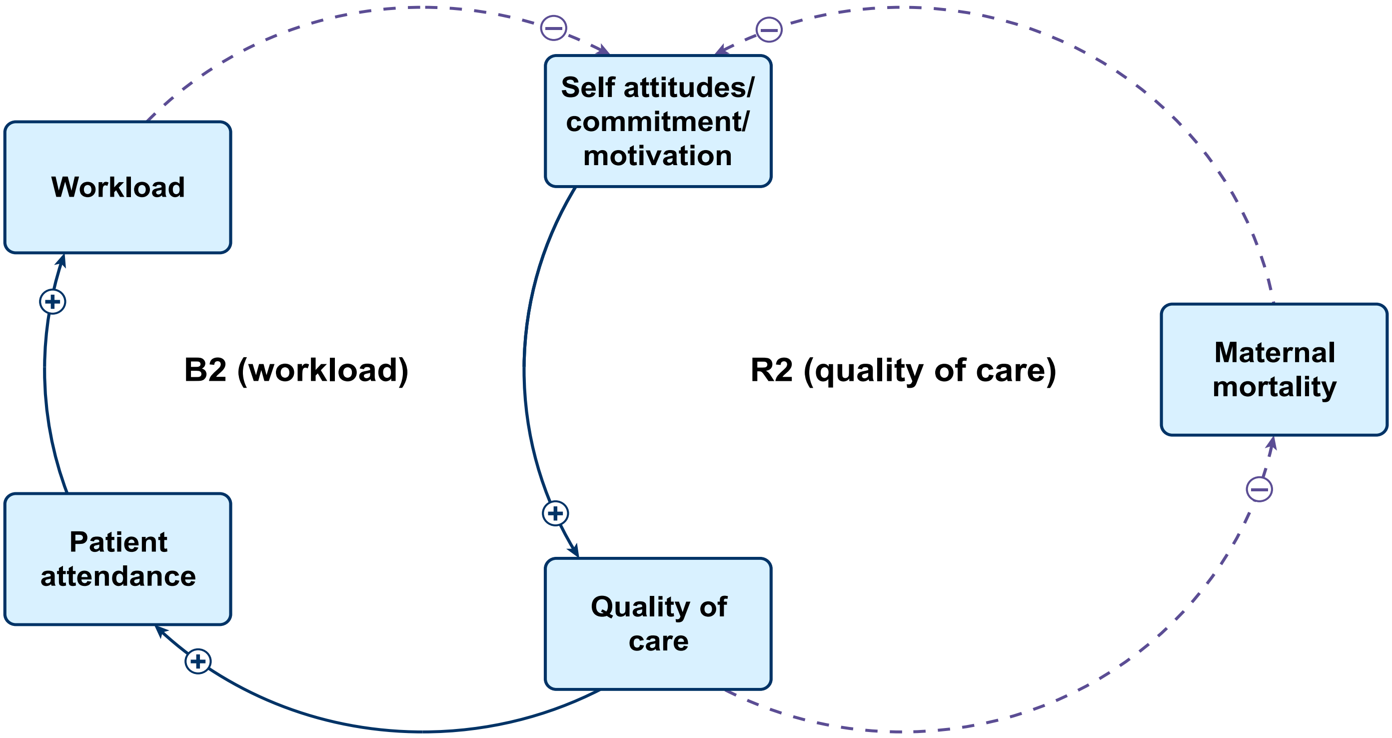


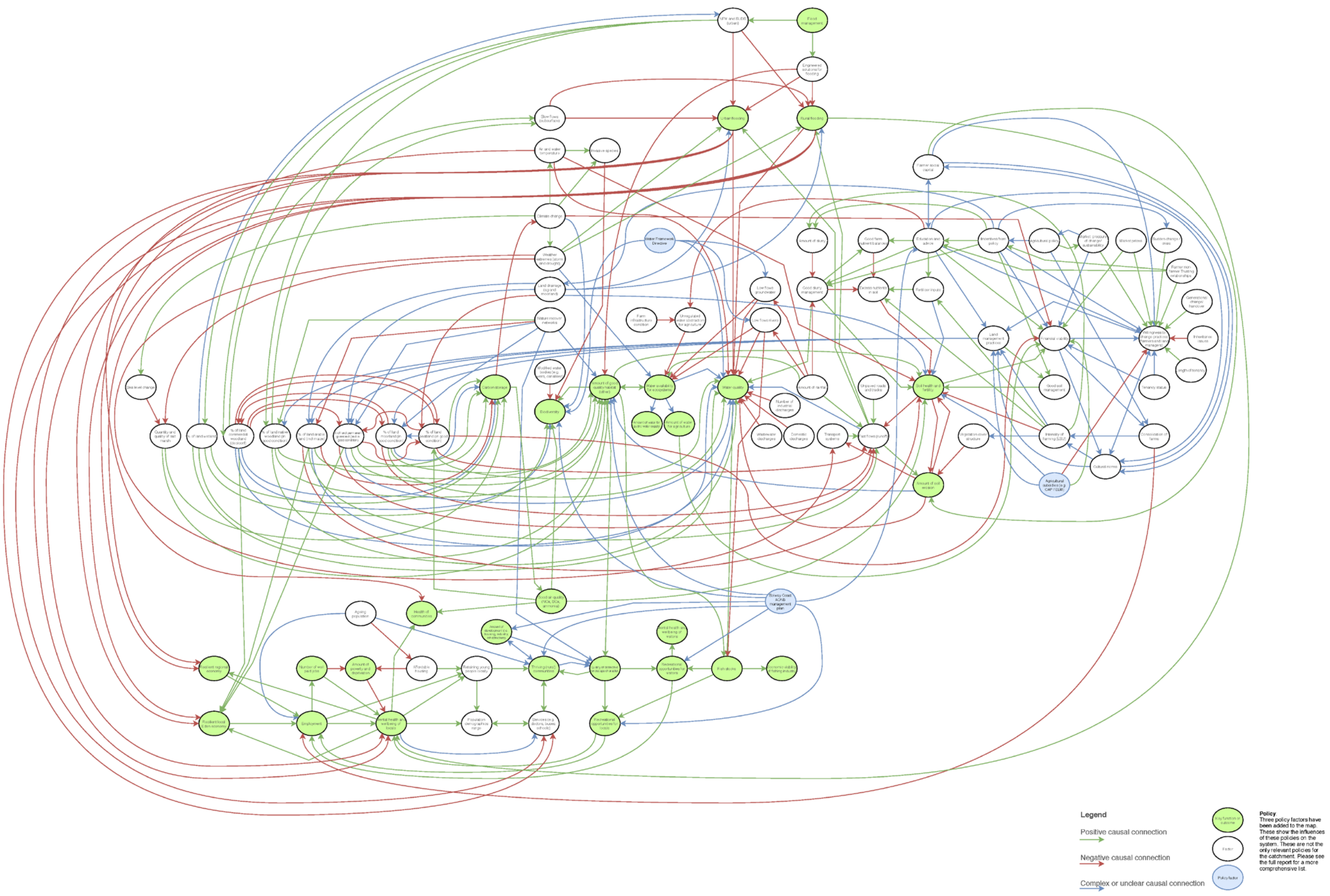
Figure 8. Example of balancing and reinforcing feedback loops – adapted from Lembani et al. (2018) as shown in Figure 5.

- **Balancing feedback loop (B2):** A change in the amount of quality of care (e.g. an increase) causes a change in patient attendance in the same direction (i.e. increase). A change in patient attendance (i.e. increase) causes a change in workload in the same direction (i.e. increase). The increase in workload leads to a decrease in staff attitudes/commitment/ motivation, which in turn causes a change in quality of care in the same direction (i.e. quality of care decreases). Thus, the initial increase in quality of care is reduced or balanced out. This cycle of causal direction continues. Balancing feedback loops can be identified by counting the number of negative (opposite direction) connections; if there is an odd number, then it is a balancing feedback loop [35].

- **Reinforcing feedback loop (R2):** In this case an increase in quality of care will cause a decrease in the rate of maternal mortality (i.e. change in the opposite direction). In turn, this increases staff attitudes/commitment/motivation – also a change in the opposite direction. This then compounds to further increase quality of care, and the cycle perpetuates. The opposite scenario is also self-reinforcing, whereby an initial decrease in the quantity of quality of care will lead to, in theory if not practice, an ever-decreasing cycle. Reinforcing feedback loops have an even number of negative connections.

Some CLDs are structured around what is known as a 'system engine.' This means that they are focussed on a set of elements that are considered core to the system, which often include a few key feedback loops and are visualised more prominently in the map (e.g. see case study 2). Alternatively, other CLDs that have no clear 'engine' are known as fluid CLDs. Causal loop diagrams are sometimes also referred to as influence diagrams or simply system maps [20].

3.4.1.3 CECAN PSM



[View original CECAN PSM map (under deliverable 8)]

Figure 9. Example CECAN PSM map. Source: [44]– see case study 10

CECAN PSM[3] is similar to other causal systems mapping methods (e.g. CLDs or fuzzy cognitive maps). However, this approach extends beyond these methods and has several distinguishing features that warrant its inclusion as a distinct method [20]. Its primary purpose is to emphasise and facilitate actionable outcomes from the mapping process by identifying important and controllable components of a system, including those particularly susceptible to change. Of particular importance is that participant-driven applications of network analysis principles are

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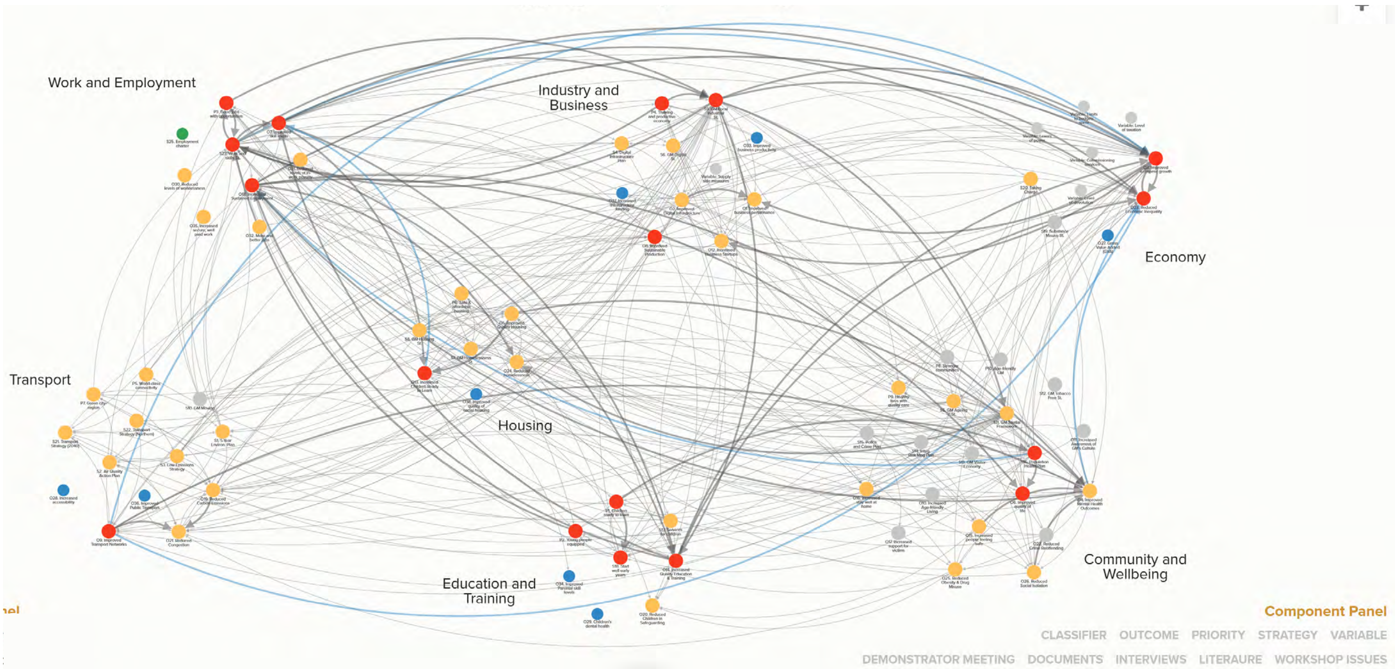
3 Researchers at the Centre for Evaluation of Complexity Across the Nexus (CECAN) developed their own approach to participatory systems mapping, which they gave the title of Participatory Systems Mapping. This guidance presents a range of causal systems mapping methods that can incorporate a participatory approach. To avoid confusion, the method discussed here, as developed by CECAN, is referred to throughout as CECAN PSM.

used to identify flows and chains of causal relations, and to develop detailed and meaningful sub-maps. This helps make sense of typically large and complex maps. The method therefore allows the construction of large inclusive maps, useful in the process of mapping, but can still produce focussed analyses on specific questions of relevance to stakeholders, useful as key outputs of a process.

CECAN PSM is a particularly useful method where a degree of flexibility is warranted, but a clear structure around the map is also required. It offers this structure in data poor contexts, or where there is likely to be insufficient understanding to develop a systems dynamics model. In this way, it is situated between the qualitative flexibility of methods such as CLDs and formal quantitative approaches (e.g. Bayesian belief networks and systems dynamics models). CECAN PSM seeks to present a solution to interpreting overly complicated and complex maps, without losing depth of understanding.

3.4.2 Semi-quantitative systems mapping methods

3.4.2.1 Fuzzy cognitive maps (FCM)



[View original fuzzy cognitive map]

Figure 10. Example fuzzy cognitive map. Source: [36] – see case study 5

Fuzzy cognitive maps (FCM) illustrate semi-quantitative ‘mental models’ of a system [37]. These maps are made up of elements and connections, which depending on the type of FCM, are assigned different numerical values by those taking part in the mapping process. The factors themselves can be either abstract or measurable. In brief, FCM acknowledges uncertainty in the knowledge of causal processes in complex systems. Their primary purpose is to identify the most influential causal factors, explore what may happen to other factors of a system if something is changed, and examine and compare stakeholders’ ‘mental models’.

Essentially, there are two broad types of FCM, which Barbrook-Johnson and Penn (2022, p.80) term *‘causal’* and *‘dynamical’* [20]. The first type (causal) is based on the idea of fuzzy logic, which is to say the connections between factors in the map are weighted to reflect degrees of truth about the state of a factor and its relation to others (i.e. the proposed certainty with which a causal chain in the map truly exists). The alternative type (dynamical, as presented in Figure 10 above) is more common in population health-related applications. It provides a representation of the proposed strength of causal change between factors, therefore helping to identify which factors are most likely to be influential in a system. Table 1, which has been reproduced from Barbrook-Johnson and Penn (2022, p.82), outlines the key differences between the two types of FCM.

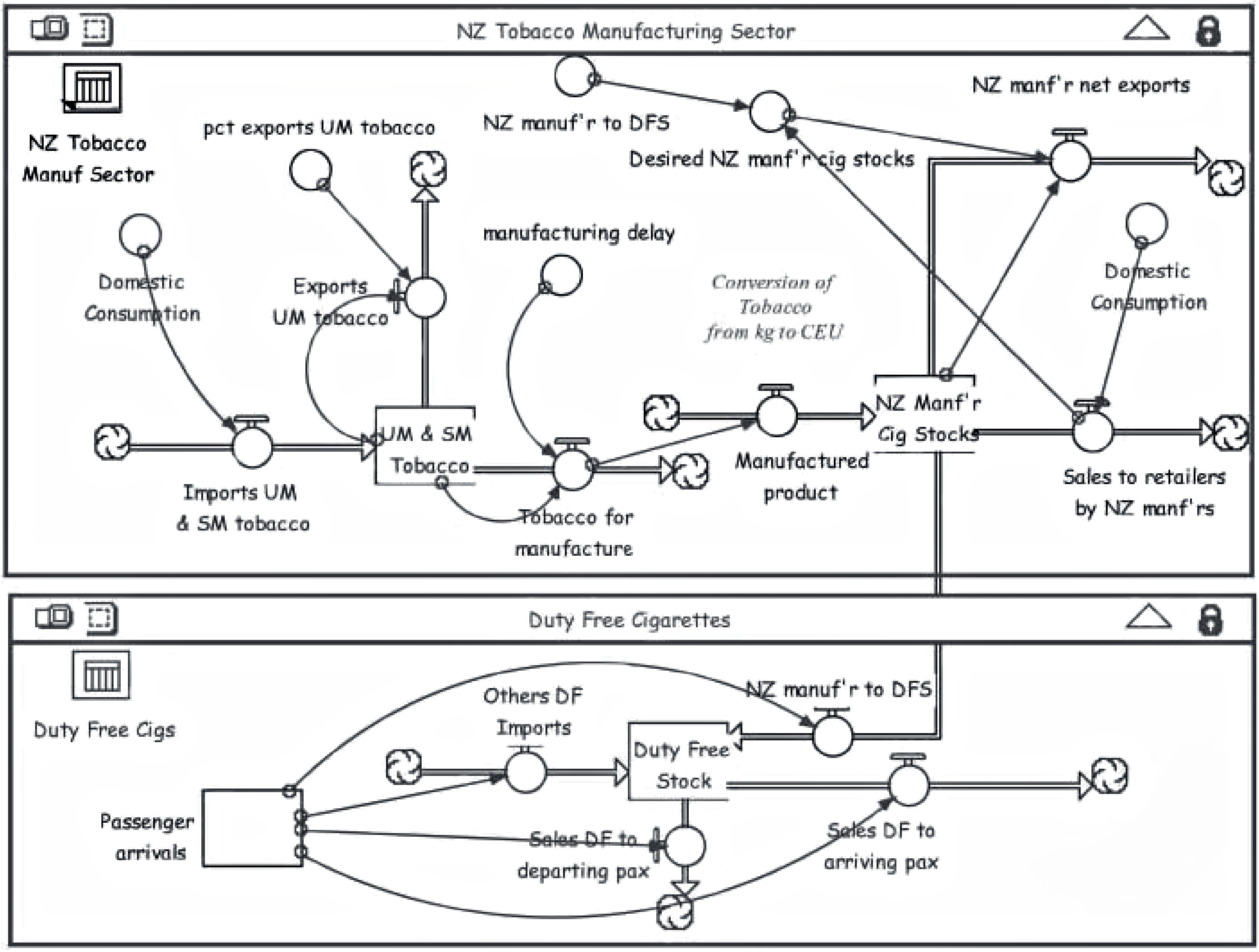
Table 1. Comparing the 'causal' and 'dynamical' approaches to analysing FCMs

Issue	Causal approach	Dynamical approach
Interpretation of arrows	Represent the degree of certainty about whether factor A causes or suppresses change in factor B	Represent the magnitude of influence of factor A on factor B
Initial values of factors	Set to either 0 or 1 depending on role in analysis/scenario	Can take any real value, but often set to 0, or to 1 if a driver or investigating impact of change in that factor
Value of edges	Must take a value between −1 and 1 (0.5 represents the most ambiguous value, whereby no information is available on whether a factor is being caused or not; 1 represents complete certainty. Positive links mean certainty to happen, while negative links mean certainty not to happen)	Can take any real value, but typically kept between −1 and 1 (often in categories corresponding to 'weak', 'medium', or 'strong' representing the strength of the effect, e.g. +0.5 means the value of the target of the arrow will be increase 0.5 units from the value of the source of the arrow)
Intuition behind the purpose of analysis	Assessing the strength of certainty that factors are caused or suppressed by changes in the system. Considers, if we change something in the system, what implications does it have for the causation of other factors in the system?	Assessing the relative changes in the magnitude of factor values in the system under different change scenarios. Considers how much (relatively) will magnitudes of different factors be affected by change and thus how much they are influenced or influence others
Outputs of analysis	Ranking of factors in terms of how much they are actively caused or suppressed by a change in the system	Plot showing the relative values of factors through iterations of the analysis. Or ranking of factors in terms of how much they influence or are influenced
Pros	Consistent with original approach	Intuitive and appealing output. More intuitive map building
Cons	Counter-intuitive interpretation of arrows and factor values. Does not tell us anything about how much something might change. Results sensitive to form of squashing function chosen	In practice, has created confusion about the appropriateness of interpreting the connections and values in this way. Dynamical output can be misinterpreted as a simulation
Background	Reflects original FCM maths and interpretation [38]	Reflects wide adoption of FCM in participatory mode with a more intuitive interpretation of maps

Source: reproduced under Creative Commons licence from Barbrook-Johnson and Penn (2022)

3.4.3 Quantitative systems mapping methods

3.4.3.1 Systems dynamics models (SDM)



[View original stock and flow diagram in published paper]

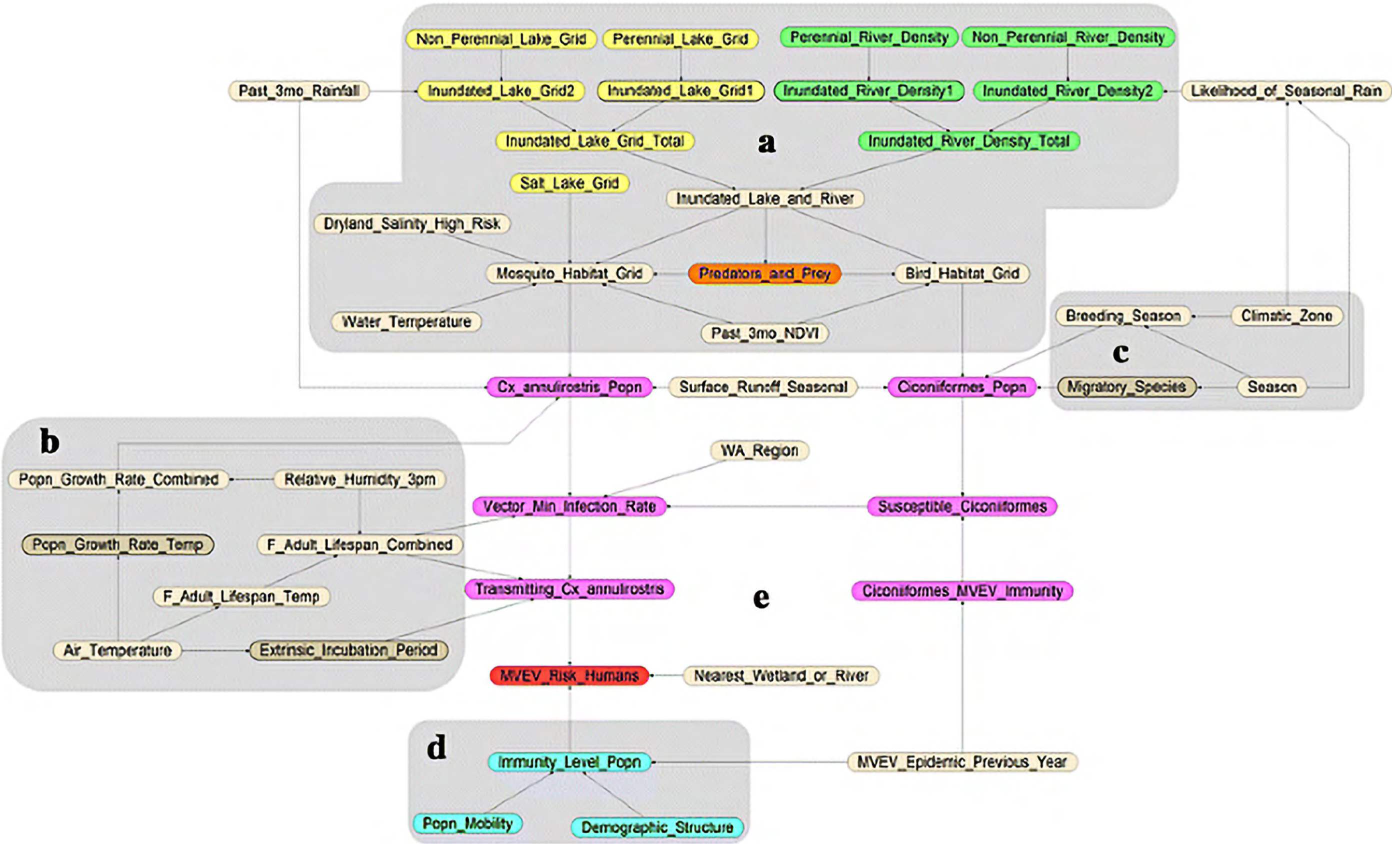
Figure 11. Example stock and flow diagram – tobacco manufacture and duty-free sector in New Zealand. Source: [39]

Unlike other mapping methods, systems dynamics modelling (SDM) aims to model part of a system that corresponds to a problem, rather than the system as a whole. SDM typically comprises three stages [40]:

1. A CLD (or similar map that includes feedback loops) is used to develop understanding of the structure of the problem system
2. Stock and flow diagrams (S&F) are then used to extend the initial system map and put it into a quantitatively modellable structure. These diagrams conceptualise the behaviour of systems as being the product of the accumulation of stocks (quantity of a variable at a given time) and flows (change in stocks over time), making this form of map distinct from a CLD
3. The S&F diagram is then specified (i.e. quantified) as a set of mathematical formulae known as differential equations, and the simulation (model) is then 'run' using computer software (see Barbrook-Johnson and Penn (2022) for an introduction to the maths behind SDM)

By running ‘what if’ scenarios through a continuous simulation[4], these models are used to understand a system’s non-linear behaviour and forecast[5] future scenarios based on changes in context or system environment, as well as to explore the potential impact of interventions in a safe environment without real-world consequences [7, 41]. Thus, this method focuses on a dynamic problem within a system, or often a sub-system, and enables the quantitative exploration of feedback loops.

3.4.3.2 Bayesian belief networks (BBN)



View original BBN

Figure 12. Example BBN - encephalitis virus risk assessment in Western Australia. Source: [42]

Bayesian belief networks are graphs informed by the mathematics of Bayesian probability.[6] Their purpose is to capture conditional probabilities of the causal connections between factors in the system, meaning: what are the chances that X happens if Y and Z are true or not? In other words, the ‘belief’[7] in an outcome is the probability that two or more events may occur simultaneously (see Figure 13) [43]. A picture of the system is built by connecting various sets of these relations, which can be analysed quantitatively. This approach helps address some of the uncertainty around how different parts of a system interact and influence one another.

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4 A continuous simulation models trends in a system throughout the programmed duration of a simulation, as opposed to a discrete event simulation that models events at given time points.

5 It is important to note that models are always incomplete and a simplification of a system. They should be considered as a tool to understand how things may play out, rather than to make ‘perfect’ predictions about the future to inform decision-making. The terms ‘prediction’ and ‘forecast’, while common in systems mapping, are accompanied with a cautionary note.

6 See Efron (2013) – ‘Bayes’ Theorem in the 21st Century’.

7 The term belief has always been used to reflect the assumptions of the mathematical underpinning, not subjective views of stakeholders.

Bayesian belief networks typically focus on the process from intervention to outcome, allowing for statistical assessment of the probable causes of an outcome or the probability of different outcomes based on input values [44]. They also present a low-risk approach to quantitative analysis in systems mapping (i.e. avoiding the potential pitfalls of dynamic simulations). This thought process can be reverse engineered, so that outcomes ('child' or 'leaf' factors) are the starting point from which to explore possible causes at the top of the network ('root' or 'parent' factors) [20]. There are generally limits to how many parent factors can be included in a BBN such that the map can still be understood and used practically (often 2-to-3 parent nodes).

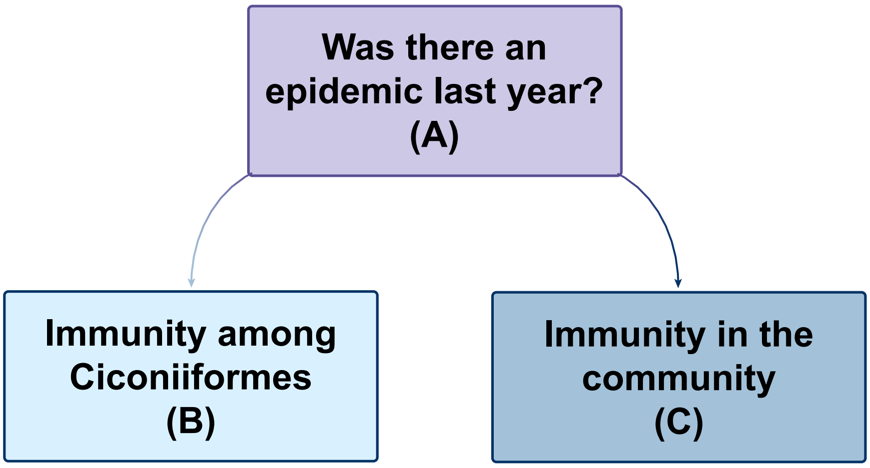

Figure 13. Example of a simple Bayesian belief network – adapted from Ho et al. [42]

Figure 13 shows a simple BBN (extracted from figure 12) containing three variables (factors) that influence the risk of the Murray Valley encephalitis virus to humans in Western Australia [42]. These are:

- Parent factor: Was there an epidemic last year? (A)
- Child factor: Immunity among Ciconiiformes (B)[8]
- Child factor: Immunity in the community (C)

The example also shows the conditional dependencies between these factors, which are depicted as directed arrows. The graph indicates that immunity in the community, and that among Ciconiiformes (child factors B and C), are conditionally dependent on whether there was an epidemic last year (parent factor A). However, the two child factors (B and C) have no effect on each other (they are conditionally independent).

BBNs include tables in the map, or alongside, that display the probability (P) that any given factor occurs. These represent observed, not calculated values. For example, there are two outcomes for the parent factor (A): an epidemic happened last year (True), or an epidemic did not happen last year (False). This can be expressed as follows:

- T: the probability of parent factor A existing (i.e. the epidemic happened)
- F: the probability of parent factor A not existing (i.e. the epidemic did not happen)

Was there an epidemic last year	
T	0.5
F	0.5

8 Ciconiiformes are waterbirds and are major non-human hosts of the Murray Valley encephalitis virus.

In this example, immunity among Ciconiiformes (B) and in the community (C) each have three possible states that represent prevalence rates: high, medium or low. These are expressed as follows:

Immunity among Ciconiiformes (B)	
High (H)	0.25
Medium (M)	0.5
Low (L)	0.25

Immunity in the community (C)	
High (H)	0.3
Medium (M)	0.4
Low (L)	0.3

The probability of each child factor (B or C) is dependent on the probability of the parent factor (A) being either true (T) or false (F), but not contingent on one another:

Immunity among Ciconiiformes (B)			
A	**High P [B^1]**	**Medium P [B^2]**	**Low P [B^3]**
T	0.5	0.5	0
F	0	0.5	0.5

Immunity in the community (C)			
A	**High P [C^1]**	**Medium P [C^2]**	**Low P [C^3]**
T	0.6	0.4	0
F	0	0.4	0.6

These data allow questions such as the following to be answered: What is the probability (P) that the prevalence of immunity to the Murray Valley encephalitis virus in the community is high [C^1], but medium among Ciconiiformes [B^2], when there was an epidemic last year [A=T]?

This can be expressed as P (C^1,B^2,A), where each of these are true events. From the observed probabilistic scan, it can be deduced that:

$= P(C^1|A) * P(B^2|A) * P(A)$

$= 0.6 * 0.5 * 0.5$

$= 0.15$

This basic BBN example, taken from a much larger map, highlights a feature that is indicative of a traditional BBN; it is acyclic. This means that the connections drawn between factors in the system do not loop back on themselves to create feedback. Recent developments, for example within the field of engineering, have attempted to address this limitation using various computational algorithms to incorporate a feedback effect [36].

Bayesian Belief Networks are also known as Bayesian networks, dependency models, influence diagrams or causal probability models. Note, a participatory approach to this method has been less commonly applied in population health research, policy and practice.

3.4.4 A summary comparison of methods

Key components of different mapping methods are presented in Table 2. Their focus, data type, participation, ease of use and outputs are presented in a further series of comparative tables in Section 4, which accompany the Participatory Systems Mapping Design Framework. A more detailed explanation about each of these methods, and how to use them, is provided by Barbrook-Johnson and Penn (2022).

Table 2. Overview of participatory systems mapping methods (basic approach, benefits and challenges) Source: [20]

Method	Basics of map creation	Map analysis	Key uses and benefits	Potential challenges
Systems-based ToC	• Start with intervention (or sometimes outcomes) • Define the long-term impacts • Connect with intermediary factors • Make assumptions explicit • Consider theories of no change, or negative change • Capture feedback, interactions and disagreements • Iterate these steps	• Remain inquisitive and challenge assumptions • Question the scale of proposed impacts • Annotate maps thoroughly • No formal analyses	• Very flexible method • Represent 'mental models' about interventions and impacts • Help frame intervention design, monitoring and evaluation • Surface assumptions about a system, and test these • Help capture important contextual factors	• Can prevent taking a whole-system view • Can reinforce false optimism • Can be difficult to identify stakeholders' place in the system • Lack of analysis • Few practical applications of method in population health research from which to learn • Dry concepts for participants to engage with
Causal loop diagram (CLD)	• Determine focal problem - sometimes focus on a system engine (drivers of change) and archetypes (generic map templates) • Map immediate factors associated with problem • It can be useful to create variable over time plots, to explore how system might behave • Identify feedback loops • Generate more factors and expand map out to the system boundary • Add further feedback loops and connections	• Thematic or network analyses • Qualitatively explore how the systems' mechanisms may look and how these affect population health outcomes • Consider and narrate the dynamic causal process in the system	• Maps aggregate behaviour of systems • Provides preliminary understanding of possible dynamics without extensive quantification • Visually appealing • Focus as much on the communication of the map, as the development of it	• Typically, maps do not show the relative strength of causal links • Focus on feedback loops can obscure other important considerations • Fewer quantitative analyses, thus difficult to determine how feedback loops interact

Method	Basics of map creation	Map analysis	Key uses and benefits	Potential challenges
CECAN PSM	• Define system boundaries and choose stakeholders • Start with focal factors important to stakeholders • Generate initial factors affecting/ affected by focal factors and build out • Add additional factors, collecting information on these and their connections dependent on analysis design • Review and verify	• Analysis is the key feature of this approach • Network and node characteristics analysis • Create sub-maps using network analysis, causal flow and stakeholder information • Bespoke analysis on system-specific questions, often co-designed with stakeholders	• Flexible method • Combining the opinions of various stakeholders • Starts from a base of little data on the system • Creates a richer understanding of the whole system, including feedback and interdependencies • Integrates bespoke analyses, without simulation • Facilitates co-design of analysis with stakeholders	• A method that captures a system in a given state, at a point in time, so system dynamics not explored • Specifically requires diverse stakeholder input • Analysis not always very intuitive • Requires thoughtful presentation and analysis to share findings beyond the mapping teams • No quantitative output
Fuzzy cognitive mapping (FCM)	• Start with focal factors • Consider, generate and agree additional map factors • Build outward – adding connections between factors, quantifying their relative strength or probability (- 1 to 1) and direction (+/-) • Digitise map	• Causal or dynamic processes • Try different scenarios by updating values of factors • Compare map structures and 'mental models' • Network analyses • Compute relative impact of causal factors to determine effective intervention points	• Quick and intuitive approach • An engaging visual method for stakeholders • Constructs high-level, top-down pictures of complex systems • Develops consensus without forcing it • Easier to represent feedback than in some other methods	• Rigid method • Quantitative outputs often over or mis-interpreted • Few applications of method in population health research to learn from • More difficult for those not involved in the mapping process to engage with the created ouput

Method	Basics of map creation	Map analysis	Key uses and benefits	Potential challenges
Systems dynamics (SD)	• Start with system engine (driver of growth) or sub-system • Determine stocks and flows • Build out, adding contextual influences and feedback loops • Quantify and generate differential equations • Try to avoid modelling the whole system • Iterate quickly and purposely, including updates to the model	• Simulation or nonlinear dynamic modelling (i.e. exploring systems dynamics over time)	• High-level strategic insights on dynamical questions • Model aggregate behaviour of systems • Create a dynamic model of the system (i.e. with changing values) • Test assumptions and the potential impacts of interventions	• Very rigid method • Time-consuming • Sensitive to assumptions, but does not easily capture important qualitative context • Typically models part, not all, of a system. Although, not ideal for micro questions either • Often lacks practical application • Dynamical thinking is not always intuitive
Bayesian belief networks (BBN)	• Start with an outcome and 'build backward' • Select parent factors, (typically 2 or 3 to limit probability table size), define their states • Define conditional probabilities as they relate to connections between variables • Can be developed either with algorithms applied directly to data, or with stakeholder input	• Use probabilistic reasoning • Limited computation options • Estimate effects of interventions or contribution of causal factors to outcomes • Generate risk-based models, running scenarios of change and calculating their impact • Compare against historical population health data	• Constructing high-level, top-down pictures of complex systems • Emphasises quantification over richness • Developing consensus without forcing it • Useful where uncertainty is high, and quantitative data is limited • Difficult to create a meaningless BBN, everything is transparent	• Map structure/ system view is constrained by data availability, the number of parent nodes and the lack of feedback loops • Few examples of participatory approaches in population health research to learn from • Requires significant technical knowledge and computational analysis skills • Hard to update live

3.5 Additional considerations in systems mapping

While each method of participatory systems mapping has benefits and disadvantages, there are several factors common across methods that are important to consider:

Representativeness and reproducibility: The nature of complexity means that system maps only ever provide a partial representation of a complex system. The depiction is bounded by the conditions and knowledge imposed upon it, at a given point in time, by its creators and users. Participatory system maps are not designed to be reproducible [21], rather reflect the combined knowledge of those involved in the process. It is not a matter of concern that if different participants were involved, a different systems map would be produced. In fact, an appreciation of how different groups understand a system can help to position potential solutions. Nonetheless, it is important to include a broad enough range of participants whose perspectives matter to the issue being examined. This may not become apparent until the mapping process begins.

Capturing distributional impacts: A second factor associated with systems mapping is that it is often difficult to capture the nuances of relations in a system that operate differently for different groups of people (e.g. a student may not experience the effects of a change in school policy in the same way as a staff member). In this way, factors important to population health policy and practice, such as inequalities, are difficult to capture. This reinforces the need for diverse participation to add qualitative and lived experience context to the observed relations being mapped.

Temporal dynamics, long-term processes and time lags: Third, systems change often takes a long time to effect, sometimes years. While time lags are integral to the dynamics of a system, these are difficult to formulate as part of the systems mapping process. The use of 'delay' marks in system maps indicate where the causal influence of one factor on another takes place over a protracted period. These delay marks, however, generally do not include information about the nature or length of such delays.

Identifying ways to change the system: A final consideration is that certain methods are better suited to different types of map building processes or analysis. For example, some mapping methods (e.g. systems dynamics) enable robust quantification of causal relations [21], and some are better suited for network analysis (e.g. CECAN PSM). However, focusing solely on known causal factors may create a limited view of a system, making it challenging to identify meaningful population health interventions [23]. Understanding of the ways in which systems mapping methods can help identify effective population health interventions is still emerging, and there is opportunity for considerable methodological development. The Participatory Systems Mapping Design Framework in this guidance can be used to identify potentially relevant methods for particular needs, while considering method-specific limitations.

4. Participatory Systems Mapping Design Framework

4.1 Purpose

Deciding which participatory systems mapping method to use is a balancing act. The Design Framework will enable you to break down and reflect on two key questions, specific to the needs of your project: 1) Which participatory systems mapping method(s) meet your needs? 2) What feasibility issues do you need to consider in making your choice?

Specifically, this Framework will help enhance the choice and design of a participatory systems mapping project, by enabling you to:

1. Consider the added value of adopting a participatory approach to systems mapping
2. Consider the differences between participatory systems mapping methods, including their advantages and disadvantages
3. Consider the feasibility of using particular methods for a given purpose

4.2 Intended users of this Framework

The Design Framework is intended for people and teams with a remit in population health research, policy and practice including, but not limited to, universities, policymaking and government, the voluntary sector, and private sector consultancies. It may be useful to those interested in using participatory systems mapping for research, monitoring and evaluation, project design or management. This Framework can be used to select a method, as well as to reflect on a method that has already been used. You do not need prior experience of participatory systems mapping to use this tool.

4.3 Using the Framework

No two projects will use participatory systems mapping in the same way, nor will they have the same objectives. How you use this Framework will depend on your background, experience in using these methods, your project aims, your context and resources, and what outputs you want to produce.

Here are a few practical tips on how to use the Framework:

1. Read through the Design Framework and familiarise yourself with the content and the 13 questions, which are divided between three overarching considerations
2. Start answering the questions that have clear responses, **using the downloadable and editable Design Framework (Supplementary file 1)**
3. Return to the unanswered questions and collect feedback from your team or external resources (e.g. literature or external experts)
4. Use the comparative table at the end of each consideration sub-section to reflect on your answers and assess which method(s) best suit(s) the project's purpose and resources
5. Reflect on what method best suits your project; and, how, if necessary, to further adapt the method you are planning to use or currently using

You may find some questions challenging to answer. Throughout, we provide links to sections of the guidance and other published resources that can assist. You may also wish to consult the glossary in Appendix D or discuss your considerations with topic or methods experts.

4.4 The Participatory Systems Mapping Framework

Consideration 1. What is the scope of the project?

1. What is the intended purpose of using systems mapping in your project?
2. What knowledge or information gaps do you seek to address?
3. What type(s) of output(s), including system map features, will be useful to your project?
4. What do you intend to do with the system map(s)?

Consideration 2: What is the added value of a participatory approach?

5. How do you intend the participatory approach to benefit your project?
6. Who are the stakeholders in the system, and who will you involve in the project?
7. What emphasis will you place on participatory approaches and involvement of stakeholders?
8. At what stages do you anticipate involving participants?

Consideration 3: Which factors may affect your capacity to use a participatory systems mapping method?

9. How much capacity building will be required to ensure meaningful involvement of participants?
10. What data or information is already available on the area of enquiry that can support the mapping process?
11. Where will the mapping process take place?
12. What skills, resources and expertise are required to implement the chosen method(s)?
13. Which data collection method(s) do you intend to use for the mapping process, and the wider project?

Figure 14. Overview of the Participatory Systems Mapping Design Framework

Consideration 1: What is the scope of the project?

The purpose of this section is to reflect on the overall aims and purpose of your project (Q1, Q2), what you want the map to provide (Q3), and how you intend to use it (Q4).

Guidelines:

1. Read through items for Consideration 1
2. Answer these as well as you can initially
3. Where necessary, collect feedback from your team, experts and external resources.

Question 1. What is the intended purpose of using systems mapping in your project?

a) Please provide a brief description of the topic of enquiry (e.g. understanding the drivers of childhood obesity in the school setting). If feasible at this stage, define your aim(s) as precisely as possible:

b) Reflecting on the purpose of using a systems mapping approach is a key step in choosing a method. Below is a list of different reasons as to why you may want to adopt a systems mapping approach. Select all that apply to your activity/project purpose(s):

- ☐ To identify systems problems or failures (i.e. those that are interconnected, dynamic or emergent)
- ☐ To understand a problem at a holistic level, with an emphasis on examining the interdependent nature of causal factors (rather than factors in isolation)
- ☐ To construct a high-level, broad view of a system
- ☐ To deepen existing understanding of systems, including their structures and boundaries
- ☐ To extend analyses of existing system maps
- ☐ To understand how specific activities and changes in one part of a system may affect other parts of the system, and vice versa, sometimes in unexpected ways
- ☐ To identify potential areas for intervention (e.g. leverage points)
- ☐ To inform intervention development
- ☐ To understand the context in which interventions are situated
- ☐ To monitor existing interventions (e.g. tracking implementation)
- ☐ To inform the evaluation of interventions or policies
- ☐ To simulate and model possible future state of the system
- ☐ Other (please specify): ____________________________________
- ☐ None of the above apply

Additional information:

- Sections 2.2-2.4 (an overview of systems thinking and complexity), Section 3 (introduction to participatory systems mapping), Section 5 (key findings from a systematic mapping review on key purposes of using these methods in population health)
- Case study 1 (formative research), case study 2 (broad system view), case study 7 (implementation tracking)
- Guidance on defining public health problem statements

Question 2. What knowledge or information gaps do you seek to address?

Please describe the gaps in information/knowledge and consider how the systems mapping process will seek to address these gaps:

Additional information:

- Case study 1 (formative research)
- Consult or conduct literature reviews to identify evidence gaps [45]
- If the gaps are unclear, informal discussions with stakeholders may be useful

Question 3. What type(s) of output(s), including system map features, will be useful to your project?

Below is a list of features that systems mapping can potentially provide. Think about which ones may be most useful for your research aims, and potential availability of data (see Q10).

Select all that apply:

View of the system

- ☐ Whole-system view (a system map that represents a high-level and broad view of an entire system)
- ☐ Sub-system view (a system map that represents a sub-section of a whole system. This is usually done with a boundary setting process)

Data represented in system map (output)

- ☐ Numbers and plots (graphical representation of causal relations using quantitative data)
- ☐ Qualitative data (visual representation of causal relations without numbers and plots)

System map form (presentation of factors)

- ☐ Acyclic (simple causal connections (no feedback loops*)
- ☐ Cyclic (connections between factors can form feedback loops)

Simulation capabilities (exploring how systems may change over time)

☐ Yes, this is important

☐ No, this is not necessary

Additional components

☐ Stocks and flows (size/quantity of system components at a given point in time, and how these sizes/quantities change over a period of time)†

☐ Time delays in the influence of one system factor on another

☐ None of the above apply

** Feedback loops describe when a change in one factor in the system influences a chain of changes through other factors, which return to reinforce or dampen the effect of the initial change. See Section 3.4.1.2.*

† Stocks and flows, and time delays are features typically associated with systems dynamics models and are used in the process of converting a causal loop diagram into a quantitative model. See glossary for further information (Appendix D).

Additional information:

- Section 3 of the guidance document
- Case study 5 (which demonstrates an interesting use of different map features)
- Case studies 4 and 6 (boundary setting)

Question 4. What do you intend to do with the map?

Whether you intend to publish the map in a peer-reviewed journal, online as grey literature, or not at all, it is important to identify the target audience for your map. Is the map you intend to produce likely to be useful and understood by this intended audience – whether among the participating stakeholders, or an external audience?

If the system map is intended to be subsequently used by system stakeholders, it is important to think about how the system map can be integrated into existing processes and identify who will be using and updating the system map. This will likely require capacity building, and early and sustained involvement of those individuals/organisations.

Select all that apply:

Analysis and future map developments

☐ Explore the effects of interventions on, or contribution of causal factors, to population health-related outcomes

☐ Use the map(s) to analyse the long-term behaviour of the causal system

☐ Create sub-maps to guide analysis and communication relating to parts of the system or particular questions

☐ Conduct network analyses

☐ Develop a quantitative model from a qualitative map

☐ Other (please specify) ____

Dissemination, communication and application

- ☐ Publish the system map for access by a wider audience
- ☐ Transfer ownership of the map and its ongoing development to key stakeholders (e.g. for project monitoring purposes)
- ☐ Use in community engagement and/or advocacy
- ☐ Adapt the system map to other media (e.g. presentation, animation, briefing paper)
- ☐ Restrict use of system map to stakeholders who were directly involved in the process
- ☐ Inform intervention(s) development (e.g. including to inform a ToC or programme theory)
- ☐ Develop an approach to evaluating actions identified through system mapping activities
- ☐ Support project implementation and/or monitoring
- ☐ Other (please specify) ____

Additional information:

- Case study 1 (developing a quantitative model)
- Case studies 2 and 7 (contrasting participatory system map uses, including mapping under constraints of certain stakeholder environments and project implementation)
- Case study 10 (use of network analysis)

Consideration 1: What is the scope of the project?

Based on your responses to the questions above, please reflect on these whilst reviewing the comparative table below. Only questions that have method-specific considerations have been included in the table.

Note, if you selected very few or no items for questions 1 or 3, then systems mapping may be less suitable for your project.

Select all methods that could be of interest, after reviewing consideration 1 items:

- ☐ Systems-based theory of change maps
- ☐ Causal loop diagrams
- ☐ CECAN PSM
- ☐ Fuzzy cognitive maps
- ☐ Systems dynamics models (including S&F)
- ☐ Bayesian belief networks
- ☐ Unsure

The remainder of the tool will help you refine your choice of participatory systems mapping method(s), by enabling you to consider the participatory approach and feasibility of implementing the identified method(s).

Table 3. Method comparison for consideration 1

Please note, the table only includes questions that have method-specific considerations (i.e. question 2 has been omitted).

Methods and points of reflection	Systems based Theory of Change	Causal loop diagrams	CECAN PSM	Fuzzy cognitive maps	Systems dynamics models	Bayesian belief networks
Q1. What is the intended purpose of using systems mapping in your project?	• Mapping the connections and pathways between an intervention and its outcomes • Describing what and how impacts might be created by an intervention	• Understanding the dynamic behaviour of systems	• Constructing large inclusive maps while also pulling out easy to use analyses and narratives of sub-sections	• Constructing a high-level, broad picture of a complex system	• Understanding and anticipating the future dynamic behaviour of systems, with quantification • To simulate and model possible future state of the system	• Constructing a high-level view of a system (but not as broad as other methods), with an intervention focus • Examining uncertainty among interdependent factors in the system • To simulate and model possible future state of the system

Methods and points of reflection	Systems based Theory of Change	Causal loop diagrams	CECAN PSM	Fuzzy cognitive maps	Systems dynamics models	Bayesian belief networks
Q3. What kind of output(s), including system map features, will be useful to your project? ***Important note:*** *These points are indicative only and will vary depending on the use of each method. The boundary setting approach will dictate the extent to which a system is mapped (see case studies 4 and 6).*	• Sub-system view • Qualitative • Typically acyclic, but it can be useful to think about feedback • Not designed for simulation • Key assumptions about how outcomes will be realised are typically included in the diagram	• Whole or sub-system view • Qualitative • Cyclic (can present feedback loops) • Precursor for simulation in SD models • Time delays	• Whole or sub-system view (developing submaps that may focus on questions or topics) • Qualitative • Cyclic (can present feedback loops) • Not designed for simulation	• Whole system view • Semi-quantitative (non-predictive, numbers) • Cyclic (can present feedback loops) • Not designed for simulation • A theory of change, with a summary of quantifiable causal relations • Time delays	• Sub-system view • Numbers and plots • Cyclic (can present feedback loops) • Simulates changes in outcomes over time • Stocks and flows • Time delays	• Sub-system view • Numbers and plots (probabilistic statistics) • Typically acyclic, although feedback loops possible • Limited simulation capabilities • Risk models (calculating the impact of changes)
Q4. What do you intend to do with the map? ***Important note:*** *The uses given in this row are in addition to describing the system with stakeholders, which is the general intention of all methods.*	• Explain the 'logic' or 'theory' of the intervention • Basis for design and/or evaluation of an intervention	• Qualitatively explore how the systems' dynamics may look, and how these affect population health-related outcomes • Network analysis	• Create sub-maps using network analysis, causal flow, and stakeholder information	• Compute relative impact of causal factors to determine points for interventions • Network analysis	• Analyse long-term behaviour of causal system to support strategic planning and decision-making	• Estimate probable effects of interventions, or contribution of causal factors to outcomes

Consideration 2: What is the added value of a participatory approach?

The purpose of this section is to reflect on participatory approaches to systems mapping. The following four questions will help you reflect on how involvement of system stakeholders could add value to your work (Q5-Q8). You may wish to read information provided in Sections 1.1, and 3.3 of the guidance, as well as case studies 1, 8 and 9 for examples of highly participatory and well-reported participatory processes in population health research.

Guidelines:

1. Read through items for Consideration 2
2. Answer these as well as you can initially
3. Where necessary, collect feedback from your team, experts and external resources

Question 5. How do you intend the participatory approach to benefit your project?

Select all that apply:

- ☐ To capture stakeholders' 'mental models' of a system
- ☐ To capture as many different perspectives as possible
- ☐ To identify convergent and divergent views among stakeholders
- ☐ To reach consensus among stakeholders
- ☐ To harness participants' domain-specific expertise in developing the system map
- ☐ To encourage systems thinking among stakeholders, enabling them to adopt a more holistic perspective on key challenges
- ☐ To encourage social learning between participants and throughout the mapping process
- ☐ To promote trust and acceptance among mapping stakeholders
- ☐ To identify, prioritise or fill evidence/information gaps
- ☐ To foster joint problem framing to ensure the map is focused on priority questions
- ☐ To produce context-specific solutions that meet the needs of stakeholders
- ☐ To facilitate the communication, dissemination and use of the map
- ☐ Other (please specify): ___________________________________
- ☐ None of the above apply

Question 6. Who are the stakeholders in the system, and who will you involve in the project?

Stakeholders can be people or organisations whose actions may influence, who hold knowledge about, or who are affected by, the system of interest. Stakeholders may include:

- Those with 'lived experience' of the main area of enquiry (e.g. people living with diabetes)
- Community members
- Experts and researchers
- Representatives of public or private organisations and institutions

Much of the value of participatory systems mapping is in the discussions held during the mapping process. Therefore, it is important to consider who to involve. As it is rarely, if ever, possible to include all stakeholders in the mapping process, it is important to reflect on which stakeholders are most important to involve based on the purpose of your systems mapping. Whose perspectives are critical to ensuring diversity of views on the system? Who has knowledge or understanding about different parts of the system? For example, you may want to include decision-makers, end-users, and those whose specific knowledge or actions can significantly influence the understanding or behaviour of the system.

In some cases, you may consider adopting a formal approach to stakeholder identification and stakeholder analyses, for which numerous resources exist [46, 47].

a) First, list all the key stakeholders in the system of interest:

b) Second, consider who are the essential stakeholders you will want to invite to take part in the mapping process:

If you are unsure about who to include in either box above, revisit your project aims, purpose of systems mapping, and identify key informants in the system that could support the identification of further stakeholders.

Question 7. What emphasis will you place on participatory approaches and involvement of stakeholders?

It is necessary to consider how important the participatory element of your project is, as different participatory systems mapping methods require, or can better foster, different degrees of involvement of stakeholders. For example, in some circumstances it may be beneficial to have very specific and focused participatory activities (e.g. domain expert inputs to a quantitative model), while in others it may be beneficial to have participation as the defining feature of the entire project (i.e. from design to dissemination). Furthermore, some methods require greater researcher input (e.g. due to requisite expertise) and therefore can be more challenging for stakeholders to engage with (see Q9). However, these factors are project specific. Use this space to reflect on these considerations:

Question 8. At what stages do you anticipate involving participants?

Select all that apply:

- ☐ Project design stage
- ☐ Scoping, assessment, and boundary setting
- ☐ Map building
- ☐ Map validation
- ☐ Map analyses
- ☐ Dissemination and use of outputs

Consideration 2: What is the added value of a participatory approach?

Based on your responses to the questions above, please reflect on these whilst reviewing the comparative table below. Only questions that have method-specific considerations have been included in the table.

Note, if you selected very few or no items for question 5, then participatory systems mapping may be less suitable for your project.

Select all methods that could be of interest, after reviewing consideration 2 items:

- ☐ Systems-based theory of change maps
- ☐ Causal loop diagrams
- ☐ CECAN PSM
- ☐ Fuzzy cognitive maps
- ☐ Systems dynamics models (including S&F)
- ☐ Bayesian belief networks
- ☐ Unsure

The remainder of the Framework will help you refine your choice of participatory systems mapping method(s), by enabling you to consider the feasibility of implementing the identified approach(es).

Table 4. Method comparison for consideration 2

Please note, the comparative tables only include questions that have method-specific considerations. For consideration 2, this is only question 5, reflecting that in most cases the potential to incorporate participatory processes in systems mapping methods is possible across methods.

The following are indicative examples of typical participatory contributions within specific mapping methods:

Methods and points of reflection	Systems based Theory of Change	Causal loop diagrams	CECAN PSM	Fuzzy cognitive maps	Systems dynamics models	Bayesian belief networks
Q5. How do you intend the participatory approach to benefit your project?	• Identifying key gaps and uncertainties that can be tested through evaluation	*No method-specific considerations*	• Facilitating the co-design of analyses	• Harnessing domain-specific expertise to determine or validate the relative weighting of connections in the map	*No method-specific considerations*	• Harnessing domain-specific expertise to determine probability states of factors in the map

Consideration 3: Which factors may affect your capacity to use a participatory systems mapping method?

The purpose of this section is to reflect on the resources available to carry out your participatory systems mapping project and assess the feasibility of implementing one or more of the potential methods (Q9-Q13).

Guidelines:

1. Read through items for Consideration 3
2. Answer these as well as you can initially
3. Where necessary, collect feedback from your team, or external resources, experts, or stakeholders

Question 9. How much capacity building will be required to ensure meaningful involvement of participants?

It is important to consider the skills and expertise required for each method, and review what skills and expertise currently exist across your project team and potential stakeholders. You may need to consider bringing in additional expertise as well as plan for capacity building of the project team and stakeholders that would be involved in map building. Consider this question alongside Q6, 7 and 8.

Select one of the following responses:

- ☐ Minimal (no or minimal capacity building required, and/or adaptation of mapping processes required)
- ☐ Moderate (some capacity building and/or adaptation of mapping processes required)
- ☐ Extensive (significant capacity building and/or adaptation of mapping processes required)

Question 10. What data or information is already available on the area of enquiry that can support the mapping process?

The aim here is to reflect on the availability of data or information because some mapping methods have prerequisites, while in others, it is possible to choose to develop a participatory systems map with prior information/data in addition to stakeholder involvement.

For example, you may have already collected qualitative or quantitative data, or conducted a literature review, which may contribute information to the mapping process. Alternatively, there may be a significant body of evidence or information already in existence that you can draw upon.

a) What is currently known about the area of enquiry; would it be useful to integrate some of this knowledge in the mapping process? What types of data may be available?

b) Will you consider using a preliminary map?

If you intend to involve stakeholders in the map building stage of the project (see Q8), it is important to consider whether it could be useful for the project to start off with a preliminary map before involving stakeholders. Consider your project aims, the availability of other systems maps on your topic of enquiry, the group of stakeholders and resources. Consider as well if it may be better to start off with a blank sheet/screen and collect participants' 'mental models' without prior influence, or if it could be more useful to present a preliminary map (sometimes called a seed map) to participants, which they can then further develop and refine. For instance, a preliminary map might be helpful if there are time limitations for workshops, or if the topic is very complex.

Select all that apply:

- ☐ No – start with a blank sheet/screen (no prior input)
- ☐ Yes – a preliminary map created by reviewing evidence on the topic
- ☐ Yes – a preliminary map based on input from domain experts
- ☐ Yes – a preliminary map based on project team knowledge, including previous research
- ☐ Yes – using a complete or partial map from elsewhere
- ☐ Other (please specify): ___________________________________

Additional information:

- Case study 3 (example of using a preliminary map)

Question 11. Where will the mapping process take place?

Think about how you would like participants to engage at each stage of the mapping process. Different approaches produce different participatory experiences; for instance, participants will engage differently with a map on a table compared with one viewed on a screen. Online practices can mean that it is easier for stakeholders to take part, especially when collaborating across geographical distances. However, if you seek a high level of interaction and discussion and/or if you wish participants to take a leading role, then this is much easier in person than online. It may be necessary to have more, and shorter, sessions online. Computer-aided participatory systems mapping software is increasingly available, however it can substantially affect the form of the map generated [48]. Thorough testing should always be undertaken, and methods adapted as needed (see Q13).

Select all that apply:

- ☐ In-person
- ☐ Online synchronous
- ☐ Online asynchronous*
- ☐ Hybrid session(s) - in-person and online participants taking part in the same session
- ☐ Separate session(s) - either in-person or online

** Asynchronous refers here to stakeholders having the possibility to contribute to map building in their own time/pace.*

Use the following box to add any further reflections on this question (e.g. stages of the process, locations, etc.).

Additional information:

- For more information on how to run online workshops, see Barbrook-Johnson and Penn (pp. 155-157) [20].

Question 12. What skills, resources and expertise are required to implement the chosen method(s)?

All methods included in this guidance require a degree of systems sensibility, as well as a basic understanding of a given subject or context, to be able to determine where there might be gaps in knowledge and facilitate mapping activities accordingly. Furthermore, more experienced facilitators/mappers will be more familiar with the methods and common pitfalls in systems mapping.

a) It is important to reflect on your project team's interest in participatory systems mapping (and that of any partners), and systems approaches more broadly. How well does it align to your existing research perspectives and practices? Do you have the means to carry out capacity building of the team? Is there suitable motivation for working with participatory systems approaches ? Use this box to reflect on these considerations:

b) What is the timescale for the participatory systems mapping process (from design to dissemination)?

Note: all methods can be used over varying timeframes. However, some methods may be more suited to less resource intensive projects (e.g. fuzzy cognitive maps), while others tend to be longer and more methodical (e.g. systems dynamics models).

c) How much time will you have with participants for map building activities (in-person/online interactions)?

Note: This includes time availability of the project team, as well as the availability of stakeholders invited to participate.

d) Which of the following skills and expertise are available to your project (i.e. in your team, through external consultants, or among participants)?

Select all that apply:

- ☐ In-depth knowledge of the context
- ☐ Expertise in the chosen research or project area
- ☐ Facilitation skills in group map building
- ☐ Mapping software expertise
- ☐ Systems mapping analysis expertise (e.g. network or sensitivity analyses, statistics)
- ☐ Qualitative research skills (i.e. familiarity with data collection methods and analytical techniques)
- ☐ Modelling and simulation expertise
- ☐ Other (please specify): ______________________________________

e) What software(s) may you need to carry out the mapping process? Is this software available to your team? See Appendix F for examples of software.

Question 13. Which data collection method(s) do you intend to use for the mapping process, and the wider project?

a) What data collection method(s) do you intend to use for each stage of the mapping process? (see Q8 for an overview of typical map building stages).

Select all that apply:

- ☐ Group-based workshop(s)
- ☐ Individual interviews
- ☐ Small group interviews/focus groups
- ☐ Survey(s)
- ☐ Online whiteboard(s) (no moderation; asynchronous)
- ☐ Other (please specify): ___________________________________

Note, in some instances due to logistical reasons, sensitivity of topics discussed, or power dynamics between participants, you may wish to consider organising several workshops or modes of involvement to ensure all sub-groups of stakeholders can take part. Integration of results from each group or mode of involvement would then need careful planning.

b) It is also important to reflect on other components of your project, which may be more or less complementary to a systems mapping approach. For instance, a stakeholder analysis or Delphi exercise. You may wish to consider these in relation to feasibility, or whether any of these methods may be useful to the mapping process itself.

What other methods have you considered, or will you be using, as part of your project?

Consideration 3: Which factors may affect your capacity to use a participatory systems mapping method?

Based on your responses to the questions above, please reflect on these whilst reviewing the comparative table below. Only questions that have method-specific considerations have been included in the table.

Considering the factors that may affect your capacity to implement the participatory systems mapping method(s), which methods seem most suitable based on available prior information, your intended project design (i.e. data collection methods), and the available resources?

Select all that may apply:

- ☐ Systems-based theory of change maps
- ☐ Causal loop diagrams
- ☐ CECAN PSM
- ☐ Fuzzy cognitive maps
- ☐ Systems dynamics models (including S&F)
- ☐ Bayesian belief networks
- ☐ Unsure

Table 5. Method comparison for consideration 3

Please note, the table below only includes questions that have method-specific considerations (i.e. questions 11 and 12 have been omitted).

Methods and points of reflection	Systems based Theory of Change	Causal loop diagrams	CECAN PSM	Fuzzy cognitive maps	Systems dynamics models	Bayesian belief networks
Q9. How much capacity building will be required to ensure meaningful involvement of participants?	• Minimal to moderate capacity building of participants	• Minimal to moderate capacity building of participants (depending on which stages stakeholders are involved in)	• Minimal to moderate capacity building of participants	• Moderate degree of capacity building of participants	• Moderate to extensive degree of capacity building of participants (depending on which stages stakeholders are involved in)	• Extensive degree of capacity building of participants
Q10. What data or information is already available on the area of enquiry; is prior mapping work relevant for the project?	• No data requirements • It is possible to develop from another systems map (e.g. CECAN PSM)	• Useful where there is limited data from which to start • Can be useful to have first built behaviour over time plots, when initiating map building	• No data requirements • Useful where there is limited data from which to start	• No data requirements	• Empirical and quantifiable data on the system of interest, particularly for map validation	• Useful where there is limited data from which to start • No specific data requirements (although data about the system's past is typically used for map validation in population health research) • Participatory approach even more useful where quantitative data is limited

Methods and points of reflection	Systems based Theory of Change	Causal loop diagrams	CECAN PSM	Fuzzy cognitive maps	Systems dynamics models	Bayesian belief networks
Q13. What skills, resources and expertise are required to implement the chosen method(s)? ***Important note:*** *These skills do not have to be requirements for using a systems mapping approach; they can be acquired throughout the project, possibly with the assistance of external experts.*	• An understanding of intervention development, evaluation and programme theory are useful	• Network analysis skills are useful	• Network analysis skills are useful	• An awareness of model calibration and sensitivity analysis • Network analysis skills are useful	• Precise technical specification and quantification of components	• An understanding of the maths and data involved • Requires specific software for map analysis

Method choice and reflections

Having worked through the Design Framework and considered the purpose of a participatory approach to systems mapping, as well as the factors that can affect implementation of methods, you should now have a sense of which participatory systems mapping method(s) may best meet your needs.

Use the following table to record which method(s) you are considering and why. Further information to support your decision can be found in Section 3 and the Appendices that accompany this guidance.

Method option 1:
Benefits: Limitations:

Method option 2:
Benefits: Limitations:

Method option 3:
Benefits: Limitations:

5. Key findings from a systematic scoping review on participatory systems mapping

This guidance was supported by a systematic scoping review of peer-reviewed literature published between 2000-2021, using two databases (MEDLINE and Scopus). The aim was to identify how participatory systems mapping methods have been used in population health research. 73 peer-reviewed papers met the inclusion criteria, which included: 1) a participatory approach to systems mapping; and 2) a population health/health improvement focus. See Appendix B for more information on the scoping review methods. Detailed methods and full results will be published elsewhere.

The following summary presents key trends from the data:

Methods

Most studies used causal loop diagrams (n=54). Of those, a third used CLDs as part of systems dynamics modelling (n=16). A minority of studies used FCM, BBN, and systems-based ToC. Eight papers used other causal maps, often described as ‘concept maps’ or ‘causal maps’. We found no studies that used CECAN PSM, which is unsurprising given its tendency to be used in other fields of research, policy and practice beyond population health.

Purpose

Most studies used participatory systems mapping with the purpose of understanding an issue/context (n=44), followed by evaluation of interventions or policies (n=13), intervention development/optimisation (n=10), simulation of the future state of a system (n=10), strategy/policy development, methods testing/development (n=1) and research question identification (n=1).

Population health areas

Obesity was the most common topic (n=13), followed by drugs and alcohol (n=11). Other common topics included food and nutrition (n=7), social determinants of health (n=7), non-communicable diseases (n=6), and maternal and newborn health (n=4). Few studies focussed on communicable diseases.

Mapping location

Where reported, papers originated from 18 countries, while 3 further articles mapped across multiple countries. Most systems mapping took place in the United States of America (21) and Australasia (19). Among the 18 countries, 4 were low-income, 9 were middle-income, and 5 were high-income.

Participation in map building

Across the most common methods (CLDs and SD), most projects involved stakeholders in both map building and validation. Papers presenting FCM tended to involve stakeholders only at map building stage. The BBN paper only involved stakeholders at validation stage. To build the system map, most studies used group map building (n=54); only a minority of studies used individual map building approaches (these maps are then later aggregated into one system map). Few studies reported on the participatory approach in a comprehensive manner. Only about a third of studies included a reflection on the adopted participatory approach.

Theory and methodological literature

There was generally limited reporting on theory and integration of other methods. Less than one-third of studies (n=22) included a discussion on theory or methodology.

6. Summary of case studies

The following ten case studies from around the world provide methodological and practical insights that highlight a range of key features and applications of participatory systems mapping. Potential studies were initially identified during the mapping review process (Section 5), with final selection confirmed following a rigorous review (Appendix B). They were developed through key informant interviews with authors from the selected papers. Here we provide an overview of subject matter, method used, and key features. Full versions, including images of the system maps, are provided in Appendix C.

1. Reporting on formative research, and including hard to reach communities [49]

The Youth Violence Systems Project helped communities build strategies to reduce youth violence in Boston, USA. This project included those with lived experiences of gangs, community residents, community-based organisations, and academic, funding, and organisational stakeholders. A formative research phase led the authors to adopt a participatory systems mapping approach. The use of participatory **systems dynamics** generated a new understanding of the problem and created a collaborative environment in which to explore strategies to reduce youth gang violence.

2. Creating policy impact through systems mapping [50]

The UK Foresight Obesity project was led by the UK Government to consider how society might deliver a sustainable response to obesity over a 40-year period. Within this project, obesity was conceptualised as a complex problem, and a **causal loop diagram** was constructed using detailed advice from diverse experts. This map had a significant impact in the public health field, including demonstrable influence on policy, which resulted from numerous engagement and knowledge exchange processes.

3. Reflecting on participatory processes [17]

This study presents findings from a growing body of evidence on systems mapping in the UK physical activity context. Working alongside stakeholders, the purpose of this study was to investigate whether systems mapping could be a useful tool in the planning, implementation, and evaluation of a whole of systems approach to physical activity. To answer this question, telephone interviews were conducted with participants to reflect on the **causal loop diagram** process. Such reflection is an important part of quality improvement and methodological development. Notably, participants were also co-authors.

4. Boundary setting and integrating theory in systems mapping [51]

This study provides insight into the complex factors and dynamic feedback that influence how effectively USA parents/caregivers and healthcare professionals can co-create asthma action plans. It integrated health behaviour and social science theories with practice-based insights using adapted **systems dynamics** procedures. A six-step process involved identifying theories relevant to plan development, selecting experts, defining the problem and its system boundaries, identifying key variables and how they change over time, and developing formal dynamic hypotheses.

5. Innovation in participatory systems mapping [36]

The SIPHER Consortium (UK) developed a new methodology based on Cybernetic principles that integrated traditional participatory mapping and new technologies. Participatory **fuzzy cognitive maps** were used to generate a shared understanding of the inclusive economies policy system with project partners. Novel features included the development of an interactive live tool (a multi-level map) to support continuous engagement, and the incorporation of novel network propagation analyses to identify hidden factors and their cascading effects on outcomes.

6. Boundary setting, and using multi-sector research teams [33]

The Eastern Cape Province in South Africa reports poor maternal health indicators. To understand key drivers of this underperformance, a systems analysis was conducted in one district, using **causal loop diagrams**. The authors also sought to explore whether a participatory approach could support stakeholders' identification of remedial actions. The research team worked closely with district representatives to set the boundary of the system, and conduct semi-structured interviews, and a one-day group model building workshop.

7. Pragmatic use of systems mapping for implementation tracking [52]

The Change4Campbelltown initiative brought together community stakeholders to translate an existing childhood overweight and obesity programme from rural and regional Australian communities to the current local government area. The authors developed a novel and comprehensive method of tracking the implementation of the programme by recording the actions and engagement of stakeholders across the system against a **causal loop diagram**. Stakeholder actions and engagement with the initiative increased throughout the study period.

8. Good practice in reporting participatory processes [53]

This **systems dynamics** study sought to model mental health in cities and urban regions. Working with stakeholders from diverse locations and professional backgrounds in Sweden, the purpose of this study was to investigate the city-systems of mental health, understand the dynamics of these systems, and progress planning toward reaching mental health objectives. Participatory map building took place with key stakeholders, followed by qualitative validation interviews with a randomly selected group of participants, to produce user-friendly maps.

9. Highly participatory mapping, and capacity building of map users [54]

To reduce suicide and improve mental health and wellbeing among youth, a research-practice partnership applied **systems dynamics** mapping and simulation to explore the strategic allocation of limited resources. The partnership was formed between a regional Primary Health Network in Australia, relevant stakeholders, and several academic institutions. The study is notable for its highly participatory approach, as well as its commitment to build the capacity of 'local' model end-users from the outset of the project.

10. Learning lessons from outside population health research, policy and practice [44]

Using the **CECAN PSM** approach, this exploratory project aimed to provide insights on, and inform the management of, two river catchments in the UK (Eden and Medway). The system maps of the water and environmental systems were co-produced with multi-sectoral stakeholders from the areas and took into consideration the wider social and environmental drivers and multiple levels of governance. The mapping processes considered factors such as development of these areas, economic demands, and environmental risks, as well as how to engage the agricultural community.

7. Key messages and reflections for participatory systems mapping in population health research, policy and practice

The purpose of this guidance was to address a gap in the participatory systems mapping literature by providing guidance that informs the choice and design of participatory systems mapping approaches in population health research, policy and practice.

This section summarises the key messages and considerations highlighted in the guidance.

In selecting and designing participatory systems mapping approaches, the following guiding questions should be considered (see Design Framework in Section 4):

1. What is the scope of the activity (including purpose of adopting a systems approach, knowledge gaps to be addressed, type and use of proposed outputs)?
2. What is the added value of a participatory approach (including how, why, and when to incorporate participation, and who should be involved)?
3. Which factors may affect your capacity to use a participatory systems mapping method (including available expertise, capacity building, availability of information on the area of enquiry, proposed data collection methods, and setting)?

Table 6. Advantages and challenges of participatory systems mapping

Advantages	Challenges
• Flexible methods that can be used as a means to an end, or an end in and of themselves, to meet project aims • Shifts people's mindset about the way they consider population health issues, and complex systems • Supports common values, sustained engagement, and consensus among broad-ranging stakeholders • Highlights subjectivities of stakeholders that need reconciling, both among stakeholders and with existing empirical knowledge • Supports the integration of stakeholder views in the design, delivery, and evaluation of interventions • Can be integrated in diverse projects and alongside other research methods • As an emerging field, there are many opportunities for innovation and further developing these participatory methods • The process can be highly beneficial in itself, in developing shared understandings, identifying important differences and developing collaborative relationships	• Sometimes difficult to identify which stakeholders to involve, or what their specific contributions to the systems mapping process and resultant data were • Power dynamics can be difficult to manage (e.g. balancing the views of experts and decision-makers against other stakeholders and potential beneficiaries; or when groups feel in competition with one another) • Maintaining participant momentum and engagement can be difficult if delivered over protracted timeframes • There can be uncertainty and reluctance toward systems mapping as a method • Participants whose role is situated primarily within population health may not be able to directly influence the issues being mapped • It can be challenging to recruit and generate buy in from participants across sectors with potentially substantial influence on the wider determinants of the health issue of concern • Participatory processes are often resource intensive (e.g. time, finances, and expertise)

7.1 Opportunities for future research, policy and practice

We have highlighted several opportunities for future participatory systems mapping in population health research, policy and practice. Derived from gaps in the literature and developments in the field, these broadly comprise five categories:

1. Methodological development
2. Advocating for and strengthening participatory approaches
3. Strengthening reporting of participatory systems mapping research
4. Understanding and demonstrating the use of maps
5. Developing skills and expertise

7.1.1 Methodological development

In population health research, participatory approaches to causal loop diagrams and systems dynamics are the most commonly used methods. This has been accompanied by a tendency to use particular systems mapping software packages (i.e. Vensim and STELLA). There is an opportunity to examine and develop the use of other systems mapping methods in a participatory way (e.g. BBN, FCM, systems-based ToC and CECAN PSM). Each method presented in this guidance has particular strengths and limitations and serves an array of purposes. We recommend that population health researchers explore, develop and apply these methods as appropriate, and document their experiences for wider learning. The increased uptake of such methods may support efforts to generate robust quantitative models, as well as open up additional opportunities for innovation through combinations of systems-orientated research methods (e.g. BBN and agent-based modelling, or FCM and social network analysis). Further potential developments include incorporating a greater theoretical emphasis and overcoming key challenges of mapping methods.

7.1.2 Advocating for and strengthening participatory approaches

There are opportunities to advocate for greater involvement of stakeholders in all phases of systems mapping, including those that do not traditionally rely on participation. Within participatory systems mapping, there is also scope to improve the degree and quality of participation. In particular, there are few examples of stakeholders being included in the design, analysis, or dissemination phases of projects. End users or people with lived experience are however increasingly involved.

The COVID-19 pandemic necessitated and accelerated the development of, and transfer to, online participatory systems mapping processes and software, as part of a wider shift toward remote research practices. These advancements need to be understood and refined, and best practice shared.

7.1.3 Strengthening reporting of participatory systems mapping research

There is a need for better reporting of participatory systems mapping research in population health research, policy and practice. There is a need to reflect on, and potentially standardise, the use of varying terminology associated with participatory systems mapping. A further area for development is to address the lack of consistency in reporting the use of these methods, particularly in relation to participatory processes, such as:

- Stakeholder recruitment and involvement (e.g. who took part, how, and when)
- More reflexivity on involvement processes, including on group dynamics
- Boundary setting processes (who was involved, and how was a decision made)

Examining the reporting of methods was not a focus of this guidance but further guidelines could be developed in future. Furthermore, the visualisation of system maps is often poor, especially in peer-reviewed journals. Static, and at times illegible, maps fail to reflect the dynamic nature of complex systems. This is compounded by a lack of compelling narratives about maps presented in the findings of research articles.

7.1.4. Understanding and demonstrating the use of maps

There also seems to be a general lack of consideration about how system maps will be used after their immediate development, as well as ensuring their sustained legacy and use following the cessation of funded projects. There is an opportunity to further synthesise lessons learned about map use from a range of systems mapping projects. These lessons could be used to further develop the Design Framework presented in this guidance. This has the potential to strengthen advocacy for these methods by helping people to see more clearly how different mapping methods can be used to generate value.

7.1.5. Developing skills and expertise

Much of the published population health participatory systems mapping research to-date originates from North America and Australasia. There is an opportunity to advance these methods in other regions. In particular, there is a need for additional training and capacity building (both in terms of facilitating participatory systems mapping activities and technical expertise, such as analysis and modelling skills). The development of practical ‘how-to’ guides will be an important next step for improving their uptake and use. In addition, the development of participatory mapping skills and expertise may also be aided by the creation and growth of collaborative communities of practice, which may incorporate learning from other fields of research and practice that have a longer history of developing and using these methods (e.g. environmental sciences).

7.2 Strengths and limitations of this guidance

Addressing a key gap in the literature, this guidance was developed by a multi-disciplinary team, and is underpinned by a rigorous methodological process, which included consultation and external validation with a group of experts across high-, middle- and low-income countries. The process ensured a thorough examination and critique of participatory systems mapping in various population health-related contexts. This was done through a combination of methods (i.e. a systematic scoping review, key informant interviews, and expert consultation activities), and input of the project team and other key experts. The dialogue generated between team members and experts throughout this process has also contributed to strengthening an emerging community of practice among systems-orientated methods users and advocates.

Regarding limitations, this guidance only discusses participatory systems mapping within set parameters (i.e. causal systems mapping methods). It is acknowledged that other systems mapping methods exist, and that these may incorporate participatory approaches. This guidance has been developed iteratively to reflect a rapidly evolving understanding of the terminology and methods used in population health research, and participatory systems mapping more broadly. In future it may be useful to consider creating a dynamic guidance resource, for example through the development of an online interface that can be updated to reflect changes in the field.

7.3 Concluding remarks

Participatory systems mapping is an exciting and evolving field – with many current opportunities for development of the methods, their application and reporting. This guidance aimed to further clarify and define thinking around the choice and design of projects using these methods, to encourage thoughtful and purposeful uptake and use of participatory approaches.

The Participatory Systems Mapping Design Framework presented in this guidance is intended to support communities of practice to develop and apply systems mapping methods, and thus facilitate a much needed expansion in the range and diversity of stakeholders and perspectives included in population health research, policy and practice.

Supplementary file

Link to supplementary file 1

Appendices

Link to appendices document

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References

1. Rutter H, Savona N, Glonti K, Bibby J, Cummins S, Finegood DT, et al. The need for a complex systems model of evidence for public health. The Lancet. 2017;390(10112):2602-2604.
2. Egan M, McGill E, Penney T, Anderson de Cuevas R, Er V, Orton L, et al. NIHR SPHR Guidance on systems approaches to local public health evaluation. Part 1: Introducing systems thinking. London: National Institute for Health Research School for Public Health Research; 2019.
3. Jebb SA, Finegood DT, Roux AD, Rutter H, Clarkson J, Frank J, et al. Systems-based approaches in public health: where next? London: Department of Social & Policy Sciences, Centre for Analysis of Social Policy (CASP), Centre for Development Studies; 2021.
4. Nobles J, Wheeler J, Dunleavy-Harris K, Holmes R, Inman-Ward A, Potts A, et al. Ripple effects mapping: capturing the wider impacts of systems change efforts in public health. BMC Medical Res Methodol. 2022;22(1):72.
5. Glouberman S, Zimmerman B. Complicated and complex systems: what would successful reform of medicare look like? Saskatoon, Saskatchewan: Commission on the Future of Health Care in Canada; 2002.
6. Boehnert J, Penn A, Barbrook-Johnson P, Bicket M, Hills D. The visual representation of complexity: Sixteen key characteristics of complex systems. Working paper presented at: Relating Systems Thinking and Design Symposium; 2018; Turin, Italy.
7. Peters DH. The application of systems thinking in health: why use systems thinking? Health res Policy Sys. 2014;12(1):51.
8. Ogilvie D, Panter J, Guell C, Jones A, Mackett R, Griffin S. Health impacts of the Cambridgeshire Guided Busway: a natural experimental study. Public Health Res. 2016;4(1).
9. Scarborough P, Adhikari V, Harrington RA, Elhussein A, Briggs A, Rayner M, et al. Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19: A controlled interrupted time series analysis. PLOS Med. 2020;17(2).
10. Snowden DJ. Cynefin framework [Internet]; 2023.
11. Barbrook-Johnson P, Proctor A, Giorgi S, Phillipson J. How do policy evaluators understand complexity? Eval. 2020;26(3):315-332.
12. Hawe P, Shiell A, Riley T. Theorising interventions as events in systems. Am J Community Psychol. 2009;43(3-4):267-276.
13. McGill E, Er V, Penney T, Egan M, White M, Meier P, et al. Evaluation of public health interventions from a complex systems perspective: A research methods review. Soc Sci Med. 2021;272:113697.
14. Rusoja E, Haynie D, Sievers J, Mustafee N, Nelson F, Reynolds M, et al. Thinking about complexity in health: A systematic review of the key systems thinking and complexity ideas in health. J Eval Clin Pract. 2018;24(3):600-606.
15. Skivington K, Matthews L, Simpson SA, Craig P, Baird J, Blazeby JM, et al. A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. BMJ. 2021;374.

16. Hassannezhad M, Chedgzoy D. 2021. Cascading effects in participatory systems mapping. 2021. Sipher Consortium [blog].
17. Cavill N, Richardson D, Faghy M, Bussell C, Rutter H. Using system mapping to help plan and implement city-wide action to promote physical activity. J Public Health Res. 2020;9(3):1759.
18. Craig P, Di Ruggiero E, Frohlich K, Mykhalovskiy E, White M. Taking account of context in population health intervention research: guidance for producers, users and funders of research. Southampton, UK: National Institute for Health Research (NIHR); 2018.
19. Carey G, Eleanor M, Carey N, Joyce A, Crammond B, Carey A. Systems science and systems thinking for public health: a systematic review of the field. BMJ Open. 2015;5(12):e009002.
20. Barbrook-Johnson P, Penn AS. Systems mapping: How to build and use causal models of systems. Cham, Switzerland: Palgrave Macmillan; 2022.
21. Rutter H, Cavill N, Bauman A, Bull F. Systems approaches to global and national physical activity plans. Bull World Health Organ. 2019;97(2):162-165.
22. Nuzzo JL, Steele J. Time for a causal systems map of physical activity. Bull World Health Organ. 2020;98(3):224-225.
23. Rutter H, Cavill N, Bauman A, Bull F. Systems approaches to support action on physical activity. Bull World Health Organ. 2020;98(3):226-7.
24. McGlashan J, Johnstone M, Creighton D, de la Haye K, Allender S. Quantifying a systems map: network analysis of a childhood obesity causal loop diagram. PLOS ONE. 2016;11(10).
25. Meadows D. Leverage points: places to intervene in a system. 1999. The Sustainability Institute, Hartland, Vermont. 2008.
26. Williams B, van 't Hof S. Wicked solutions: a systems approach to complex problems. 2nd ed ed. Wellington, New Zealand: Bob Williams; 2016.
27. National Institute for Health and Care Excellence. Patient and public involvement [Internet]. National Institute for Health and Care Excellence; 2023.
28. Hassmiller Lich K, Kuhlberg J. Engaging stakeholders in mapping and modeling complex systems structure to inform population health research and action. In: Apostopoulos Y, Lemke MK, Hassmiller Lich K, editors. Complex Systems and Population Health. Oxford, UK: Oxford University Press; 2020:119-134.
29. Freebairn L, Occhipinti JA, Song YJC, Skinner A, Lawson K, Lee GY, et al. Participatory methods for systems modeling of youth mental health: Implementation protocol. JMIR Res Protoc. 2022;11(2):e32988.
30. Vennix JAM, Akkermans HA, Rouwette EAJA. Group model-building to facilitate organizational change: an exploratory study. Syst Dyn Rev. 1996;12(1):39-58.
31. Wilkinson H, Hills D, Penn A, Barbrook-Johnson P. Building a system-based theory of change using participatory systems mapping. Eval. 2021;27(1):80-101.
32. Barbrook-Johnson P, Penn A. Participatory systems mapping for understanding complex societal issues: Methodological innovations to meet 21st century societal challenges. Unpublished paper presented 2019; Manchester, UK.
33. Lembani M, de Pinho H, Delobelle P, Zarowsky C, Mathole T, Ager A. Understanding key drivers of performance in the provision of maternal health services in eastern cape, South Africa: a systems analysis using group model building. BMC Health Serv Res. 2018;18(1):912.

34. Haraldsson HV. Introduction to system thinking and causal loop diagrams: Department of chemical engineering, Lund University Lund, Sweden; 2004.

35. Lannon C. Causal loop construction: the basics [Internet]; 2018.

36. Hassannezhad M, Gogarty M, O'Connor CH, Cox J, Meier PS, Purshouse RC. A cybernetic participatory approach for policy system of systems mapping: Case study of Inclusive Economies. Futures. 2023;152:103200.

37. Malek Ž. Fuzzy-logic cognitive mapping: Introduction and overview of the method. In: Gray S, Paolisso M, Jordan R, Gray S, editors. Environmental Modeling with Stakeholders: Theory, Methods, and Applications. Cham, Switzerland: Springer; 2017:127-43.

38. Kosko B. Fuzzy cognitive maps. Int J Man-Mach Stud. 1986;24(1):65-75.

39. Cavana RY, Clifford LV. Demonstrating the utility of system dynamics for public policy analysis in New Zealand: The case of excise tax policy on tobacco. Syst Dyn Rev. 2006;22(4):321-348.

40. Currie DJ, Smith C, Jagals P. The application of system dynamics modelling to environmental health decision-making and policy-a scoping review. BMC Pub Health. 2018;18(1):402.

41. Homer JB, Hirsch GB. System dynamics modeling for public health: background and opportunities. Am J Pub Health. 2006;96(3):452-458.

42. Ho SH, Speldewinde P, Cook A. A Bayesian belief network for Murray Valley encephalitis virus risk assessment in Western Australia. Int J Health Geogr. 2016;15(1):1-9.

43. Mitchell T. Does machine learning really work? AI Magazine. 1997;18(3):11.

44. Bromwich B, Penn AS, Barbrook-Johnson P, Knightbridge J, Walters N. Systems analysis for water resources. Final report. [Internet] UK Department for Environment, Food and Rural Affairs; 2020.

45. Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC Med Res Methodol. 2018;18:143.

46. Brugha R, Varvasovszky Z. Stakeholder analysis: a review. Health Policy Plan. 2000;15(3):239-246.

47. International Rescue Committee. Stakeholder analysis and social network guidance note; 2019.

48. Penn AS, Bartington SE, Moller SJ, Hamilton I, Levine JG, Hatcher K, et al. Adopting a whole systems approach to transport decarbonisation, air quality and health: an online participatory systems mapping case study in the UK. Atmos. 2022; 3(3):492.

49. Bridgewater K, Peterson S, McDevitt J, Hemenway D, Bass J, Bothwell P, et al. A community-based systems learning approach to understanding youth violence in Boston. Prog Community Health Partnersh. 2011;5(1):67-75.

50. Butland B, Jebb S, Kopelman P, McPherson K, Thomas S, Mardell J, et al. Foresight: Tackling Obesities: Future Choices – Project Report. London, UK: Government Office for Science; 2007.

51. Gillen EM, Hassmiller Lich K, Yeatts KB, Hernandez ML, Smith TW, Lewis MA. Social ecology of asthma: engaging stakeholders in integrating health behavior theories and practice-based evidence through systems mapping. Health Educ Behav. 2014;41(1):63-77.

52. Maitland N, Wardle K, Whelan J, Jalaludin B, Creighton D, Johnstone M, et al. Tracking implementation within a community-led whole of system approach to address childhood overweight and obesity in south west Sydney, Australia. BMC Pub Health. 2021;21(1):1233.

53. Moustaid E, Kornevs M, Lindencrona F, Meijer S. A system of systems of mental health in cities, digging deep into the origins of complexity. Adm Policy Ment Health. 2020;47(6):961-71.

54. Occhipinti J-A, Skinner A, Iorfino F, Lawson K, Sturgess J, Burgess W, et al. Reducing youth suicide: systems modelling and simulation to guide targeted investments across the determinants. BMC Med. 2021;19(1):61. https://doi.org/10.1186/s12916-021-01935-4

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