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# Building a Fuzzy Cognitive Map from stakeholder knowledge: An Episodic, asynchronous approach

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ABSTRACT

Participatory modelling (PM) processes involve stakeholders in developing a simplified representation of reality based on stakeholders' knowledge, perceptions, values and assumptions about a system in which they live and/or work. There has been an increase in the need for structured methods for the implementation of PM processes, to elicit knowledge from stakeholders and to represent this knowledge in a model. This paper presents a method to support the participatory component of modelling processes without the need for face-to-face interactions. The method, which we term Episodic and Asynchronous (EAsy) was applied to construct a Fuzzy Cognitive Map of the Nigerian rice agri-food system. The stakeholder determined Fuzzy Cognitive Map was further applied to develop scenarios and identify leverage points for intervention in the system. The results demonstrate that the EAsy approach is an effective way for co-production to be achieved. The EAsy approach can thus be considered valid to construct a representation of a complex social-ecological system. Using the results and analysis of our process, we discuss the limitations and benefits of this PM method.

## 1. Introduction

Many complex agricultural systems are characterized by factors that are not merely ecological but which also relate to social processes. Developing complete knowledge and understanding of such systems requires input from both scientists and stakeholders that are part of the system. This co-production integrates lay and scientific knowledge, using a diverse group of stakeholders to contribute towards understanding the system of interest in which they live and work (Voinov and Gaddis, 2017). Using the valuable knowledge base of stakeholders, which is locally relevant and contextual, can increase the understanding of a system's dynamics and unravel complex system processes. Stakeholders participation also ensures that there is an engagement with all those involved, and this fosters social learning and collective action towards desired goals, contributing to decision making concerning a system (Butler and Adamowski, 2015; Voinov and Gaddis, 2017).

### 1.1. Choice of methods for participatory modelling

In participatory modelling (PM), input from stakeholders is incorporated in form of their perceptions, values, opinions; into formalized and shared representation(s) of the system (Voinov et al., 2018). Several methods have been used in PM processes and there has been increased interest in these methods in recent years. Methods include concept mapping, causal loop diagrams, fuzzy cognitive mapping, scenario building, system dynamics, Bayesian networks, cellular automata, agent-based modelling; social multi-criteria evaluation (Munda, 2004; Scholz et al., 2015; Le Page and Perrotton, 2017; Olazabal et al., 2018; Büssing et al., 2019). These methods rely on graph theory; using cognitive thinking and social networks to describe complex and dynamic systems (Yoon and Jetter, 2016). In this wide range of tools/methods, co-production takes place when stakeholders are involved at one or more stages of the modelling process. The involvement of stakeholders knowledge and values follow the extended science perspective and the post-normal construct for complex systems characterized by uncertainties (Funtowicz and Ravetz, 1994; Munda, 2004; Bremer and Meisch, 2017).

Recent studies have provided guidance for the selection of methods to be used in a PM process. First and foremost, the purpose of the PM should be considered (Kelly et al., 2013; Gramberger et al., 2015; Voinov et al., 2018). PM is embarked upon with different aims in mind: to achieve social objectives such as mutual learning, communication, problem-solving; to describe and enhance understanding of a system; to predict what might happen in the future; to support decision making,

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policymaking and management of a system (Gray et al., 2018; Voinov et al., 2018). When the aim of the PM is clear, it can be decided how and when to involve stakeholders in the process. For instance, group settings allow for interaction between stakeholders which can enhance mutual learning and problem-solving, as stakeholders take up each other's views and work together to integrate differing views into a system description (Jetter and Kok, 2014). These occur less in individual stakeholder participation and more in group settings (Jetter and Kok, 2014).

Secondly, the choice of method should be guided by how easy the method will allow for diverse groups of stakeholders to be involved (Voinov et al., 2018). Stakeholders' resource constraints, technical ability and capacity to be able to use and continue with a particular tool should be considered (Diniz et al., 2015). A wrong choice of methods can lead to exclusion of groups whose knowledge should be represented in the model (Fairweather, 2010; Denney et al., 2018).

A third consideration for choosing a method is the need to bridge the gap between a qualitative phase of the PM process and a quantitative phase of mathematical modelling. The ease with which stakeholder-derived knowledge, which is often qualitative can be converted to quantitative data to be used in a model should be considered; as well as the use of visualizations to communicate model outputs (Voinov et al., 2018).

### 1.2. Realizing stakeholder participation in participatory modelling

Stakeholder participation in a given PM method can be realized in various ways. Fig. 1 presents a matrix that shows different methods of participation according to the characteristics of the process in space and time. Co-production efforts in PM can be deployed in face-to-face settings, where a group of stakeholders meet in one place and at the same time. Workshops, forums, and group modelling processes fall under this category (Quadrant 1 of Fig. 1). In Quadrant 3, stakeholders are consulted to provide feedback, usually as a way to validate a product. In this case, stakeholders are in different places and not brought together in one location to provide this feedback. Such inclusion of stakeholders who are at different times and places is termed asynchronous participation (Pahl-Wostl, 2008).

In the type of approach mentioned in Quadrant 4, inputs from a wide range of stakeholders groups are collected at different times and locations (asynchronous) over different short intervals of the process (episodic). While the original representation by Pahl-Wostl (2008) refers to consultation over the internet in Quadrant 4, many other methods could be included here. Individual interviews which are done over the telephone, completing online forms, use of self-administered surveys, or web applications are all asynchronous modes of participation (Voinov

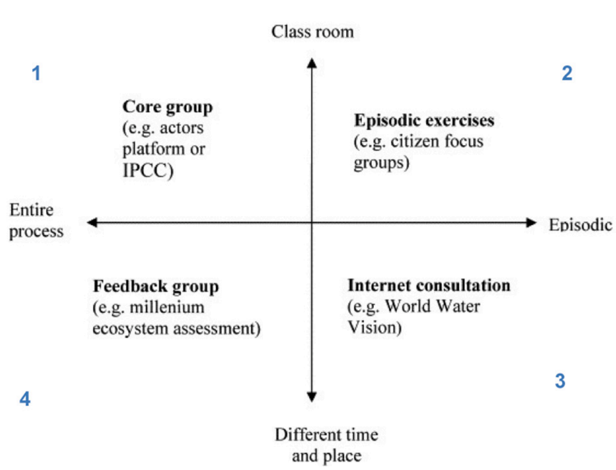


**Fig. 1.** Matrix for the categorization of participation and methods according to the characteristics of the process in time and space (Pahl-Wostl, 2008).

et al., 2016; Gray et al., 2018).

With the advent of technology, a host of 'online' techniques and new media offer different and possibly more effective ways to support the participatory component of modelling processes without the need for face-to-face interactions (Kolagani and Ramu, 2017; Afzalan and Muller, 2018; Voinov et al., 2018). These online techniques use asynchronous participation and offer solutions to the challenges of implementing face-to-face PM settings. Challenges such as logistical constraints of gathering people in one place at the same time, time and resource constraints in arranging meetings, the need for managing group dynamics in group modelling settings (Diniz et al., 2015; Gramberger et al., 2015; Denney et al., 2018).

### 1.3. Objectives

To ensure implementation of PM processes, structured methods proposing good practices and detailed step-by-step methodologies have been a research target (Gray et al., 2018). Structured methods allow for standardized reporting, increasing transparency and reproducibility at every stage of a PM process (Gray et al., 2018; Olazabal et al., 2018). In this paper, we propose a structured method for asynchronous participation of stakeholders in PM. Structured methods in asynchronous participation will ensure that the PM process achieves its aims, the products represent stakeholder input on their knowledge of the system, without tipping the balance of co-production to the researchers. This method is both episodic and asynchronous; involving two episodes of stakeholder engagement and devoid of face-to-face interactions/visual means of engaging with the stakeholders.

Although it builds on documented methods to develop FCMs (Alizadeh and Jetter, 2017; Kokkinos et al., 2018; Olazabal et al., 2018) we apply the proposed method which we refer to as the Episodic and Asynchronous (EAsy) approach to develop a Fuzzy Cognitive Map (FCM) of the current rice agri-food system in Nigeria.. Fuzzy Cognitive Mapping is described below (Section 2.1). In the rest of the paper, we show the novel aspects of the EASy approach as a concrete method, using standardized reporting to increase transparency and reproducibility of the method. We discuss the benefits and drawbacks of this approach and the related challenges that this approach could address in PM processes.
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## 2. Background of study

### 2.1. Fuzzy Cognitive Mapping

Fuzzy cognitive mapping is a technique, that builds quasi-quantitative models from the knowledge of interconnected variables in a system (Jetter and Kok, 2014). FCM is suitable for linking stakeholders' knowledge and scientific knowledge in modelling a complex social-ecological system and has been praised for the ease and speed of obtaining and combining different knowledge sources (Kok, 2009; Jetter and Kok, 2014; Alizadeh and Jetter, 2017; Voinov et al., 2018).

An FCM represents the variables of a system as 'concepts' and assesses the strength between these concepts as causal 'connections' represented by arrows with positive (+) or negative (−) values between −1 and 1 (Fig. 2a). The particular strength of FCM is in the fact that it can be used to analyze the quasi-dynamic behavior of the system derived by multiplying the FCM's weight matrix by the state vector (Fig. 2b). There is a wealth of scientific literature that offers further details on the structure and functioning of FCMs (e.g. Kok, 2009; Papageorgiou and Salmeron, 2012; Jetter and Kok, 2014; Diniz et al., 2015; Gray et al., 2018).

FCMs are useful in modelling complex social-ecological systems as perceived/understood by the stakeholders living and working in the system (Voinov and Gaddis, 2017). The nature of FCM makes it easy for stakeholders to participate in the diagramming of the map or in contributing knowledge for the map building either individually or as a

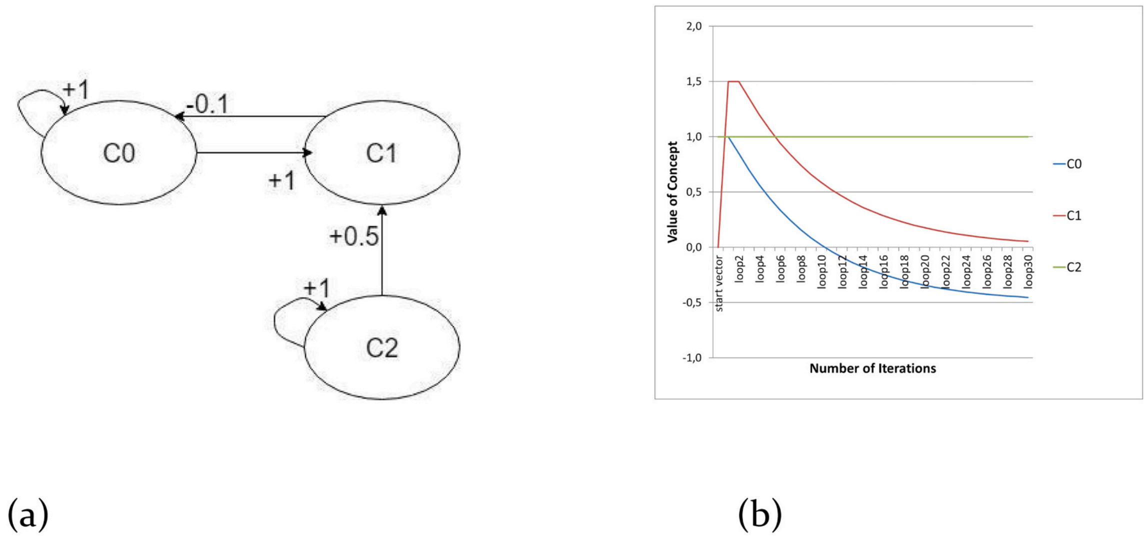


**Fig. 2.** An example of a Fuzzy Cognitive Map (a) a directed graph, showing concepts, C1, C2, C3 linked by weighted connections (arrows with positive or negative values) (b) showing a dynamic graph, number of iterations by the value of concepts (Kok, 2009).

group. FCMs are particularly flexible in allowing the inclusion of both quantifiable and difficult to quantify aspects of a complex system; as well as the different domains of the system (Kafetzis et al., 2010). Crucial steps in the development methods of an FCM include the data collection which in PM settings is knowledge elicitation from stakeholders; knowledge analysis and FCM aggregation. These will all receive ample attention in the application presented here.

### 2.2. *Case study: rice agri-food system in Nigeria*

A demonstration of the method which we discuss in this paper is provided using a case study of the rice agri-food system in Nigeria. FCMs have been used in similar studies to elicit and represent knowledge on a complex agricultural/social-ecological system (Fairweather, 2010; Halbrendt et al., 2014; Bardenhagen et al., 2020). The case study is at the national level and approaches the rice system from farm-to-fork.

Rice, a staple food for half of the world's population, is designated as one of the ten crops that feed the world, especially feeding consumers in Asia and Africa (Seck et al., 2012). In Africa, rice is an all-important crop, for food security and foreign exchange, and indirectly also, for example, for gender equality and youth employment. Annual rice consumption has more than doubled and continues to increase rapidly in most African countries, caused by high rates of population growth and changing consumer preferences (Maclean et al., 2013).

Over the last decade, Nigeria has become the second-largest producer of rice in Africa, yet at the same time, rice consumption has greatly increased, necessitating rice import to close the gap between production and consumption (P/C ratio) (Obayelu, 2015; Van Oort et al., 2015). It is projected that Nigeria will become the third most populous country in the world by 2050, which will further increase rice demand (Seck et al., 2012; Riahi et al., 2017). The Federal Government of Nigeria has made rice food security a major policy priority, intending to achieve rice self-sufficiency (P/C ratio $\geq 1$). This is implemented through programmes such as Agriculture Promotion Policy (APP) (2016–2020) and Economic Recovery and Growth Plan (ERGP) (2017–2020), proposed to increase domestic rice production and improve its competitiveness with imports by employing a combination of trade policies (import tariffs and bans), input subsidizing and other direct investments along the rice value chain (Sule et al., 2019).

Despite these policy efforts, rice food demand is far from met. The complexity of the rice agri-food system with multiple interactions between human and natural components poses a major challenge for the Government and stakeholders to actualize rice food security. Achieving rice food security, and/or the Government's goal of self-sufficiency requires a systems approach. For a system fraught with uncertainties and instabilities, a systems analysis will enhance the current understanding of the system and allow us to explore future scenarios and pathways (Arnold and Wade, 2015; Zhang et al., 2018).

## 3. Methodology

Fig. 3 shows the step-wise process and products of the method that was followed. Our approach builds on Olazabal et al. (2018) for FCM based on individual interviews and Alizadeh and Jetter (2017) on using secondary sources to augment stakeholders' knowledge. The method includes two episodes of stakeholder engagement, first through telephone interviews (Step 3) and secondly, through online forms (Step 5). In Step 4, knowledge from stakeholders is analyzed and aggregated qualitatively. In Step 5, stakeholders provide qualitative weightings to connections. In Step 6, the qualitative weightings are converted into quantitative values.

The process has a funnel shape design (Fig. 3). Beginning with broad

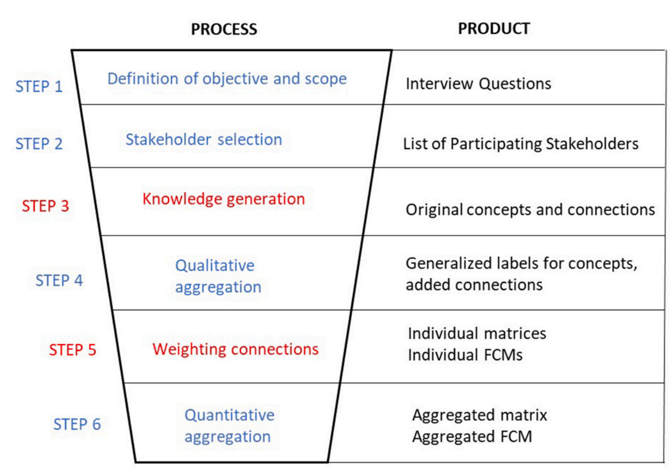


**Fig. 3.** Fuzzy Cognitive Map building steps and products. The steps in red represent stakeholder participation steps, while the steps in blue are researcher-led. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

steps of defining the objective of the study to stakeholder selection to eliciting knowledge from stakeholders (Steps 1–3); narrowing stakeholder knowledge by grouping similar concepts under generalized labels (Step 4). Further narrowing takes place as established connections are presented to stakeholders to be weighted (Step 5). These weights are aggregated to make the final FCM, a single representation of stakeholder knowledge of the system (Step 6). The step-wise process is explained in the next sections.

### 3.1. STEP 1: Definition of objective and scope

FCM development begins with defining the objective and the scope of the study. The objective and the scope both guide stakeholder identification and guide the questions posed to stakeholders to elicit knowledge on the system. The scope refers to the study area the FCM aims to describe. Delineating the scope is important as discussions at different levels yield different results. For instance, describing a system at the farm level will yield a different set of concepts from describing a system on a larger level such as the national level.

The objective of FCM development for this study was to understand and map the rice food system and the scope was at the national level in Nigeria. The central issue discussed was "what are the drivers of rice production in Nigeria?" As such, rice production became the central concept and the beginning of FCM diagramming.

### 3.2. STEP 2: stakeholder selection

Integrating multiple perspectives in understanding a complex system is highly dependent on the participating stakeholders, which makes stakeholder selection very important. Stakeholder selection was based in broad outlines on the Prospex-CQI method.

C = Criteria: Defining a set of criteria and categories for stakeholder groups that are either affecting or affected by the system.

Q = Quota: Setting specific minimum quota for all categories.

I = Individuals: Identifying individuals that fit the categories, with the overall selection fitting the quotas set (Gramberger et al., 2015).

Following these criteria, in this study, 4 categories were present - academia, research institute staff, farmers, and government agencies etc. We began by contacting stakeholders affiliated to institutions and then within each stakeholder category, other individuals were reached using snowballing. Participating stakeholders consisted of multi-actor and multi-scale set of stakeholders.

### 3.3. STEP 3: knowledge generation

Stakeholder involvement alone is not enough to satisfy that a PM process took place. It is necessary to ensure that stakeholder knowledge is elicited, analyzed and represented in the intermediate and final products of the PM (Olazabal et al., 2018). The researcher is tasked with designing and executing the stakeholder engagement during the PM process. The role of the researcher becomes crucial as it determines the balance of co-production, regulating how much stakeholder input versus the researcher's input is used in the process.

To elicit knowledge from stakeholders, semi-structured interviews were held separately with each individual over the telephone. All the interviews were conducted by the same interviewer to reduce bias and risks of losing important knowledge (Olazabal et al., 2018). Stakeholders were asked to respond to the questions according to their perception, experience and/or expertise. Interview sessions ranged from 30 to 90 min in duration. All the interviews were conducted within a 3 month period.

At the start of the interview, the objective and the scope of the study were explained to the stakeholder. Stakeholders were briefed to consider as wide a range as possible of concepts/factors/drivers including social, economic and environmental factors influencing rice production. The stakeholders were asked to describe the relationships and interconnections between concepts and rice production (the central concept). No predefined list of concepts was provided for stakeholders. The interview questions (Table 1) served as a guide to navigate the interview. Depending on the response of the stakeholder, follow-up questions were asked to obtain more detail, while keeping rice production the central focus of the interview.

### 3.4. STEP 4: qualitative aggregation

In this step, we collated a list of concepts mentioned in all stakeholder interviews. We further analyzed these concepts by clustering similar concepts/terms together. To support this aggregation, we conducted a content analysis of scientific publications in the field of rice that refer to the case study country, Nigeria. It is good practice to consider stakeholder knowledge together with scientific knowledge when aggregating stakeholders' knowledge. This ensures the internal consistency of the model and validates the model with empirically established relationships (Hobbs et al., 2002; Özesmi and Özesmi, 2004).

Thereafter we analyzed the statements made by stakeholders one after the other to establish connections. For example, stakeholder A3 made the statement: "there is an increase in local demand and this serves as a stimulus for rice farmers to produce due to unavailability of competing alternatives". The above statement directly converts to Fig. 4a.

The statement gives the reason for the increase in demand for local rice as "unavailability of competing alternatives". The root cause for the "unavailability of competing alternatives" is the government policies on rice imports, so we linked this concept to the "increase in demand for local rice" (Fig. 4b).

Increases in (total) rice production are attributed to an increase in the rice production area (hectare) and/or increased productivity of rice production (yield/ha). Consequently, the only concepts that directly influence total rice production are expansion in the rice production area and an increase in productivity of rice. During the interviews, many stakeholders do not mention these sub-connections but rather link other concepts directly to rice production. This is where the need for the researcher to granulate and augment concepts and connections arises (Alizadeh and Jetter, 2017). For this process, the content analysis of literature provided the commonly used terms in literature. For the statement under analysis, "there is an increase in local demand and this serves as a stimulus for rice farmers to produce due to unavailability of competing alternatives", the concept 'area under production' is what changes to increase 'rice production'. Therefore, the connections are

**Table 1**
Guiding questions used in individual telephone interviews with stakeholders.

| | |
|---|---|
| Stakeholder information | 1. Name, gender, organization, the objective of your organization?<br>2. a) What is the key focus of your organization as regards rice? Is it one or 2 of the following<br>• production<br>• research<br>• policy<br>b) What are the main tasks and responsibilities in your current role? |
| Current system | 3. How is the current rice production situation in Nigeria?<br>4. What factors influence rice production in Nigeria?<br>5. Is there a relationship between these factors? Positive and negative relationships.<br>6. What factors are influenced by rice production in Nigeria?<br>7. Identify 3 drivers that impact the nation's rice production sector? Think bigger scale, national, international, external etc. |
| Actors | 8. Who are the most important actors /stakeholders?<br>9. Who are the most affected stakeholders? |
| Trends | 10. Do you see certain trends in these factors in the last 10 years? |

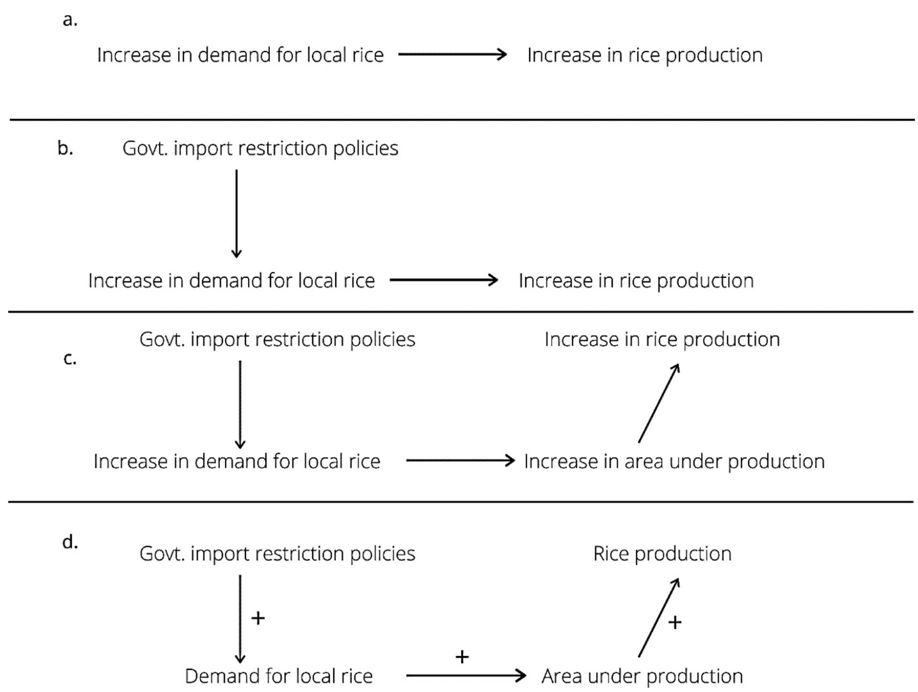


**Fig. 4.** (a-d) Conversion of a statement "there is an increase in local demand and this serves as a stimulus for rice farmers to produce due to unavailability of competing alternatives" to part of the fuzzy cognitive map.

expanded to give the following in Fig. 4c.

This process needs to be repeated by revisiting statements and checking the logic and internal consistency within the concepts and connections. We worked through all the initial concepts and connections provided by stakeholders during the interviews. We removed the terms 'increase' or 'decrease' and attached signs (positive or negative) to each connection. For the statement under analysis, Fig. 4d results.

### 3.5. STEP 5: weighting connections

Stakeholders participated in a 2nd episode by completing an online form. Stakeholders are presented with connections as pairwise relationships. FCMs can be considered representations of pairwise associations using qualitative terms which we convert to quantitatively assigned weighted edges between −1 and 1. These pairwise relationships allow computation of the cumulative strength of connections between the concepts with weighted edges, highlighting all of these connections as a system (Gray et al., 2015).

Stakeholders were asked to choose from the qualitative values – strong, medium and weak, to weight 52 connections one after the other. We asked the stakeholder "How much does the value of concept A impact on the value of concept B (Strong, medium or weak impact)?" (Wei et al., 2008; Carvalho, 2013). The perceived amount of change a concept contributes to another is what is used and not the measure of certainty of the connection. The visual output of the previous step was provided in the online form to enable stakeholders' easy visualization of the entire system while they carried out pairwise associations weighting. A glossary of the original concepts in clusters and their generalized labels were also attached to the online form. The data were downloaded as spreadsheets and the qualitative weights were assigned the numerical values 0.9, 0.5, 0.1 for strong, medium and weak connections respectively.

### 3.6. STEP 6: quantitative aggregation

The individual weightings per stakeholder are coded into separate spreadsheets to form adjacency matrices, and these represent individual FCMs (Diniz et al., 2015). In the matrices, connections between concepts that are not part of the FCM are put in as zero and where connections exist, the weighted value is entered. With these data using a matrix-

**Table 2**
Participating stakeholders' background, description and stakeholder involvement.

| Stakeholder group | Stakeholder description | Code | Participation in 1st episode of stakeholder engagement | Participation in 2nd episode of stakeholder engagement |
|---|---|---|---|---|
| Academia | Works in a higher education institution conducting research/ teaching in rice and related studies | A-01 | Yes | Yes |
| | | A-02 | Yes | Yes |
| | | A-03 | Yes | Yes |
| | | A-05 | Yes | Yes |
| | | A-06 | Yes | Yes |
| Research Institute | Works in a research institute related to rice production and extension services (such as IITA, AfricaRICE, Nigerian Cereals Research Institute).. | R-07 | Yes | Yes |
| | | R-08 | Yes | Yes |
| | | R-09 | Yes | Yes |
| | | R-10 | Yes | Yes |
| | | R-11 | Yes | Yes |
| | | R-12 | Yes | Yes |
| Farmer | Small scale farmer | F-13 | Yes | Yes |
| | | F-14 | Yes | Yes |
| | | F-15 | Yes | Yes |
| | Large scale farmer/head of farmers union | F-16 | Yes | No |
| | | F-17 | Yes | Yes |
| | | F-18 | Yes | Yes |
| Government agencies/ Government departments | Works at state, federal or West African region level, based in Nigeria | G-19 | Yes | Yes |
| | | G-20 | Yes | No |
| | | G-21 | Yes | Yes |
| | | G-22 | Yes | Yes |
| | | G-23 | Yes | Yes |
| Total no. of participants | | | 23 | 21 |

**Table 3**
Concepts' generalized labels and their connections. 4 Connections in red were added by the researchers, all other connections (in black) were mentioned by at least one stakeholder.

| ID | Generalized label | Arrows out | Arrows in |
|---|---|---|---|
| C1 | Govt. Import restriction policies | C1 → C6<br>C1 → C7 | - |
| C2 | Financing and subsidies | C2 → C4<br>C2 → C5<br>C2 → C14<br>C2 → C17<br>C2 → C18 | - |
| C3 | Insecurity and conflicts | C3 → C12<br>C3 → C20 | - |
| C4 | Commercialization | C4 → C20 | C2 → C4<br>C5 →C4<br>C11 → C4<br>C12 → C4<br>C18 → C4 |
| C5 | Mechanization | C5 → C4<br>C5 → C19<br>C5 → C20 | C2 → C5<br>C7 → C5 |
| C6 | Demand for local rice | C6 → C20<br>C6 → C8 | C1 → C6<br>C7 → C6<br>C8 → C6<br>C9 → C6 |
| C7 | Local economic growth | C7 → C5<br>C7 → C6 | C1 → C7<br>C13 → C7 |
| C8 | Market price of local rice | - | C6 → C8<br>C15 → C8 |
| C9 | Consumer preferences | C9 → C6 | C10 → C9 |
| C10 | Quality of milled rice | C10 → C9 | C14 → C10 |
| C11 | Land holding | C11 →C4<br>C11 → C20 | C24 → C11 |
| C12 | Profitability | C12 → C4 | C3 → C12<br>C16 → C12<br>C15 → C12 |
| C13 | Value chain activities | C13 → C7 | C14 → C13<br>C16 → C13 |
| C14 | Processing technology | C14 → C10<br>C14 → C13 | C2 → C14 |
| C15 | Cost of production | C15 → C8<br>C15 → C12<br>C15 → C20 | C2 → C15 |

| | | | |
|---|---|---|---|
| C16 | Rice production | C16 → C12<br>C16 → C13 | C20 → C16<br>C19 → C16 |
| C17 | Improved farm technology | C17 → C19<br>C17 → C22<br>C17 → C25<br>C17 → C26 | C2 → C17 |
| C18 | Irrigation facilities | C18 → C4<br>C18 → C20<br>C18 → C26 | C2 → C18 |
| C19 | Productivity | C19 → C16 | C5 → C19<br>C17 → C19<br>C22 → C19<br>C24 → C19<br>C25 → C19 |
| C20 | Area under production | C20 → C16<br>C20 → C21<br>C20 → C22<br>C20 → C23 | C3 → C20<br>C4 → C20<br>C5 → C20<br>C6 → C20<br>C11 → C20<br>C15 → C20<br>C18 → C20 |
| C21 | Fertilizers and pesticides use | C21 → C26 | C20 → C21<br>C25 → C21 |
| C22 | Soil degradation | C22 → C19 | C17 → C22<br>C20 → C22<br>C24 → C22 |
| C23 | Biodiversity loss | **C23 → C26** | C20 → C23 |
| C24 | Climate impacts and variability | C24 → C11<br>C24 → C19<br>C24 → C22<br>C24 → C25 | - |
| C25 | Pests and diseases | C25 → C19<br>C25 → C21 | C17 → C25<br>C24 → C25 |
| C26 | GHG emissions/ environmental impact | - | C17 → C26<br>**C18 → C26**<br>**C21 → C26**<br>**C23 → C26** |

vector multiplication, the quasi-dynamic output of FCM was calculated for each stakeholder. In a real mathematical sense, the output is static rather than dynamic, so we adopt the term 'quasi-dynamic' to indicate the dynamic character of the interpretation of system changes (Jetter and Kok, 2014). After multiple iterations, values of concepts stabilize and the system attains a steady state. The number of iterations here is not related to time but to the relative influence concepts have on each other (Kok, 2009; Diniz et al., 2015; Voinov et al., 2018).

To build an aggregate FCM, the weighting outcomes for the participating stakeholders were quantitatively aggregated by using the mean value per connection. This combination of individual knowledge into one FCM is considered a representation of shared knowledge (Gray et al., 2015).

## 4. Results

### 4.1. Participating stakeholders

By using the criteria and quota system, participating stakeholders included 6 from academia, 6 from research institutes, 6 farmers and 5 Government agency workers; from 11 states of Nigeria. Table 2 presents details on stakeholders' background and participation in the episodes of

**Table 4**
All Concepts mentioned by each stakeholder during the interviews.

| Concept/ Stakeholder | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 | C21 | C22 | C23 | C24 | C25 | C26 | Total/ stakeholder |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | x | x | | x | | x | | | x | x | | x | x | x | | x | | x | | x | | | | | | | 12 |
| A2 | x | x | | | x | x | x | | x | x | | | x | | x | x | | x | | x | | | | x | | | 13 |
| A3 | x | x | | | x | x | | x | | | x | x | x | | x | x | x | x | | x | | | | | | | 13 |
| A4 | x | x | | | x | | x | x | | | | | | x | | x | | | | x | | | | x | x | | 10 |
| A5 | x | x | | x | | x | | | | | x | x | | | | x | | x | x | x | x | | | | | | 11 |
| A6 | x | | | x | | x | x | | | | x | | | | | x | | | | x | | | | x | | x | 9 |
| R7 | x | x | | | x | | x | x | | | | | x | | x | x | x | x | | x | | | | x | x | | 13 |
| R8 | x | x | | x | | x | | x | x | | | | x | x | x | x | x | x | x | x | x | x | | | x | | 17 |
| R9 | x | | | | x | | | x | | | | x | x | x | x | x | x | x | | x | | | | x | x | | 13 |
| R10 | x | x | x | | x | x | x | x | x | | x | | x | x | x | x | | | | x | | | | | | | 14 |
| R11 | x | x | x | | x | x | | x | | | x | x | x | | x | x | x | | | x | | | x | x | | | 15 |
| R12 | x | x | | x | | x | | | | | x | | | | | x | | x | | x | | | | x | | | 9 |
| F13 | | x | x | x | x | x | | x | | | | x | | | | x | | | | x | | | | x | | | 10 |
| F14 | | x | | | | x | x | | x | | | | | x | | x | | x | | x | | | | x | | | 9 |
| F15 | x | x | | | x | | | x | | | | | | | | x | | | | x | | | | x | | | 7 |
| F16 | | x | | x | x | | | | | | | x | | | x | x | x | x | | x | | x | x | x | | | 11 |
| F17 | x | x | | x | x | x | | | x | x | x | | x | x | | x | x | | | x | | | | x | | | 14 |
| F18 | | x | x | | | | x | | | | | | | | | x | x | x | x | x | x | | | | | | 9 |
| G19 | x | x | | | | | | | x | | | x | | | x | x | x | | x | x | | | | x | | | 10 |
| G20 | x | x | x | | | | x | | | x | | x | | x | x | x | x | x | x | x | | | | x | | | 14 |
| G21 | x | x | | | x | | x | x | | x | x | x | | x | | x | x | | x | x | x | | | | | | 14 |
| G22 | | x | | | x | | | | | | | | | | | x | x | x | x | x | | | | x | | | 8 |
| G23 | x | x | | x | | | x | | | | x | | x | x | | x | x | x | | x | | | | | | | 11 |
| Total no of mentions | 18 | 21 | 5 | 9 | 13 | 12 | 10 | 10 | 7 | 5 | 9 | 10 | 10 | 10 | 10 | 23 | 13 | 14 | 7 | 23 | 4 | 2 | 2 | 15 | 4 | 1 | |

stakeholder engagement.

### 4.2. *Concepts and connections*

The knowledge generation by stakeholders yielded concepts mentioned as phrases/terms in many different forms. All original concepts mentioned (as variables, inputs, outputs, factors, values, states) by stakeholders and the generalized labels chosen for each group of concepts, with the scientific literature used to back these up are presented as Supplementary Material (A1). In Table 3, we show all 52 concepts and highlight 4 connections which were added by the researchers. The 4 added connections represent 7.4% of the total connections.

Table 4 shows which concepts were mentioned by each stakeholder. Fewer mention is made of biophysical concepts, which are the negative externalities of rice production. The lowest mentioned concepts are C26 (GHG emissions/environmental impact), C23 (Biodiversity loss) and C22 (Soil degradation). All stakeholders mentioned C16 (Rice production). The concepts C20 (Area under production), C2 (Financing/subsidies), C1 (Government import restriction policies), and C24 (Climate impacts and variability) are highly mentioned too.

On the online form, a section was provided for comments to be added by stakeholders. Comments (presented in Supplementary Materials, A2) were received from 10 stakeholders. Stakeholders emphasized the importance of already mentioned concepts even using quantitative metrics such as percentages. Stakeholders also mentioned additional concepts such as farm size. Stakeholders made mention of the relevance of the study to the current situation reiterating that the results should be shared with decision makers.

### 4.3. *FCM outputs*

#### 4.3.1. *FCM graph*

Each weight provided by each stakeholder represents the value of the influence of one concept on another (weights of connections) for their individual FCM. An average of all weights per connection provided a value for the aggregate FCM presented in Fig. 5 below. The FCM consists of 26 concepts (C1 – C26) and 52 connections.

Some concepts have only outgoing arrows to other concepts and no incoming arrows. These concepts are termed system drivers, they have a strong outgoing influence on the system. In the FCM (Fig. 5), the system drivers are represented in circles. They also have a reinforcing effect on themselves, so there is an arrow on them. Receiver concepts are influenced by other concepts but are themselves not influencing the system. These are represented in the FCM (Fig. 5) with gray boxes – C8 and C26. Feedback loops are another feature of FCMs, and 9 occur in this FCM. ). Feedback loops are a key characteristic of FCM that make them suitable for analyzing the dynamics of a complex system dynamics. They occur as concepts activate each other in a cyclic manner, accounting for the non-linear, dynamic nature of the system (Papageorgiou, 2013).

#### 4.3.2. *FCM dynamic output*

The weights obtained from the second episode of stakeholder engagement yielded a simple matrix multiplication which produced a dynamic output indicating the state of the system. The model stabilized in the first attempt and so there was no need for further calibration. The dynamic output for the aggregated FCM is presented in Fig. 6.

## 5. Discussion

### 5.1. *Benefits*

#### 5.1.1. *Stakeholder engagement is enhanced*

The challenges earlier mentioned that accompany group PM processes (Section 1.2) are eliminated or mitigated in the EAsy approach. The episodic nature of our approach can be implemented with the same stakeholders without extra challenges to their involvement after initial

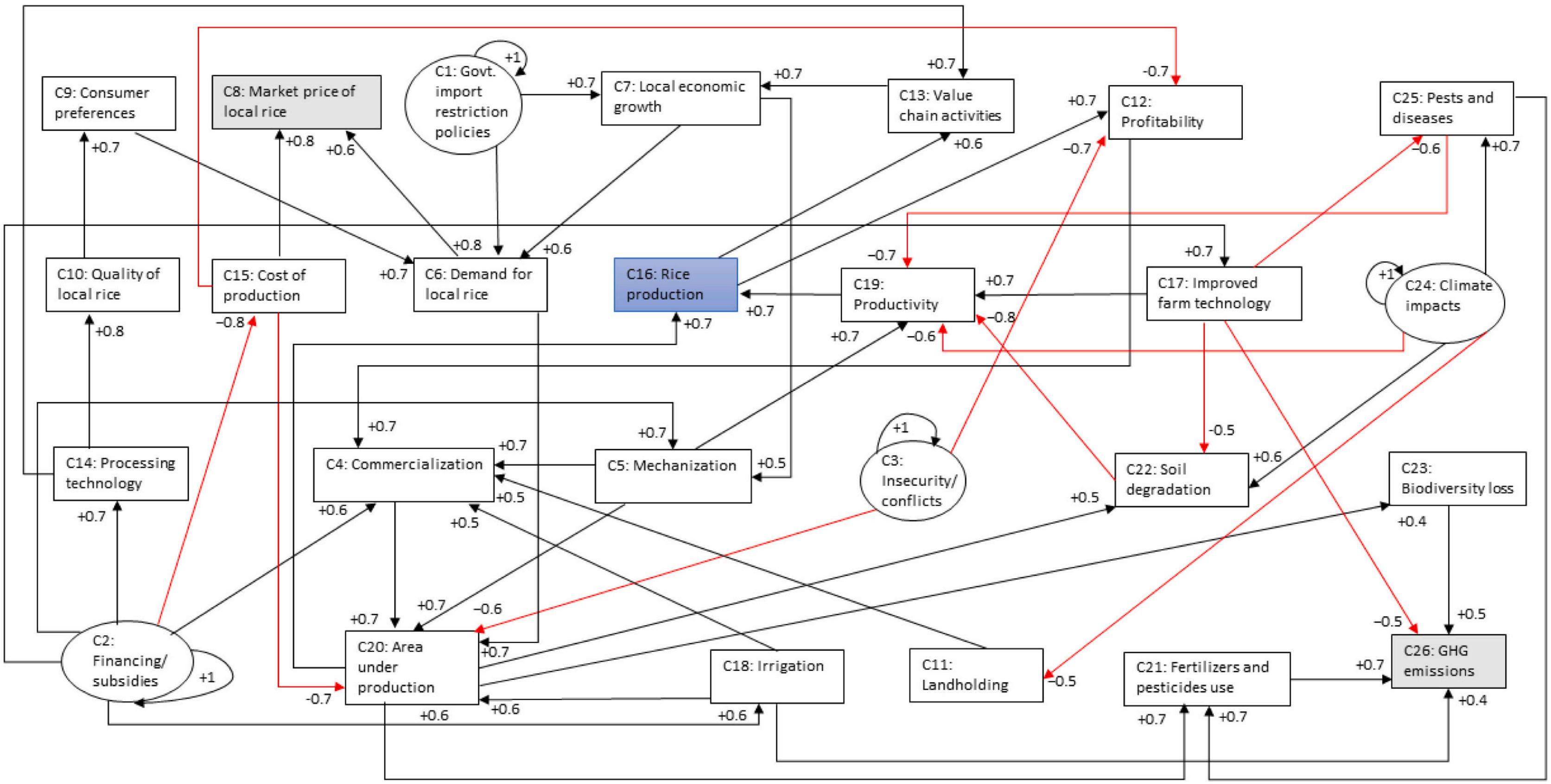


**Fig. 5.** Aggregate Fuzzy cognitive map of the current Nigerian rice agri-food system. General concepts are in white boxes; system drivers are in white circles, the central concept 'Rice production' is in the central blue box and the two gray boxes represent the receiver concepts (i.e., 'market price' and 'GHG emissions'). The connections are represented by arrows: black arrows represent positive connections (causal increase), and red arrows represent negative connections (causal decrease); the numbers present the weights of each connection. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

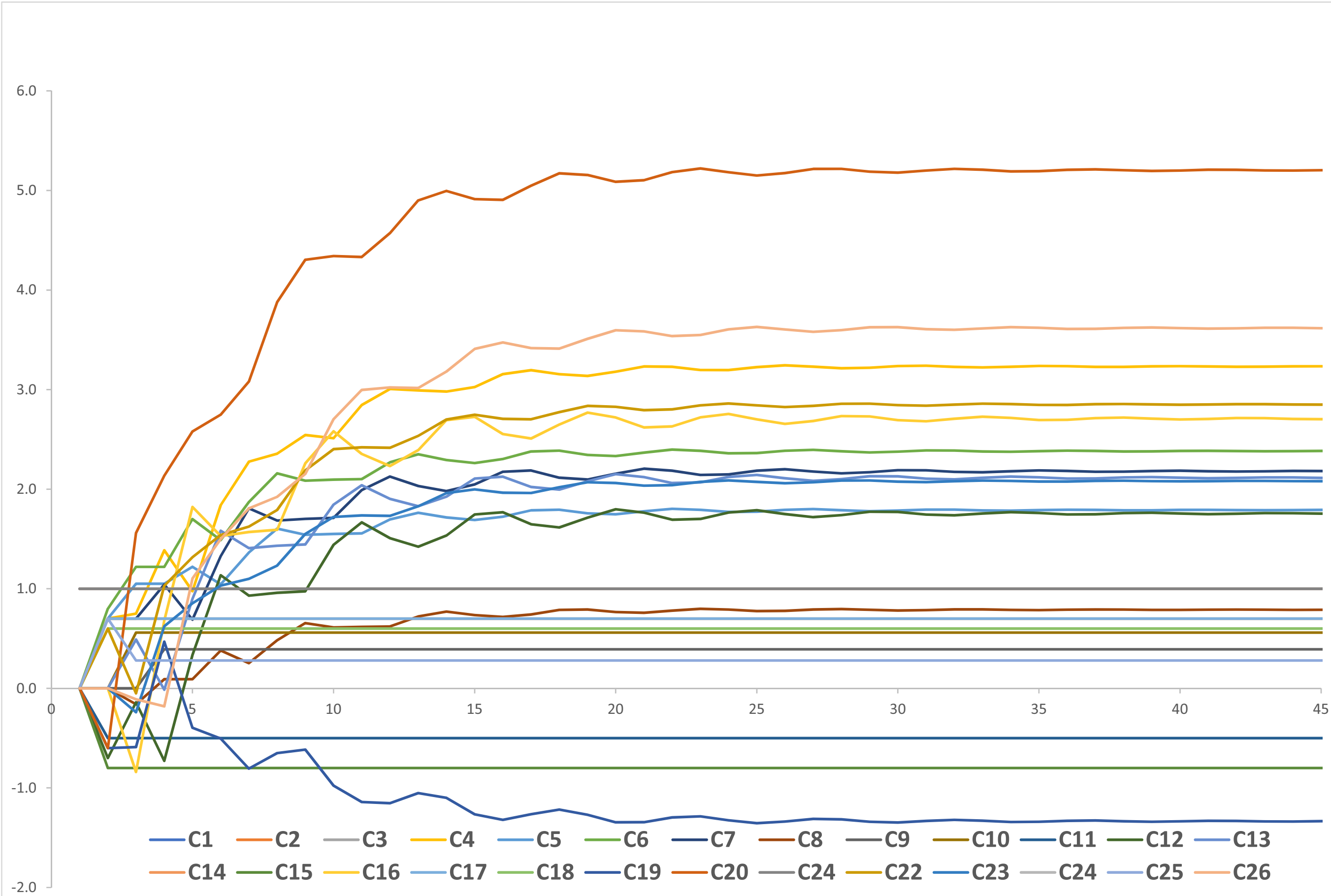


**Fig. 6.** Aggregate FCM of the rice agri-food system (dynamic output). The x-axis represents the number of iteration steps. Each line indicates the current dynamic situation of each concept. The y-axis represents the value of the concepts.

episodes. It is not often the case in PM settings that the same set of stakeholders can remain involved in all episodes of the PM process. In this study, 21 out of 23 stakeholders, 91% of initial participating stakeholders participated in the 2nd episode of the stakeholder engagement. Asynchronous participation of stakeholders addressed the challenge of retaining the presence of the same stakeholders between the PM stages while eliminating the logistic constraints of gathering people in one location at a suitable time.

#### *5.1.2. Individual knowledge is elicited*

Our approach also eliminates the power imbalances that often happen in group modelling settings. Possibly, a workshop setting might give rise to products reflecting the opinion of some and not all the stakeholders present. Not all stakeholders may be able to express the knowledge they carry where others are present due to power imbalances related to gender, cultural, socioeconomic status or the 'stronger' voices dominating the participatory process. Also, in seeking consensus among stakeholders, some opinions may be lost. FCMs built on individual participation allow stakeholders to express individual perception without being influenced or seeking to reach consensus with other stakeholders (Jetter and Kok, 2014). It allows for a wider and deeper knowledge of the system with the diverse, rich understanding that each individual has about the system (Olazabal et al., 2018). Individual participation eliminates intersubjectivity that is a result of workshop settings (Penn et al., 2013; Knight et al., 2014). In any group of people, individual perspectives offer more insights than a group perspective shaped by consensus (Vervoort, 2011). Thus the approach we employ is effective at individual knowledge elicitation from stakeholders.

#### *5.1.3. No prior technical skills or systems thinking needed*

In many PM settings, where groups of stakeholders gather or where the researcher meets with an individual stakeholder for an interview, the FCM diagramming could be participatory. In one case, the stakeholder draws the diagram connecting concepts to concepts. In another case, the stakeholder supplies the knowledge while the researcher draws the diagram receiving feedback from the stakeholders. This structured mapping process is not always effective. Situations have been recorded where stakeholders may be uncomfortable with a structured mapping approach and so it may be better to capture their knowledge through interviews while the researcher does the diagramming (Fairweather, 2010; van Vliet, 2011; Vanwindekens et al., 2013). In this study, the individual stakeholders listed the concepts and the connections during the telephone interview while the researcher drew the diagram afterwards; therefore stakeholders did not participate in a structured FCM diagramming activity. The advantage is that no specific knowledge or familiarity with systems thinking is required. This allows for a broader engagement than a structured diagramming or group modelling activity. It also allows for a diversity of stakeholders to be involved since no prior technical knowledge nor systems thinking is required.

#### *5.1.4. Choice of media promotes stakeholder inclusiveness*

It is best to employ the media that is most comfortable to stakeholders, that allow them to provide knowledge and input, and allow for the inclusion of diverse groups of stakeholders in the PM process (Butler and Adamowski, 2015). We used individual telephone interviews and online form technology. The telephone has become the most important and common form of communication in the local context, Nigeria.

**Table 5**
Overview of how the EAsy method solves the challenges of PM processes.

| Shortcomings of PM | The EASy approach | | |
|---|---|---|---|
| | Eliminates the problem | Mitigates the problem | Still a problem |
| Logistic constraints with gathering people in one location at a suitable time for group modelling. | ✓ | | |
| Inclusion of diverse groups of stakeholders even less organized groups and individuals | | ✓ | |
| Ability to retain the interest and presence of the same stakeholders between the PM stages | | ✓ | |
| Power imbalances where groups of stakeholders gather to share their perception of a system | ✓ | | |
| Seeking consensus on contrasting viewpoints in group modelling sessions | ✓ | | |
| Technical/structured modelling knowledge/systems thinking required of stakeholders | ✓ | | |
| Parts of the system not included in the final model due to heterogeneity of stakeholder knowledge | | ✓ | |
| Balance of co-production | | ✓ | |
| Social learning | | | ✓ |
| Visual aids to enhance communication | | | ✓ |
| Room for feedback from stakeholders on intermediate products | | | ✓ |

Mobile phones, with easy-to-use touch screens, are easily accessible by stakeholders; providing a low barrier form of media for both episodes of stakeholder engagement. While using a video conferencing tool would have allowed for more interaction with stakeholders and possibly participatory diagramming of the FCM, in the local context (Nigeria) currently, the telephone is more stable than the internet. Therefore, using the most common media promoted the inclusiveness of all stakeholder groups in the PM.

#### 5.1.5. Knowledge generation begins with stakeholder

Stakeholders were not offered a predefined list of concepts to choose from and so knowledge generation began with the stakeholders. Some studies offer stakeholders a predefined list with the reason that stakeholders can use identically worded concepts in drawing their individual FCM (Fairweather and Hunt, 2011). Another reason given is that a predefined list saves time used by stakeholders in identifying concepts before drawing their FCM (Fairweather, 2010; Fairweather and Hunt, 2011). Providing a predefined list aims at drawing a map with concepts the researcher has pre-chosen and determined as what makes a 'proper' description of the system (Christen et al., 2015). This can be problematic because concepts selected and provided to stakeholders may not be the most relevant for people in the local context, or may use different wordings than what stakeholders are used to.

In this study, we aim to integrate several stakeholders' knowledge in understanding and mapping the system. Therefore, stakeholders generating their concepts allow the expression of their original knowledge and opinions on which concepts are of importance, without an influence from a list of concepts. When the differently worded concepts are qualitatively aggregated, we have an aggregate cognitive map that represents all stakeholder knowledge. We observed that different stakeholders mention same concepts using different terms (see Supplementary Material). Allowing stakeholders this expression promotes inclusiveness of different stakeholder groups.

#### 5.1.6. All stakeholder knowledge is included

Table 4 reflects how individual stakeholders emphasize the part of the system that they perceive as most relevant. If each stakeholder description is mapped into an individual FCM, their description will miss feedback loops (Gray et al., 2015). We included all stakeholder knowledge to give equal credence to the knowledge of each stakeholder as their valid perception of the system. Including all stakeholder knowledge facilitated the piecing together of different parts of the system, which led to an understanding of the complexity of the system and showed the interplay between interdependent factors. The inclusion of all stakeholder knowledge can be considered a strength, as the heterogeneity of stakeholder knowledge is reflected in the final FCM (Fig. 6).

#### 5.1.7. Use of scientific literature to support stakeholder knowledge

Concerns have been raised about the confusion that may arise on the use of generalized labels which were not agreed upon by stakeholders (Olazabal et al., 2018). Also, Fairweather and Hunt (2011) criticise the use of a qualitative aggregation which leads to generalized labels rather than providing a predefined list of concepts for stakeholders to choose from. They argue that this post-processing of stakeholder knowledge relies a lot on the researcher's subjective interpretation of stakeholder expressions. After knowledge elicitation from stakeholders, more decisions need to be made by the researcher as part of post-processing activities. This researcher subjectivity can tip the balance of co-production, and researcher input may outweigh stakeholder input (Voinov et al., 2016). To mitigate these concerns, we use scientific literature to provide an objective way to aggregate stakeholder knowledge and allocate generalized labels to groups of concepts; thereby reducing subjective interpretation of stakeholder expressions. The most commonly used expressions in literature are used for concepts clustering, concepts generalized labels, in establishing sub-connections and filling in missing connections. To ensure stakeholder understands what the final terms used mean, in the 2nd episode of stakeholder engagement, on the online form for weighting connections, a glossary of the original concepts in clusters and their generalized labels is included for stakeholders (Supplementary materials).

#### 5.1.8. Aggregation method reduces loss of heterogeneity

PM processes often include qualitative and quantitative aggregation to put together individual cognitive maps or those of separate groups in one social/aggregate map (Diniz et al., 2015; Singh and Chudasama, 2017; Singh et al., 2019). Aggregation can lead to the loss of heterogeneity in stakeholder perceptions (Mehryar et al., 2019). Some group modelling studies carry out quantitative aggregation before qualitative aggregation to arrive at a social aggregate cognitive map (Singh and Chudasama, 2017; Singh et al., 2019). We moved from individual knowledge to aggregated knowledge in two steps. First, in Step 4, a qualitative aggregation is done on individual stakeholder knowledge through analysis, clustering into groups, and allocating generalized labels to groups of concepts. In Step 5, stakeholders individually assigned weights to the same connections and these weights are qualitatively aggregated with the common mathematical average. By including all stakeholder knowledge and aggregating qualitatively before presenting for weighting, we retain the heterogeneity in stakeholder knowledge.

### 5.2. Drawbacks

#### 5.2.1. Balance of co-production

Models are simplified representations of reality in which the process of simplification is guided by the knowledge and assumptions of those involved in the model development process (Schlüter et al., 2019). When researchers and stakeholders are involved in the process, as is the case with PM, we want to ensure that the balance of co-production does not shift to the researchers. The main issue with the EAsy approach is that with asynchronous stakeholder participation, much of the PM post-processing activities rely on the researcher and this post-processing involves crucial decisions on the structure of the FCM. At the end of the process, the role of the researcher is relatively large as compared to the face-to-face PM settings such as group modelling. The researcher needs to have good interviewing and cognitive mapping skills and needs to be able to translate expert statements into an FCM (Jetter, 2006). Like any interpretive method, the knowledge elicitation and map diagramming are sensitive to the subjectivity of the researchers, their preferences, biases, as well as mapping skills (Elsawah et al., 2015).

Howbeit, we mitigate these risks and achieve a representation based on stakeholder knowledge by validating our decisions with previous scientific studies (Supplementary Material). Jetter and Kok (2014) advice for a combination of map diagramming with face-to-face interviews which will help stakeholders to carefully consider their mental models. This can still be achieved asynchronously by using online diagramming tools and other web services or video conferencing tools. The EAsy approach can be enhanced by use of technology to reduce the post-processing activities carried out by the researchers only.

#### 5.2.2. Weighting connections as pairwise associations and with linguistic values

We chose pairwise connection weighting as a participatory design to accommodate diverse stakeholders with their skills and knowledge. However, pairwise connection weighting has the drawback that the system may not be considered as a whole but as linear causalities only. We reduced the effect of this drawback by including in the online form a diagram of the mental model being weighted to provide a visualization of the whole system to stakeholders. Also, instructions were included to consider the linear casualties being weighted as part of the system.

On the use of linguistic scales, the stakeholders must be weighting on purely linguistic scales so as not to confuse this with the weighting within the FCM where strengths are relative (Jetter and Kok, 2014). From the additional comments provided by stakeholders, stakeholder A5 made a comment using numerical values to describe some connections; one of which is “acceptability of local rice among consumers has improved significantly (about 70% by my perceived estimate)” (see supplementary material). As is the case in this additional comment received, it is common for stakeholders to perceive the degree of change in the system in numerical values even though they are offered linguistic values for weighting connections. This raises concerns with the use of pairwise connection weighting whether stakeholders are weighting causalities in the system relative to each other in the FCM or with their numerical estimates of the system in reality.

Stakeholders use linguistic values of strong, medium and weak which the researchers need to convert to numerical values. Realizing the subjective character of the translation, we analyzed the effect of various sets of numerical values on the dynamic output :0.9/0.5/0.1; 0.9/0.6/0.3 and 0.8/0.5/0.3. We found that although absolute stabilizing factors differ, in relative terms the outputs were very similar. In an aggregate map, the choice of weights has much less impact on the overall output as differences in assigned values average out.

#### 5.2.3. Consideration of learning

Social learning and communication are an important part and aim of many PM processes and can be used for method appraisal in PM. Although the goal of this study is to elicit and represent knowledge, an avenue to enhance social learning would have increased the benefits of the approach. In addition to the missing interactions between stakeholders, the approach would have benefitted from more interaction between the researchers and the stakeholders. A more detailed discourse and room for feedback during the map diagramming and other post-processing activities carried out by the researchers could enhance the final output. Stakeholder R7 as an additional comment in the 2nd episode mentioned an additional concept (family size) that was not mentioned earlier during the interviews. This indicates the need for other episodes of interaction between the PM steps to receive feedback from stakeholders on the intermediate and final products of the PM process.

Also, an analysis may demonstrate changes in the ways individuals conceptualize the system as the result of interaction with the intermediate products and final model (Radinsky et al., 2017). Smetschka and Gaube (2020), in a workshop PM setting, presented the initial model design to stakeholders to fine-tune their perceptions via an interactive interface. Further development of the EAsy method would benefit from the use of interactive interfaces to capture stakeholders concerns on the initial model design.

## 6. Conclusions

We finalize the paper by presenting the shortcomings of PM processes together with an assessment of the degree to which the EAsy method we applied in this paper can overcome them (Table 5). We finalize the paper showing how the EAsy method has the potential to decrease shortcomings in PM processes.

In this paper, we offered a structured method to elicit systems knowledge from stakeholders and represent this in an FCM. Our method was applied in a case study of the rice food system in Nigeria. This co-production method is characterized in time and space as episodic and asynchronous (EAsy). We also provided a detailed process with standardized reporting, ensuring transparency and reproducibility at every stage. Also, we offered a method that does not require special software or hardware, or specific qualities of stakeholders in systems thinking or FCM construction.

The emphasis in this paper has been on the process and method, yet the results demonstrate that co-production can be achieved in PM settings without face-to-face interactions with stakeholders. The final output of this method is similar to that of other studies. The method can thus be considered equally valid to construct a representation of a complex social-ecological system. The output of this approach yielded a FCM of the current rice agri-food system of Nigeria. From this FCM, we developed scenarios, using the current situation as the baseline scenario, for which the current drivers apply. The dynamics of the FCM coupled with the scenario analysis yielded leverage points for intervention in the system that would lead to more desirable system outcomes. The 3 leverage points identified are 1) Higher levels of productivity would lead to less need to expand the agricultural area to compensate for soil degradation-related yield decline 2) Increasing the productivity of land through mechanization prevents further agricultural area expansion 3) Import restriction policies divert private sector investment to local agricultural development (such as mechanization investment). In (REF), more results are discussed in detail.

From a methodological point of view, we can thus question the need for live, in-person participation as an indispensable component in the growing number of applications of participatory modelling. Especially in the light of health pandemics and the urgent need to reduce our carbon footprint, an approach like we apply offers an alternative to live, in-person participation. Research engaged in participatory processes with local stakeholders should decide for which issues and in which phases certain participatory elements could be implemented with asynchronous participation of stakeholders. Further research should explore how asynchronous participation of stakeholders in participatory processes can benefit from technological advancement, especially with incorporating the use of visuals. It is important to emphasize that specific cases should use the media outlets that present low entry and usability barriers to the stakeholders involved while achieving the purpose of the PM.

## Author contributions

**GIE:** Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing - original draft, Writing - review & editing. **KK:** Conceptualization, Supervision, Writing - original draft, Writing - review & editing.

## Declaration of interests

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

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crsust.2021.100053.

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