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# PUBLIC POLICY PLANNING TO ENHANCE THE RESILIENCE OF SOCIO-ECOLOGICAL SYSTEMS TO CLIMATE CHANGE: OPERATIONALIZING RESILIENCE CONCEPTS FROM A DYNAMIC PERSPECTIVE.

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# Abstract

This study outlines a system dynamic based approach to the planning for resilience in food systems to climate change. The processes described and the insights gained are novel in the literature since they focus on describing operational aspects of resilience that can be generalized to multiple contexts and problems. On the one hand, the process described offers an aid for researchers and practitioners operationalizing resilience in public sector settings. Simultaneously, the insights gained from multiple stakeholder discussions and modelling work open new questions regarding the general mechanisms driving resilience in food systems.

Climate change is threatening the extent to which social, economic and technical development will contribute to increase global food security. The increase on weather variability and extreme events are expected to have a direct impact on crops' yields and hence on the three main outcomes of food systems: food affordability, access and quality. The impacts of climate change are likely to increase food insecurity, specially among the rural poor, and there is a need urgent actions are needed for adapting food systems to the new and challenging conditions.

Resilience is commonly used to describe the means to maintain food systems' outcomes despite extreme weather events or unpredictable weather. Resilience, as a concept, is appealing to researchers and policymakers but is rarely used beyond a metaphor for describing an idealized system. Limited applications of resilience as policymaking and planning framework are related, among other factors, to the lack of an approach to operationalise the concepts described in the literature into a planning process

This study contributes to close this gap by outlining an approach for operationalising resilience in socio-ecological systems. Specifically, it explores the use facilitated system dynamics to support the planning for resilience in small-scale agricultural systems within public sector settings.

Namely, the lessons learned while working with two small-scale agricultural systems in Guatemala are used as instrumental cases to provide insights about the benefits and

challenges of using facilitated system dynamics in the process of planning for resilience. The process consisted of intense field work (collecting data, interviewing stakeholders, organizing participatory workshops) and back office modelling. Tangible outcomes and feedback from the stakeholders were later analysed and confronted in the literature to yield the conclusions synthetized into academic articles and this study.

This study concludes that the interpretation of what resilience means is socially constructed by the stakeholders addressing the problem. This process benefits of including a wide range of stakeholders engaged in a facilitated modelling exercise to ensure that different perspectives are taken into account.

Moreover, the complexity embed in the adaptive mechanisms driving resilience requieres, or at least benefits, from using computer simulations to explore potential behaviours of the systems' outcomes. Evaluating this outcomes in the light of resilience characteristics not only offers an operational perspective of resilience, but also helps to identify thresholds and to plan accordingly.

Finally, the experience documented in this study shows that planning for resilience benefits of focusing on key strategic social, environmental and economic resources. Strategic resources play an important role on resilience mechanisms and can be directly linked to concrete activities and process. Moreover, focusing on managing resources showed to be a good way to engage with process oriented policymakers in the public sector.

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# Chapter 1

# Introduction

## 1. PROBLEM DEFINITION

Food systems are a particular type of Socio-Ecological System (SES) managed with the primary purpose of producing food (Ericksen, 2008a). As described by Ericksen (2008), one of the primary purposes of food systems is to provide food security to its stakeholders. FAO (2002, p. 50) defines food security as "all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life".

Social, economic and technical development have evolved during the last century improving food systems productivity, reliability and quality. The productivity of food systems has increased to such extent that food production has not only being able to keep the pace of population growth but has been able to improve food security in many regions (Vermeulen, Campbell, & Ingram, 2012). While these gains have not been equal across the globe, and in many countries, food insecurity and undernutrition conditions are still alarming, there has been considerable progress in reducing undernutrition in a global scale (von Grebmer, Bernstein, Prasai, Amin, & Yohannes, 2016).

Nonetheless, this progress made toward eliminating hunger is now at risk. Climate change and other factors are threatening the extent to which the gaps on food security will continue reducing at the same pace, or continuing reducing at all (Campbell et al., 2016; Ericksen, 2008b; Schmidhuber & Tubiello, 2007; Vermeulen, Campbell, et al., 2012; Wheeler & von Braun, 2013). This threat is higher among those already food insecure countries with high dependency on local production and rudimentary production systems (Schipanski et al., 2016; Schmidhuber & Tubiello, 2007).

This study focus on the effects of climate change on food security particularly in subsistence economies. An increase in temperatures and changes in climate patterns have been consistently observed since the 1950s (Pielke et al., 2007; Wheeler & von Braun, 2013). This climate change, primarily attributed to anthropogenic reasons, has significant, long-lasting and complex effects on local ecosystems (Pielke et al., 2007). Researchers have hypothesised that a moderate increment in temperature may increase the productivity of some food systems (Schipanski et al., 2016; Tendall et al., 2015). However, weather variability and more severe and frequent extreme weather conditions (e.g. droughts and floods) have mainly adverse effects on small-scale farming systems and food security.

Weather variability and extreme conditions reduce yields and productivity of agricultural systems affecting food availability (Schipanski et al., 2016). The potential reduction in yields is particularly important on communities that depend on subsistence agriculture and local production to access food. Under the new conditions resulting from climate change, food might just not be available. The scarcity of food is compound by poverty, and vulnerable groups are likely to be more affected (Ericksen, 2008b; Schipanski et al., 2016; Vermeulen, Campbell, et al., 2012). Since poverty translates to limited purchasing power and limited access to markets, underprivileged communities are strongly sensitive to increases in food prices and local scarcity (Headey, 2011; Schmidhuber & Tubiello, 2007). This sensitivity is aggravated by a simultaneous reduction in incomes resulting from economic dependence on climate-sensitive sectors like agriculture (Vermeulen, Aggarwal, et al., 2012; Vermeulen, Campbell, et al., 2012).

These effects are already noticeable. For example, FAO (2017, 2) reports a sharp detriment of food security during 2016 in parts of the world where droughts or floods, at least partially linked to climate change, have combined with war and conflicts. In the medium term, as the increase in weather variability drills small-scale farmers' incomes, similar effects might be observed in other parts of the world (Vermeulen, Campbell, & Ingram, 2012). Society needs to adapt to these "gradual changes in the means and distributions of temperatures and precipitation" (Vermeulen, Campbell, et al., 2012, p. 196).

The need for climate change adaptive strategies in food systems is urgent (Vermeulen, Aggarwal, et al., 2012). Food systems, especially those feeding the poor, need to be rethought and redesign to be able to continue fulfilling their purpose and sustainably provide food security despite this challenging conditions. The concept of resilience is defined, as it basics, as the system adaptive ability to maintain its functionality even when the system is being affected by a disturbance (Gallopín, 2006; Holling & Gunderson, 2002). Unsurprisingly, the concept of resilience has become incredibly popular in the discussion of adaptive strategies in food systems (Bahadur, Ibrahim, & Tanner, 2010; Davoudi et al., 2012). Resilience is often seen in this discussions as complementary to sustainability and is commonly associated with the means to maintain food availability, quality and access despite extreme weather events or unpredictable weather (Tendall et al., 2015).

Hence, resilience if frequently used not only to describe the state of the system but also in a prescriptive manner to draw policies and recommendations. While the socio-ecological literature is extensive on describing characteristics of systems that have shown resilience (Berkers, Colding, & Folke, 2003; Berkes & Jolly, 2001), the prescriptive usage of resilience remains underdeveloped. Notably, and despite its popularity, in the policymaking domain resilience still has a long way to go (Duit, 2015; Duit, Galaz, Eckerberg, & Ebbesson, 2010).

Translating the ambition of making food security more resilient into effective policies still dodges conventional approaches (Chapin III et al., 2009; Folke, 2006). There is an abundant amount of literature that elaborates on hypotheses about the theoretical principles that underpin resilience (Biggs et al., 2012; Carpenter, Westley, & Turner, 2005; Chapin III, Kofinas, & Folke, 2009). However, little has been discussed so far on how to analyze and plan for resilience (Davoudi et al., 2012; Duit, 2015; Marshall & Marshall, 2007; Pizzo, 2015). Namely, there is not a defined approach that operationalises concepts described in the literature into the planning activities and processes (Davoudi et al., 2012; Davoudi, Brooks, & Mehmood, 2013; Duit, 2015).

This study contributes to close this gap by reviewing the current state of the art and building on the current body of knowledge to outline an approach for operationalising resilience in SES. By compiling experience documented in case study research, the first steps towards such analytical approach have been taken (see for example Berkes & Jolly, 2001; Marshall & Marshall, 2007), but a clearly defined, transferable and replicable approach is still missing. The need for such approach is more pressing since the traditional policymaking approaches are dodged by the challenges of dealing with complex SESs, the uncertainties about adaptive mechanisms and our limited understanding about the social aspects of resilience itself (Davoudi et al., 2013; Marshall & Marshall, 2007).

Alternatives to deal with the aforementioned challenges can be found in the socio-ecological literature. On the one hand, simulation and mathematical modelling has been since long time ago applied to complex problems in many disciplines including social and ecological science.

Similarly, participation had gained attention as a methodological option for addressing messy and politically contested problems.

Based on previous case study research in the socioecological literature, this study builds on the early work of Walker et al. (2002) and explores the use participatory modelling approaches for analysing and planning for resilience in food systems. Particularly, this study focuses on tailoring the approach proposed by Walker et al. (2002) to: a) the planning of resilience of food security in small-scale agricultural systems and b) the planning and managing process of the public sector.

While the results presented in the next chapters are bound to exploratory, they outline steps to follow during the planning for resilience, answer methodological questions needed to enable this process and provide empirical evidence of the potential benefits of the proposed approach. While further case study research it is still needed to refine it, the lessons learned and documented in this study offer a helpful "crib sheet" for practitioners willing to apply it to other settings (e.g. different countries, different food systems).

## 2. BACKGROUND

### *2.1 Socio-Ecological Systems, Food Systems*

In this study, the term system is used to describe a collection of elements within certain boundaries that depend on each other (Checkland, 1981). SES are coupled systems in which human activities influence and modify ecosystems to gather resources and services (Berkers et al., 2003; Chapin III et al., 2009). SESs vary from forests to cities, and the degree and type of interactions between their social and ecological components are also different among them. In this study, the terms "social system" or "social component" of an SES are broadly used to cover a wide range of human activities and interactions including economic transactions. Similarly, "ecological systems" or "ecological component" of SES is used to cover the ecosystems and the services they provide.

Of the broad variety of SES, there are probably no SES that are as old and essential to human subsistence as the food systems. Food systems are a particular type of SES which primary purpose is to produce food. The activities associated to food systems are surely among the first type of humans' interventions in their ecosystems, particularly with the introduction of agriculture. This study focuses on food systems because their importance in covering basic human needs but also because of their vulnerability to climate change (Ericksen, Ingram, & Liverman, 2009; Zezza & Tasciotti, 2010).

In this study food systems are conceptualised using the characterisation provided by (Ericksen, 2008a). Food systems are conceived as a set of activities to supply food from production to consumption, including intermediate activities as packing, transport and retail (Ericksen, 2008a). Examples of food systems include: livestock, fishery and the ones of particular interest of this study, agriculture systems.

In particular, this study focuses on food security. Food security and the lack of it (food insecurity) have many dimensions (e.g. nutrition value of food consumed, chronic shortages of food, accessibility) and Ericksen (2008a) links them into three main outcomes of food systems (see Figure 1): food access, food affordability and food utilisation.

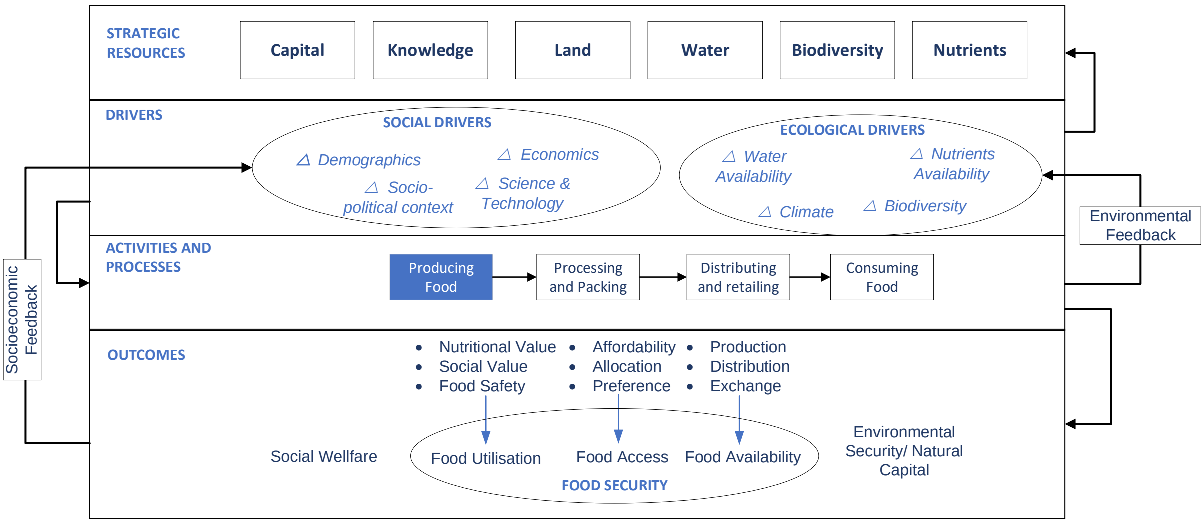


*Figure 1:* Simplified representation of a food system
*Note:* adapted from (Ericksen, 2008a)

To achieve these outcomes, a number of process and activities are required. Ericksen et al. (2008, p.238) classify the activities in food systems into four groups: a) producing food, b) processing and packing, c) distributing and retailing food and d) consuming food. This thesis focuses on the first group, producing food. Production of food includes all the activities related to the production of raw materials used to produce food. For instance, activities needed for agricultural production are planting, caring for plantations and harvesting as well as pest and soil management.

Each of these activities consumes or deplete resources in the system (e.g. capital, nutrients in the soil, water in reservoirs, labour). The interaction of different strategic resources and their status over time result on drivers that influence (foster or constraint) the outcomes of the system by driving efficiencies, effectiveness and productivity of the activities described above.

### 2.2 Climate change effect on food systems

There is substantial evidence that shows that climate conditions are quickly changing around the globe as result of a sustained increase in the global mean temperature (Wheeler & von Braun, 2013). Food systems, particularly agricultural systems, are intrinsically sensitive to changes in the weather and highly vulnerable to climate change (Campbell et al., 2016; Ericksen, 2008b; Vermeulen, Campbell, et al., 2012; Wheeler & von Braun, 2013). The magnitude and type of climate change effects on food systems will vary with the location.

In general, climate change is likely to have a direct effect on the environmental drivers in ways that will diminish food system capability to support food security. The increase of floods and weather variability is expected to result in a net reduction in crops yields (Schmidhuber & Tubiello, 2007; Wheeler & von Braun, 2013). This reduction in crops yields is particularly expected among countries close to the equator where the production techniques are underdeveloped, and the poverty index is high (Thompson & Scoones, 2009; Wheeler & von Braun, 2013). In fact, the constant reduction in undernutrition worldwide has already slowed down as consequence of climate events and its pressures on food prices (Wheeler & von Braun, 2013). Quality and safety are also likely to be affected as production, transport and storage conditions might not be appropriate for new weather conditions (Ericksen, 2008b).

While direct impact can be expected on yields and hence food affordability, impacts are expected to quickly spread to other environmental and social drivers affecting incomes, trade, and equality (Wheeler & von Braun, 2013). Thus, climate change will not only reduce food availability but, when combined with other social drivers, it is likely to increase poverty and reduce food affordability and to increase social conflict (Ericksen, 2008b). Not surprising, poor households are likely to be more vulnerable to become food insecure as result of climate change through failures in food systems that prevent them from providing any of the three main outcomes contributing to food security (Maxwell, 2001).

Hunger and poverty are closely related and reinforce each other. The lack of money to purchase food reduces labour productivity, prevents educational achievements and reduces tolerance to diseases, restricting opportunities for accessing higher incomes (Fischer, Shah, & Velthuizen, 2002; Hallegatte, Bangalore, Fay, Kane, & Bonzanigo, 2015). Since poor households are unable to secure food through market channels, they often rely on subsistence agriculture and production for self-consumption as primary source of food. For these poor households strongly dependent on local production food security will be at risk even if food is globally abundant (Thompson & Scoones, 2009).

### *2.3 Resilience and climate change adaptation*

Undertreat of climate change effects it is fundamental to address the limitations of current agricultural policy and practice to ensure long-term and sustainable food security. In practice, resilience is often used as a measure of a system capability to respond and adapt to new conditions in the environment (Davoudi, Brooks, & Mehmood, 2013). However, the meaning of this measure is not precise (Tendall et al., 2015). As its basics, there is at least two distinctive interpretation of resilience: the engineering one focused on stability and the ecological one, focused on adaptability and transformation (Holling, 1996). Within an engineering paradigm, resilience can be measured as the systems' ability to absorb a disturbance or a shock without showing visible changes in its main outcomes (Holling, 1973). Alternatively, within an ecological paradigm, resilience is measured regarding the system's ability to adapt and reorganise itself to recover from a shock (Folke, 2006; Walker, Holling, Carpenter, & Kinzig, 2004).

From stability to transformation, resilience concept offers a wide open framework for understanding how food systems might succeed in providing food security. First, the resilience theory provides a useful analytical framework for identifying ways for stabilising system outcomes by keeping them in equilibrium or making them go back to it (Ludwing, Walker, & Holling, 1997). In this case, resilience can be understood as the means for stabilising food security, when the system is affected by climate disturbances (e.g. floods). Hence, resilience helps to identify the resources and system infrastructure that can help the system to stabilise its primary outcomes (food utilisation, availability and access).

Second, resilience theory also offers a framework for analysing how the system adapts to "to return to an equilibrium state after a temporary disturbance" (Holling, 1973, p. 17). While stability can be associated with the system infrastructure, adaptability is directly linked to the actors and their capacity to react and influence the system to bounce back (Walker et al., 2004). Resilience goes beyond the analysis of natural systems and their organisation and accounts for social systems and their capacity to reorganise. This capacity of institutions to react and reorganise themselves is a crucial ingredient of socio-ecological resilience (Folke, 2007; Lebel, Anderies, Campbell, & Folke, 2006).

Finally, resilience theory also offers a framework for exploring how systems might transform when the system is forced to go beyond its limits (Folke et al., 2010). Transformation has been defined by Walker et al. (2004, p. 5) as “the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable”. If climate conditions change beyond system adapting capacity, new process, structures and institutions will be needed for human subsistence and anticipate and manage this transformation becomes crucial for ensuring smooth and successful changes (Carpenter et al., 2005). Resilience can be used to understand transformation as an opportunity. In a resilient system, disturbances are windows for innovation and new developments (Berkers et al., 2003; Holling & Gunderson, 2002). Contrary, in a vulnerable system, even small disturbances might results on significant adverse social consequences, especially for those who are most vulnerable, such as the rural poor in developing countries (Adger, Arnell, & Tompkins, 2005; Ericksen, 2008b; Thompson & Scoones, 2009)

Berkes & Jolly (2001, p.18) define adaptive strategies as the “ways in which individuals, households, and communities change their productive activities and modify local rules and institutions to secure livelihoods”. The lens of resilience offers a privileged perspective to assess which changes are needed and their broad implications in the system. Resilience hence is compelling concept for framing adaptation and has been used in many different context and problems (Berkes & Jolly, 2001; Larsen, Calgaro, & Thomalla, 2011; Lebel et al., 2006; Pelling, 2011)

While increasingly popular, resilience openness complicates to use it beyond a simple metaphor of what an idealised system might look like (Davoudi et al., 2013; Pizzo, 2015). The wide definition of resilience means that there is a lack of clarity on what it has been assumed about the “type of resilience” used in a particular case and while taking about resilience researchers and policymakers might talk pass each other (Tendall et al., 2015). As noted by (Alexander, 2013, p. 2707), “as a concept, resilience involves some potentially serious conflict or contradictions, for example between stability and dynamism or between dynamic equilibrium and evolution”. It is probably for this reason that the literature is unclear about how to analyse resilience and how to plan for it. The questions about: “how to replicate resilience observed in one case to different contexts and different systems?” remains and, despite its potential, the application of resilience in the policymaking world continue underdeveloped.

Duit (2015) presents a synthesis of the limitations of resilience in policymaking settings. In his review, Duit (2015) identifies at least three main complications to the application of resilience in policymaking setting: a) the often oversimplified understanding of participation and how human interactions affect the outcomes of it, b) the lack of quantification and fuzziness of the practical means of resilience and c) the disconnection between resilience abstract processes and concepts and the policymaking world.

The first complication identified by Duit (2015), relates to how the social component of SES makes of resilience a contentious concept. The definition of what outcomes of the system should be resilient and to what is not a given but a reflection of stakeholders' values, preferences and social relationships. Even the definition of the system itself, its boundaries and drivers is filtered through the lenses of those defining and analysing the problem. Simultaneously, there are also complications related to define and anticipate social processes like self-organisation and adaptation (Davoudi et al., 2012). In the social context, adaptation is politically and ideologically contested (Davoudi et al., 2012). The discussion about what institutions and structures should be kept or protected to ensure stability and which ones to change to embrace adaptation is not politically neutral.

The second complication derives from the lack of clarity about what does resilience means in practical terms. Although the literature on resilience yields insight about resilience characteristics (e.g., Berkers, Colding & Folke, 2002; Chapin et al., 2009; Walker et al., 2006; 2004), many gaps remain regarding what resilience means in terms of precise variables and how resilience can be measured (Bennett, Cumming, & Peterson, 2005; Cumming et al., 2005; Marshall & Marshall, 2007). This lack of measures challenges the analysis by complicating the quantification of benefits, comparison of scenarios and transferability of results.

Moreover, the relationship between actions or policies and resilience is not direct, measuring the impact of an intervention or the performance of the project is cumbersome (Marshall & Marshall, 2007). Resilience is not a direct product, but a consequence of multiple attributes mutually reinforcing that contribute to stability, adaptation or transformability (Marshall & Marshall, 2007; Pizzo, 2015). This complexity poses a problem for measuring policy impact and complicates planning, setting objectives and measuring performance in the public sector (Pizzo, 2015).

Finally, the third complication described by Duit (2015) is to some extent a combination of the previous two. The disconnection between resilience theory and the policymaking that Duit (2015) describes, arises from a) the lack of a clear and operational definition of resilience and b) the oversimplified understanding of a governance process that needs such definition in order to applied in a meaningful manner (Davoudi et al., 2012; Pizzo, 2015). If it is true that governance is often mentioned as part of the necessary ingredients for resilience (Biggs et al., 2012), literature often presented it at an aggregated and simplified level where some characteristics identified as desired but are rarely operationalized. How to manage resilience from a policy perspective remains mostly unexplored.

The limitations described by Duit (2015) arise from the disconnection between theory and practice manifested in the lack of operational approaches for managing resilience. Just calling for resilience, is to abstract and to open for actually meaning something about any actions that need to be undertaken (Pizzo, 2015). Despite the efforts to demonstrate the importance of resilience, few studies have tried to cope with the limitations described by Duit (2015) and separately identified by other authors (Cote & Nightingale, 2012; Davoudi et al., 2012) by proposing tools to analyse resilience in its operation dimension.

Walker et al. (2002) present, so far, the closest attempt to outline an operational approach to resilience that informs a policymaking process. The approach proposed by Walker et al. (2002) builds on two elements widely discussed in the literature, modelling and stakeholder participation, and organise them in a logical way to analyse the mechanisms that contribute to resilience in a given system. However, there is little evidence, as far as the I'm aware, of this approach being additional developed or implemented in additional case study research and real-world cases.

While compelling in theory, the approach proposed by Walker et al.(2002) seems to face similar difficulties than the concept of resilience itself. Translating the working hypothesis developed by Walker et al.(2002) into practice needs to resolve methodological questions like: what model? how to manage stakeholder participation? how to measure resilience? among others. To understand the nature of the methodological challenges to be resolved, this study dissects the approach proposed by Walker et al.(2002) in its two main elements, modelling and stakeholder participation, and analyses each of them from the perspective of its applicability to the analysis of and planning for resilience in SES.

### 2.4 Modelling resilience in SES

Food systems, and SES in general, are complex systems characterised by non-linear relationships, past dependency and a high number of interrelated elements (Berkers et al., 2003; Chapin III et al., 2009; Folke et al., 2004; Levin et al., 2013). Because of this complexity, management of food systems tends to be classic wicked problems, where the problem definition is unclear and the "causes, while at times apparently simple, when final understood, are always multiple" (Thompson & Scoones, 2009, p. 387).

In SES, the observed behaviours emerge from the complex interactions and feedback loop structures linking different parts of the system over different time scales. Because of this dynamic complexity, it is difficult to anticipate the system behaviour by using only analytical methods (Carpenter & Gunderson, 2001). Modelling is a widely used alternative in ecosystems management literature to deal with these wicked problems (Davies, Fisher, Dickson, Thrush, & Le Heron, 2015; Franco & Montibeller, 2010). Models are simplified representations of the system complexity that help researchers and policymakers to understand systems behaviour and to anticipate unexpected outcomes. In practice, models often act as virtual laboratories where it is possible to validate assumptions and test policies in ways that are unfeasible in the real world.

Costanza, Wainger, Folke, & Mäler (1993) made a useful analogy between models and maps. Like a map represents a terrain to help the user to navigate through it, models represent systems, or parts of them, to help policymakers to navigate through problems they face. In the same way that a map only represents the relevant elements of the terrain, a model only represents some aspects of the system that are relevant to solving a problem or making a decision. Simulation models are valuable tools for exploring situations that would be very difficult and costly to examine with field experiments as their outcomes offer valuable insights to inform the policymaking process (Costanza et al., 1993). Models are not an end by themselves but a mean for having a structured debate about how to tackle a problem (Checkland, 1981).

However, as the lack of application of modelling in the resilience literature shows, resilience openness added to SES complexity entails substantial modelling challenges. For instance, as part of analysing resilience, the adaptive features of complex systems must be understood in a holistic way (Carpenter & Gunderson, 2001). Modelling these adaptive process is difficult. Next, there is a summary of some of the challenges for using modelling for the analysis of and planning for resilience:

*Nonlinearity:* Food systems and SES are constituted by a complex network of resources, drivers and outcomes linked in non-linear ways (Thompson & Scoones, 2009). The dominance of nonlinear dynamics in the behaviour of the system means that steady-state modelling is often not enough for analysing resilience (Marshall & Marshall, 2007). Moreover, understanding the dynamics that led to such states and the transition process is key if adaptation and transformability are to be considered (Davoudi et al., 2012).

*Delays and slow variables:* Food systems are also characterised by the presence of "variables that change slowly but strongly influence internal dynamics" of the system (Chapin III, Kofinas, & Folke, 2009, p. 12). These slow variables create a delay between action and observed effects in the system making it difficult to policymakers to establish cause and effect relationships. Examples can be found in the problems for regulating fisheries resulting from the biomass dynamics and economic decisions happening in different time scales (Levin et al., 2013; Moxnes, 1998). Like Sterner et al. (2006) pointed out, there is no quick fix for this type of problems, and policymakers that fail to acknowledge the effect of critical slow variables might risk system collapse.

*Heterogeneity:* Another challenge for modelling resilience is heterogeneity and the role of diversity in resilience. In general, resilience literature agrees that heterogeneity supports resilience by offering functional redundancy – more than one part of the system performing the same function- (Biggs et al., 2012; Chapin III et al., 2009). However, modelling diversity and heterogeneity requires a level of detail and dis-aggregation that is hard to achieve in most modelling approaches. Moreover, even if heterogeneity is represented in a model it will come with a trade-off against the geographical scale of the system to represent, and the extent conclusions and insights might be transferred to other systems.

*Risk and uncertainty:* Resilience is to a large extent a concept to prepare and manage the unexpected. Hence, risk and uncertainty are always present in the analysis. Uncertainty is not a foreign concept in the modelling literature. When modelling SES, researchers and policymakers often need to make assumptions about some parameters and make estimates about how the future might look like. These assumed parameters and estimates are subject to a degree of uncertainty due to the impossibility of accurately measure them and infeasibility of experiments to estimate them to an appropriate degree of confidence. However, there is a more complicated type of uncertainty associated with resilience. When affected by a disturbance, a system might transform into new systems, and alternative structures might emerge or become relevant. Incorporate all potential paths that the system might follow in a single model is challenging if not impossible.

While the challenges above are difficult to manage, ignoring them gives a misleading representation of how the system works and what to expect in the future. Hence, it is vital for using resilience as policymaking framework to overcome these difficulties and unlock the full potential of models. Even simple and incomplete models might bring novel insights to the analysis of resilience if appropriately used in a well-designed framework.

### *2.5 Stakeholders and stakeholders' input*

Similar to the use of models, a common element in tackling wicked problems is the usage of participation and stakeholder input (Antunes, Santos, & Videira, 2006; Franco & Montibeller, 2010; Vennix, 1999). The reasons for engaging stakeholders in the process are twofold. First, participation and stakeholder inputs are helpful to deal with uncertainty and to compensate for our limited understanding of SES (Giampietro, Allen, & Mayumi, 2006). Literature recognises that while it is not possible to fully understand SES, bringing different perspectives and types of knowledge to the analysis results on a more round and holistic interpretation of it (Funtowicz & Ravetz, 1994; Mayumi & Giampietro, 2006).

The second reason is political. The allocation and distribution of the access to natural resources have been, historically, an expression of power tension between different groups. Power and its manifestations are always present in all social interactions operating within the SES (Cote & Nightingale, 2012; Nightingale & Ojha, 2013). While often presented as politically neutral, resilience can be a highly contested concept (Herrera, 2017; Nightingale, 2005; Raik, Wilson, & Decker, 2008). In the planning for resilience, the definition of the desired state of a system conforms to the values, goals and expectations of those analysing the problem (Pizzo, 2015). Hence, those participating in the process have the power to represent their views and agendas and to influence the system toward their goals. Increasing the diversity of the stakeholder participating in the process is seen as a way to get a more balanced definition of objectives, essential outcomes and performance measures. Otherwise, resilience risks being used as a way to legitimise the power of particular groups and to impose particular agendas for managing scarce resources (Peterson, 2000).

However, outcomes like a more robust interpretation of the system or a more democratic definition of its objectives do not automatically spring from bringing stakeholders together. In fact, years of experience using participation to discuss ecological problems raises concerns about it being used only as a mean to legitimise agendas previously agreed (Duit, 2015; Nightingale, 2005).

Underestimating the challenges of stakeholder engagement can easily result in an inadequate participatory process that perpetuates power structures and inequalities that halt the system to adapt and transform (e.g. Larsen, Calgaro, & Thomalla, 2011; Lebel, Anderies, Campbell, & Folke, 2006). Despite the importance of participation, and the broad agreement about its usefulness in the planning for resilience, there is still a gap in the literature about how and when participation needs to be undertaken in the process (Cote & Nightingale, 2012; Cretney, 2014; Duit, 2015; Pizzo, 2015).

## 3. RESEARCH QUESTIONS

The previous sections have described the importance of enhancing stability, adaptation and transformability of food systems to reduce the threat that climate change represents to the food security of small-scale farmers in subsistence economies. With this aim on mind, resilience, with its focus on adaptability, seems a compelling concept for framing the discussion about food security in systems undergoing climate change. However, the application of resilience theory in policymaking settings is lagging behind and some issues need to be addressed before unlocking it usage in climate change adaptive policies.

An outstanding issue that summarises many of the limitations for applying resilience in practice is the lack of a well-defined approach that operationalise concepts described in the literature into the planning and managing process. Without a bridge between theory and practice, policymakers are left with an open and abstract concept to deal with, and it is not clear how they can a) analyse the adapting mechanisms contributing to resilience, b) measure resilience and c) link resilience theory to real plans, policies.

Some authors, like Walker et al. (2002) have taken the first steps towards such operational approach, but a concrete method is still missing. Based on the experience documented in the ecosystem management literature, Walker et al. (2002) suggest that analysis of complex SES benefits from using models in participatory settings to anticipate unexpected and unpredictable responses impossible to anticipate using other analytical methods. Nonetheless, since the literature still misses, the specifics about what models and the modelling methods to use, type and time for participation, the approach proposed by Walker et al. (2002) falls in the same pitfalls than resilience and ends up being too general and too broad for being widely applicable.

This study contributes to close these gaps by developing an operational approach to the analysis of and planning for resilience in food systems to climate change adaptation. This approach is built over the foundation of the work of Walker et al. (2002) and adds some specifics about how to take their proposed approach into practice by discussing fundamental questions that need to be solved to unlock its usage. The questions addressed in this study are:

- How is possible to deal with many, and sometimes contradictory, definitions of resilience?
- How should stakeholders bee involved in the process of managing resilience?
- How can resilience be measured?
- How can the different dimensions of resilience (stability, adaptability, transformability) been analysed?
- How does resilience link to policymaking in the public sector?

While insights gained are transferable and applicable to multiple settings, this study frames these questions in the context of resilience planning in the public sector. Next, there is a brief description of the method followed to answer these questions. Details about the specific process followed can be found in each of the chapters that make up this study.

## 4. METHODOLOGY

### 4.*1 Research Strategy*

Yin (1994, p. 4) suggests to consider three conditions at the moment of selecting a research strategy: a) type of research questions, b) the extent of control the research has on the phenomena to investigate and c) the focus on contemporary versus historical events.

Regarding the type of research questions, this study uses explanatory ones and “how” questions. These questions aim a) to understand the challenges faced when operationalising resilience and b) to shed light on a specific approach to planning for resilience. To answer these questions, it is needed to understand the context in which resilience planning is taking place, and to analyse the process in detail. Therefore, strategies that focus on describe incidence of an event (e.g. surveys) are not suitable,

Regarding the degree of control about the phenomena to analyse this study faces a low degree of control. An essential and contentious ingredient of resilience planning is the existence of different agendas and objectives among stakeholders. These stakes cannot be simulated or artificially introduced, and the resilience planning process cannot be accurately recreated under controlled conditions (e.g. experiments). Contrary, the process of planning for resilience needs to be observed in its natural settings.

Finally, regarding its temporal focus, contemporary versus historical, this study focus on the first ones. Since this study focuses on understanding how to operationalise resilience to be used as part of climate change adaptation strategies the focus is on the current systems and how they can adapt to climate change. While effects of climate change start to be visible, they are still novel, and it is not possible to extrapolate adaptation mechanisms of the past to these new challenges. This study also focuses on how decisions are made and how changes occur rather than its outcomes. In these circumstances, archive research and sole analysis of historical data would offer an incomplete picture and the research strategy to be used needs to look at the thoughts and perspectives of the current stakeholders.

Based on the above mentioned grounds case study has been selected as a research strategy. Case study encompasses close, in-depth, and detailed examination of a subject of study (the case) in a particular context. Case study research is useful for carefully examining an issue in its natural settings and allows to examine the relations and interactions between the current stakeholders of the system. Case study research is especially appropriate for researching those areas where the body of knowledge is still in immature, like the application of resilience in policymaking, and hypotheses about how and why are still underdeveloped.

Figure 2 illustrates the steps followed in this study. Beside literature review (briefly presented in the background section), the two steps framing the research design are the selection of a) the case studies to explore and b) the modelling approach to use. Next, these two are briefly described and to explain methodological options that underpin the rest of the study.

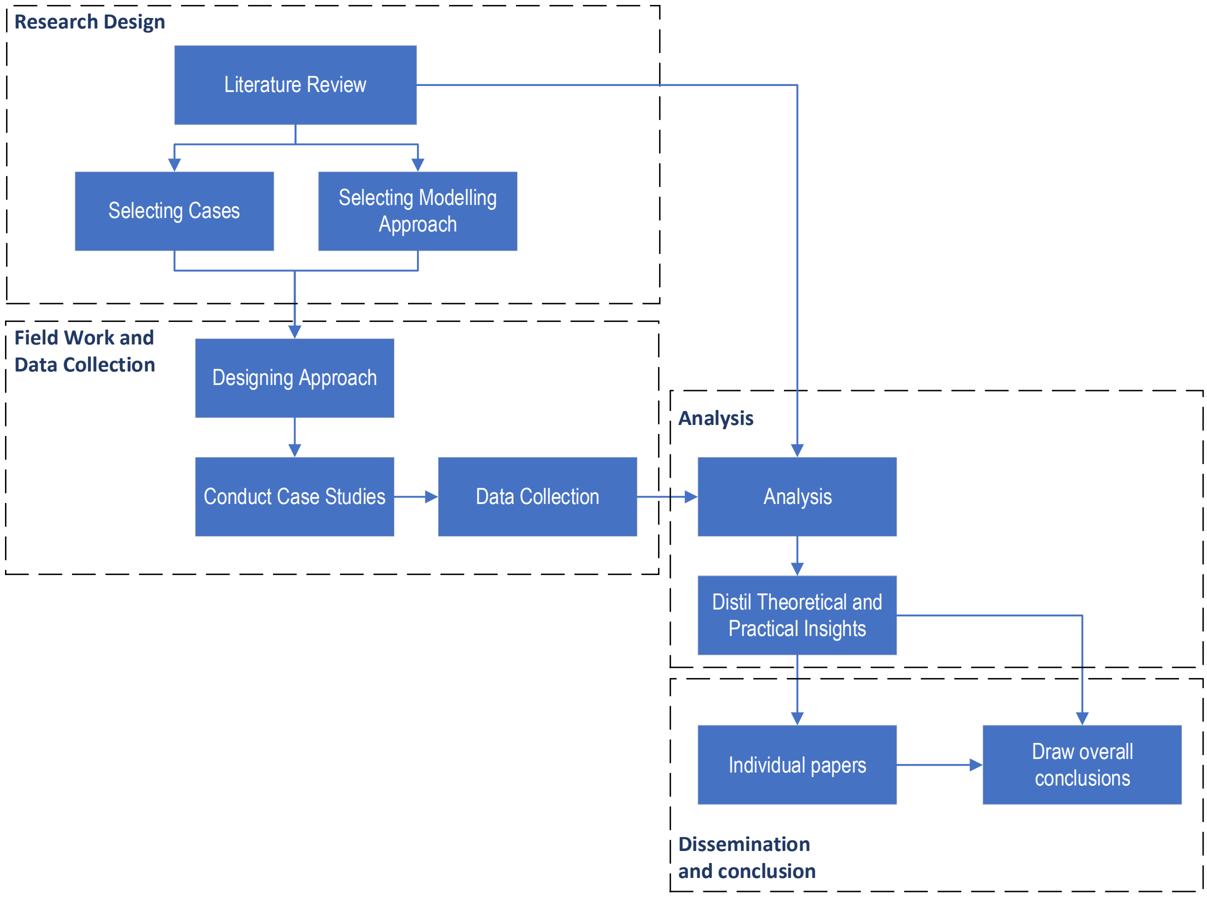


*Figure 2:* Graphical illustration of the research design used in this study

### 4.2 *Selecting cases*

This study uses what Stake (1995) defines as instrumental case study research. Instrumental cases are used to provide insights about an issue, and the case itself is of secondary interest (Baxter & Jack, 2008). Such is the case of this study and the cases later presented are used as a mean to understand the general process of analysing and planning for resilience with the purpose of generalising the lessons learned into a replicable approach (Baxter & Jack, 2008; Cousin, 2005).

Beside practical criterion (such as easy access to information and stakeholder interest), the criterion for selecting the cases were to study:

a) cases where effects of climate change are already visible and are expected to increase in the near future,

b) cases where it is possible to trace a link between climate change effects and food security and

c) cases where the cultural, technical and socioeconomic conditions of agricultural systems to study are non-specific, common to other systems and have similarities with other food systems.

On this basis, the small-scale maize systems in two regions of Guatemala were selected as suitable cases for this research. Next, there is a brief description of the general description of the cases studied.

Guatemala is a multi-ethnic country with a long history of poverty and inequality (World Bank, 2003; WorldBank, 2009). The high levels of poverty and inequality in Guatemala are captured in two key indicators: a) its low Human Development Index (HDI) 0.64 (UNDP, 2016) and b) its high Global Hunger Index (GHI) 20.7. To put this numbers in context, regarding the HDI, Guatemala ranks 125 of 188 countries and has third worst HDI in Latin America. Similarly, regarding the GHI, Guatemala, is after Haiti, the country with more severe hunger and undernutrition in Latin America with a GHI similar to The Gambia, Nepal and Kenia (von Grebmer et al., 2016).

Poverty and undernutrition conditions are like to worsen as result of Climate change. Since most of the Guatemalan population lives in rural areas (52%) and most of them are in poverty (71%), the country is particularly vulnerable to climate change. While most of the poor peasants in Guatemala have access to land, its dependence on subsistence agriculture makes them highly vulnerable to extreme weather events. For example, in 2014, the dry spells resulting from the climatic phenomenon “El Niño” exhausted the food reserves of more than 100,000 families in the arid regions of Guatemala putting circa of 3% of the total population at the limits of starvation (World Food Programme, 2016).

This vulnerability of the rural poor to climate change urges mitigation and adaptation actions to improve food security resilience to climate change especially among peasants depending on subsistence agriculture (de Janvry & Sadoulet, 2010). Recognising the urgency of this problematic, different project and studies have been commenced at different scales and in different areas. Examples of this projects are:

- Project to Strengthen the Resilience of the Maya and Rural Residents Facing Food Insecurity and Climate Change in Guatemala’s Arid Corridor, sponsored by the World Bank (World Bank, 2016),
- Food for Assets Initiative, sponsored by the World Food Programme (WFP, 2016), and

- Project Strengthening resilience of households affected by dry spells, sponsored by the Food and Agriculture Organization (FAO, 2016).

This study adds to these initiatives and was independently conducted by the author with the cooperation of numerous stakeholders in the districts of Huehuetenango and Jutiapa. The purpose of this study was twofold. First, it aimed to discuss potential policies to enhance local food security resilience in response to climate change at a local level while working with small-scale farmers. The lessons learned during the process and the practical insights gained from it are expected to be used to define future policies in the region.  Second, the study offers a suitable couple of case studies to explore how to operationalise resilience and test the proposed approach.

Using small-scale agricultural systems, and particularly maize systems, as case study offers several advantages:

- Relevance: Maize production is an important driver of food security in many countries in  Latin America and Asia at the same time it is particularly susceptible to droughts. For communities depending on maize production for their subsistence, it is easy to establish a link between climate change and food security.
- Transferability: While systems might differ from country to country, it is expected that systems will share enough in common to allow some of the lessons learned to be transferable to other contexts.
- Replicability: The cultural, historical, institutional and geographical background of the cases selected is common to many communities in Central America and the south of Mexico. Hence, it should be relatively straightforward to replicate the process follow in this study to other cases.

Next, there is a brief description of the two specific cases explored. Main differences between the two cases are: population ethnic background, demographics and climate. However, it is the first one the one that motivated to include both cases. While the population in Jutiapa has a predominantly white background, Huehuetenango is predominantly indigenous. Guatemala has a history of ethnic social and economic inequality, and it was considered relevant to observe the same process in two political settings. More details about the two specific cases are discussed in subsequent chapters.

*Case Study 1: Huehuetenango, Guatemala*

Huehuetenango is located in the Northwest region of Guatemala, on the border with the South of Mexico. Huehuetenango is one of the poorest, most vulnerable districts in Guatemala. In 2014, its population was estimated at 1,150,000 people, with 67.6% of these people under the line of poverty (Instituto Nacional de Estadística,INE, 2012). Huehuetenango's main economic activities are the mining industry of silver and gold and the production of coffee (Camposeco, Thomas, & Kreynmar, 2008). Nevertheless, the production of maize is an important activity for self-consumption. The majority of the population is indigenous, from the ethnics of Mam and Quechi, with a cultural dependence on maize as the main source of calories. Among indigenous groups, maize represents a 71.2% of share in basic grains consumption.

*Case Study 2: Jutiapa, Guatemala*

Jutiapa is located in the Southeast region of Guatemala, on the border with Honduras. Jutiapa covers an area of 3,219 km2 with a population estimated at 426,000 of which only a 3% has an indigenous background (one of the lowest in the country). Jutiapa is among the poorest districts in Guatemala and has a long history of starvation and food insecurity due to its dry weather. However, the recent increase of severity of droughts in the region has exacerbated the problem even more (see for example Rehum 2015).

### *4.3 Selecting a modelling approach*

Before selecting a particular modelling approach for using it as the basis for developing an analytical framework for planning resilience, it is necessary to understand what types of models might be able to tackle to some extent the challenges described in Section 2. Even before exploring the different techniques it seems evident that complexity and diversity of the challenges mentioned in Section 2 are unlikely to be solved by a single method but rather for an integrated approach capable of bringing different methods together. However, integrating modelling approaches, possess additional complications such as keeping consistency between different levels of aggregation and different nomenclatures. To avoid these complications, this study makes the methodological decision of starting by identifying one method while leaving open opportunities for integrating it with other modelling approaches in further studies.

Next different model classifications are used to create a grid that allows to systematically identify the approach that could deal with the challenges of modelling in resilience planning. The classifications presented are particular for models dealing with SES and management of natural resources. Since there are many alternatives for classifying models, the approach does not seek to be exhaustive but rather to provide an assessment of aspects of modelling methods relevant to resilience planning in SES.

While there is a distinction between modelling methods according to the ways they represent mathematically the relationships in the model (linearly or non-linearly). It is understood that non-linearity is a prerequisite for any model to be considered for modelling resilience. Hence, the description and assessment of these different modelling methods are not discussed in this study.

*Model types according to its purpose*

In the case of modelling SES, the purpose of a model can range from developing simple conceptual models for providing a general understanding of system behaviour to detailed, realistic models for evaluation of specific policies. Constanza et al., (1993) classifies modelling approaches for complex SES in four groups using three criteria:

- ***Precision:*** Correspondence between real data and model outputs
- ***Realism:*** Degree to which the model represents the underlying process in the system
- ***Generality:*** Degree to which the model insight can be applicable to many different concepts

These criteria were initially used by Holling (1966) to describe the trade-offs between different modelling approaches and are used by Costanza, Wainger, Folke, & Mäler (1993) as a mean to differentiate between approaches. The four groups described by Constanza et al. (1993) are briefly described in Table 1.

**Table 1.** Model classification according to their purpose

| Model Type | Realism | Generality | Precision | Description | Examples |
|---|---|---|---|---|---|
| *High-generality conceptual models* | Low | **High** | Low | Models which are applicable in many different contexts but have low realism and precision. The purpose of these models is to answer basic and high-level questions about the idealise principles governing the system. | • Econometric models<br>• Game Theory |
| *High-precision analytical models* | Low | Low | **High** | Models that require high correspondence between data and the model outputs. "One strategy here is to keep the resolution high but to simplify relationships and deal with short time frames" (Costanza, Wainger, Folke, & Mäler, 1993, p. 547). | • Input-Output models<br>• Spatial economics |
| *High-realism impact-analysis models* | **High** | Moderate | Low | There is often a trade-off between models' precision in the short term and realistic assessment of the long-term behaviour of complex systems. This types of models prioritise to accurately representing the underlying process in a specific system rather than precisely matching quantitative data. | • System Dynamics (SD)<br>• Agent-Based Modelling (ABM)<br>• Geographic Information Systems (GIS) |
| *Moderate-generality and moderate-precision indicator model* | Moderate | Moderate | Moderate | When the purpose is to understand the overall magnitude and direction of change. These models trade realism for gaining some level of generality and precision. | • System Dynamics (SD)<br>• Markovian models<br>• Agent-Based Modelling (ABM) |

*Model types according to the dynamics they represent*

In the specific context of natural resource management Bots & van Daalen (2008) describes that models can be of different types depending on which dynamics of the systems they represent. Bots & van Daalen (2008) starts by describing that, an aggregated level, there are three main dynamics in the SES: a) physical dynamics, b) actors dynamics and c) social dynamics (see Figure 3). Physical dynamics include chemical and ecological processes like nitrogen mineralisation and crop production. The physical dynamics include the process connecting ecological drivers like nitrogen in the soil with tangible outcomes like crops yields.

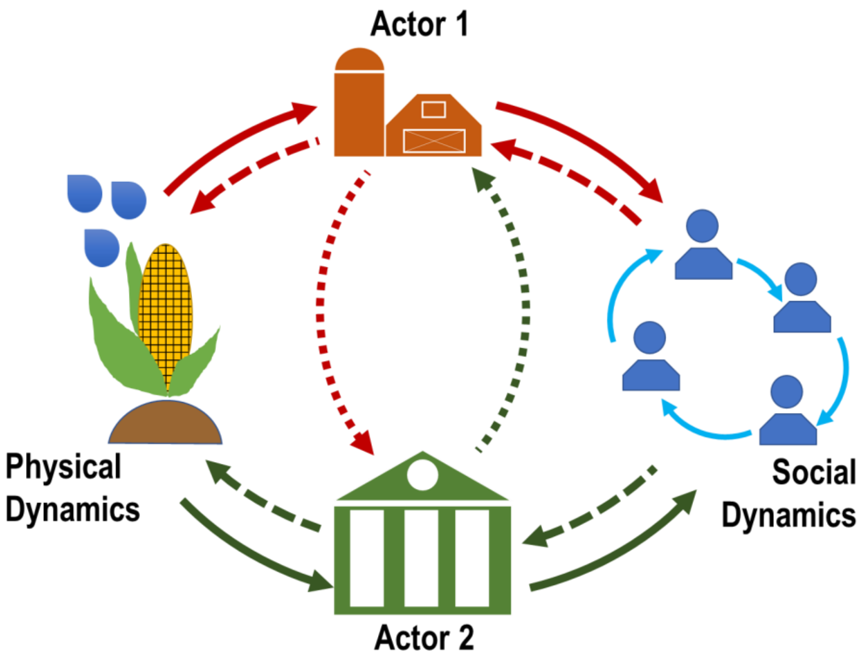


*Figure 3:* Dynamics in natural resources management systems

Alternatively, social dynamics include rules, institutions, regulations, utilisation of land and market dynamics. For instance, social dynamics describes how food is trade and transform into revenues for the farmers. Finally, the actors represent individuals and groups that actors may influence the state of the physical system either directly by acting on the physical system or indirectly by influencing the social system, triggering actions by other actors. Actors take action in response to what outcomes they perceive from the physical system and/or the social system. Based on the extent to which the model represents these three dimensions, Bots & van Daalen (2008) propose five model types briefly described in Table 2.

**Table 2.** Types of SES models. Adapted from Bots & van Daalen (2008)

| **Model Type** | **P** | **A** | **S** | **Description** | **Examples** |
|---|---|---|---|---|---|
| *Socio-physical system model* | **X** | **X** | **X** | Models of this subtype can represent a complete NRM system: the physical mechanisms of the natural resource, the actors involved in its utilisation, and the social mechanisms that codetermine actor behaviour | • System Dynamics *(where social mechanisms can also be represented by people in a gaming simulation/role-playing game)*<br>• Agent-Based Models<br>• Integrated models (including different sub-models) |
| *Individual actor Impact model* | **X** | **X** | | Models of this subtype can represent how individual actors influence the physical system through their decisions and actions, but do not take into account social mechanisms among actors | • Spatial Economics<br>• Econometric models |
| *Physical system model* | **X** | | | Models of this subtype can represent the structure and dynamics of the physical, biological and ecological characteristics of the resource, but disregard its utilisation. | • System Dynamics<br>• Geographic Information Systems (GIS) |
| *Social System Model* | | | **X** | Models of this subtype can represent the structure and dynamics of the social space (institutional context and 'policy arena') about actor behaviour, but do not take into account how this behaviour affects the physical aspects of the natural resource.<br>The goals and preferences of actors become inputs for the model, which represents the interaction between the actors in a way that social behaviour can be inferred. | • Network Analysis<br>• Agent-Based Models<br>• Game Theory<br>• Utility Theory |
| *Single actor decision model* | | **X** | | Models of this subtype can represent the structure and dynamics of the physical, biological and ecological characteristics of the resource, but disregard its utilisation.<br>The type of model that represents policies (or merely their outcomes) as external influences, and predicts the reaction (or merely the appreciation) of actors (but not the consequences of these actions, as that would represent other parts of the system as well!) will be termed a single-actor decision model. | • Methods of estimating the willingness to pay:<br>• contingent valuation<br>• conjoint analysis |

P= physical mechanisms are modelled
A=actors and their behaviour (decisions and subsequent actions) are modelled
S=social mechanisms are modelled

*Types of models that can be used for modelling resilience*

Table 3 shows what is needed from the model in terms of purpose and dynamics to be able to cope with challenges for modelling resilience. As mentioned before, no single method can fully tackle all of them, and some trade-offs are needed when using a single methodology. There is a trade-off between the realism needed for representing non-linearities, delays and uncertainties and the precision needed to capture heterogeneity. Similarly, uncertainty and heterogeneity benefit of capturing dynamics between different actors what complicates the high realism needed to capture slow variables and non-linearities.

**Table 3.** Requirements for an approach to modelling resilience in SES

| | **Generality** | **Realism** | **Precision** | **P** | **A** | **S** |
|---|---|---|---|---|---|---|
| *Non linearity* | Moderate | High | NA | X | | X |
| *Slow variables* | Moderate | High | Low | X | | X |
| *Heterogeneity* | Low | Moderate | High | X | X | |
| *Uncertainty* | Low | High | Low | | X | X |

The analysis above suggests that a modelling approach for resilience planning should:

a) either be a "high-realism impact-analysis" model or a "moderate-generality and moderate-precision indicator model", and
b) be Socio-physical system model able to represent to some degree physical and social dynamics as well as potential decisions of different actors.

This conclusion reduces the list of potential modelling approaches to broadly two alternatives. On alternative is to use Agent-Based Modelling (ABM), the other alternative is to use System Dynamics (SD). Next, the two approaches are briefly described

*Agent-Based Modelling (ABM)*

ABM is a simplified simulation method used to represent the interactions between autonomous (Bonabeau, 2002; North & Macal, 2007). The idea of agent-based modelling was developed as a relatively simple concept in the late 1940s. Since it requires computation-intensive procedures, it did not become widespread until the 1990s (North & Macal, 2007).

Most computational modelling research describes systems in equilibrium or as moving between equilibrium. ABM, however, using simple rules, can result in different sorts of complex and interesting behaviour. The three ideas central to ABM are i) agents as objects, ii) emergence, and iii) complexity.

ABM consist of dynamically interacting rule-based agents. The systems within which they interact can create real-world-like complexity. These agents are “intelligent and purposeful” and reside in networks and lattice-like neighbourhoods. The location of the agents and their conscious and purposeful behaviour are encoded in algorithmic form in computer programs.

The modelling process is best described as inductive. The modeller makes those assumptions thought most relevant to the situation at hand and then watches phenomena emerge from the agents' interactions. Sometimes that result is an equilibrium; sometimes it is an emergent pattern. As North (2007) mention in his book, ABM is handy to understand the emergent and possible patterns from the iteration of the agents.

ABM approach is used to produce models with high realism. This realism is however not equal to all the dynamics of the system. ABM is ideal for capturing actors decisions and their relationships with social and physical systems but lagging behind on the realism for capturing relationships in physical systems.

Where analytic methods enable humans to characterise the equilibrium of a system, ABM allows the possibility of generating those equilibrium states. This contribution may be the most mainstream of the potential benefits of the method. For example, ABM can explain the emergence of higher-order patterns—network structures of terrorist organisations and the Internet, power-law distributions in the sizes of traffic jams, wars, and stock-market crashes, and social segregation that persists despite populations of tolerant people. ABM also can be used to identify leverage points, defined as moments in time in which interventions have extreme consequences, and to distinguish among types of path dependency.

While having many advantages, ABM limitations arise from the level of detail represented in the models. With thousands and sometimes millions of agents interacting at every single point in time it is difficult to understand the underlying causes of the observed behaviour. While the emergent behaviour produced by the ABM can be a breakthrough, it is difficult to fully understand its reasons and how to prevent it/ enhance it.

*System Dynamics*

SD is a modelling method focus on studying behaviour from an endogenous perspective (Richardson, 2011). Namely, SD focuses on understanding the circular relationships (feedback loops) driving the outcomes of the system (Richardson, 2011). Jay Forrester originally developed SD as a method to explore and improve the performance of complex systems (Forrester, 1961). SD assumes that the behaviour of complex systems arises from the causal relationships of its components encompassing social goals, economic pressures and physical constraint of the system (Meadows, 1976). Analysing the structure formed by these relationships and identifying its feedback mechanisms, it is possible to understand system's behaviour and build computer simulation models to explore the effect of policies to improve it.

Forrester (1961) explains how short-term policies can produce adverse unintended effects in the long-term. According to SD, these unexpected negative results are a consequence of a poor understanding of the feedback loops and accumulations operating in the system (Sterman, 1994). Due to cognitive limitations, the human mind is unable to successfully predict the behaviour of complex systems (Diehl & Sterman, 1995; Sterman, Henderson, Beinhocker, & Newman, 2007) and therefore, trying to manage such complexity, policymakers can make decisions with unexpected and undesired results (Sterman, 2000). To help policymakers to understand this causality computer simulations can be used to explore scenarios, evaluate and communicate public policies (Antunes et al., 2006; Sterman, Fiddaman, Franck, & Jones, 2012; Sterman & Sweeney, 2002).

SD is a versatile method and can be combined with other methods like GIS (Xu & Coors, 2012), performance management (Cosenz, 2014) or be in facilitated sessions with stakeholders. When used in facilitated modelling settings, SD is commonly known as Group Model Building (GMB). GMB is a "bundle of techniques used to construct SD models working directly with client groups on key strategic decisions" (Andersen et al., 2007, p. 691). In GMB a SD model is not only a realistic representation of the system studied and its outcomes but also a "socially constructed artefact" that helps stakeholders to gain understanding about the system by exploring "what happens if?"(Andersen, Vennix, Richardson, & Rouwette, 2007, p. 692).

In that sense, SD has an important role in helping to gain insights about the system's structure and the leverage points to design resilient systems. By building causal explanation and supporting them with computer simulations, system dynamics allows policymakers to identify the feedback loops in the system and to explore policies that can potentiate or cancel them to improve the system's performance.

SD approach offers a high level of realism and is an excellent alternative for representing slow variables (stocks in the SD nomenclature). While SD models do not explicitly represent the actors in the system, this can be compensated by using the model in role play games where real actors input their decisions in the model.

*Selected modelling method*

Even both SD and ABM have strengths and weakness; this study uses SD as the basis for outlining an analytical framework for planning resilience. Reasons for this decision being:

a) SD is transparent on capturing underlying dynamics of social and physical systems what might prove helpful for using the model as tool for learning.

b) SD has long history of building models in participatory settings

c) SD has been used before for developing Dynamic Performance Management (DPM) systems in the public sector linking modelling with public policy implementation.

The opportunity for smoothly translating insights form SD models into public policy settings using DPM is a significant advantage of SD over ABM. Next, there a brief description of DPM and more detail can be found in further chapters.

*Dynamic Performance Management*

DPM is a combination of performance management approaches and system dynamics (SD). DPM supports policymaking process by modelling organisational systems (in system dynamics model) and using simulation techniques to understand the behaviour of the complex systems public policies deal with (Bianchi, 2016; Bianchi & Rivenbark, 2012). The contribution of DPM is to help policymakers to assess middle and long-term impacts of their actions in the system outputs by placing the measure of performance in a broader context of the system (Bianchi & Tomaselli, 2013).

DPM operationalises the policy analysis on a holistic performance framework (see Figure 4).

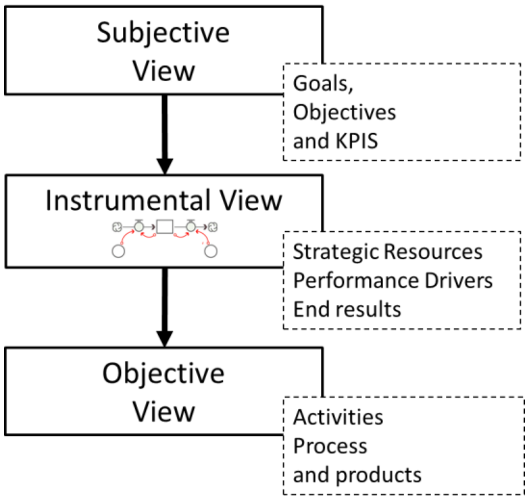


*Figure 4:* Three interconnected views of a Dynamic Performance Management system. Adapted from Bianchi (2016)

The DPM framework groups three inter-connected views of the system performance (Bianchi, 2016)

1. an "objective" view (activities and processes);
2. an "instrumental" view (conceptual representation of the system from an SD perspective);
3. a "subjective" view (targets and explicit ways to measure them).

## 5 CHAPTERS OVERVIEW

The remainder of this thesis consists of six chapters additional initially written in article format. To increase the coherence of this thesis, 'interludes' in-between the chapters explaining how the connections between the chapters and the overall objectives of this study. Next, there is an overview of the chapters included in this study. The full chapter is presented in the subsequent chapters.

**Chapter 2: Resilience for whom? The problem structuring process of the resilience analysis.** Herrera, H. (2017). Resilience for Whom? The Problem Structuring Process of the Resilience Analysis. *Sustainability, 9*(7), 1196

One of the first challenges for using an operational framework for resilience is finding non-arbitrary ways of delimiting and identifying the system which is to be modelled (Chu et al., 2003; Duit, 2015). The scope of the problem and the fact that it is considered a problem itself depends on the goals and values of those analysing a particular set of information and the same information might have different interpretations. This chapter explores the definition of resilience as a constructed meaning that results from the problem structuring process rather than a given starting point (Mingers & Rosenhead, 2004).

Observations made while working with different stakeholders are used in this chapter to illustrate the different, and to some extent conflictive, interpretations of resilience and the adaptive mechanisms existing in a SES. The results presented in the chapter are used to argue that a) resilience is socially constructed and b) the interpretations of resilience, later to be used in the analysis, reflect the agendas, mental models and power relations of those involved.

**Chapter 3: Together, we think differently: Using group model building to frame resilience analysis in policymaking settings**

Stakeholder participation has been extensively discussed in the literature as a strategy for enhancing understanding about complex systems. However, the same literature still lacks practical details about how and when participation should take place. As an alternative this chapter shows how facilitated modelling methods serve as a framework to operationalise the participatory process in the analysis of resilience.

The experience described in the chapter, using group model building to frame the discussion of food security resilience, indicates that facilitated modelling methods help those participating in the process to gain a more robust and holistic understanding of the system and to increase awareness about the existence of different agendas in the group. On the one hand, the presence of facilitator helps to set a process where all participants have the same opportunities to voice their perspectives. The intervention of the faciliator prevents the conversation to be steered in a particular direction by bringing different, sometimes competing, ideas to the discussion. Simultaneously, the task of building a joint diagram encourages participants to recognise how different links and overlaps among the different perspectives and explanations. The result of the joint modelling exercise, is a joint explanation of the system that provides stakeholders with a wider and more robust understanding of the risks to the system’s resilience.

**Chapter 4: From metaphor to practice, operationalising the analysis of resilience using system dynamics modelling.** Herrera, H. (2017). From Metaphor to Practice: Operationalizing the Analysis of Resilience Using System Dynamics Modelling. *Systems Research and Behavioral Science, 34*(4), 444–462

One of the most significant challenges to operationalise resilience is the fact that it is not clear what resilience means regarding the simulation results. Although the literature on resilience yields insight about its characteristics (e.g., Berkers, Colding & Folke, 2002; Chapin III, Kofinas & Folke, 2009; Walker, Gunderson, Knizig, Folke & Carpenter, 2006; Walker, Holling, Carpenter & Kinzig, 2004), many gaps remain regarding what resilience means in terms of specific variables and how resilience can be measured (Bennett, Cumming, & Peterson, 2005; Cumming et al., 2005).

These gaps are, to a large extent, a consequence of the fact that resilience is complex and context-specific (Marshall & Marshall, 2007). Notably, there is not a way to measure resilience in a system using the results produced by a SD simulation model. This absence of a clear framework to measure resilience is a limitation for applying models and complicates it usage for policymaking purposes. Moreover, lack of measures also complicates generalisation of principles, quantitative comparisons among similar cases.

To address this challenge this chapter proposes to focusing on five characteristics of the system response that can be measured from the behaviour of the outcome function when the system is shocked by a disturbance. While many other characteristics might be found in the literature (Hosseini, Barker & Ramirez-Marquez, 2016; Tendall et al., 2015), these five characteristics can be directly measured using the simulated behaviour of outcomes of the systems and offer a wide caracterisation of resilience.

**Chapter 5: Public policy design for climate change adaptation: a dynamic performance management approach to enhance resilience.** Herrera H. (2018) Public Policy Design for Climate Change Adaptation: A Dynamic Performance Management Approach to Enhance Resilience. In: Borgonovi E., Anessi-Pessina E., Bianchi C. (eds) Outcome-Based Performance Management in the Public Sector. System Dynamics for Performance Management, Vol 2. Springer, Cham

Lack of application of the outcomes from the resilience analysis in management settings is suggested to be the result of a missing step for connecting analysis and practice. In particular in the public sector, the disconnection between resilience theory and resilience policymaking is manifested in (a) the simplified understanding of the political process described in the literature on resilience (Eriksen et al., 2015) and (b) its contradictions to policymaking and management processes in the public sector (Arnaboldi et al., 2015). The abstract and conceptually based approach to resilience particularly clashes with results-oriented views held within new public management (NPM). NPM is a development system that introduces practices used in the private sector into public administration (Arnaboldi et al., 2015). NPM is embedded in the public administration of many countries and government sectors by now, and it is and has been a key element supporting the implementation of outputs-oriented standards of performance (Arnaboldi et al., 2015; Pallot, 1999).

In practice, the public sector faces, by far, more difficult problems than any business in the private sector (Pallot, 1999, p. 22). While SD modelling can be helpful to capture complex and abstract dynamics of vast an highly interrelated systems described in the resilience literature, the model should be carefully of connected with the activities, process and outcomes measured in the NPM. Otherwise results of the SD modelling process risk of being perceived too vague, too abstract and too meaningless for the implementation of public policies. Researchers and practitioners need to find creative ways for connecting the results driven administration in the public sector and the abstract dynamics describing SESs adaptation.

This chapter discusses the gap between analysis and policymaking. Namely, it explores DPM as an approach to bridge the literature on resilience thinking and the public-sector policymaking world. The results described in this chapter shows DPM provides a means for discussing the concept of resilience in a more operational manner. DPM is used as a bridge between accountable elements needed to manage policies in public administration and abstract concepts needed to describe and interpret the resilience of SES.

**Chapter 6: Resilience planning, a facilitated modelling approach**

This chapters offers a holistic perspective of how the overall approach proposed in this study looks like. While the previous chapters offer a more detail description of specific challenges and contributions of this study, in this chapter the whole approach is finally presented.

The chapter starts by describing the steps proposed for using GMB and SD in the planning of resilience and how they fit within the framework proposed by Walker et al. (2002). The chapter also illustrate the final step added to the four steps proposed by Walker et al. (2002) for assessing policy implementation and management. This step uses DPM to link to next steps in the policymaking process (e.g. project evaluation and benefits realisation). The steps are carefully described and experiences applying them are used as real world examples. The chapter concludes with a discussion about the type of insights and intangible outcomes that can be expected from the proposed approach.

Finally, the conclusions section summarises the main findings presented in this thesis.

Finally, Chapter 7 summarises the main findings presented in this thesis.

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# Interlude A

# Resilience interpretation and stakeholder’s participation

The previous chapter presented a brief review of the literature and a description of the research design used in this study. Particularly, the previous chapter focused on describing the fundamental challenges faced for using resilience to plan for climate change adaptation and pointed out to some fundamental issues that need to be resolved to move resilience closer to policymaking.

In this endeavour of developing an operational approach to resilience planning a fundamental issue to deal with is the openness of the resilience concept and plurality of perspectives. First, there is the issue of how to agree on what resilience means.  Recognising the political content of resilience, agreeing on an interpretation of resilience needs stakeholder input. Likewise, stakeholder participation is fundamental to gather the diversity of knowledge needed to address the complexity of SES. However, there is still a long way to go about the practicalities of how to engage stakeholders in the resilience planning process. The next two chapter discuss these operational aspects stakeholder participation in the resilience planning process and answer the research questions:

- **How is possible to deal with many, and sometimes contradictory, definitions of resilience?**
- **How should stakeholders bee involved in the process of managing resilience?**

# Chapter 2

# Resilience for whom? The problem structuring process of the resilience analysis[1]

**Keywords:** food security; resilience; power; system dynamics; problem structuring process

**Abstract:** Resilience is a flexible concept open to many different interpretations. The openness of resilience implies that while talking about resilience, stakeholders risk talking past each other. The plurality of the interpretations has practical implications in the analysis and planning of resilience. This chapter reflects on these implications, so far not explicitly addressed in the literature, by discussing the problem structuring process (PSP) of a modelling-based resilience analysis. The discussion is based on the analysis of food security resilience to climate change in Huehuetenango, Guatemala, jointly undertaken by the author, governmental authorities, small-scale farmers and academics of the national university. The aim of this discussion is to highlight the underestimated challenges and practical implications of the resilience concept ambiguity and potential avenues to address them. The contributions of the results presented in this chapter are twofold. First, they show that, in practice, resilience concept is constructed and subjective. Second, recognising the aforementioned, this calls for participatory and contested framework for the PSP of resilience.

[1] Apart from several minor adaptations, this  is a direct copy of the article: Herrera, H. (2017). Resilience for Whom? The Problem Structuring Process of the Resilience Analysis. *Sustainability*, *9*(7), 1196

## 1. INTRODUCTION

Climate change effects start to be recognised as threats to food systems sustainability and food security (FAO, 2016). Sustainability involves maintaining the functionality of the system without compromising its capacity to do so in the future (Tendall et al., 2015). However, undergoing effects of climate change compromise food systems functionality by contributing to water scarcity and pests' exacerbation (Campbell et al., 2016). Resilience is understood as the system adaptive ability of maintaining its functionality even when the system is being affected by a disturbance (Gallopín, 2006; Holling & Gunderson, 2002; Walker et al., 2002). For this reason, resilience is a compelling framework for researchers and policymakers seeking to understand how socio-ecological systems (SESs) adapt and transform to withstand changes in the environment. In practice, resilience is often used as a measure of a SES's capability to respond and adapt to new conditions (e.g., climate change). Like Tendall et al. (Tendall et al., 2015, p. 18) describe, "sustainability is the measure of system performance, whereas resilience can be seen as a means to achieve it". Resilience has the potential to contribute to food security by enhancing farmers, and other stakeholders, capacity "for foreseeing and adapting to possible changes" [5, p. 270]. For instance, in the food systems literature, a number of studies have used resilience as framework for understanding how systems can adapt and transform in presence of disturbances in the environment while still providing needed amounts and quality of food (Maleksaeidi & Karami, 2013; Tendall et al., 2015).

Applications of resilience can be found in numerous disciplines, ranging from engineering to psychology to disaster risk management (Duit, 2015). The increased popularity of resilience is due, at least partially, to the flexible meaning of the concept (Duit, 2015; Pizzo, 2015). Resilience definitions have often been characterised as vague and unprecise in practical terms (Pizzo, 2015; Tendall et al., 2015). While the flexibility of resilience has moved it to the category of mainstream concepts and buzzwords, the same ambiguity represents a challenge to its application in prescriptive and normative settings. These challenges manifest when practitioners need to operationalise the concepts described in the literature to the context in which resilience will be applied. Unsurprisingly, different stakeholders of the analysed system have different and sometimes conflicting interpretations of what resilience means in practical terms.

Since each stakeholder interprets resilience differently, the scope of the analysis to be undertaken is not a given but is constructed through a problem structuring process (PSP). The term PSP is used in this chapter to describe the “process by which presented set of conditions is translated into a set of problems, issues sufficiently well-defined to allow specific research action”(Woolley & Pidd, 1981). During the PSP, stakeholders interpret the available information in light of their values and knowledge and negotiate what is the purpose and the boundaries of the study to commence (referred to from now on as the “scope of the resilience analysis”) (Shaw, D., Westcombe, M., Hodgkin, J. and Montibeller, 2004; Weingart, Bennett, & Brett, 1993). The cognitive, social and political components, involved in the construction of the scope of analysis, condition its development and outcomes. The social and political nature of the PSP make it impossible to separate the conclusions and recommendations produced from the context in which they were produced. When talking about resilience, we cannot avoid the question: resilience for whom?

Literature has recently started to recognise some of the practical challenges of resilience ambiguity (Pizzo, 2015; Quinlan, Berbés-Blázquez, Haider, & Peterson, 2016; Tendall et al., 2015); however, it still lags behind on recognising the political implications of resilience ambiguity in the analysis and its outcomes (Cote & Nightingale, 2012; Duit, 2015). While some progress has been made by operationalising the definition of resilience (see for example (Quinlan et al., 2016; Tendall et al., 2015)), resilience frequently continues to be presented as a “politically neutral approach” (Pizzo, 2015, p. 134). The influence of stakeholders’ agendas and power relationships are often overseen by practitioners (Cote & Nightingale, 2012; Duit, 2015). Although, these dimensions of the PSP have been discussed for a long time in the literature regarding problem structuring methods (PSMs), their implications for the resilience analysis are still unexplored.

This chapter contributes to closing these gaps by discussing the political and social implications of resilience ambiguity in the PSP. To this purpose, this chapter looks at the PSP of a modelling-based analysis of food security resilience to climate change. This case is used to discuss some of the cognitive and political challenges of resilience. This discussion is informed by the personal construct theory (Kelly, 1955) and enriched by a post-normal science epistemology (Funtowicz & Ravetz, 1994b) for managing a wide range of perspectives. The aim of this discussion is to reflect on a) the implications of having a diversity of resilience interpretations in the PSP and b) the potential avenues to mediate stakeholder engagement and mitigate the challenges this diversity entails.

## 2. CASE STUDY: ANALYSING THE RESILIENCE OF FOOD SECURITY TO CLIMATE CHANGE IN GUATEMALA

This research was conducted within the qualitative paradigm of case study research (Merriam, 2002; Stake, 1995) and is part of an independent modelling-based discussion for the analysis of and planning for food security resilience to climate change in Guatemala. Specifically, this case study describes the PSP followed to define the scope of the resilience analysis undertaken in the district of Huehuetenango. As part of this PSP, the author conducted a series of semi-structured interviews among relevant stakeholders in the local maize production system.

### *2.1 Background*

Guatemala, similar to other developing countries, faces food security challenges that will only increase as climate change affects small-scale farmers' capabilities to produce food. Guatemala's chronic malnutrition, an accepted measure of food insecurity, is one of the highest in the world (World Food Programme, 2016), reaching 55% in rural areas (Guardiola, Gonzáles, & Vivero, 2006). Climate change effects, such as severe droughts and increased average temperatures, already compromise the food production in Guatemala, especially among small-scale farmers (Bouroncle et al., 2015).

Recognising this as problematic, some studies that explore potential means to mitigate climate change effects have been commenced separately by academics, nongovernmental organisations (NGOs) and the local and central government in Guatemala. This research is part of these initiatives, independently conducted by the author with the cooperation of numerous stakeholders, in the district of Huehuetenango.

Huehuetenango is located in the Northwest region of Guatemala, on the border with the South of Mexico. Huehuetenango is one of the poorest, most vulnerable districts in Guatemala. In 2014, its population was estimated at 1,150,000 people, with 67.6% of these people under the line of poverty (INE, 2012). Huehuetenango's main economic activities are the mining industry of silver and gold and the production of coffee (Camposeco, Thomas, & Kreynmar, 2008). Nevertheless, the production of maize is an important activity for self-consumption. The majority of the population is indigenous, from the ethnics of Mam and Quechi, with a cultural dependence on maize as the main source of calories. Among indigenous groups maize represent a 71.2% of share in basic grains consumption).

### *2.2 Methodology*

The intention of the study was to discuss potential policies to enhance the food security resilience and to explore in an operational manner the impacts of these policies on different parts of the system. The author with the support of two academics from the Universidad de San Carlos de Guatemala (national university in Guatemala), started by identifying (mapping) and engaging relevant stakeholders as early as possible and throughout the PSP. The following stakeholder groups accepted the invitation to participate in the PSP: i) the central government, ii) NGOs, iii) farmers from Huehuetenango and iv) academics and agronomists from the University. The number of delegates from each group and their backgrounds are presented in Table 1.

**Table 1:** Stakeholders' group representatives

| Stakeholder group | Number of delegates participating | Background |
|---|---|---|
| Central Government (CG) | 4 | Agronomists<br>Policymakers |
| Non-Governmental Organization (NGO) | 3 | Agronomist<br>Project Managers |
| Farmers (F) | 6 | Maize farmers |
| Academics (AC) | 2 | Agronomist professor<br>Researcher |

During the PSP, the author conducted semi-structured interviews to gather stakeholders' perspectives about the food security resilience of the small-scale maize production system of the region. In the first part of the interviews, the author asked the delegates of the different stakeholder groups about the agendas they have for the local food system. Subsequently, causal loop diagrams (CLDs) were used to capture stakeholders' broad understanding of the underlying causes of system vulnerability (the extent to which the system will be affected by) to climate change . Finally, the delegates were also asked to rank the stakeholders in the system in terms of influence on and interest in the local food system.

The elicitation of stakeholders' agendas for the local food system was done by discussing the following general questions with the delegates of each stakeholder group:

- What would you like to get from the small-scale maize production system?
- In this context, what does resilience of food security to climate change mean?
- What are the critical success factors of policies enhancing food security?

After the interviews, the author compiled and summarised the different answers. Similar answers were grouped in the same variable or short statement to simplify further analysis. The resulting statements were discussed in further interviews with each delegate to ensure they reflected their own perspectives. When needed, changes were made and again discussed with the specific delegate requesting the change.

Beside the narratives provided by the delegates, this chapter uses CLDs as a means for capturing stakeholders' assumptions. CLDs are diagrams representing, in a simple manner, a possible set of causal relationships between different variables of the systems (Lane, 2008; Richardson, 1986). CLDs are particularly useful for identifying circular relationships known in the systems' literature as feedback loops. The rigor of diagramming forces the participants to "carefully and consistently" make their assumptions explicit and to "put their problem definition to test"[17] (p. 384). Thus, CLDs are a suitable way to represent and compare different interpretations of the problem and the causal explanations held by the stakeholder groups participating in the PSP.

CLDs might be employed in the PSP (also known as the conceptualisation stage of the modelling process) (Luna-Reyes & Andersen, 2003; Randers, 1980) to elicit participants' understanding of the problem. During the conceptualisation, the modeller focuses on "a verbal description of the feedback loops that are assumed to have caused the reference mode"[19] (p. 119). Namely, in this chapter, the CLDs were used to diagrammatically represent the causal explanations for the lack of resilience of food security in the region. This elicitation might be done, as it was in the case of this chapter, during one to one interviews with experts in the field, in our case agronomist from the university, and stakeholders of the problem at hand.

During the semi-structured interviews the author drafted CLDs representing what the delegates were describing.  The author started by asking the delegates what were the main causes of the decrease and fluctuations of the affordability of maize (as a measure of food security (Ingram, Ericksen, & Liverman, 2012)) experienced in the past 10 years in the region of Huehuetenango (see Figure 1). The causes stated by the delegates were summarized by the author in relevant variables while transcribing them to the diagram. Then, the author asked delegates to explain how those variables influenced each other. These causal links between different variables were represented in the diagram by arrows connecting the cause with its effects. When needed, new variables were added to the diagram.

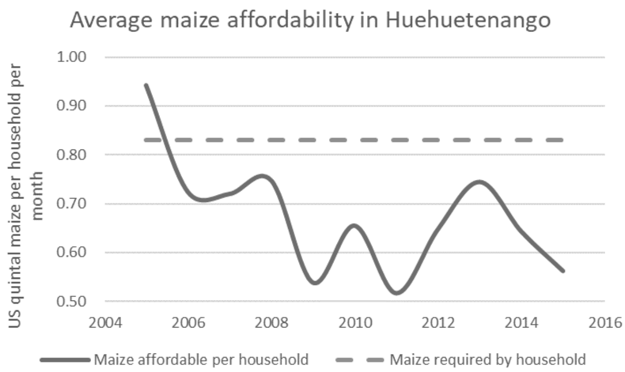


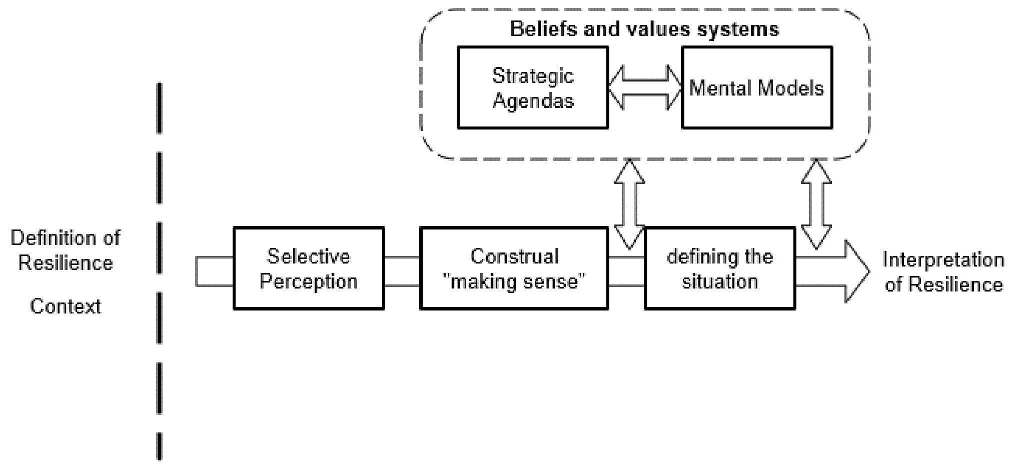

*Figure 1:* Maize affordability in Huehuetenango.

At the end of the interview, the delegates were asked to complete the CLDs drafted by the author by adding variables, causal relationships or any elements missing in the diagram. Later, the author worked on his own by summarising all the CLDs produced by each delegate into a single CLD per stakeholder group. The single CLDs were validated and discussed with the delegates of each stakeholder group in separate interviews to ensure all of their views were appropriately captured in the diagrams. If participants found important issues missing in the diagram, those issues were added to the final version.

Finally, delegates were asked to characterise the different stakeholders in the system. To be precise, participants were asked to rank from 1 (low) to 5 (high) the level of influence each stakeholder group has on the local food system. During this characterisation, participants were invited to consider in their assessment what resources each stakeholder can allocate for this purpose and the level of organisation and the reputation of each of them. Similarly, participants were asked to rank the stakeholders from 1 (low) to 5 (high) according to their interest in the problem (i.e., resilience of food security). The author tabulated the results into a single chart showing the average level of influence of each stakeholder group.

*Analytical Framework*

The results were analysed in the light of personal construct theory (PCT) (Kelly, 1955). PCT is based on the assumption that a person needs to make sense of the problem to address it: "a person's processes are psychologically channelized by the ways in which he anticipates events" (Kelly, 2003, p. 7). Thus, to analyse resilience, stakeholders need first to make sense of what resilience means. To illustrate how this cognitive process unfolds, this chapter adapts the simplified model proposed by Eden (Eden, 1994) to examine how stakeholders construct their own interpretations of resilience (see Figure 2). According to Eden's (Eden, 1994) model, stakeholders make sense of the concept of resilience by selecting particular elements that are applicable to the problem at hand and its context. This perception is then filtered through the individual system of values and beliefs to articulate its own interpretation of what resilience means in practical terms. This separation of selective perception and construal follows the personal construct theory of Kelly (Kelly, 1955).




*Note: Adapted from Eden* (Eden, 1994)

*Figure 2:* Construction of stakeholders' interpretation of resilience.

There is no clear distinction between values and beliefs, as they are closely interconnected (Eden, 1994). However, for analysis purposes, this chapter explores two separate interconnected aspects of the beliefs and values systems: strategic agendas and mental models. The term strategic agenda is used here to describe the set of goals each stakeholder has for the system. Similarly, the term mental model is used to describe the conceptual representations each stakeholder has about how the system works (Doyle & Ford, 1999). Strategic agendas and mental models are not separate entities. They support each other, and together, they are supported by wider individual value systems (Eden, 1994).

In policymaking settings, closely linked to the understanding of what resilience means in practical terms, is the concept of adaptability or the "the capacity of actors in the system to influence resilience" (Walker, Holling, Carpenter, & Kinzig, 2004, p. 5). Stakeholders' adaptive actions depend on how they perceive the disturbance is changing the conditions of their system. Since timing, magnitude and origin of the disturbance are, at least to some extent, unpredictable, the nature of the change the disturbance produces deviates from normal system-near-equilibrium analysis (Darnhofer, Bellon, Dedieu, & Milestad, 2011). In these conditions of high uncertainty, identifying the mechanisms driving adaptation is not straight forward but depends on the stakeholder's mental models about how the system works.

To analyse how stakeholders' understand the system this chapter uses the reflections of Mayumi and Giampietro (Mayumi & Giampietro, 2006) about self-modifying systems and the theories of Funtowicz and Ravetz (Funtowicz & Ravetz, 1994a) on emergent systems. According to the aforementioned sources, the explanations each stakeholder group gave to the system behaviour were classified into:

a) endogenously driven: the observed effects of disturbances affecting the system are the result of the functional links between its different elements. Adaptation emerges from the mechanisms the system has to regulate itself and can only be enhanced by strengthening them (Mayumi & Giampietro, 2006). The solution to the problem is within the system boundaries.

b) exogenously driven: the disturbance affecting the system comes from outside the system and, to adapt to the new conditions introduced, the system needs of external interventions that "push" it back to its equilibrium state. The solution is outside the system boundaries.

c) chaos: the uncertainty about the disturbance affecting the system and complexity of the system itself are perceived so high that it is impossible to identify links between actions (outside or within the system) and their consequences. The solution is unknown.

This classification offers a helpful analytical framework to explain how delegates from different stakeholder groups understand the system and the differences in the policies they will propose in further stages.

Nonetheless, the agendas and mental models used by stakeholders to construct their own interpretation of resilience are only some of the ingredients for the scope of the resilience analysis. The manifestation of power in the PSP is indeed critical analytical lens to understand complications of resilience ambiguity. In fact, power effect on resilience is one of the most unexplored but most contested characteristics of resilience (Cote & Nightingale, 2012).

Case study research shows that in prescriptive settings, the PSP of resilience is predominantly a negotiation endeavour. For instance, Lebel et al.(Lebel, Anderies, Campbell, & Folke, 2006) describe that in many case studies, undertaken by the Resilience Alliance, the scope of resilience analysis reflects, to large extent, the interest of powerful stakeholders, undermining perspectives of ethnic minorities and small-villages (powerless stakeholders). Similarly, Larsen et al.(Larsen, Calgaro, & Thomalla, 2011) highlights the tensions regarding roles, control and ownerships between powerful stakeholders during the process of building resilience in Thailand tourism-dependent communities.

These cases studied in the literature show that, during the PSP of resilience, stakeholders will try to persuade the others to join or accept their own interpretation of resilience and to articulate the scope of the resilience analysis accordingly. As illustrated in Figure 3, the scope of analysis is a negotiated outcome of the PSP that reflects not only the interpretations of each stakeholder in the system but also the power relationships between them.

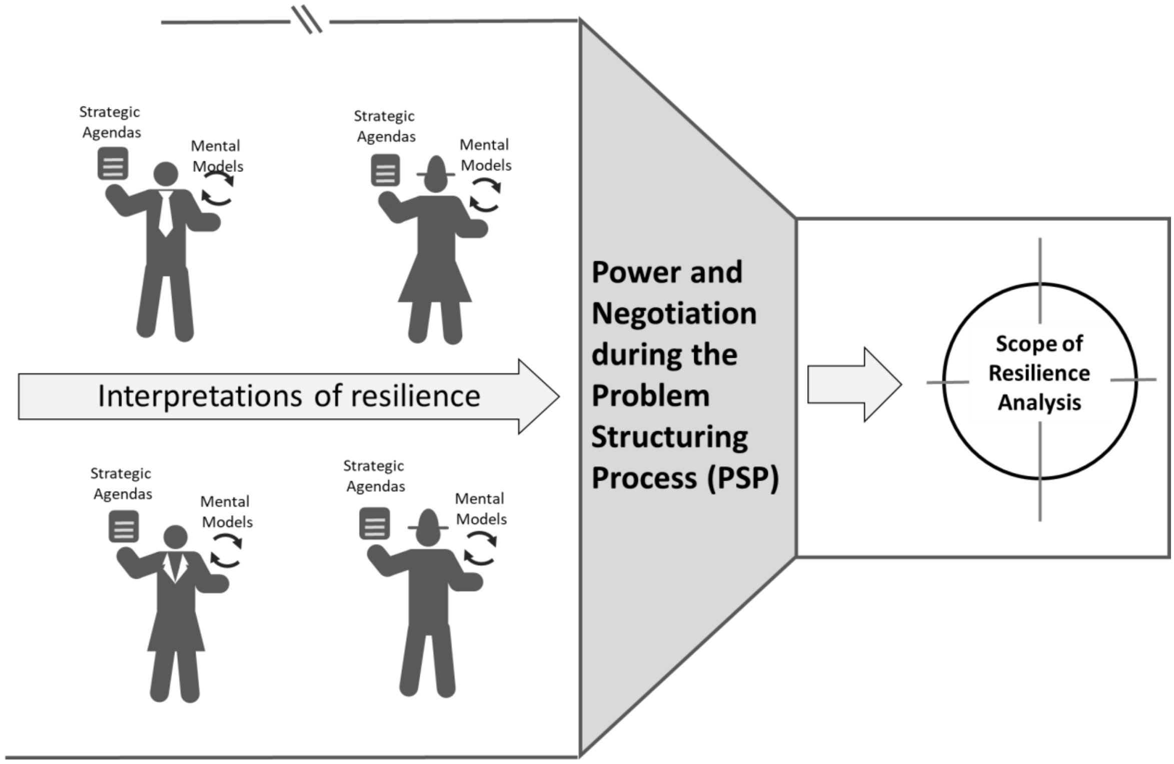



*Figure 3:* Simplified representation of the problem structuring process (PSP) of resilience analysis

## *2.3 Results*

*Strategic agendas*

Tabulated results from the interview show that delegates from the same group coincide to a large extent in the answers they provided about their agendas. Table 2 summarizes these tabulated answers. In Table 2 it is noticeable that most of the delegates of the same group agreed on a similar answer.

**Table 2.** Summarized answers to the semistructured interviews

| Delegate code | | CG1 | CG2 | CG3 | CG4 | NGO1 | NGO2 | NGO3 | AC1 | AC2 | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **What would you like to get out from the small-scale maize production system?** | Increase households' wealth | X | X | | X | | | | | | | | | | X | |
| | Produce revenues | | | X | | X | X | X | | X | | | X | | | |
| | Produce food | | | | | | | | X | | X | | | | X | |
| | Produce food for locals | | | | | | X | | | X | | X | X | X | | X |
| **In this context, what resilience of food security to climate change means?** | Being able to afford food even when droughts | X | X | X | | | | X | | | | | | | | |
| | Produce food constantly in despite of the droughts | X | | | X | X | X | | X | X | | X | | | X | |
| | Don't starve during the bad years | | | | | | | | X | | | | | | | |
| | Have always enough food | | | | | | | | | | X | X | X | X | X | X |
| **What are the critical success factors of policies enhancing food security?** | Money available for purchasing food | X | X | X | | | | | | | | | | | | |
| | Crop productivity | | X | X | X | X | | | | | | | | | | |
| | Maize Yield | | | X | X | | X | | X | | | X | | | | |
| | Maize reserve | | | | | | | | | X | X | X | | X | X | X |

*Note: CG: Central Government, NGO: Non-Governmental Organization, AC: Academics, F: Farmers*

Based on the interviews results, the strategic agenda held by each stakeholder group can be summarized as follow:

*Central Government (CG):* The purpose of the analysis is to identify how to increase the household's wealth and particularly the money available to buy food so that households can afford enough food even when droughts reduce the yields of maize in the region.

*Non-Governmental Organization (NGO):* The purpose of the analysis is to identify how to enhance crop productivity so that households can produce food and revenues constantly despite the droughts. Note that in the words of the NGO delegates crop productivity is understood as the amount of crop (not exclusively maize) produced from each Guatemalan Quetzal invested by the farmers.

*Academics (AC):* The purpose of the analysis is to identify how to increase maize yields and reserves as a mean to prevent starvation by increasing farmers revenues and food supply to the region.

*Farmers (F):* The purpose of the analysis is to identify how to increase food production (not limited to maize or crops in general) and maize reserves to have food all the year around.

*Causal loop diagrams*

Figure 4 presents the CLD's prepared jointly by the author and delegates of each group. In general, diagrams are relatively simple and focused (with the exception of diagram in Figure 3c) on one or two main causal explanations of the problem to address (decrease and fluctuations of maize affordability in the region).

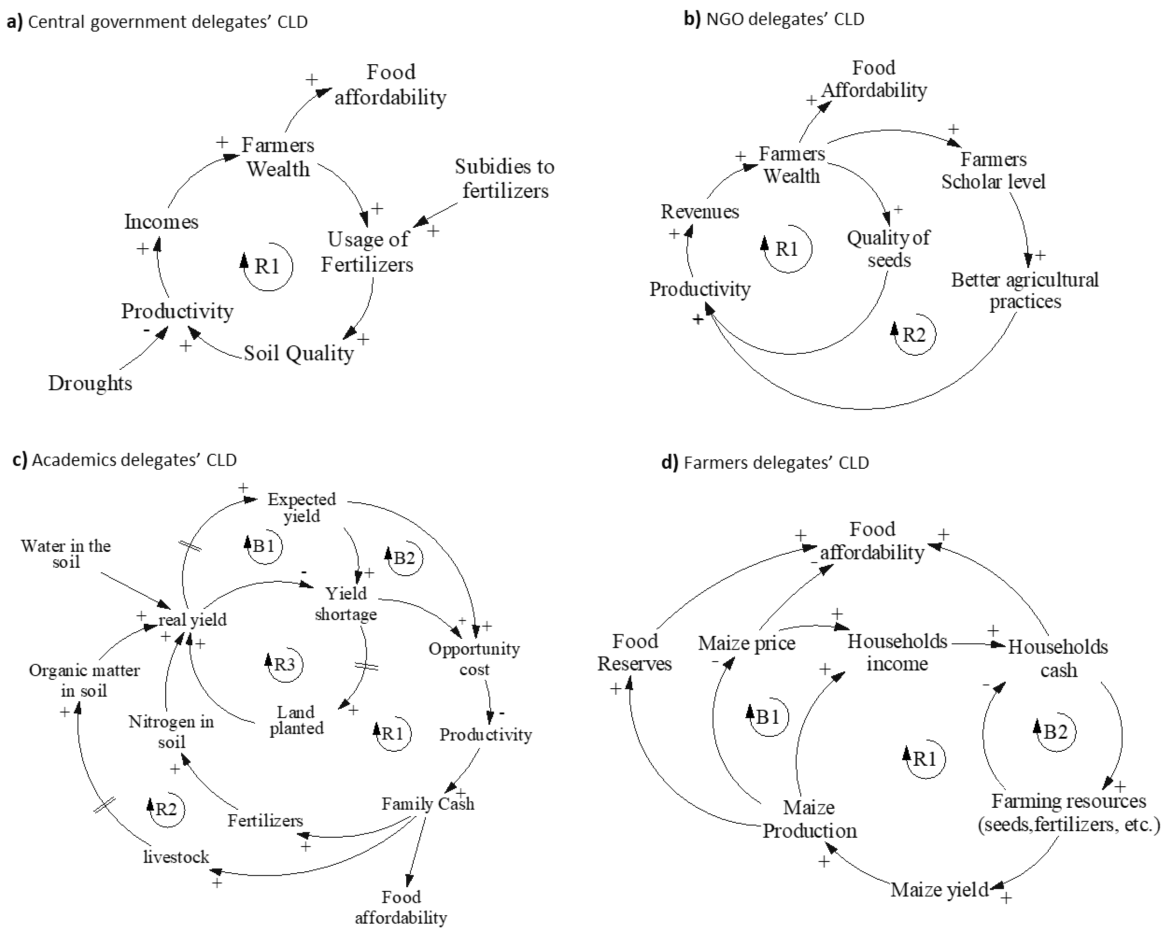



*Figure 4:* Causal loop diagrams (CLDs) explaining the decrease and fluctuations of maize affordability in Huehuetenango. CLDs were produced by a) central government delegates, b) NGO delegates, c) academics delegates and d) farmers delegates; during one-to-one semi structured interviews.

Next, there is a brief explanation of each diagram.

*Central Government (CG):* Farmers productivity increases the incomes and, therefore, the wealth of the farmers. Higher wealth increases farmers' capacity to use fertilizers (fertilizers are more affordable). Usage of fertilizers is directly related to the productivity and, therefore, the more fertilizers the farmers use the more productive they become in a virtuous cycle represented by the R1 feedback loop in Figure 4a. This loop, however, is perturbed by droughts (disturbances of the system) that reduce farmers productivity, reducing their overall wealth and hence their capacity to acquire food (food affordability).

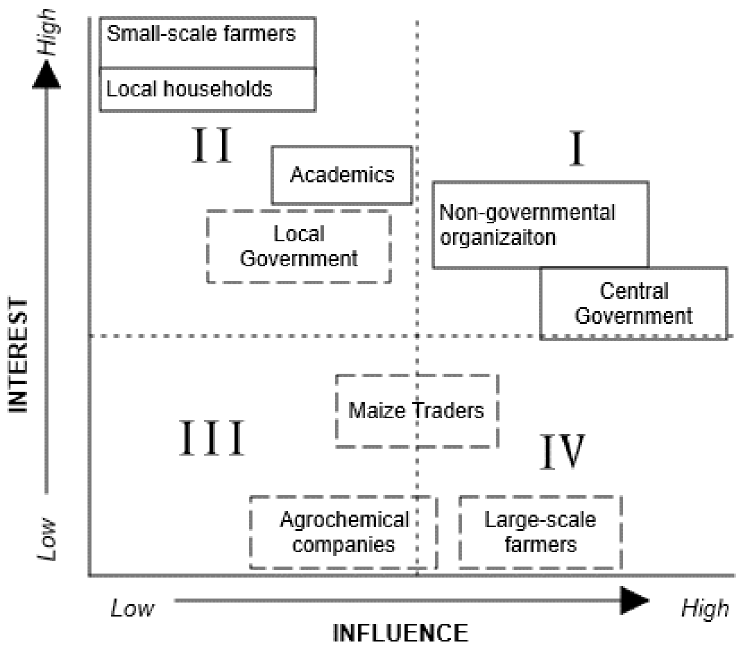
*Non-Governmental Organization (NGO):* Farmers productivity increases the incomes and therefore the wealth of the farmers. Higher wealth increases farmers' capacity to access better seeds and formal education. Seeds of improved varieties, less water demanding ones, are assumed to increase crop productivities, especially during drought seasons, compared to seeds coming from informal sources (on farm save seeds for example). Better seeds increase wealth in the virtuous cycle represented by R1 in Figure 4b. Access to formal education is assumed to be linked to better agriculture practices (e.g. appropriate usage of fertilizers and land planning). Better agriculture practices increase revenues and wealth in the virtuous cycle represented by R2 in the Figure 4b.

*Academics (AC):* The causal explanation represented in the Figure 3c focuses on the variation of the real yield against the expected one (yield shortage in the diagram). Yield shortage results into lower productivities and opportunity costs that reduce families' cash and their capacity to invest in fertilizers and livestock (see feedback loops R1 and R2 in Figure 4c). Higher yield shortage also translates into a reduction of the land planted each season (see R3 in Figure 4c), because farmers need to spend more time on other activities (e.g. working on coffee plantations) and less time farming. The expected yield eventually gets adjusted, decreasing the yield shortage and opportunity costs (see loops B1 and B2 in Figure 4c.). The increase in droughts occurrence increases yield shortage by affecting the maize system and its real yield, reducing at the same time the land planted and the cash available for the next season's harvest.

*Farmers (F):* Maize production increases incomes and households' cash, allowing farmers to acquire more resources needed in the farming activities (seeds, fertilizers, etc.). That eventually increases the maize production. Higher production results into a) higher food reserves and b) higher incomes (see feedback loop R1 in Figure 4d). However, there are two drawbacks from the feedback loop R1. First, the acquisition of resources decreases households' cash (see feedback loop B1 in Figure 4d) thereby reducing the food affordability. Second, higher production will eventually translate into lower maize prices, reducing farmers' income and profit margins (see feedback loop B2 in Figure 4d).

*Influence-interest grid*

Figure 4 presents the stakeholders' grid produced by the delegates. The four stakeholder groups participating in this case study were consistently identified by all the delegates as those with the highest interest in the problem (see Figure 5). Central government and NGO working in the area were described as the stakeholders in a better position to solve the problem or those with higher influence in the problem (see quadrant I in Figure 5). Other stakeholders, like the large-scale farmers producing food in the region and traders, were also recognised as highly influential ones. However, there was an agreement among delegates of all the stakeholder groups participating that, unfortunately, large-scale farmers and maize traders have no interest in enhancing food security in the region (quadrant IV in Figure 5). While recognized as those with higher interest in the problem, small-scale farmers were portraited as the group with the lowest influence on it (see quadrant II in Figure 5). Academics and stakeholders not participating in the PSP (local government) were also portraited as interested parties with low influence.




*Note: stakeholders in dotted lines did not take part in this research*
*Figure 5:* Influence/interest diagram summarizing stakeholders rank in the small-scale maize production system in Huehuetenango.

## 3. COMPLICATIONS OF THE PSP IN THE ANALYSIS OF RESILIENCE

The results presented in Section 2 offer relevant evidence to discuss the ambiguity of resilience and its complications. The ambiguity of resilience, in this case, does not arise from the differences between many definitions of resilience (Quinlan et al., 2016), but from the way in which stakeholders interpret it for their specific context and problem. The differences that emerged during the PSP might already be noticeable for the reader, but the analytical lenses proposed in this chapter offer a perspective of the deeper and more conflicting differences in the agendas and mental models held by each stakeholder group.

These cognitive differences set the scene for analysing the conflict that could unfold during the negotiation of a single scope of resilience. The more mutually exclusive agendas and mental models are, the harder it is to reach a scope of resilience that satisfies all the stakeholders. As Eriksen et al. (Eriksen, Nightingale, & Eakin, 2015) pointed out, adaptation will change social, political and economic relationships between stakeholders, "yet not all these changes are desirable for everybody".

This section finalizes by discussing practical implications of resilience ambiguity in the policymaking process. These implications are not only political but also methodological and require a thoughtful planning of the PSP. While it might be possible to mitigate some drawbacks, more research is needed before outlining a comprehensive framework for addressing the political challenges resilience entails.

### *3.1 Constructing an interpretation of resilience*

The experience in the district of Huehuetenango in Guatemala shows that different stakeholders have different interpretations of resilience. These interpretations of resilience are context specific (Carpenter, Walker, Anderies, & Abel, 2001; Marshall & Marshall, 2007) and reflect the values and beliefs of the stakeholders involved. In other words, stakeholders make sense of what resilience means in their particular context and frame the analysis process accordingly. In this case study, different interpretations of resilience are reflected in a) the different goals and desired outcomes (strategic agenda) stated during the interviews (see Table 2) and b) the different descriptions of the causes of the problem (mental models) captured in the CLDs (see Figure 1).

When looking at the strategic agenda, stakeholders see the maize production system at different levels of aggregation (household level vs. regional level). As presented in the results section, delegates from the same stakeholder group share similar perspectives about the purpose of the system (see Table 2). With the exception of the farmers, the groups also share some alignment among themselves. The answers in Table 2 and summarized strategic agendas in the Results section show that most of the delegates have local/regional goals for the system, namely to promote local economic development. Alternatively, farmers focus on their current urgent problem of living in insecure food conditions.

In other words, there are two main strategic agendas for the system. One agenda (shared by many stakeholders) is seeking to use the system as a tool for local and/or regional economic development. The other agenda, held by the farmers, is to have food all year around. While there might be different arguments in favour of one agenda over the other one, it is unlikely that regional solutions will have any impact unless urgent issues challenging the farmers' own subsistence are addressed. Similarly, small-scale solutions, addressing farmers immediate needs, might prove to be unsustainable in the mid-term if the wider problem is not tackled.

Wider differences are found when looking at stakeholders' mental models reflected in the CLDs developed. Academics and NGO delegates describe the system in endogenous terms. This endogenous perspective is reflected in the feedback loops identified in the CLD they drafted (see Figures 4b and 4c). They look at the problem in a systemic way and try to find solutions within the system boundaries. They have, however, a different understanding of the vicious circles constraining food security. On the one hand, academics focus on the management of the water resources and reservoirs as a potential leverage point.

*"The obvious cause of the problem is the deficiencies the communities face to access water…. This is why that, now that droughts are becoming more common, farmers face more problems.*" (Academic delegate 1)

On the other hand, NGO delegates blame farmers' lack of technical skills and training as the cause of their poor productivity and, hence, food insecurity. The solution they propose is to increase training and to provide farmers with better seeds to increase their productivity in a sustainable way.

*"You see, there are several complications in the situation of these poor people because their culture doesn't let them move forward. They use the same techniques they have been using since pre-colonial times. They have no formal education. You know that most of them cannot read. It is really difficult to teach them and change their minds. We need to make an effort to*

*provide them with the right seeds and the proper instruction to use them well."* (NGO delegate 2)

The government delegates describe the system as exogenous driven. These delegates think the way to influence the system is through the artificial enhancement of farmers' productivity (see Figure 4a). Even though they identified a feedback loop in the system, their proposed solution focuses on ways to quickly boost the system performance, namely by using more fertilizers to increase productivity.

*"The government is committed to provide a sustainable and plausible solution by providing the fertilizers they (farmers) need to increase their productivity and become more competitive…. Once they (farmers) level up with the market, the food affordability should be a natural condition."* (Central government delegate 2)

Farmers perceive the problem in a very different way. In their perspective, the increasing uncertainty about rainfall is transforming the system into a chaotic one. In their perspective, using more expensive seeds or more fertilisers will be useless if the weather conditions are not good. Farmers do not feel in control of the system. They feel they are victims of the uncertainty about the yields they will get at the end of the season.

*"The problem is you don't know if the yield is going to be good or not…. Now you never know…. If the yield goes bad, we lost the money we spent on seeds and fertilizers."* (Farmer delegate 4)

*"The weather now cannot be predicted…. You gamble every time you plant."* (Farmer delegate 1)

Furthermore, the farmers do not see higher production as a mean to increase their revenues but as a means to increase their food reserves (see Figure 4d). In their view, the region is isolated, and they do not have access to other markets to trade. The benefit they perceive from a higher production is in having more maize to build food reserves for the future.

Understanding and acknowledging different goals and mental models about the system will lead to a wider scope of analysis and might result in a more balanced decision-making process (Darnhofer et al., 2011). Short-term solutions and systemic interventions could provide a balanced view between achieving short-term outcomes and their long-term consequences. Farmers' chaotic view of the world challenges the mechanistic understanding other stakeholders might have and balances their deterministic view by the acknowledgement of uncertainty. The system cannot be assumed mechanistically following economic rules since human behaviour under stressful situations adapts in sometimes unexpected ways (Maleksaeidi & Karami, 2013). An oversimplified understanding about how different groups will react during a crisis might lead to policy failure (Nightingale, 2005). For instance, while most of the stakeholders expect farmers to use a potential production surplus to increase their revenues, farmers will use it to increase their food reserves, affecting the policy's effectiveness.

### *3.2 Negotiating the scope of analysis*

The power to influence the final outcome is not symmetrical among stakeholders, with those holding key resources being in an advantageous position to impose their own interpretations in the final scope. System adaptation will "influence social relations, governance and distribution of resources in any given population or place" (Eriksen et al., 2015, p. 2). However as shown in this case, there is not always an agreement about the changes and the scale at which those changes should be made. Those with higher level of influence in the scope of analysis might not be those directly affected by its outcomes. For instance, the small-scale farmers in Huehuetenango are the stakeholders directly affected by potential decisions about how to enhance resilience, but they are also those with the least influence on the decision-making process (see Figure 5).

Power differences have contentious repercussions considering that those with higher level of influence have different strategic agenda than those suffering the bigger impacts of the policies implemented. This is particularly relevant since there is a clear difference between the farmers' interpretations and those held by the rest of the stakeholders. Considering the different interpretations of resilience, the power to set agendas about what issues are to be addressed needs to be an important consideration during the PSP.

Competitive agendas and mental models set the scenario for a game of power where different stakeholders seek to impose their own agendas on the scope of the analysis that will follow. The allocation and distribution of the access to natural resources have been, historically, an expression of power tension between different groups (Cote & Nightingale, 2012; Eriksen et al., 2015). While building the resilience of the system outcomes, the resilience of the institutions and relationships defining those outcomes are also enhanced (Peterson, 2000). Many stakeholders perceive the resilience analysis as an opportunity to gain power or to influence the system towards their own interests(Cote & Nightingale, 2012). This power might be exercised in many ways. For instance, stakeholders might scope the problem in isolation, ensuring their interpretations are the only ones represented. Alternatively, some groups could try to undermine those with competitive or opposite views by diminishing their credibility as shown in this case. For instance, note the comment above from NGO delegate 2 in which the delegate undermines farmers' practices because they have no formal education. Any analysis that does not account for these tensions would result in an incomplete understanding of the scope of potential responses (Adger, Arnell, & Tompkins, 2005; Cote & Nightingale, 2012).

In short, recognising that there might be different interpretations of resilience implies accepting the PSP as a negotiation and political process. Seeing the PSP as a negotiation forum means that practitioners need to acknowledge the social and political factors (e.g., inequality and legitimacy) shaping the scope of analysis and need to be transparent about the implications of these factors on their recommendations. Otherwise, the resilience analysis risks being used, possibly inadvertently, as a way to legitimise the power of particular groups and to impose particular means to manage natural resources (Peterson, 2000).

### *3.3 What are the potential implications?*

There are at least two implications resulting from the flexibility of resilience to interpretation. First, it seems unlikely that a proper analysis would result in a PSP that does not account for the many different interpretations of resilience in each particular context. If the scope of analysis has been defined by only a few groups, it risks being too narrow, excluding important elements from the analysis and reducing the range of solutions explored. For instance, the analysis might focus on short-term solutions, ignoring important feedback loop mechanisms of the system. Alternatively, a pure systemic view of the problem might fail to recognise uncertainty and might oversimplify decision rules and human behaviours.

Second, stakeholders who have a different understanding of the problem will rarely support or get actively engaged in the implementation of a solution that is not addressing their initial understanding of the problem (Größler, 2007). The contribution of any solution is null if those ultimately responsible for implementing them are not willing to do so (Ackermann, 2012). For instance, stakeholders might sabotage the policies proposed at the end of the analysis by refusing to participate in the implementation (e.g., training and the introduction of new practices) or, even worse, by explicitly opposing them (e.g., demonstrations against the introduction of new seeds).

### *3.4 Potential avenues for mitigation*

Recommendations are not conclusive, but it is possible to outline avenues for further development with the aim of reducing the potential drawback of power in the PSP. A possible avenue is to advocate for more participatory settings. So far, the SES literature has extensively discussed stakeholders' participation as a requirement for the enhancement of resilience in the SES. However, very little has been elaborated on the role of participation in the formulation of the problem as such. Facilitated modelling approaches, such as Group Model Building (Vennix, 1996) or Cognitive Mapping (Eden & Ackermann, 2001), might contribute to mediating this process (e.g., by introducing the CLD as a transitional object that helps to leverage power differences) (Davies, Fisher, Dickson, Thrush, & Le Heron, 2015; Franco & Montibeller, 2010). These methods contribute in leveraging the power between groups by forcing participants to make their assumptions explicit in a diagram that is challenged by the group (Akkermans & Vennix, 1997; Rouwette, Vennix, & Felling, 2009; Vennix, 1996). In this case, the diagram is used to jointly represent the problem definition shared by and agreed upon by different stakeholders through a process of negotiation and dialogue (Franco & Montibeller, 2010).

Alternatively, another option is to aim for a broader perspective in the analysis of resilience and to consider possible trade-offs and asymmetries in resilience between different groups and communities within the system. A broader perspective might be particularly useful when there is a conflict between long-term and short-term goals or when the boundaries of the system are not clear (Duit, Galaz, Eckerberg, & Ebbesson, 2010). By using computer simulations, for example, it is possible to uncover long-term unintended consequences that might result from short-term perspectives. Uncovering unintended effects is possible because computer simulations are especially useful when the delays between the policies and their results are too big to allow for assessment by simple intuition. Simulations might also uncover unexpected and unintended consequences of policies that are beneficial to one group but negative for others.

The latest is particularly important when analysing climate change problems because there are time lags or delays between policy measures (or non-action), and effects often extend beyond the normal period of analysis (Warner, 2010; Young, 2010). When important consequences of current policies materialise several years later (in some cases decades later), significant future stakeholders will not be present to voice their concerns and weigh in when preferences are aggregated into policy decisions. Present stakeholders might be willing to compromise the overall future detriment of the system for short-term benefits. Namely, in the resilience analysis, present stakeholders might favour policies that yield more efficiency in the short term but diminish the capability of the system to continue providing the desired outputs in the long term. The benefits for a few who are defining the problem now might be preferred over the benefits for the many tomorrow.

## 4. CONCLUSIONS

The ambiguity of resilience is a challenge for practitioners that want to implement it as an analytical and policymaking framework in real life problems. This chapter addresses the ambiguity of resilience from a cognitive and political perspective by focusing on how resilience is interpreted in practice instead of its theoretical definition. This chapter argues that the interpretation of what resilience means in a specific context (resilience of what?) and the ways to achieve it are results of the values and beliefs of those with a stake in the system. In this light, the case study presented helps to identify and highlight some of the challenges and practical implications of resilience ambiguity. To be specific, this chapter focuses on strategic agendas and mental models as observable expressions of stakeholders' values, beliefs and knowledge about the system. The results discussed in this chapter, show that in practice different agendas and mental models compete during the PSP to be part of the scope of resilience analysis. The question of what needs to be resilience has many answers (revenues, yield, food supply).

The results presented in this chapter show that stakeholders have different understandings of how the system works. For instance, while academics and delegates from the NGO participating in the study focused on enhancing virtuous cycles within the system, the central government delegates proposed solutions outsides the system's boundaries. All of these solutions, however, ignored the bounded rationality of the farmers and the premises of their decision-making process. Including only a few stakeholders in the process risks leaving many important aspects out of the scope of the analysis undermining its results.

It is also necessary to acknowledge the role of power shaping and filtering different interpretations of resilience into a formal scope of analysis. It is expected that those with more power will attempt to influence the PSP to reflect their views and agendas. In the case presented in this chapter, farmers have little influence in the PSP and their agendas might, intentionally or accidentally, be bypassed by experts (e.g. academics and researchers) and policymakers. For instance, as discussed in this chapter, farmers bounded rationality and socioeconomic position might be used as an argument for disregarding their knowledge and their claims.

In short, results show that the practical meaning of resilience is socially constructed by those participating in the PSP and the way this process is conducted will affect the result of the analysis. There are at least two practical implications of underestimating resilience ambiguity while structuring the scope of the resilience analysis. First, including only a few stakeholders in the process risks leaving many important aspects of the system out of the scope of the analysis to be undertaken. Second, poor stakeholder management also risks obstructing the implementation of proposed policies and, in the worst case, unintentionally harming those in more vulnerable positions. While literature starts to acknowledge the challenges and contentious implications of power in the resilience analysis (see for instance (Cote & Nightingale, 2012; Eriksen et al., 2015; Maleksaeidi & Karami, 2013)), more research is needed toward defining a framework of how to facilitate negotiation during the PSP.

If resilience is to play a significant role in climate change adaptation, policymakers should be careful when structuring the scope of the resilience analysis and should seek for broader participation. Such broadening is not a simple case of bringing more perspectives. Instead, it is a "fundamental shift in how knowledge is understood to operate and consequences of this for the kinds of questions we formulate prior to our analyses" (Cote & Nightingale, 2012, p. 484). Increasing participation is not a normatively uncontroversial route either, but at least it acknowledges that resilience-based policy solutions and institutions will have distributional and, thereby, moral consequences (as most other forms of public policy).

**Acknowledgments:** To the stakeholders in Huehuetenango who participated in this research and kindly agreed to share their perspectives in this chapter.

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# Chapter 3

# Together, we think differently: Using group model building to frame resilience analysis in policymaking settings

**Keywords:** stakeholder engagement, resilience, policymaking

**Abstract:** This study proposes to use facilitated modelling methods in an analysis of resilience in socio-ecological systems (SES). While resilience is a compelling framework for analysing adaptation mechanisms, our limited understanding of how SES works limits the extent to which resilience can be applied to real-world problems. Broad participation has been extensively discussed in the literature as a strategy for enhancing understanding regarding complex systems. However, the same literature still lacks practical details regarding how and when participation should occur. In this study, we present how facilitated modelling methods serve as a framework to operationalise the participatory process in the analysis of resilience. We focus on the specific facilitated modelling method of group model building (GMB), that is, the use of the system dynamics (SD) approach in a participatory way. With this aim, we use our experience facilitating a model-based discussion regarding how to enhance the resilience of food security in Guatemala as a case study. We use our experience in this case to discuss advantages of using GMB during the early stages of the resilience analysis process. We argue that the presence of a neutral facilitator and the use of a jointly built diagram help those participating in the process develop a joint definition of what resilience means and gain a more robust understanding of system adaptive mechanisms.

# 1. INTRODUCTION

Food systems are socio-ecological systems (SES) in which a variety of stakeholders interact through a wide range activities such as production, packaging, selling and consumption of food (Ericksen, 2008). The objectives for food systems include long-term sustainability of food security and social and environmental outcomes. A prerequisite for long-term sustainability is the capacity of a system to maintain its functionality without compromising its ability to do so in the future. There is an increased awareness of the vulnerabilities of food systems to the effects of climate change such as water scarcity and increased occurrence and diffusion of pests (Campbell et al., 2016; Tendall et al., 2015). Resilience is essentially understood as a system's adaptive ability to maintain its functionality even when the system is being affected by a disturbance (Folke, Carpenter, Walker, Scheffer, & Chapin, 2010; Holling, 1996). While sustainability provides a framework for long-term planning, resilience focuses on adaptive mechanisms that will support a system's functionality in the medium- and long-term future. The emphasis on adaptive mechanisms to unpredictable changes has made resilience a compelling forward-looking approach to adaptation (Berkes & Jolly, 2002; Pizzo, 2015b) attracting the attention of researchers and policymakers.

However, despite its popularity, the application of resilience in policymaking settings is still lagging behind. This underdevelopment is at least partially due to the openness of the resilience concept (Duit, 2015; Pizzo, 2015a). Rather than a stable theory, resilience is an abstract, vague and sometimes ambiguous concept, hard to operationalise when addressing real-world problems (Pizzo, 2015a; Tendall et al., 2015). The complex adaptive nature and irreducible uncertainties of SES make it difficult to define the system, its boundaries, its goals and the leverage points to enhance the resilience of its outcomes. These difficulties manifest particularly during the early stages of the analysis process when it is necessary to operationalise the scope to study, or in other words, to decide what is expected to be resilient and in response to what.

The definition of resilience is not a given but is rather constructed during the problem structuring process. During this process, stakeholders defining the problem to address use their values and knowledge to define what is the system to study, what outcomes are important and what are their desired estates. Different stakeholder groups might hold different agendas and understandings of the system and hence propose different definitions for the problem (Herrera, 2017). Defining resilience is not only technically complex but might also be politically contentious (Eriksen, Nightingale, & Eakin, 2015).

Recognising our limited understanding of resilience in SES and the plurality of perspectives regarding resilience operational meaning and implications, and based on post-normal science epistemology (Funtowicz & Ravetz, 1994; Mayumi & Giampietro, 2006), the literature suggests to using broader participation as a means for integrating different types of knowledge into the resilience analysis and policymaking process. Resilience literature argues that our understanding of SESs is always incomplete (Biggs et al., 2012) and that we constantly need to rethink the ways we define their boundaries and the mechanisms driving their outputs. Although a full understanding of an SES might be impossible, including different types of knowledge in the analysis helps to obtain a more robust understanding of the specific aspects of it (Berkers & Folke, 1998; Olsson, Folke, & Hahn, 2004; Woodhill & Röling, 1998). While finding an optimal solution might not always be possible, a robust understanding of the system is likely to lead to more informed decisions and enhanced capabilities to address the unexpected (Bond, Morrison-saunders, Gunn, Pope, & Retief, 2015; Mayumi & Giampietro, 2006).

The combination of different types of knowledge during the analysis of resilience results in a more robust "mental model, or cognitive framework, used to interpret and understand the world and decide on appropriate actions" (Biggs et al., 2012, p.432). A robust understanding of the system and its adaptive mechanisms allows policymakers to consider the wider effects of their decisions, links between different parts of the system, feedback loops and delays between action and consequences. Participation supports the creation of such a robust understanding through a learning process that brings different perspectives together and generates new knowledge of the system and its adaptive mechanisms (Biggs et al., 2012). Learning in this context occurs through social interactions (Brömmelstroet & Schrijnen, 2010). This process generates a productive dialogue in which each party encourages the others to search for a wider understanding (Tavella & Franco, 2015; Tsoukas, 2009)

However, broader participation does not spontaneously result in a productive dialogue. Criticism in the literature mainly concerns the ways in which participation has been managed in many governance contexts and particularly in the context of resilience (see Cooke & Kothari, 2001; Cote & Nightingale, 2012; Sam Hickey & Toit, 2007; Samuel Hickey & Mohan, 2004; Mosse, 1994). Assuming that participation always results in a broader understanding of the system undermines the usefulness of resilience in tackling real-world problems (Cote & Nightingale, 2012; Duit, 2015; Stringer et al., 2006). A rudimentary understanding of the political and social dimensions of SES reflects a lack of practical details regarding when and how participation should be conducted (Duit, 2015). In practice, inadequate management of the participatory process might result in the perpetuation of power structures and asymmetries that might reduce a system's ability to adapt and endanger the resilience of the most vulnerable stakeholders. For instance, case study research shows that when discussing resilience in participatory settings, powerful stakeholders might try to impose their interpretation of resilience and override the goals and interests of vulnerable stakeholders (e.g., Larsen, Calgaro, & Thomalla, 2011; Lebel, Anderies, Campbell, & Folke, 2006).

In this chapter, we aim to contribute to the underdeveloped discussion of when and how participation can support analysis of resilience in the policymaking world. With this aim, we explore the use of facilitated modelling methods for operationalising the participatory process in resilience analysis and policymaking. Facilitated modelling methods use models as transitional objects to facilitate communication, exchange knowledge and learn. The literature is rich in examples of facilitated modelling methods used to address "wicked" problems, where stakeholders have different and conflicting standpoints (e.g., Davies et al. 2015). In particular, we analyse the outcomes of a group model building workshop used to frame a model-based discussion regarding food security resilience to climate change in Guatemala. Group model building (GMB) is also known as mediated modelling (see Van der Belt 2004), and it is a facilitated modelling method based on the system dynamics (SD) approach. It emphasises causal structures of the system driving its outcomes (Andersen, Richardson, & Vennix, 1997). We use the tangible and intangible outcomes of the GMB process (the construction of diagrams and elicitation of stakeholders' perspectives) to discuss how participation supported by facilitated modelling methods might foster learning and result in a robust understanding of the system.

## 2. BACKGROUND

The term facilitated modelling methods is an umbrella term used to group a broad range of methods that build models in a participatory process with the assistance of a facilitator (Franco & Rouwette, 2011). A model is a simplified representation of the world used to analyse a problem, learn about a system and explore consequences of possible decisions (Franco & Montibeller, 2010; Sterman, 2000). For instance, diagrams help to represent causal relationships underlying observed effects in the system. During the facilitated modelling process, the model also plays a role in the knowledge management process serving as an artefact to elicit and connect relevant information (Brömmelstroet & Schrijnen, 2010; Davies et al., 2015; Franco & Montibeller, 2010; Ravera, Hubacek, Reed, & Tarrasón, 2011). The other common element to all facilitated modelling methods, the facilitator, can be defined as "the person who aids the group in building a model of their problem" (Vennix, 1996, p.141). The facilitator plays the role of knowledge elicitor, drawing out "knowledge and insights from the group," and of process manager, focusing on group dynamics (Richardson & Andersen, 1995, p.114).

GMB is a popular facilitated modelling method used to explore wicked environmental problems. Andersen et al. (2007, p.691) defined GMB as the "bundle of techniques used to construct SD models working directly with client groups on key strategic decisions." SD models are especially useful for "representing systems where dynamics and feedback loops are important" (Franco & Montibeller, 2010, p. 495) and usually combine causal diagrams and computer simulations (Richardson, 2011, p.219). Nevertheless, many GMB processes end short of the construction of a full simulation model and focus instead on constructing diagrams that are used as social artefacts to facilitate discussion and knowledge creation (Zagonel, 2002, 2004).

Facilitated modelling methods support learning by making mental models explicit and confronting them with hard data. The simplified description by Brömmelstroet & Schrijnen (2010) of the knowledge management process originally described by Nonaka and Takeuchi (1995) can be used to illustrate the learning process during a facilitated modelling workshop. According to this process (summarised in Figure 1), the learning process involves iterations between mental and formal models.

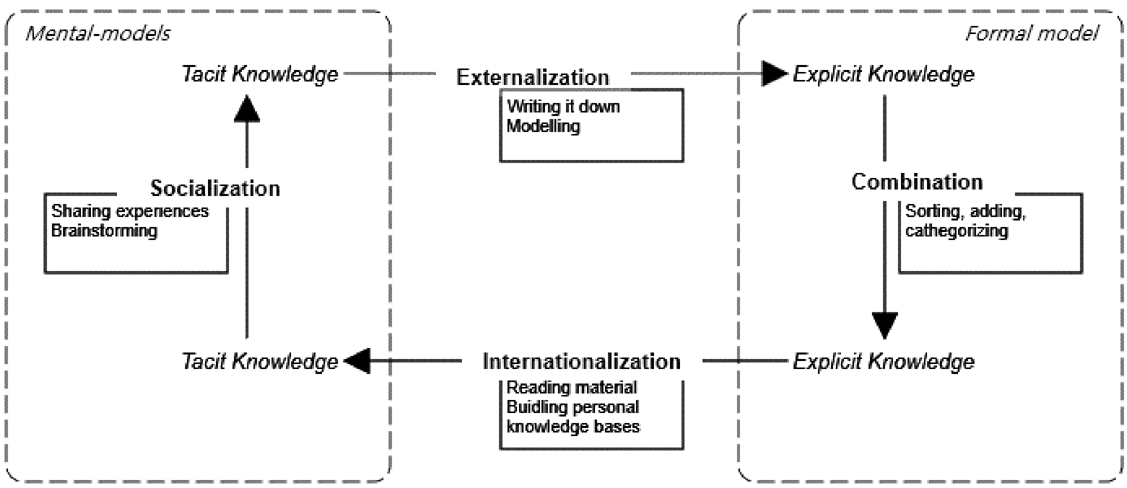


*Figure 1:* Learning process in group model building process. Adapted from Nonaka and Takeuchi (1995)

Mental models are mental representations of how a system works and they are a soft, experience-based type of knowledge. Mental models are what Nonaka and Takeuchi (1995) call "tacit knowledge," something that is held by each individual. During the modelling process, mental models are socialised through brainstorming and elicitation exercises, for instance, asking participants about variables and the causal relationships linking them. Variables and relationships shared by the participants are externalised and transformed into explicit knowledge by putting them in a formal model (see Figure 1). Explicit knowledge is a hard-coded form of data that can be accessed by many individuals and can be combined with other forms of explicit knowledge (e.g., other assumptions, statistical data, simulation results) into a new and more complete representation of the system. This new model of the system combining many different mental models can be used to inform, challenge and refine participants' own mental models through internalisation.

## 3. METHODOLOGY

In this study, we use facilitated modelling as a participatory framework for developing a common and robust understanding of small-scale farming systems in Guatemala and the challenges they face in terms of food security resilience. We provide an operational procedure for integrating different types of knowledge and enhancing our understanding of the system and the interpretations of resilience. GMB was used as an approach for managing participation in the problem structuring process of the resilience analysis.

Food systems in Guatemala are particularly vulnerable to climate change due to its geographical position and high poverty (UNISDR, 2009). Recent studies indicate that temperature is increasing and average rainfall is decreasing and extreme weather events are becoming more frequent (Aguilar et al., 2005). Effects of climate change are generated and exacerbated by social and economic factors limiting options of vulnerable groups to access other sources of food. For this reason, the consequences of droughts and extreme weather conditions are mainly seen among small-scale farmers and poor communities regularly facing chronic food insecurity to extremes that threaten their own subsistence (OXFAM, 2011). The dramatic situation experienced by these vulnerable groups is reflected in the high malnutrition among children of rural areas (approximately 50%, according to the World Food Programme, 2016).

Recognising the challenges that climate change creates, many studies have been initiated by different stakeholders (scientists, NGOs and the government itself) to explore potential means to mitigate climate change effects (see for example BCIE, 2017; UNDP, 2017) This research is part of an independent modelling-based discussion for the analysis and planning of food security resilience in Guatemala. The overall project aimed to discuss potential policies to enhance local food security resilience in response to climate change at a local level while working with small-scale farmers in the district of Huehuetenango. The project included one-on-one interviews, a GMB workshop for structuring the problem, formulation and application of SD models and GMB workshops for discussing policies and interventions that might enhance resilience. In this chapter, we focus on the first two elements and particularly on the contributions of the initial GMB workshop to the understanding of the problem.

Huehuetenango is located in the northwestern region of Guatemala, which is on the border with Mexico. Huehuetenango is one of the poorest and most vulnerable districts of Guatemala, with a population estimated at 1,150,000 inhabitants in 2014, 67.6% of which live under the poverty line (INE, 2012). The mining industry and coffee production are the main economic activities in Huehuetenango. Nevertheless, the production of maize is an important activity for self-consumption. Because the coffee harvest is a seasonal activity occurring from January to April, small-scale farmers usually complement their incomes from coffee harvesting with small-scale production of maize and vegetables for self-consumption. Particularly important is the production of maize, which, despite the low yields achieved, is the main source of calories in the local diet.

Local farmers traditionally combine self-subsistence agriculture with work in coffee plantations. During the months of February to September, farmers work on their small farm to produce maize and vegetables for self-consumption. During the winter (November to February), coffee farms require intensive labour and farmers use this opportunity to increase their incomes. However, this delicate economic balance has been disrupted by the effects of climate change. On the one hand, unstable prices and severe weather conditions have affected the productivity of coffee farms reducing their need for labour. At the same time, similar conditions have reduced the yields of self-consumption farms. As a result, farmers have lost or have seen reduced incomes from picking coffee at the same time that they are producing less food and their food reserves decrease. Figure 2 illustrates these effects by showing the average amount of kcal consumed per day per person over the past ten years. As seen in the figure, since 2004 when droughts intensified in the area, local households have not been able to fulfil their requirements. Fluctuations in prices and variability in weather conditions might be, at least partially, the reasons for the fluctuation depicted in the figure.

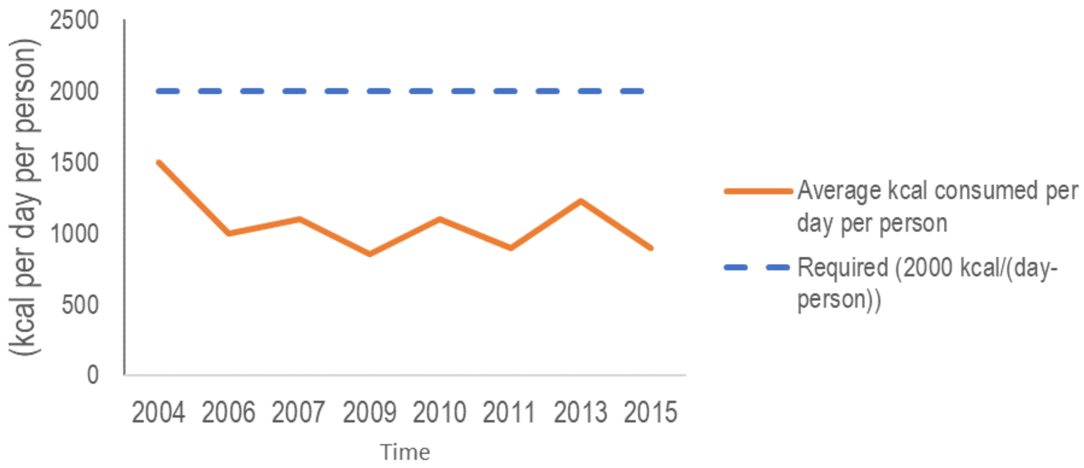


*Figure 2:* Mazie affordability in Huehuetenango
*Source: MAGA 2016*

This study started by investigating what, from the perspective of the local stakeholders, the reasons were for the fluctuations and overall reduction of food affordability in the region. Stakeholders invited to participate in the study were identified with the help of local experts based on a) their interest in local food security and b) their leverage to decide and implement policies. The power/interest grid as described by Bryson (2004) provided a suitable matrix to differentiate among different types of stakeholders (see Figure 3). Due to time and logistical constraints, from the identified stakeholder groups only those with high interest in the problem (subjects and players in Figure 3) were invited to participate in the process. The stakeholders' groups who took part in the discussion were (the number of participants from each group in parentheses) the central government (3), internationally sponsored NGOs working with farmers to increase maize production (2), academics from the national university (2) and local farmers (4).

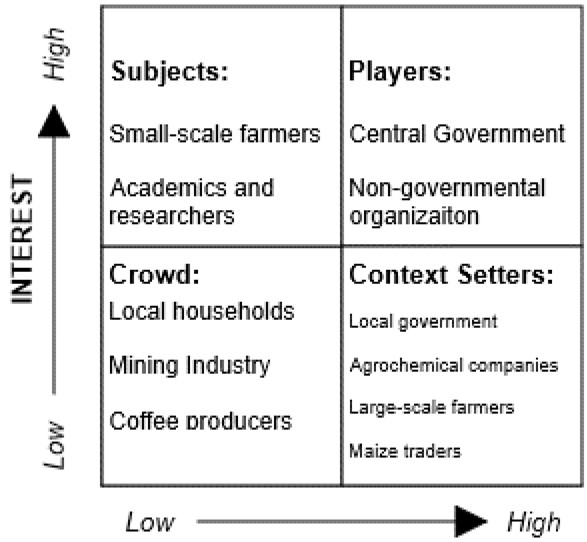


*Figure 3:* Power/interest grid of stakeholders in a small-scale maize production system in Guatemala

### *3.1 Data collection and the problem structuring process*

The problem structuring process (PSP) is the "process by which a presented set of conditions is translated into a set of problems, issues sufficiently well-defined to allow specific research action" (Woolley & Pidd, 1981, p. 197). In this case, the PSP followed two stages. First, we individually interviewed all the representatives from the stakeholder groups invited that accepted to participate in the process. The purpose of the interviews was twofold. First, we use them as a mean to introduce participants to the problem we wanted to discuss (resilience of local food security to climate change). Second, we use them to elicit information about participants goals and mental-models.

The interviews started discussing three questions regarding each representative interpretation of the system purpose. Each interview was broadly a 30 minutes conversation around three issues:

- What would you like to get out from this system (small scale maize production system)?
- In this context, what resilience of food security to climate change means?
- What are the critical success factors of policies enhancing food security?

Narratives provided were documented by the author on written notes made by the first author during the process. When possible, summaries of the interviews were shared with the interviewees to assure we have properly captured the meaning of their statements.

The second part of the interviews used causal loop diagrams (CLDs) as means for capturing stakeholders' assumptions. CLDs are "broad representations of the variables and feedback structures" of a system (Lane, 2008). CLDs might be employed in the problem structuring (or conceptualisation) stage of the modelling process (Luna-Reyes & Andersen, 2003; Randers, 1980) to elicit participants understanding of the problem. During the conceptualisation, the modeller focuses on "a verbal description of the feedback loops that are assumed to have caused the reference mode" (Randers 1980, p. 119). The rigour of diagramming forces the participants to "carefully and consistently" make their assumptions explicit and to "put their problem definition to test" (Vennix, 1999, p. 384).

During the interviews, the first author worked together with each representative to build a CLD representing, at a high level, how the small-scale farm systems in the region contributed to food security to climate change. After the interviews, we combined the CLDs produced by the representatives of each stakeholder into a single diagram containing all the variables and links described in the diagrams produced during the interviews. These aggregated CLDs were validated and discussed with representatives of each stakeholder group to ensure all their views were appropriately captured in the diagram. If participants found important issues missing in the diagram, they were added to the final version.

After the interviews were completed and diagrams drafted and agreed, all the representatives collaborating in the problem structuring process participated in a three hours GMB workshop. During the workshops, participants worked together on building a CLD diagram explaining the small-scale farm systems in the region contributed to food security to climate change. Despite having initial CLDs developed during the semi-structured interviews, the author decided to start from scratch. The decision to restart the mapping process from scratch was justified by the differences found in the CLDs elaborated during the semi-structured interviews. Start with a particular conceptual structure risked, in this case, to bias the conversation towards a particular interpretation of resilience. Besides the delegates of each stakeholder group and the facilitator, a recorder supported the modelling process. The recorder is the person responsible for documenting the ideas and concepts voiced during the workshop and to keep a log of the process. The descriptions of the workshops presented in the results section are mainly based on those notes.

In both cases, the workshops were facilitated by the first author and broadly followed the agenda presented in Table 1. The agenda was built around three scripts widely used in GMB workshops and described by Andersen & Richardson (1997) to elicit variables and causal relationships.

**Table 1:** Workshop general agenda

| Type of process | Agenda item | Time (min) | Description |
|---|---|---|---|
| Kick off | 1. Introduction | 15 | Round of introductions, presentations of the objectives for the workshop and overall agenda |
| Socialisation/externalisation | 2. Script 1: Variable elicitation process | 35 | Participants were asked about the three main outcomes of the system to achieve food security resilience. Outcomes were captured in the form of variables in a flip chart. |
| Combination | 3. Script 2: Structure elicitation process | 35 | Participants connected variables produced in the previous step by linking causes and effect with arrows. |
| | 4. Break | 15 | |
| Combination | 5. Script 3: Direct feedback loop elicitation | 30 | Participants were asked to find circular relationships between variables, for instance, virtuous circles. |
| | 6. Script 4: Capacity utilisation | 30 | Participants were asked to describe how different strategic resources were connected with each other. |
| Internalisation | 7. Wrap-up | 20 | Facilitator summarised the discussion held in the workshop and gave a quick overview of the CLD produced. |

*Note:* Details about the scripts used in the workshop can be found in Appendix 1.

The GMB workshop started with a description of the objectives for the day, introductions and an overview of the agenda to cover (agenda item 1 in Table 1). Then, the facilitator asked the participants to write down three key outcomes of the system that they relate to food security. Then, participants had to pick one of their three outcomes (the most important one) and share with the group while the facilitator wrote down the outcomes mentioned in a flip chart. The exercise was repeated one more time to elicit a second round of variables. When an outcome was mentioned more than one time, the facilitator acknowledged the contribution but did not add any extra mark in the flipchart (agenda item 2, in Table 1).

Then, the facilitator asked the participants to connect, if possible, the different variables mentioned so far. During the process, participants were invited to add intermediate variables if they were necessary to connect two of the variables previously mentioned to each other. The facilitator asked participants to take turns contributing to the exercise and asked all the participants to contribute at least twice during the exercise (agenda item 3, in Table 1).

After the break, the conversation focused on eliciting feedback loop structures. Feedback loops are circular connections that link a chain of variables (see Figure 4). While some feedback loops had already been identified during the structure elicitation process, the direct feedback loop elicitation (agenda item 5) and the capacity utilisation (agenda item 6) script (see Table 1) helped the group to focus on this type of causal relationship. More details regarding the workshop agenda and the scripts used can be found in Appendix 1.

The workshop concluded with a wrap-up in which the facilitator summarised the discussion held by the group and walked through all the loops included in the diagram (agenda item 7, in Table 1). After the workshop participants were asked to answer a short questionnaire regarding their impressions of the workshop. The latest was done using the same questions discussed during the first set of interviews. The questionnaire used can be found in Appendix 2.

## 4. CASE RESULTS

### *4.2 One-on-one interviews*

When engaging with representatives of each group, it quickly became apparent that participants held different perspectives of what the problem was, how the system works and even what the system is. For instance, delegates from the government stated that the purpose of the system was fostering economic wealth (see statement 1 in Table 2). Alternatively, delegates of the university and farmers focused on food production and how food production could support farmers and their families (see statements 13, 14 and 16 in Table 2).

**Table 2:** Selected statements provided by delegates during the interviews

| | |
|---|---|
| **Central Government** | |
| Q1 | (1) *"Increase farmers wealth through a competitive production system. Their* (farmers) *low competitiveness is the root of their poverty and hence the main cause of their vulnerability in the first place."* |
| | (2) *"We believe small-scale economies could be a sustainable source of revenues for farmers and their families."* |
| Q2 | (3) *"Productivity… and the government is engaged in providing a sustainable and plausible solution by providing the fertilisers they need for increasing their productivity and become more competitive…Once they (farmers) level up with the market, the food affordability should be a natural condition."* |
| | (4) "Enough purchase power to be able to afford a diverse and sufficient diet. You see… it is not only the quantity but also the quality of the diet. " |
| Q3 | (5) *"The problem is indeed the lack of technical knowledge and lack of competitiveness."* |
| | (6) *"We look for a sustainable solution to helping the farmers to become more productive and more competitive so that they do not depend on the government anymore."* |
| **NGO** | |
| Q1 | (7) "*The system needs to provide enough revenues for them* (farmers) *to go out of poverty and gain purchasing power to be resilient to new conditions."* |
| | (8) "*A robust source of revenues enough to support the farmers and their families."* |
| Q2 | (9) *"Sustainable yields backed by appropriate seeds and techniques. We need to make an effort to provide them with the right seeds and the proper instruction to use them well."* |
| | (10) *"Better and more efficient techniques. Like they have not formal education, you know that most of them cannot read, it is challenging to teach them and change their mind."* |
| Q3 | (11) *"Technology adoption; they* (farmers) *use the same techniques and seeds they have been used since pre-colonial times."* |
| | (12) *"Farmers cannot be blamed as they do not do it with that aim, but they are the ultimate responsible for the problem they currently face….Farmers need to understand that they need to move forward new techniques."* |
| **University** | |
| Q1 | (13) *"The purpose is to produce food. This is a small-scale subsystem and needs to produce enough food for the community."* |
| | (14) *"Feed the farmers and their families by sustainably generating enough revenues."* |
| Q2 | (15) *"Is about finding mechanisms that allow the farmers to feed themselves and their families even during bad* (dry) *years."* |
| | (16) *"Prevent starvation among vulnerable stakeholders despite the change in the weather conditions."* |
| Q3 | (17) *"Good management of soil and access to land are basic for agriculture; we do not deny it. However, the direct effect of climate change in the agriculture is the change in the amount of rain….Farmers are too poor to invest in the required infrastructure to solve the problem."* |
| | (18) *"Increase of land productivity through appropriate management of soil and water available."* |
| **Farmers** | |
| Q1 | (19) "*Food; having enough food all the year around."* |
| | (20) *"Producing maize."* |
| Q2 | (21) *"Is about having food even if the conditions were not good"* |
| | (22) *"Food all the time, we need to have enough maize to feed our families…in case there are droughts, we still need to have some food stored."* |
| Q3 | (23) *"The problem is you do not know if the yield is going to be good or not….now you never know….If the yield goes bad, we will lose the money we spent on seeds and fertilisers."* |
| | (24) *"The weather now cannot be predicted…you gamble every time you plant."* |

*Note:* Q1: What would you like to get from this system? Q2: In this context, what does resilience of food security to climate change mean? Q3: What are the critical success factors of policies enhancing food security?

The CLDs produced during this stage can also be used to illustrate these differences in more detail (see Figure 4). For instance, central government delegates focused on describing the system as a source for generating revenue in a virtuous circle (see Figure 4a). Farmers' productivity increases their incomes and, therefore, the wealth of the farmers. Higher wealth than increases farmers' capacity to use fertilisers (fertilisers are more affordable). Usage of fertilisers is directly related to productivity and, therefore, the more fertiliser the farmers use, the more productive they become in a virtuous cycle represented by the R1 feedback loop in Figure 4a. Interviewed representatives observed two external pressures affecting the system: drought and subsidies to fertilisers. While subsidies increase soil quality and overall improve incomes, drought hinders the system and reduces the overall productivity of the system.

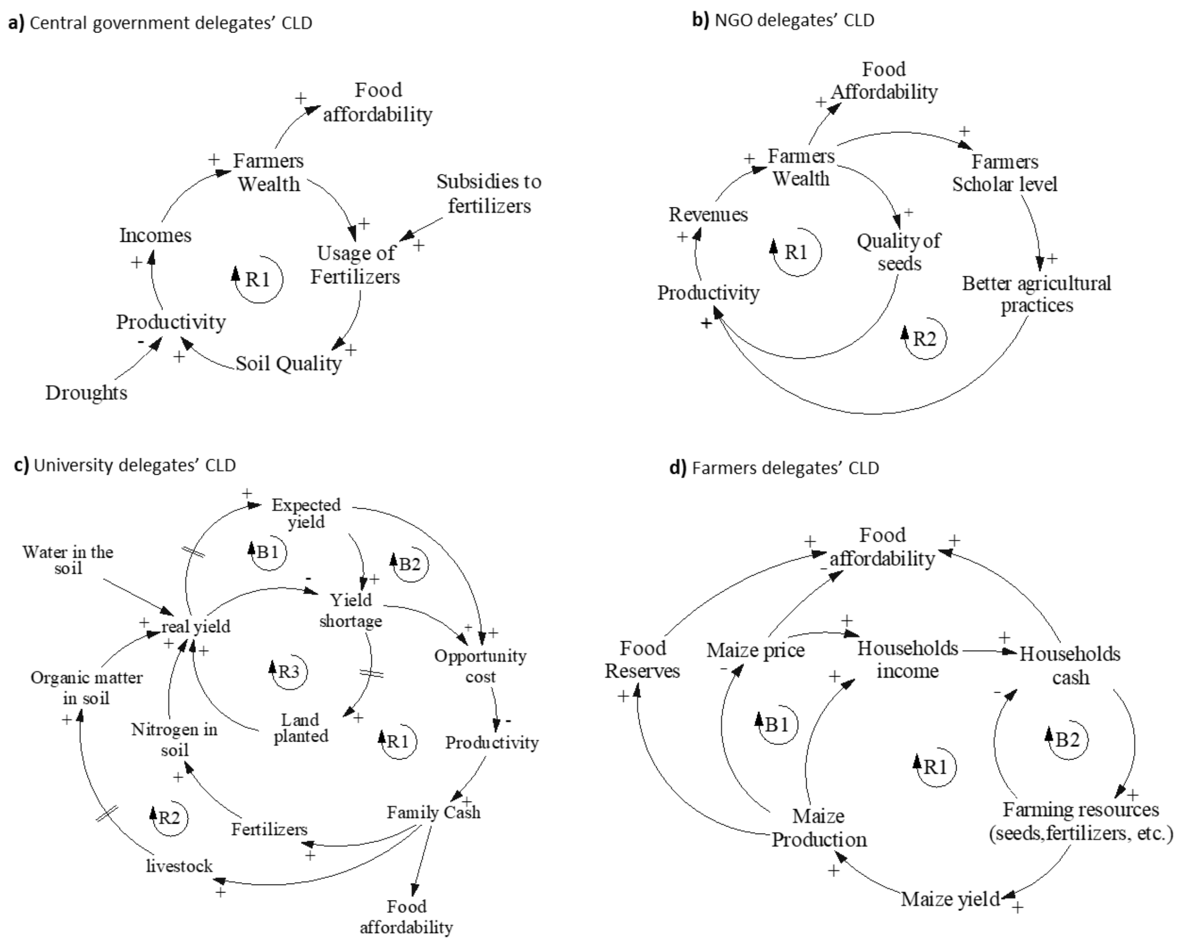


*Figure 4:* Causal loop diagrams developed together with delegates from stakeholders' groups in Huehuetenango in one-on-one interviews.

Alternatively, the system description provided by the farmers is less straightforward. The maize is, in their description, not only a commodity for trading but a source food by itself. (see Figure 4d) Higher production does not only lead to better incomes but also to higher reserves of food. Having food available means farmers need to purchase less food than otherwise, making the amount of food they require become more affordable. Additionally, the farmers identified two drawbacks from the feedback loop R1 praised by central government representatives. First, the acquisition of resources decreases a households' cash (see feedback loop B1 in Figure 4d) thereby reducing food affordability. Second, higher production will eventually translate into lower maize prices, reducing farmers' income and profit margins (see feedback loop B2 in Figure 4d).

The other two descriptions provided by representatives from the university and NGO lie somewhere between the two previously mentioned while introducing new concepts to the discussion. For instance, NGO representatives focused on the importance of having seeds of improved varieties, less water-demanding seeds, for increasing crop productivity. Better seeds increase wealth in the virtuous cycle represented by R1 in Figure 4b. NGO representative also identified a longer-term link between a farmer's wealth, education and productivity. Access to formal education is assumed to be associated with better agricultural practices (e.g., appropriate usage of fertilisers and land planning). Better agricultural practices increase revenues and wealth in the virtuous cycle represented by R2 in Figure 4b.

Representatives from the university identified the role of livestock as a source of organic matter in maintaining and improving soil quality. The representatives of the university are also the only stakeholders identifying the role of expectations and opportunity costs in the land planted each year. Higher yield shortage also translates into a reduction of the land planted each season (see R3 in Figure 4c), because farmers need to spend more time on other activities (e.g., working on coffee plantations) and less time farming. The expected yield eventually is adjusted, decreasing the yield shortage and opportunity costs (see loops B1 and B2 in Figure 4c.). The increase in drought occurrence increases the yield shortage by affecting the maize system and its real yield, reducing at the same time the land planted and the cash available for the next season's harvest.

### *4.2 GMB workshop*

The variables mentioned in the first round of variable elicitation are listed in Figure 5a. During the workshop, variables were not written on the whiteboard in a specific order (see Figure 6a). However, for this chapter, and using the notes from the recorder, those provided by delegates from the same stakeholder group are grouped in Figure 5b. Note that the perspective voiced by delegates from each group is recognisable in the variables listed by the participants from the same stakeholder group.

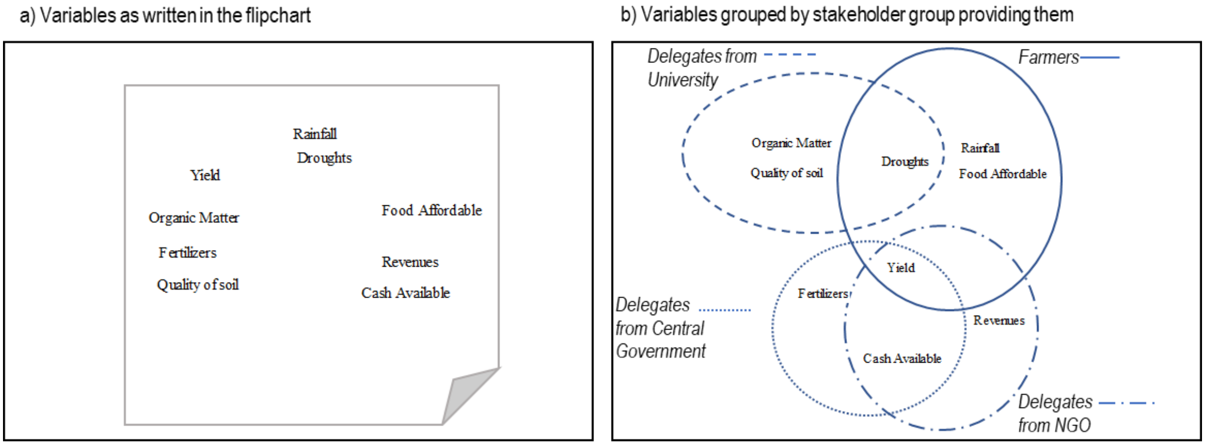


*Figure 5:* The results of the first round of variable elicitation a) variables as written on the whiteboard and b) variables grouped by the stakeholder group providing them.

The elicitation process was followed by the structure elicitation process (point 3 of the agenda in Table 1). In this case, it was noticed that farmers had problems contributing to the exercise. To alleviate this, the facilitator asked them to do it as experience-based detailed descriptions (or "stories") of "what would occur with this variable if…". The participation of the farmers increased following this suggestion.

As the whiteboard was populated with variables and arrows connecting them, the contributions came in a more agile way. While the facilitator prepared a direct feedback loop elicitation script, the participants naturally began to identify feedback loop structures, such as those they identified prior during the one-on-one interviews with the help of the first author. Figure 6 shows how participants connected variables during the structure elicitation script. Note that the variables provided by different stakeholder groups were linked together to form feedback loops such as that among "*yield*", "*cash available*", "*livestock*" and "*organic matter*".

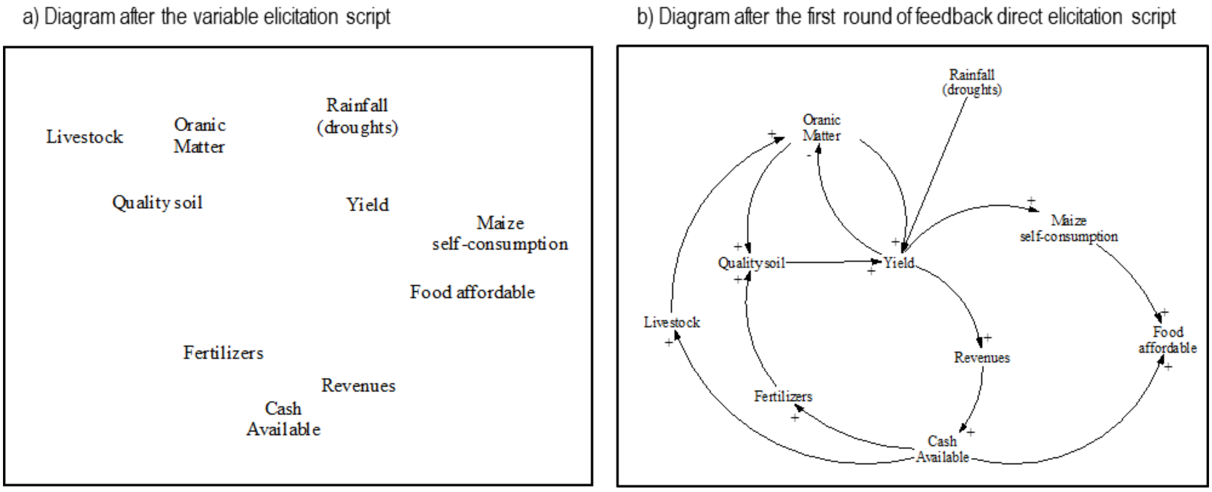


*Figure 6:* Intermediate CLD diagrams jointly developed with stakeholders from Huehuetenango after a) variable elicitation script and b) the first round of feedback direct elicitation script.

Moreover, the capacity utilisation script proved also to be useful to identify loops between strategic resources like "water in the reservoirs" and the "planted land" (see Figure 7). During the capacity utilisation script, participants alternated between divergent and convergent thinking since they have to build loops using the variables. In this case divergent activities included for instance to think creatively about what variables were needed to complete the causal relationships between important elements of the systems. Alternatively, convergent thinking was used to keep participant focus on closing the loop and find connections with the variables already in the diagram.

The final CLD produced during the workshop is shown in Figure 8, the nickname of the feedback loops (e.g. R1) was added later on by the first author when transcribing the results of the workshop. Note the nicknames in the diagrams shown in Figures 4, and 9 are consistent and identify the same feedback loop. Feedback loops didn't mention during the interviews but identified in the workshop are shown in italic in Figure 7. These additional feedback loops identified during the GMB workshop help to improve the description of the system by a) introducing elements important elements to consider for the enhancement of resilience of food affordability and b) recognising constraints of the system.

Moreover, the capacity utilisation script also proved to be useful in identifying loops between strategic resources such as "water in the reservoirs" and the "planted land" (see Figure 7). During the capacity utilisation script, participants alternated between divergent and convergent thinking as they had to build loops using the variables. In this case, divergent activities included for instance to think creatively about what variables were needed to complete the causal relationships between important elements of the systems. Alternatively, convergent thinking was used to maintain participant focus on closing the loop and finding connections among the variables already in the diagram.

The final CLD produced during the workshop is shown in Figure 8, the nicknames of the feedback loops (e.g., R1) were added later by the first author when transcribing the results of the workshop. Note the nicknames in the diagrams shown in Figures 4 and 9 are consistent and identify the same feedback loop. Feedback loops not mentioned during the interviews but identified in the workshop are shown in italics in Figure 7. These additional feedback loops identified during the GMB workshop helped to improve the description of the system by a) introducing elements important elements to consider for the enhancement of resilience of food affordability and b) recognising constraints of the system.

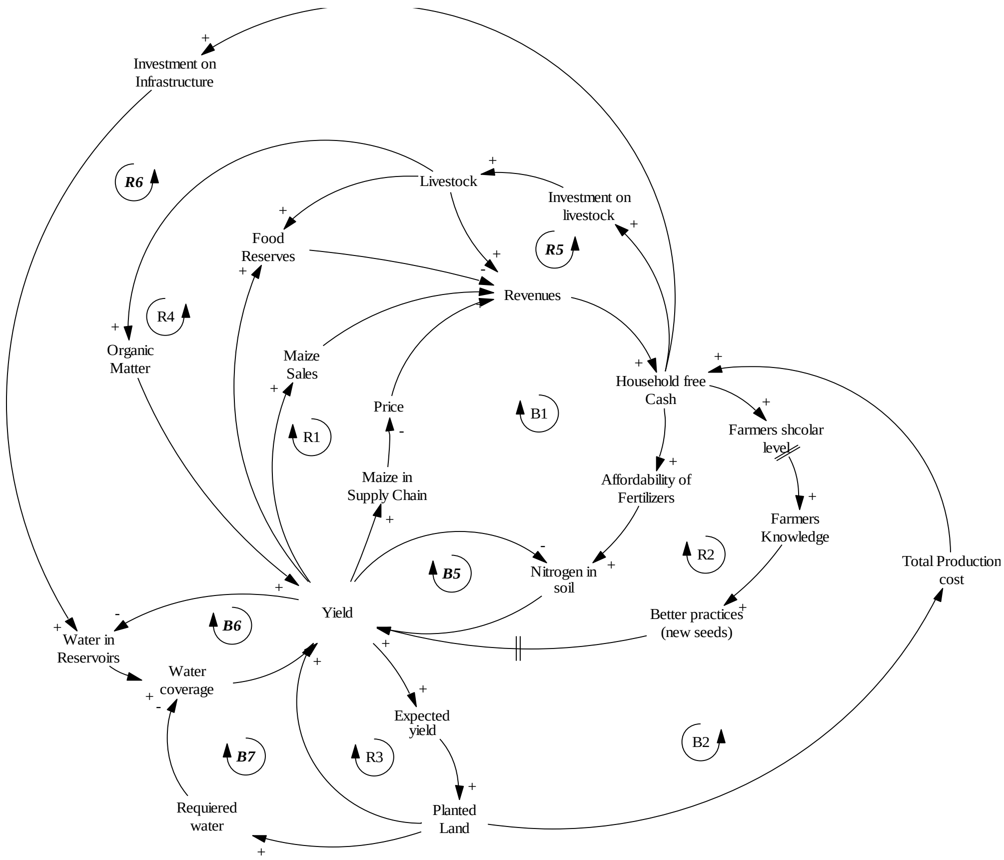


*Figure 7:* Causal loop diagrams developed by stakeholder groups of Huehuetenango during the GMB workshop.

The additional loops include loops B5, B6 and B7 representing natural constraints of the system (water availability, land and nitrogen in soil). These new loops in the diagram explicitly describe the systems' limited carrying capacity, meaning the limited amount of yield and planted land that can be achieved within the geographical boundaries of the system.

It was only in the GMB workshop when these dynamics slowing down the shifts in system behaviour were explicitly mentioned. These constraints are important because they define to what extent productivity and revenue from agriculture can be increased.

The other additional loops mentioned were loops R5 and R6 describing mechanisms reinforcing revenue growth. The loop R5 describes the potential role of livestock production in the system as an additional source of revenue. While this loop has little importance in the current system, it was discussed as an alternative for agriculture dependence. Similarly, the loop R6 describes how revenues translate into better production resources, particularly better irrigation systems that might eventually result in higher yields and revenues. Irrigation systems and their role in a drier future was also an important topic of debate among stakeholders who recognised them as a potential means for increasing resilience to drought.

## 5. TOGETHER, WE THINK DIFFERENTLY

Based on the results previously presented, we theorise that GMB helps the group obtain a more robust understanding of the system during the PSP. The development of a holistic understanding is appreciated in the evolution of the diagram built by the group. During the interviews, representatives focused their descriptions on specific parts of the system and their interpretation of how the system works and what resilience means. In the participatory process, these perspectives meet each other in a mediated forum that steers participants towards understanding and connecting these perspectives rather than arguing about which one best represents the real world. During this process of “connecting the dots” participants do not only learn about other theories of system behaviour but also build new theories by adding new relationships or new variables previously not stated in their individual mental models.

Individual CLDs and initial variable elicitation show that stakeholder groups share their understanding of the system and how it works. Their interpretation of what needs to be resilient varies. For instance, the central government sees food security resilience as an expression of economic wealth and farmers see it as a practical matter of having sufficient food.

The GMB process started by externalising these assumptions and mental models through the elicitation process. During variable elicitation, participants are asked to formalise (in written form) what are, according to their criteria, the key outcomes that drive resilience. Formalizing their goal in specific outcomes is the first step to externalise the mental model each participant holds of the system. Nonetheless, because delegates are limited, at this point, the number of outcomes (or variables) each can provide is as well, and the list of variables does not fully represent any of their mental models.

Then, during the structure elicitation script, the delegates are instructed to seek relationships among the available variables and connections between outcomes provided by different stakeholders' groups started to appear quickly. From this point onwards, the diagram is owned by the group and the workshop delegates sorted, categorised and combined various elements from their mental models to produce coherent explanations regarding how the system worked. Figures 7b and 8 show the diagram at the end of this process. The final diagram in Figure 8 and comments provided by the delegates in questionnaires and the wrap-up reflect how delegates from different groups managed to combine their interpretations into a single theory and learned from each other during the process.

There are at least two indications of a learning process occurring during the GMB process. First, the CLD produced integrated all the main loops described during the interviews (compare Figures 5 and 8). However, these feedback loops are not isolated such as in the different diagram in Figure 5, but they are linked into a single network of causal relationships. Second, new feedback loops resulted from integrating these different structures. For instance, the farmers noticed that livestock mentioned by the representatives from the university as a source of organic matter was an important resource generating both revenues and food reserves. Because most of the livestock held by small-scale farmers is poultry, they receive some revenue from selling eggs to neighbours (see R5 in Figure 8). Meat and poultry are not a normal part of the local diet, but eggs are commonly consumed and constitute an additional food reserve.

It is also interesting that three out of the five new feedback loops identified were balancing loops. Feedback loops B5, B6 and B7 describe resource constraints in the system that have been left out of prior analysis. For instance, higher yields increase expectations among farmers and are linked to more land planted every year (see R3 Figure 8). However, more land planted requires more water and, with water in reservoirs remaining the same, this will mean lower yield per area (see B7 Figure 8). Hence, the continuous increase in yield and wealth described by R1 in Figures 5 and 8 is constrained by the amount of water in the system.

Additional evidence can be found in the statements provided by the participants in the questionnaires at the end of the workshop. When asked about the main contribution of the workshop to the process, participants replied as follows:

> "We got to hear other perspectives about the micro-systems operating in the region" (Delegate Central Government)
>
> "We could express our points about the scarcity of food" (Farmer)
>
> "The diagram, show connections between different parts of the problem and the solutions" (Delegate from an NGO)

The benefits of the learning process facilitated by the GMB workshop to the PSP of resilience are twofold. First, as more elements and perspectives from the same systems are incorporated into the scope of analysis, there are higher chances to identify unintended consequences. As different scales of the system merge into one, underestimated links appear between elements previously disconnected. For instance, the loop connecting small-scale livestock production and potential revenue (R5 in Figure 6a) is a result of linking the household production system with the local market. Therefore, just by bringing different perspectives together to the PSP it is possible to obtain a wider understanding of how the system works. This wider more comprehensive understanding of the system reflected in more complex CLDs is of particular importance in the resilience analysis as unexpected problems might arise from the interactions between small- and large-scale systems when affected by a disturbance, sometimes separated by long time delays

The second benefit is the refinement of explicit knowledge in the form of theories using first-hand experiences from those in the system. For instance, in both cases, the decision-making acknowledged the way farmers make real decisions in an environment of uncertainty and sometimes ignorance of what will occur in the future. Contrary to the well-informed decision-making process initially described by some of the stakeholders (see for example the central government CLD in Figure 3) farmers rarely have enough and appropriate information to make good decisions regarding the allocation of their resources. During the workshops, it became evident that farmers were overwhelmed by uncertainty and did not feel in control of the system and the outcomes. During the workshop, the farmers often repeated "si Dios quiere" (if God wants it) or "Dios mediante" (through God) when talking about the effect of resources on the outcomes. Underestimating farmers' own decision rules and own means to allocate resources might result in policy inefficacy, wasting of resources and unintended consequences.

Finally, it is important to remark that a key element of the learning process previously described is the facilitator in their role of neutral architect of the diagram. During the GMB process, the diagram is not owned by an individual or by a group of participants but by the whole group. The facilitator manages the diagram on behalf of the group by equally representing all the perspectives voiced. In this way, by preventing any idea to be discarded during an early stage, the facilitator prevents the group committing to a specific explanation or representation of the system. In contrast, by including all perspectives it increases the boundaries of the system to study and foster learning among participants by encouraging them to find the links between their perspectives and those held by the others. As shown in both cases, the total is more than the sum of the parts.

## 6. CONCLUDING REMARKS

The analysis and management of resilience in SES are challenged by the complexity of their adaptive mechanisms to the uncertainty of the environment and the openness of the resilience concept itself. In such conditions, it is important to recognise that while an optimal solution might not be possible due to the plurality of perspectives, goals and values, it is important to gain a robust understanding of the system for underpinning decisions regarding how to increase its adaptability. To generate a more robust understanding of the system resilience advocates for combining many different types of knowledge in structuring the problem as well as finding and implementing solutions.

Broad participation is often recognised as a way to integrate knowledge and generate learning. Nonetheless, participation by itself rarely results in such outcomes but at least it is carefully managed and designed with this purpose. Our experience using GMB in the problem structuring of resilience shows that this type of approach offers an ideal framework for including different stakeholders in the discussion. During the process participants learn about each other and become aware of the existence of different agendas and perceptions among the stakeholder groups.

The experience previously described indicates that the presence of a neutral facilitator and the use of a jointly built diagram, two of the key elements of any FMM, help those participating in the process to gain a more robust and holistic understanding of the system and increase awareness of the existence of different agendas and perceptions in the group. First, the facilitator set a process where all participants have the same opportunities to voice their perspectives and interpretations of the problem and the system. This prevents the conversation to be steered in a particular direction and brings different, sometimes competing, concepts to the table. Then, the task of building a joint diagram combining and connecting these concepts encourages participants to recognise how different outcomes are linked and to identify the links and overlap among the various explanations. The result is a single joint explanation, wider and more robust than those initially held by individuals.

More research is needed to validate and better understand the results discussed in this chapter. For example, further research is required to validate the positive link between FMM and learning and to identify what particular conditions during the facilitated modelling process are driving knowledge creation. While our results are bound to be exploratory, we think they suggest that the analysis of and planning for resilience in SES might benefit from using FMM. Having an operational framework for managing participation is a key enabler for unlocking the potential of resilience in the policymaking world, and FMM seems to offer a perfect starting point to develop a formal approach to a participatory analysis of resilience.

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# Interlude B

# Operationalising resilience in public sector settings

The previous chapters described the details about how to engage with stakeholders to foster consensus what resilience means and to gain a more robust understanding of the system. As pointed in the previous chapters stakeholder engagement is a cornerstone to construct robust plans but also a fundamental for improving chances for their successful implementation.

The next two chapter takes a closer look at these plans and discuss some of the complications faced when trying to conceptualise abstract concepts of resilience. The lack of quantitative and operational measures and links between adaptive concepts and the real-world process is a significant complication for policymakers in the public sector. The next two chapter discuss these complications and shed light on potential ways to tackle them by answering the research questions:

- **How can resilience be measured?**
- **How does resilience link to policymaking in the public sector?**

# Chapter 4

# From metaphor to practice, operationalising the analysis of resilience using system dynamics modelling[2]

**Keywords:** system dynamics, resilience, social-ecological systems

**Abstract:** This chapter operationalises an analysis of resilience for social-ecological systems (SESs) using system dynamics (SD) modelling. Resilience is a versatile concept that continues to gain popularity among researchers who study ways to reduce the vulnerability of SESs to a wide range of disturbances. However, its application in the policymaking domain still remains underdeveloped because it is difficult to understand the mechanisms that might enhance resilience and to measure the impact of potential policies. This chapter proposes to use SD modelling as a tool to analyse resilience using simulations to quantify system response to disturbances and a causal analysis to identify ways to influence this response. With this aim, this chapter proposes a set of fundamental characteristics of resilient responses and describes how to measure them using the results produced by SD models.

## 1. INTRODUCTION

The term 'resilience' has gained increasing popularity in research, policymaking and risk reduction (Bahadur, Ibrahim & Tanner, 2010). While there is broad agreement about what resilience means, the concept of resilience exists in many different disciplines, with different interpretations depending on the context and application (Gunderson, 2000). Additionally, there is no clear way to analyse and estimate a system's resilience, making it difficult to

[2] Apart from several minor adaptations, this chapter is a direct copy of the article: Herrera, H. (2017). From Metaphor to Practice: Operationalizing the Analysis of Resilience Using System Dynamics Modelling. *Systems Research and Behavioral Science*, *34*(4), 444–462

apply resilience in the policymaking domain (Todman et al., 2016). The difficulties in applying and operationalising the concepts described in the literature have raised criticism (Duit, 2015, Cote & Nightingale, 2012).

The two paradigms describing resilience that are widely accepted in the literature are engineering resilience and ecological resilience. The engineering paradigm defines resilience as the rate at which a system returns to equilibrium after a disturbance (Pimm, 1984). The ecological paradigm defines resilience as a measure of the amount of disturbance or stress required to transform a system while "keeping its essential function" (Folke, 2006, p. 253).

While resilience theory is becoming increasingly more sophisticated (Bennett, Cumming & Peterson, 2005; Holling & Gunderson, 2002), practical applications of resilience remain underdeveloped to a great extent (Bernnett, 2005; Chapin, Kofinas & Folke, 2009; Duit et al., 2010; Folke, 2006). The reasons for this have been explored in different fields, casting doubt and raising criticism regarding the extent to which resilience can be applied. The following are three important critiques in the contemporary environmental governance literature of the complications of applying resilience in practical settings: the lack of quantification and measures for resilience; the alienation of resilience theories from the policymaking world (Arnaboldi, Lapsley & Steccolini, 2015; Duit, 2015); and resilience simplification, that is, that there is only a rudimentary understanding of the political processes (Eriksen, Nightingale & Eakin, 2015). This chapter focuses on the first critique, the lack of quantification and measures for resilience. Regarding that critique, Marshall and Marshall (2007) offered a detailed survey of the issues. The following diagnosis is based closely on their analysis and their sources. Although the literature on resilience yields insight about its characteristics (e.g., Berkers, Colding & Folke, 2002; Chapin et al., 2009; Walker et al., 2006; 2004), many gaps remain regarding what resilience means in terms of specific variables and how resilience can be measured (Bennett et al., 2005; Cumming et al., 2005). These gaps are result largely from the fact that resilience involves many different elements which are dynamically interrelated (Berkers & Folke, 1998; Kallstrom & Ljung, 2005; Walker et al., 2002). Even in theory, it is hard to identify clearly the thresholds between different states of a system due to: the wide network of relationships between its elements; the delays between the actions taken and the observed effects (Berkes & Jolly, 2002). This complex nature of resilience makes it difficult to properly define and measure the concept and this hampers its application in management and policymaking settings (Olsson, Folke & Hahn, 2004; Walker & Meyers, 2004).

This chapter contributes to closing this gap by proposing to operationalise the analysis of resilience by using system dynamics (SD) modelling to simulate, analyse and measure resilience characteristics of a system's response to a disturbance. The chapter starts by identifying and discussing key characteristics of a resilient response to a disturbance and describing measures to quantify these characteristics. Next, the chapter discusses how the SD modelling process can be used to analyse the structures driving the system response to a given disturbance and to simulate the effects of policies to enhance the system's resilience. The rapid increase and subsequent decay of the Kaibab deer population at the beginning of the 20$^{th}$ century illustrate how the analysis is outlined and the use of the measures proposed in this chapter.

## 2. OPERATIONALISING THE ANALYSIS OF RESILIENCE

Extending the application of resilience in the policymaking process requires operationalising the analysis of resilience. Operationalising (i.e., defining indirect measures of) resilience, however, is challenging because social-ecological systems (SESs) are complex and nonlinear and exhibit behaviours far from equilibrium (Berkers & Folke, 1998; Levin et al., 1998). The behaviour of SESs is characterised by an underlying causal structure of accumulation processes that are interrelated by way of nonlinear feedback structures. These structures, made of interconnected variables that operate at different time scales, represent a challenging complex and dynamic context for the assessment of SES resilience (Walker et al., 2006).

With the aim to operationalise resilience in a complex and dynamic context, this chapter uses SD modelling. SD modelling is a computer simulation modelling technique focused on the understanding of the effects of feedback loop relationships and delays (Richardson, 2011) in the observable behaviour of complex systems. In the context of resilience, SD modelling can be used to simulate system responses to disturbances and as a tool for analysing the causal structures driving those responses.

## 3. QUANTIFYING AND MEASURING RESILIENCE FROM THE SIMULATED BEHAVIOUR

When two different food systems (i.e., system 1 and system 2) are affected by the same disturbance (σ) in the time t+2, their outcome function F(x) (e.g., food produced) behaves as shown in Figure 1. Which behaviour is more resilient? Arguably, the answer will depend on the way we measure resilience, and there is not one generalised way to do measure it (Frankenberger & Nelson, 2013). Because resilience itself is hard to measure, the alternative is to measure "attributes of systems that are related to the resilience of the system and are measurable" (Bennett et al., 2005, p. 946). Henry and Emmanuel Ramirez-Marquez (2012) proposed to measure resilience in terms of the behaviour of the desired outcomes provided by the system. These outcomes could be food, housing or safety and can be represented by a "quantifiable and time dependent" outcome function F(x) (Barker, Ramirez-Marquez & Rocco, 2013; Henry & Emmanuel Ramirez-Marquez, 2012).

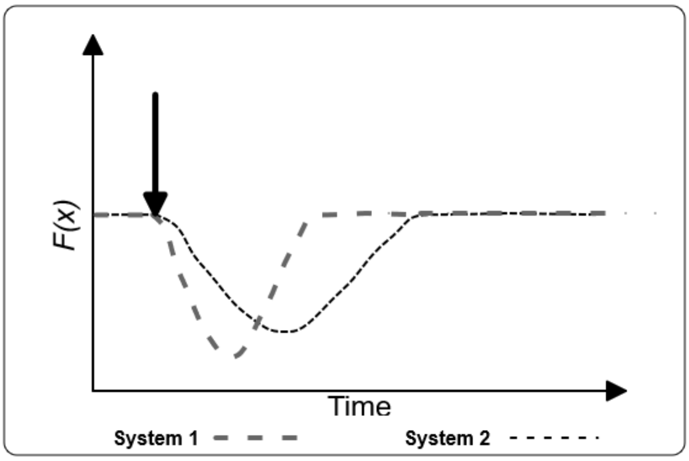



*Figure 1:* Comparison of two hypothetical responses (1 and 2) of two food systems with outcome function F(x) to a disturbance σ.

Rather than define a single way to measure resilience, this chapter proposes focusing on five characteristics of the system response that can be measured from the behaviour of the outcome function *F(x)* when the system is shocked by a disturbance σ. While many other characteristics might be found in the literature (Hosseini, Barker & Ramirez-Marquez, 2016; Tendall et al., 2015), these five characteristics have been selected because they can be directly measured using the simulated behaviour of F(x), and they address the fundamental elements described in both the engineering and ecological paradigms.

The engineering resilience paradigm bases its assessment on system equilibrium (Pimm, 1984). Engineering resilience is a measure of the system's ability to maintain system equilibrium after a perturbation, the rate at which the system recovers and the degree to which such perturbation deviates the system from equilibrium (Folke et al., 2004). The following are the formal definitions of the measures used in this chapter to assess engineering resilience:

- Hardness($\sigma_H$): the ability of the system to withstand a disturbance σ without presenting a change in the performance of the outcome function F(x). The bigger the value of hardness, the bigger the disturbance needed to produce any change in the observed behaviour.
- Recover rapidity ($\bar{R}$): the average rate at which a system returns to equilibrium after a disturbance σ (Martin, Deffuant & Calabrese, 2011; Pimm, 1984). The bigger the $\bar{R}$, the faster the system recovers after the disturbance.
- Robustness ($\bar{\rho}$): the system's ability to withstand big disturbances σ without significant loss of performance (Attoh-Okine, Cooper & Mensah, 2009). The more robust the behaviour, the smaller is the change produced by the same disturbance.

Alternatively, ecological resilience literature assumes that a system can exist in alternative self-organised states (Holling 1973). The approach to assessing resilience using the ecological paradigm is to estimate the potential drivers and disturbances that can change the behaviour of the system from being driven by one set of structures and processes to another set (Scheffer et al. 2001). This chapter proposes the following two measures to assess ecological resilience: a) the amount of disturbance needed to move the behaviour of the system from one stable state to a different one and b) the likelihood of this to happen. These two measures of ecological resilience are formally described as:

- Elasticity ($\sigma_E$): the ability of the system to withstand a disturbance σ without changing to a different steady state (Holling, 1996; Holling & Gunderson, 2002). The more elastic the system, "the larger the disturbance it can absorb without shifting into an alternate regime" (Walker et al., 2006 p.13).
- Index of Resilience ($I_R$): the probability of keeping the current steady state or regime (Holling, 1996; Holling & Gunderson, 2002; Martin et al., 2011). The higher the $I_R$, the smaller is the probability that the system will change from one state to a different one.

Next, how to estimate these measures using the behaviour of F(x) simulated with an SD model is described. The following are the main parameters needed to quantify the resilience characteristics:

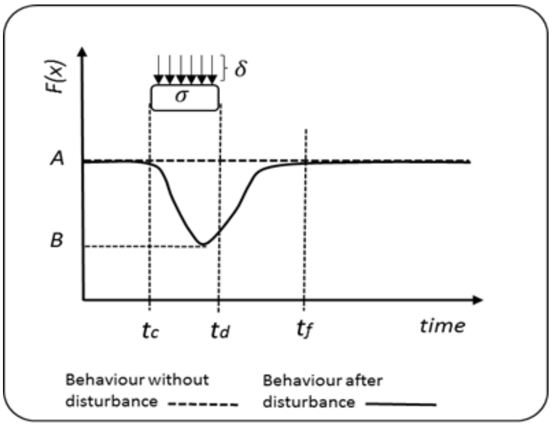
δ: magnitude of disturbance

$t_c$: time when the disturbance starts to affect the system

$t_d$: time when the disturbance stops

$t_f$: time when the system fully recovers

These parameters can be measured from the simulated behaviour of the outcome F(x) as illustrated in Figure 2. As illustrated in the figure, the disturbance σ is calculated as the product of the magnitude of disturbance δ and the duration of the disturbance ($t_d - t_c$) (see Equation 1).




A: outcome function value *F(x)* of the system without the disturbance.

B: outcome function value *F(x)* of the system when affected by disturbance.

$$\sigma = \delta \times (t_d - t_c) \qquad \text{(Equation 1)}$$

*Note:* δ: magnitude of disturbance, $t_c$: time when the disturbance starts to affect the system, $t_d$: time when the disturbance stops, $t_f$: time when the system fully recovers, σ: disturbance affecting the system

*Figure 2:* Hypothetical response of the system to a disturbance σ with magnitude δ and duration ($t_d$ - $t_c$)

The measures of resilience are calculated using the behaviour (produced) by a previously calibrated and validated SD model. The model allows simulating the system response to different disturbances. To test different disturbances affecting the system, Monte Carlo simulations can be used to test a range of plausible disturbance magnitudes (δ) and durations ($t_d$ - $t_c$) following a particular probability density function (PDF). In addition, these parameters in the model can be changed manually. In cases where the parameters are changed manually, it is assumed there is the same probability of occurrence for all disturbance parameters tested. Independent of the method used to adjust the parameters, the measures can be calculated as follows:

a) Identify the outcome function F(x) and disturbance σ affecting it.

b) Start with the model representing the current behaviour of the outcome function $F(x)^0$. This behaviour might be in equilibrium or might exhibit a pattern as shown in Figure 3a.

c) Adjust the disturbance σ manually by increasing its magnitude δ while keeping $t_d$ and $t_c$ constant or use Monte Carlo simulations with appropriate PDFs for δ, $t_d$ and $t_c$. The smallest disturbance σ that produces a different outcome function $F(x)^H$ (see Figure 3b) represents the hardness of the system and can be calculated as:

$$\boldsymbol{Hardness}\ (\sigma_H) = \delta_H \times (t_d - t_c) \qquad \text{(Equation 2)}$$

d) Continue increasing δ, keeping $t_d$ and $t_c$ constant, until the behaviour does not bounce back ($F(x)^E$ in Figure 3c) and until the disturbance ceases to its original trend. Record the values of δ, A, B, $t_f$ and $t_d$ for each iteration and calculate the recovery rapidity for each δ as:

$$\boldsymbol{Recovery\ Rapidity} \quad (\bar{R}) = \frac{A-B}{t_f - t_d} \qquad \text{(Equation 3)}$$

$$\boldsymbol{Robustness}\ (\bar{\rho}) = \frac{\sigma}{A-B} \qquad \text{(Equation 4)}$$

Calculate the average $\bar{R}$ and $\bar{\rho}$ using a) an arithmetic average (Equation 5) if δ was adjusted manually or b) a weighted average (Equation 6) if Monte Carlo simulations were used, where the probabilities of each disturbance *P*(σ) act as the relative weight:

$$Aritmethic\ average = \frac{a_0 + a_1 + \ldots + a_n}{n} \qquad \text{(Equation 5)}$$

$$Weighted\ average = \frac{a_0 P(\sigma)_0 + a_1 P(\sigma)_1 + \cdots + a_n P(\sigma)_n}{n \sum_{i=0}^{n} P(\sigma)_x} \qquad \text{(Equation 6)}$$

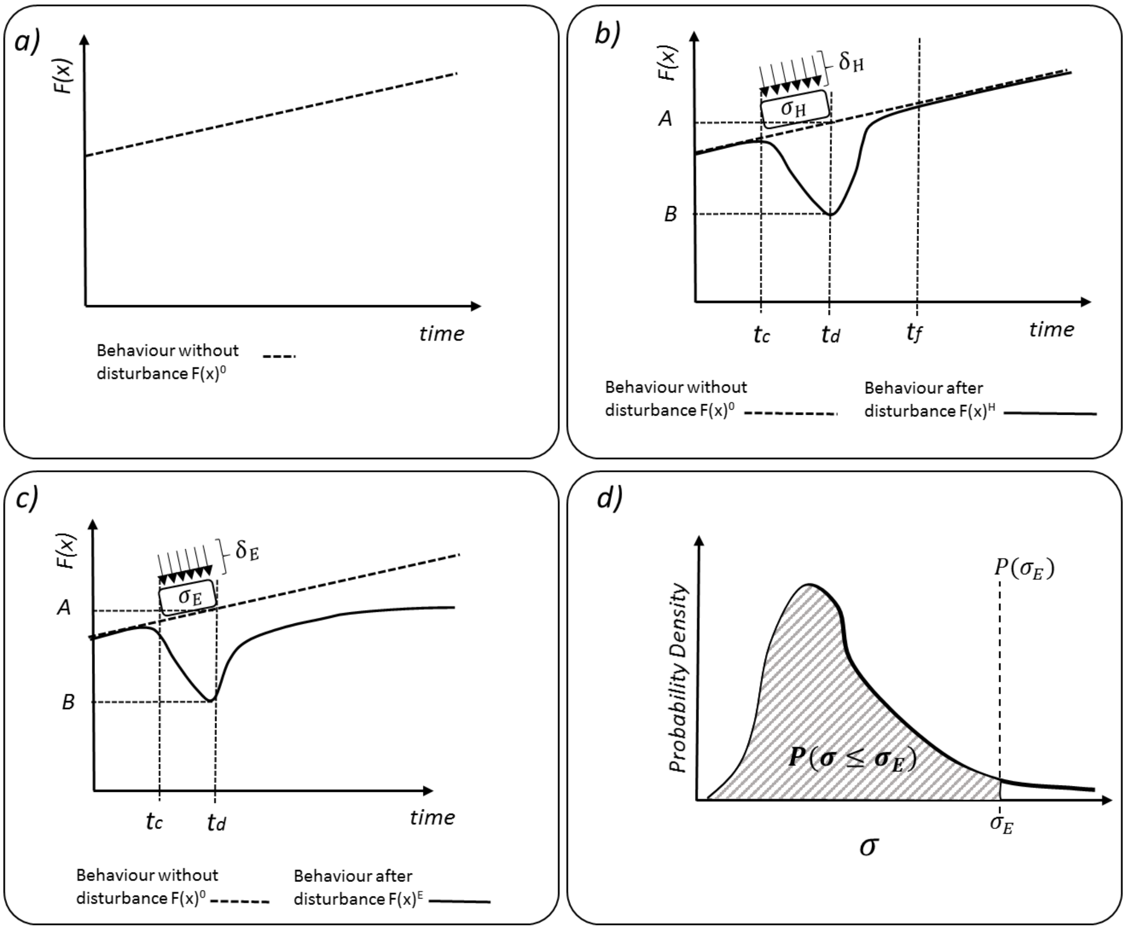
e) Calculate the disturbance σ that produces $F(x)^E$ (the amount of disturbance necessary to move the system to a different equilibrium) as:

$$\boldsymbol{Elasticity}\ (\sigma_E) = \delta_E \times (t_d - t_c) \qquad \text{(Equation 7)}$$

f) Calculate the index of resilience $I_R$ as:

$$\boldsymbol{Resilience\ Index}\ (I_R) = P(\sigma \leq \sigma_E) \qquad \text{(Equation 8)}$$

The probability of the disturbance being smaller than $\sigma_E$, $P(\sigma \leq \sigma_E)$ can be obtained from the PDF resulting from the Monte Carlo simulations by calculating the areas underneath the curve (i.e., the shaded area in Figure 3d). If the disturbance σ was adjusted manually, the probability of the disturbance being smaller than $\sigma_E$, $P(\sigma \leq \sigma_E)$ can be calculated as the proportion disturbance σ that is smaller than $\sigma_E$ out of the total of plausible disturbances.




*Note: δ:* magnitude of disturbance, $t_c$: time when the disturbance starts to affect the system, $t_d$: time when the disturbance stops, $t_f$: time when the system fully recovers, σ: disturbance affecting the system

*Figure 3:* a) Hypothetical behaviour of the outcome function when the system is not affected by any disturbance $F(x)^0$, b) Hypothetical behaviour of the outcome function when the system is affected by a disturbance $\sigma_H$ big enough to produce a change in the observed behaviour $F(x)^H$, c) Hypothetical behaviour of the outcome function when the system is affected by a disturbance $\sigma_E$ so big that the system moves to a different state $F(x)^E$ and never bounces back to $F(x)^0$ and d) Probability density of the disturbance σ produced using Monte Carlo simulations

### *3.1 Modelling process in the context of resilience*

The SD modelling process includes the following five main steps: i) conceptualisation, ii) dynamic hypothesis, iii) formulation, iv) testing and v) policy design and evaluation (Sterman, 2000). These steps, with some additions proposed in the SES literature (e.g., Bennett et al., 2005; Cumming et al., 2005), constitute an ideal framework to support an operational analysis of systems' resilience and to identify potential policies to increase it. Figure 4 shows the SD modelling process tailored for use in the resilience analysis.

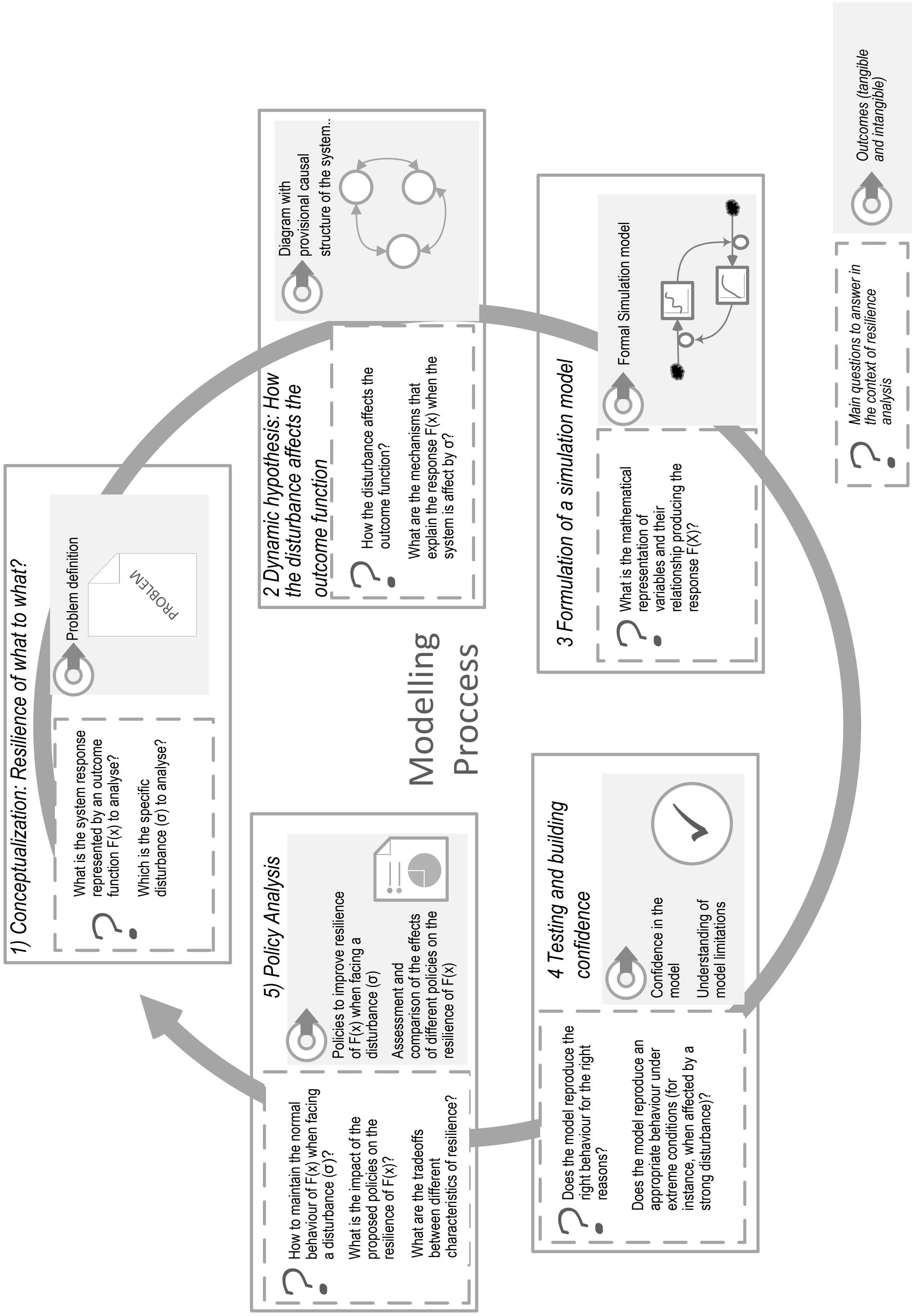



*Figure 4:* System dynamics modelling process tailored for the analysis of resilience.

Of the steps shown in Figure 4, the policy analysis is particularly interesting in this chapter due to the prescriptive nature of the resilience analysis. The policy analysis can be divided in the following two iterative processes: a) measuring system resilience and b) analysing system structure. First, is needed to simulate and measure outcome function F(x) resilience to the disturbance identified during the conceptualisation step for the current configuration of the system. Next, the system structure is analysed to identify the means to enhance the resilience of this response through the introduction of policies. The expected effect of those policies in the system response is then measured again, and before and after results can be compared. Policy effectiveness can be assessed in terms of the policy contributions to foster specific characteristics of resilience in the system's response. Thus, the policy formulation is an iterative process, as illustrated in Figure 5.

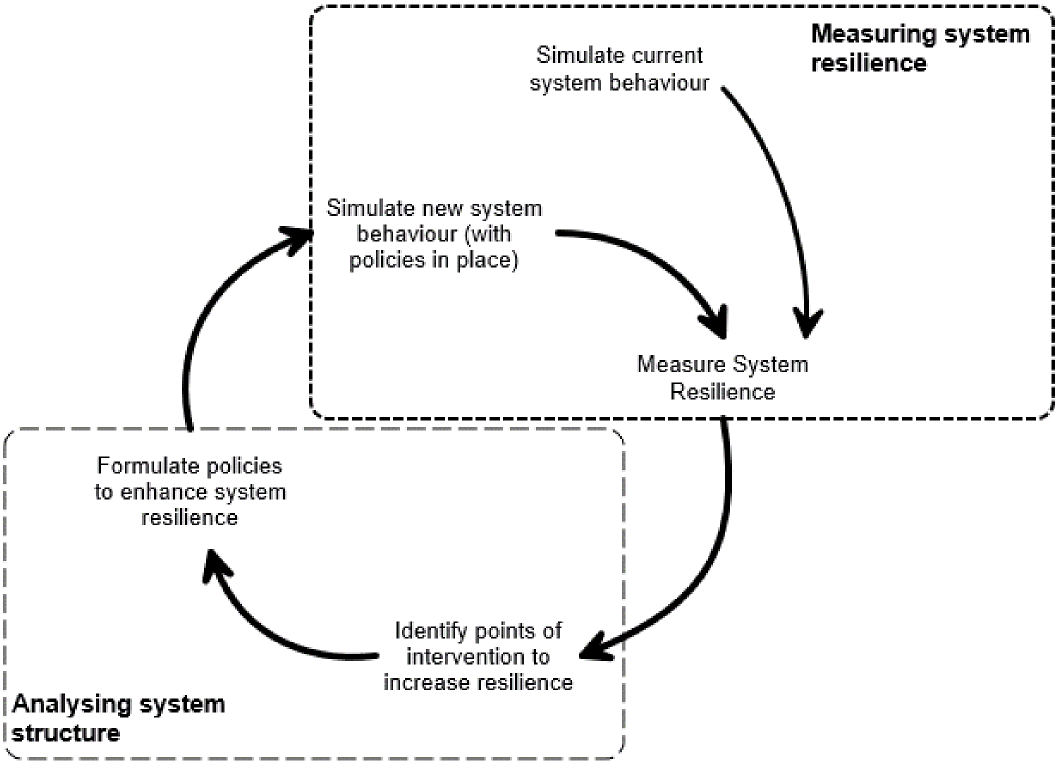



*Figure 5:* Iterative process for policy analysis in the context of resilience

By analysing the system structure, it is possible to identify the mechanisms that currently contribute to or can potentially contribute to enhancing resilience by maintaining the behaviour of $F(x)$ when facing the disturbance σ of concern or by improving its ability to recover after the disturbance ceases. The analysis of the system structure focuses on identifying:

i) Critical stocks, which are variables that represent accumulations (Richardson, 2011).

Stocks can enhance resilience by acting as buffers that reduce the impact on the outcome function of the disturbance affecting the system and give time for the system to recover. Stocks create a delay between the disturbance and its effect that might give the system time to recover.

ii) Balancing feedback loops, which are also known in resilience literature as stabilising feedbacks (Chapin et al., 2009) These loops act by changing variables in the opposite direction to that from a given condition, counteracting the effects of the condition on the systems (Morecroft, 2015). In isolation, the balancing loops act as stabilising feedback and ”tend to reduce fluctuations in process rates” (Chapin et al., 2009, p. 9). Stabilising feedback is important because it can help a behaviour to bounce back to its original trend after a disturbance disappears. However, when combined with delays, balancing loops can drive oscillations and increase the difficulties of managing system behaviour (Morecroft, 2015; Sterman, 2000).

iii) Reinforcing feedback loops or amplifying feedback loops, which amplify the effects of the disturbances that contribute to destabilising the system. Policies that aim to enhance resilience might use reinforcing feedback loops by counteracting them to reduce or interrupt their effects on the outcome function of the system to reduce the impact of disturbances. Alternatively, policies might also look for other reinforcing feedback loops that have contrary effects to the ones amplifying the consequences of the disturbances.

## 4. ENHANCING RESILIENCE OF THE KAIBAB DEER POPULATION

The model used by Ford (2010) to analyse the overshoot and collapse of the Kaibab deer population is used to illustrate how to operationalise the analysis of resilience using SD simulations. The Kaibab deer is a rocky mountain deer species introduced at the end of the $19^{th}$ century in the Kaibab Plateau region in the north rim of the Grand Canyon. The model is used to explain the overshoot and collapse of the deer population between the 1910s and the 1970s. Russo (1970) explains that the deer population grew at an accelerated rate at the beginning of the 1920s, increasing more than five times in size. The quick growth rate of the deer population resulted in overgrazing and quickly exhausted the standing biomass of the area. Soon, thousands of deer were starving, and the population started to decrease rapidly.

The sudden changes in the deer population were attributed to large reductions in the populations of natural predators between 1915 and 1920. Human intervention (i.e., coyote poaching) is assumed to be the main cause of the decline of the predator populations. Under this assumption, an obvious strategy might be to reduce the poaching of coyotes or to stop the poaching entirely (to avoid the sudden changes in deer population). However, as other policies have shown, this strategy might not always be feasible or timely. For instance, many policies have been implemented to stop the poaching of wild tigers in Asia (O'Donoghue & Rutz, 2015; Robinson et al., 2015) with unfortunate underperformance. Similarly, one may think that reducing carbon dioxide ($CO_2$) emissions is a logical action to avoid the undesired effects of climate change. Nonetheless, the efforts and negotiations that have taken place over the last 20 years have been unsuccessful in reducing $CO_2$ emissions to the required levels (Aldy & Pizer, 2016; Wang & Li, 2016). Moreover, as Sterman et al. (2012) describe, even if the $CO_2$ emissions were now reduced, we still must address some climate change effects.

Acting to enhance resilience should be understood as an alternative plan if remediation policies are not as effective as expected. In that sense, the Kaibab deer study case is a good example because it prompts us to think not only about how to stop the poaching of coyotes in the area but also about how the deer population can be more resilient if the attempts to stop poaching are ineffective.

### *4.1 Conceptualization: Defining resilience of what to what?*

In this example, the Kaibab model is simply used to answer the question:

> *What policies could enhance the resilience of **the deer population** - F(x)- to the **reduction in the predators' population** (σ)?*

Therefore, analysis focuses on the behaviour of the deer population as outcome function F(x) and the disturbance σ affecting it is a sudden reduction of the predators over a given period of time. For illustrative purposes, in this example it is assumed that the desired outcome is to maintain a stable deer population.

### *4.2 Dynamic hypothesis: How the disturbance affects the outcome function*

Ford (2010) describes that the sudden changes in the deer population were attributed to the large reduction in the populations of natural predators between 1915 and 1920. Under normal conditions, the deer population is controlled by the "*deer density control*" balancing loop (B2 in Figure 6). As the deer population increases, there is more food available for predators, and the predator population increases. Eventually, the increase in the number of predators means that more deer are killed per predator, reducing the deer population and ultimately reducing the amount of food available for predators. However, when the predator population was quickly reduced, the balancing loop stopped governing the deer population, which began to grow as a result of the "*deer population growth*" reinforcing loop (R in Figure 6). More deer led to more net births, which increased the deer population. Net births is equal to the difference between deer births and deaths during a given period of time (Ford, 2010). More and more deer consumed an increasing amount of forage, which depleted the standing biomass (i.e., the amount of grass available) of the area. When the standing biomass reached a tipping point, the "*forage limiting growth*" (B1 in Figure 6) balancing loop started to govern the system because there was not enough available forage; the deer began to starve. Starvation eventually reduced the deer net births and produced the collapse of the deer population in the Kaibab area, almost to the point of extinction.

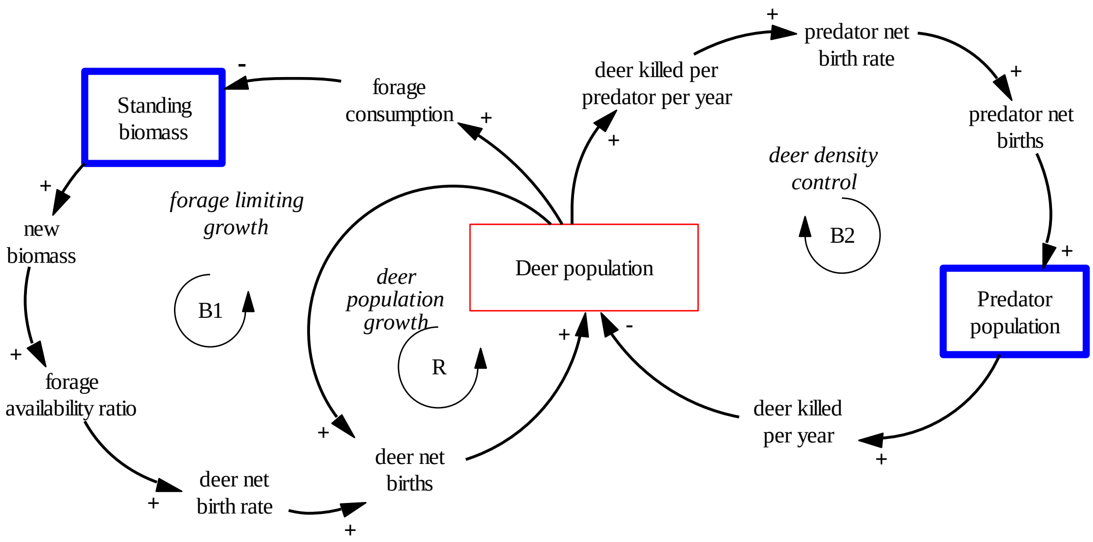
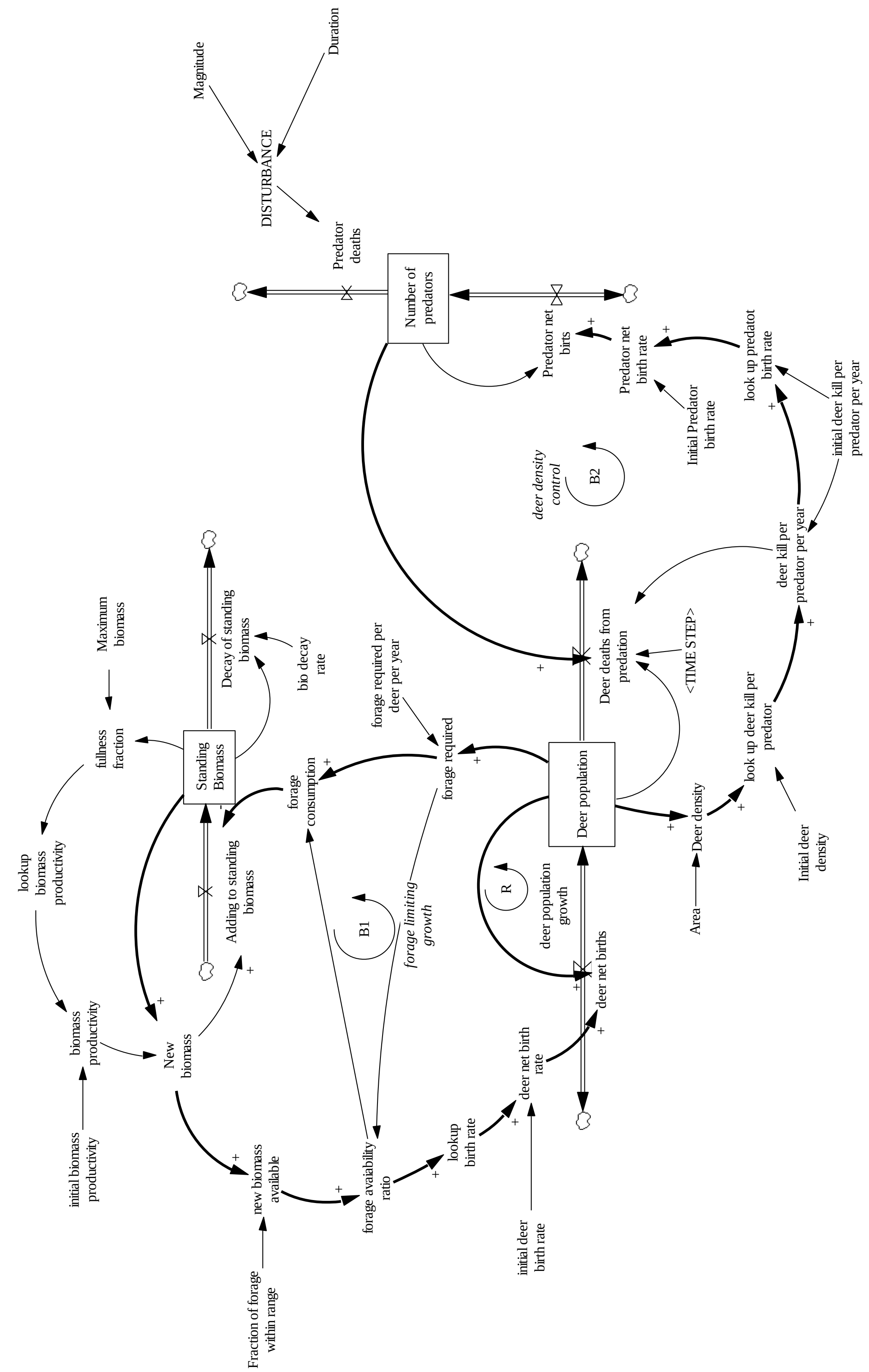



*Figure 6:* Causal loop diagram summarising feedback loop structure of Kaibab deer population

### *4.3 Formulation of the simulation model*

The dynamic hypothesis summarised in Figure 4 was used by Ford (2010) to build an SD model that was able to reproduce the reference mode behaviour described by Russo (1970). The stock and flow diagram of the model is shown in Figure 7. More details about the model can be found in Chapters 20 and 21 of Ford (2010).

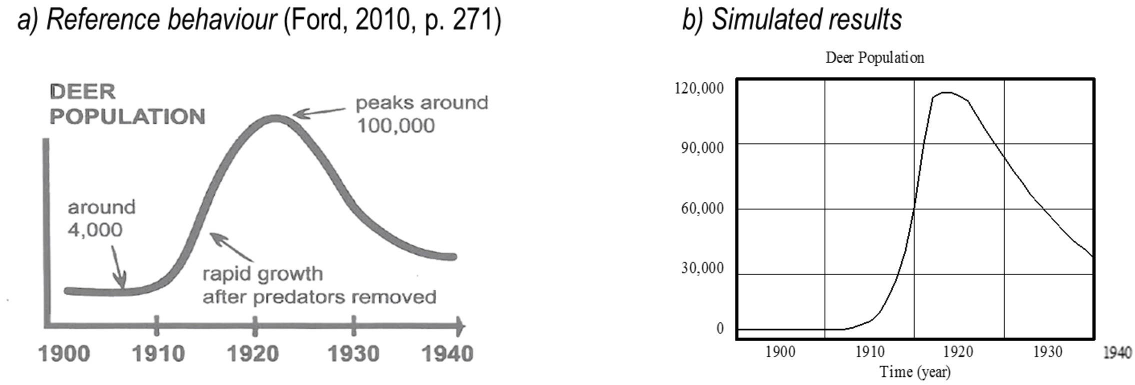



*Note: Adapted from Ford (2010) Chapters 20 and 21*

*Figure 7: Stock and flow diagram of the Kaibab deer model*

### *4.4 Testing and building confidence in the model*

Because the model is used as an illustrative example, it was calibrated against a qualitative reference model drawing based on the descriptions of Russo (1970), as presented in Figure 8a. The model was validated against the results of Ford (2010). In addition to reproducing the reference mode behaviour, other validation tests, such as unit consistency test, extreme value test and sensitivity test, were used for developing confidence in the model and its results.



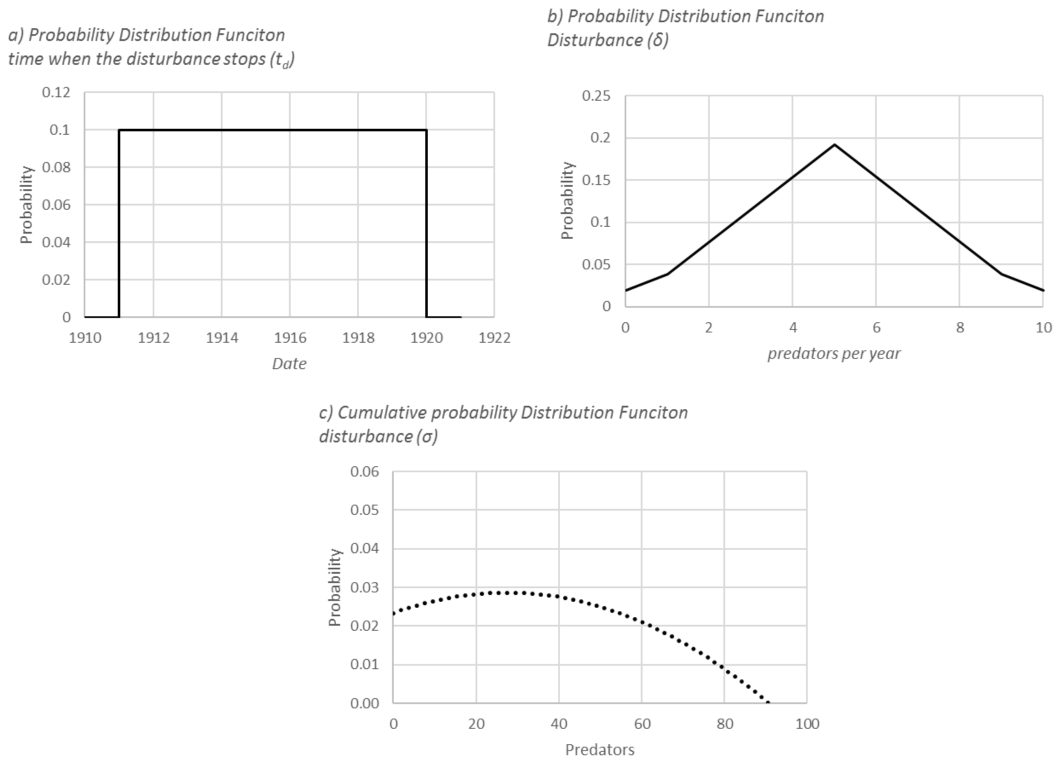

*Note: The reference behaviour "is sketched by hand, and that the vertical axis is not labelled. The sketch is not a compilation of precise estimates" (Ford, 2010, p. 271).*

*Figure 8: Kaibab deer population F(x) a) reference behaviour (Ford, 2010, p. 271) and b) simulation results*

Note that the desired state of the system in this example is a stable deer population; therefore, the increase and subsequent collapse (see Figures 8a and b) of the deer population after the system is affected by a disturbance are undesired. A stable population is assumed only for illustrative purposes, although it also exemplifies the fact that the definition of the desired state is arbitrary to a certain extent and strictly depends on the objectives of those defining the problem set. For example, an increase of the outcome function might be desired in the case of crop production or energy supply. Alternatively, the increase of river levels due to an increase in rainfall might be undesired because it increases the risk of flooding.

### *4.5 Policy Analysis*

In this case, the disturbance σ (i.e., the reduction of the predators over a given period of time) was adjusted using Monte Carlo simulations in Vensim DSS. PDFs were used to change the magnitude δ and the time when the disturbance σ stops ($t_d$), while the time when σ starts ($t_c$) was kept constant (1910). The specific PDFs used and the range of resulting σ are presented in Figure 9.




*Note:* The disturbance σ is calculates using Equation 1

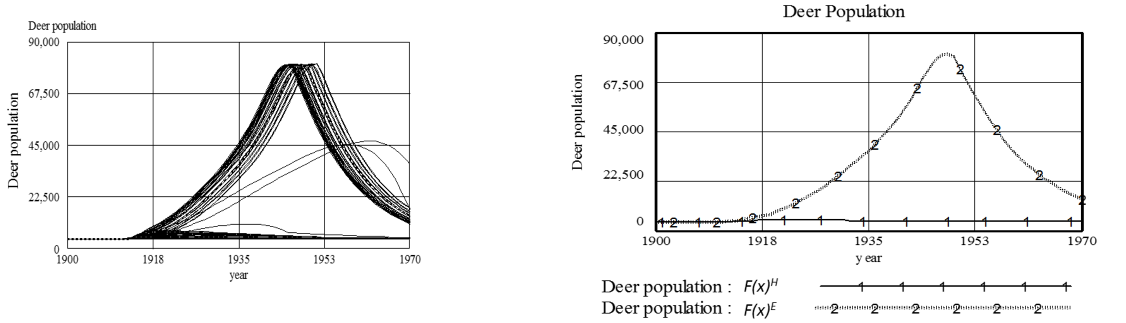
*Note:* $\sigma = \delta \times (t_d - t_c)$ (Equation 9)

*Figure 9*: Probability distribution functions (PDFs) for the magnitude of a) disturbance (δ) in predators per year, b) time when the disturbance stops ($t_d$) in years and c) cumulative probability distribution functions for disturbance (σ) in predators keeping time when disturbance starts ($t_c$) constant (1910)

The Monte Carlo function in Vensim DSS produces the simulated behaviour of F(x) –deer population in Figure 10- when the system is affected by each disturbance σ shown in Figure 9. The original simulation horizon (1940) was extended until 1970 to determine whether or not the deer population would eventually bounce back to the original behaviour of F(x). Figure 10a shows the simulated F(x) for all the different disturbances. The simulated behaviours are used to assess resilience as described in Section 2.

*a) Monte Carlo Simulation results for the deer population*

*b) Main thresholds of the deer population response to a drastic reduction of predators over a given period of time*




| **Paradigm** | *Engineering Resilience* | | | *Ecological Resilience* | |
|---|---|---|---|---|---|
| **Measure** | *Hardness* | *Recovery Rapidity* | *Robustness* | *Elasticity* | *Index of Resilience* |
| **Units** | (Predators) | (Deer/year) | (Predator/deer) | (Predators) | (%) |
| **Value** | 6 | 57.48 | 0.0071 | 36 | 79% |

*Figure 10:* a) Simulated behaviour of F(x) (deer population) to a range of disturbances (σ) -reduction of predators over a period of 10 years- b) system thresholds Hardness and Elasticity and (table inset) the five measures of resilience for the original systems' behaviour.

The solid line in Figure 10b shows the behaviour of F(x) when affected by a disturbance $\sigma_H$ of six predators between 1910 and 1920. This is the highest σ the deer population can withstand without showing significant changes in its behaviour and constitutes the engineering resilience threshold, the hardness of the deer population. The dashed line (see Figure 10b) represents the ecological resilience threshold, the behaviour of F(x) when affected by a disturbance $\sigma_E$ of 36 predators between 1910 and 1920. This is the lowest σ the deer population can withstand and still bounce back to the original behaviour. Any disturbance above $\sigma_E$ results in the eventual extinction of the deer population; the probability of the system experiencing $\sigma_E$ is 79% (see Figure 9). Average recovery rapidity $\bar{R}$ and robustness $\bar{\rho}$ are calculated for F(x) responses to disturbances higher than $\sigma_H$ but lower than $\sigma_E$, as described in Section 2. The full set of resilience measures are shown in the inset of Figure 10.

The measures shown in Figure 10 give a quantitative assessment of the resilience of the deer population F(x) in the current configuration of the system. For instance, the extinction of the deer population seems quite likely (21%) to happen. Moreover, changes in the behaviour of the population might also be expected since the hardness shows that a small reduction of the number of predators due to poaching (six predators over a period of 10 years) already produces significant changes in the deer population. Next, the structure driving F(x) is analysed to identify policies (i.e., changes in the system structure) that can improve its resilience.

*Policy 1 - Looking for the slow variables*

The model identifies the following two stocks that affect the deer population behaviour: a) the standing biomass (i.e., the biomass existing in a system at a given time) and b) the predators' population (see Figure 6). Increasing these stocks or adding stocks that might perform the same function are ways to enhance system resilience. In this case, one potential policy to affect the stocks in the system could be to make other grazing areas available when the deer population is starving (see Figure 11).

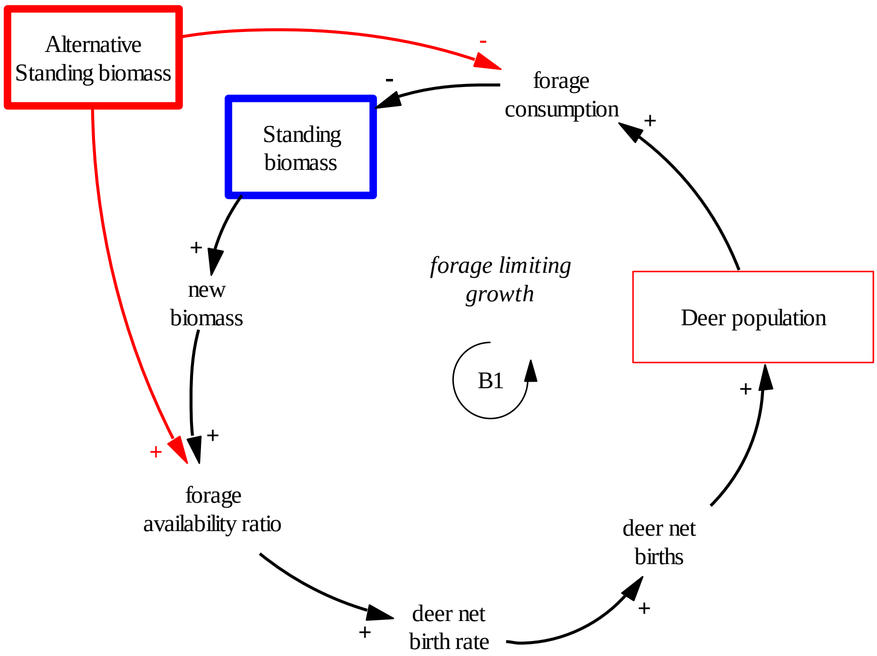



*Figure 11:* Causal loop diagram summarising Policy 1

*Policy 2 - Bouncing back; the effect of balancing loops*

There are two balancing loops in the model: a) forage limiting growth (B1) and b) deer density control (B2) (see Figure 6). These balancing loops naturally control the deer population growth to avoid overpopulation. However, the delays created by the stocks that are part of the loop constrain its effectiveness if the conditions of the system change too quickly. A policy alternative might be to introduce a third feedback loop (B3) and artificially control the deer population (see Figure 12). The maximum sustainable number of deer in the area could be estimated based on the standing biomass available and the excess deer would be slaughtered by hunters to keep the population at a sustainable level.

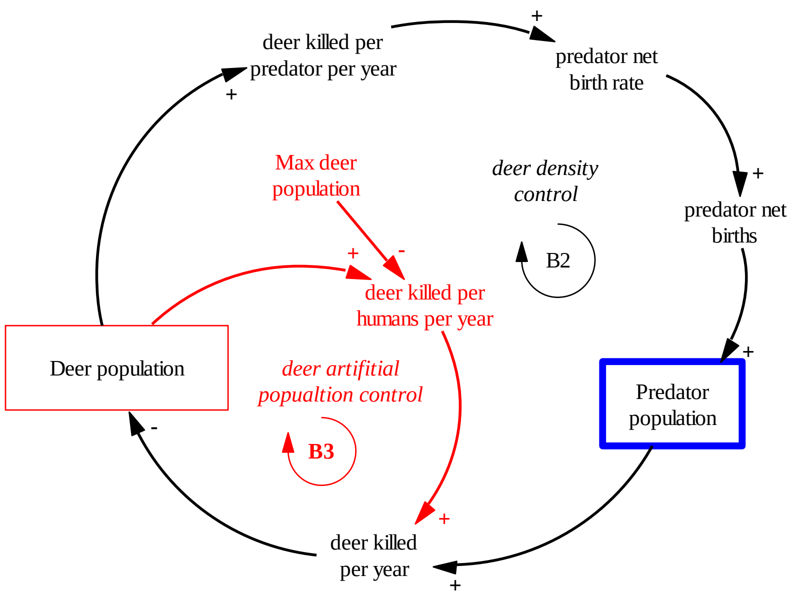



*Figure 12:* Causal loop diagram summarising Policy 2

*Policy 3 - Moving out of balance: the effect of reinforcing loops*

The main reinforcing loop affecting the deer population is deer population growth (R) as shown in Figure 13. The more deer that breed, the more deer there are, which increases the population size exponentially until the balancing feedback loop B1 stops the population growth and makes the population collapse by starvation. Reducing the effect of reinforcing loops driving the system to unsustainable behaviours is another way to enhance system resilience. In this example, a potential policy to reduce the effect of deer population growth could be to alter the net birth rate by, for example, isolating the female deer during their fertile period. The temporal reduction of the deer population growth will slow down the increase in the deer population and will give sufficient time for the loops B1 and B2 to naturally balance the system into a new equilibrium that prevents the collapse of the system.

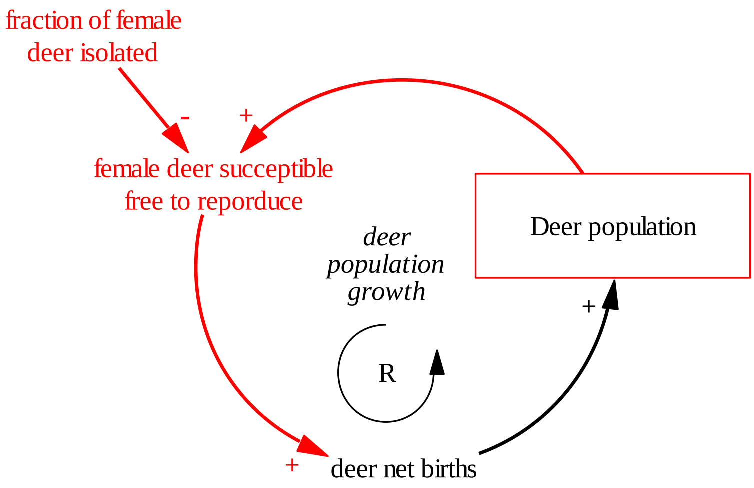



*Figure 13:* Causal loop diagram summarising Policy 3

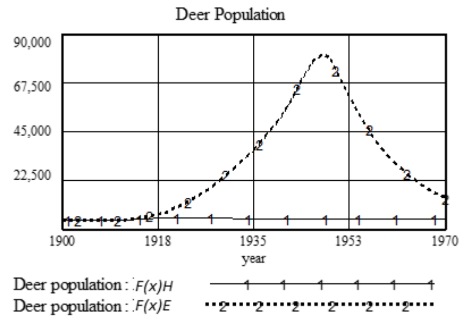
In short, the structure analysis identifies three potential policies to increase the resilience of the Kaibab deer population.

i) Manage the stocks by providing alternative standing biomass. An alternative stock of standing biomass that becomes available only when the system is under stress may act as a buffer mechanism between the disturbance and the outcome function.
ii) Introduce a new balancing loop (e.g., artificial deer population control) that performs the same functions as the "deer density control" loop in the absence of sufficient numbers of natural predators. The timely introduction of this new balancing loop may help the system to bounce back when the deer population starts to grow out of control.
iii) Alter the reinforcing loop "deer population growth" by limiting breeding when the deer population starts to grow out of control.

*Evaluating the policies proposed*

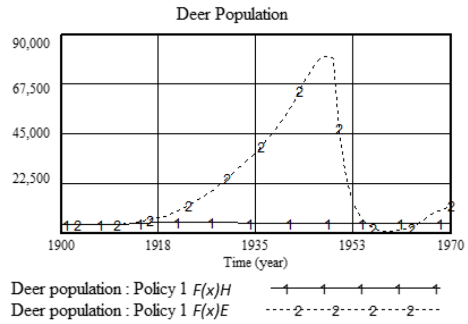
Modified models, including the policies described above, were used to simulate the new responses of the system to the same range of disturbance σ shown in Figure 7. The simulated F(x) are used to assess and compare the effect of each policy in the deer population resilience. The resilience of the new system configurations (i.e., a system including a proposed policy) is measured as described in Section 2, and the results are presented in Figure 14.

**a) Current System**



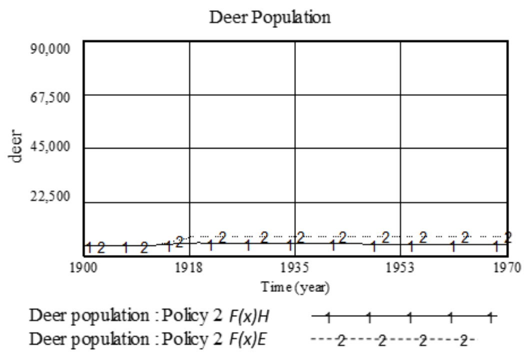

| Hardness | Recovery Rapidity | Robustness | Elasticity | Index of Resilience |
|---|---|---|---|---|
| (Predators) | (Deer/year) | (Predator/ deer) | (Predators) | (%) |
| 6 | 57.48 | 0.0071 | 36 | 79% |

**b) Policy 1:** to introduce an alternative source of biomass when deer population is starving



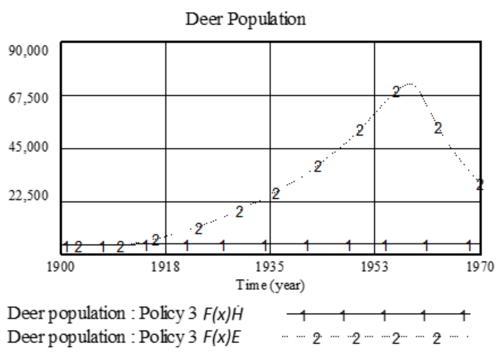

| Hardness | Recovery Rapidity | Robustness | Elasticity | Index of Resilience |
|---|---|---|---|---|
| (Predators) | (Deer/year) | (Predator/ deer) | (Predators) | (%) |
| 6 | 57.48 | 0.0071 | 48 | 85% |

**c) Policy 2:** to artificially control the deer population




| Hardness | Recovery Rapidity | Robustness | Elasticity | Index of Resilience |
|---|---|---|---|---|
| (Predators) | (Deer/year) | (Predator/ deer) | (Predators) | (%) |
| **9** | **170.6** | 0.011 | 40 | 81% |

**d) Policy 3:** to isolate the deer females during reproductive period




| Hardness | Recovery Rapidity | Robustness | Elasticity | Index of Resilience |
|---|---|---|---|---|
| (Predators) | (Deer/year) | (Predator/ deer) | (Predators) | (%) |
| 6 | 109.8 | 0.015 | **63** | **88%** |

*Figure 14:* Response of the deer population to the σ -reduction of predators over a period of 10 years- and (tables inset) measures of the characteristics of resilience for a) current system, b) Policy 1, c) Policy 2 and d) Policy 3. Lines plotted in the graph represent the thresholds $F(x)^H$ and $F(x)^E$ of the system.

The potential impact of the policies proposed is seen in the five measures described rather than in a single one. While Policy 2 (to artificially control the deer population) is the one that increases the characteristics related to the engineering resilience paradigm (Hardness and Recovery Rapidity), Policy 3 (to isolate the deer females during their reproductive period) outperforms in the ecological resilience paradigm (Elasticity and Index of Resilience). The quantitative assessment uncovers a trade-off between different types of resilience, the better policy to enhance engineering resilience has little impact to enhance ecological resilience characteristics and oppositely. Because these trade-off between different characteristics of resilience might not be exclusive of this example it is important of agree with policymakers and stakeholders about what resilience really means in each particular context.

When assessing the results shown in Figure 14, it is also possible to compare the effectiveness of different policies. For instance, if the criterion is elasticity, Policy 3 is the most effective. Policy 3 increases the elasticity of the deer population from a threshold of 36 predators over a period of 10 years to 63; however, Policy 1 only increases the elasticity to 48; Policy 2 increases it to only 40. This means that more predators could be poached over the same period when Policy 3 is in place, and it still will be possible to prevent the extinction of the deer population. A similar analysis can be done for the other measures. For instance, policy effectiveness can be assessed in terms of the Index of Resilience where the differences are smaller (88% for Policy 3 vs. 85% and 81% for Policy 1 and Policy 2, respectively); however, Policy 3 is the most effective one.

## 5. DISCUSSION

One of the criticism to resilience as a policy-making approach is the lack of quantitative measures for resilience and the difficulties for assessing the impacts of policies to improve the resilience of a particular outcome function. Whether or not there are several elements needed to overcome this difficulty, an important ingredient is to anticipate what a system response might look like. Hence, the use of simulation techniques, like SD modelling, as tools to simulate a potential system response to a disturbance is now trending (e.g. Duveneck & Shceller [2016], Masys et al. [2014] and Schattka, Puchkova & McFarlane [2016]). Simulations open up the possibilities to estimate and analyse the responses of a system and experiment with different changes in the environment.

However, the use of simulations by themselves is not enough because the assessment of resilience by only qualitatively comparing the simulated different responses to the same disturbance is difficult and leads to different conclusions. For instance, the charts shown in Figure 14 tell little about the effect of the proposed policies on increasing the resilience of the deer population. Quantification is needed not only for substantiating policymaking but also for being able to discuss what resilience means in practical terms.

The five characteristics proposed in this chapter provide policymakers and researchers with consistent and practical means to compare the effect of different policies in the system. Instead of sticking to one single characteristic of resilience and measuring it, five measures provide a wider and more comprehensive picture of the effects of different policies. As shown in the Kaibab example, the engineering paradigm and the ecological paradigm might have competing goals, and policies that properly enhance the characteristics of one paradigm may not necessarily perform well in the other one. Quantifying the effects of potential policies also opens the discussion about their cost effectiveness, which policy can increase resilience at a lower cost and trade-offs with other properties of the system, such as productivity or efficiency.

The set of resilience measures described in this chapter can be applied to many simulation modelling techniques. However, this chapter proposes to use SD modelling over other simulation methods because of its transparency and its focus on feedback loop relationships. The understanding of the underlying feedback loop structures allows for the in-depth exploration of the mechanisms driving the resilience and for the identification of the structural ways to enhance it. As shown in the Kaibab model, SD modelling can be used not only as a simulation tool but also as framework for the analysis of resilience in operational terms.

## 6. CONCLUSION AND FURTHER RESEARCH

The use of resilience in the policymaking world, as a mean to adapt our SES to changing environment, requires a more operational approach. Computer simulations, and SD in particular, have to be an important ingredient of these operational approaches because they are instruments to anticipate systems behaviour and to compare the effectiveness of interventions. In this context, SD offers additional advantages over other simulation techniques by supporting the analysis of system structure and focus on feedback loop relationships.

However, in order to uncover the potential of SD modelling, the assessment and interpretation of resilience using simulated results needs to be formalised. This chapter describes how to measure five fundamental characteristics of resilient behaviour formulated in the engineering and ecological resilience paradigms. These characteristics provide a quantitative basis to discuss, compare and select policies to enhance the resilience of SESs.

The Kaibab example shows how SD modelling can be used to understand the system, identify policies and assess their impact. However, since it is only one example, the approach proposed in this chapter calls for replication in different real-world contexts. Extending the use of resilience from pledges to actions is not straightforward; however, if widely applied, SD modelling and the measures proposed in this chapter can contribute to take resilience from a metaphor into practice, supporting policymakers with the insights needed to successfully adapt SESs to a changing world.

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# Chapter 5

# Public policy design for climate change adaptation: a dynamic performance management approach to enhance resilience[3]

**Keyword:** performance management, resilience, system dynamics

**Abstract:** This chapter proposes dynamic performance management (DPM) as a suitable method to identify policies in the context of climate change adaptation. Namely, it focuses on the role it can play to support the analysis of how to enhance resilience of social and economic systems to climate change. While 'resilience' is a buzzword in the policymaking world, putting the concept into practice is still undeveloped. In a public administration focused on accountability, intangible outcomes of resilience represent a complication. The chapter discusses the findings and lessons from a case study applying the proposed approach. The results highlight the role of a dynamic performance approach to support stakeholder engagement, outcome-based policymaking and integrated solutions in the process of climate change adaptation.

[3] Apart from several minor adaptations, this chapter is a direct copy of the article: Herrera H. (2017) Public Policy Design for Climate Change Adaptation: A Dynamic Performance Management Approach to Enhance Resilience. In: Borgonovi E., Anessi-Pessina E., Bianchi C. (eds) Outcome-Based Performance Management in the Public Sector. System Dynamics for Performance Management, Vol 2. Springer, Cham

# 1. INTRODUCTION

Effects of climate change are now hard to deny. In the past years, climate change has been manifested in a rise in temperatures and changes in rainfall seasonality around the globe. These effects of climate change have shocked our social and economic systems, exacerbating water scarcity, hunger and even social conflicts in many parts of the world. These events evidenced the dependence of social and economic systems on their natural counterparts and increased the interest in identifying ways to reduce vulnerabilities and foster successfully managed adaptation.

In this context, resilience has become a buzzword in the literature and politicians' discourses (Adger, 2000, 2009; Carpenter et al., 2001; Folke, 2006). Resilience is the state of a system that withstands external changes due to its ability to absorb a certain amount of disturbances (Gallopín, 2006; Gunderson, 2000). In the social-ecological systems (SES) domain, resilience has been used to describe the properties of a system that allow it to continue providing desired outcomes, such as food, water supply and energy, even when the system has been affected by disturbances or shocks, like the effects of climate change.

The emergence of resilience has not gone unnoticed, capturing the interest of researchers and practitioners while remaining a cumbersome concept in the policymaking domain. In public administration, the concept of resilience still has a long way to go (Duit et al., 2010). Translating the ambition of making our social and economic system more resilient into effective policies presents a challenge to conventional policymaking and public managing approaches (Chapin III et al., 2009; Folke, 2006).

Many critical voices have appeared in the contemporary environmental governance literature pointing out the current complications of transferring resilience thinking into practice. Three points of critique are as follows: (a) the lack of quantification and measures for resilience, (b) the alienation of resilience theories from the policymaking world and (c) simplified or rudimentary understanding of political processes (Duit et al., 2010).

This chapter focuses on the second point of critique, in particular in the context of the new public management (NPM) phenomenon and its outputs-based perspective. The literature on resilience is vast, with interesting and appealing concepts and theories, but so far it has failed to translate theories into real-world policies. The disconnection between resilience theory and resilience policymaking is manifested in (a) the simplified understanding of the political process described in the literature on resilience (Eriksen et al., 2015) and (b) its contradictions to policymaking and management processes in the public sector (Arnaboldi et al., 2015). The abstract and conceptually based approach of resilience particularly clashes with results-oriented views held within NPM. NPM is a development system that introduces practices used in the private sector into public administration (Arnaboldi et al., 2015). NPM is embedded in the public administration of many countries and government sectors by now, and it is and has been a key element supporting the implementation of outputs-oriented standards of performance (Arnaboldi et al., 2015; Pallot, 1999).

In the subsequent sections this chapter explores a dynamic performance approach (DPM) as a means to support the identification and design of policies for climate change adaptation based on the enhancement of resilience. Explicitly, it focuses on how DPM can be used as suitable bridge between the abstract concepts of resilience thinking and the concrete and measurable policies the public sector needs to design and account for. The resilience of food security to climate change in Huehuetenango, Guatemala, is used to illustrate the opportunities DPM might offer to policymakers analysing resilience within the public sector.

The chapter proceeds as follows: First, it describes the current position and challenges of resilience in the context of policymaking in the public sector. Next, it briefly describes how DPM can be used in the context of resilience analysis. The case study of food affordability in Huehuetenango, Guatemala, is used to illustrate how DPM is applied in real-world contexts. Finally, the chapter discusses the opportunities to formalise resilience analysis in public administration by using DPM.

## 2. LITERATURE REVIEW

### *2.1 Resilience, climate change adaptation and public policy*

Even if resilience is widely applied, a defining characteristic of the concept in SES literature is that ‘there is no single theoretical framework under which all resilience-related research is subordinated’ (Duit, 2015, p. 5). Instead there is a diverse set of definitions, concepts and descriptions of what resilience means (Berkers et al., 2008; Chapin III et al., 2009; Folke et al., 2004; Walker et al., 2006, 2004); hence, scholars usually refer to the research related to resilience as resilience thinking rather than resilience theory (Walker & Salt, 2006). In this chapter, resilience is understood, as defined by Walker and Meyers (2004), as the capacity of a system to absorb disturbance while retaining its essential function.

The recognition gained by resilience thinking in the context of climate change comes from the opportunities resilience could offer to the analysis. Resilience has become a common objective of climate change adaptation across a whole range of systems and activities, and it is an overarching concept in many strategies (Heller & Zavaleta, 2009; Mawdsley et al., 2009).

In the public policy administration domain, the idea of resilience is not new. Already in the late 1980s, Wildavsky (1988) described resilience as a means to manage risk in modern societies; nowadays, it is a familiar concept in the crisis management literature (Aldrich, 2012; Boin et al., 2010). However, the translation of resilience concepts into effective policies is still to a considerable extent unexplored in the public administration domain.

Current research on resilience policymaking is mainly found in the SES domain (Biggs et al., 2012; Chapin III et al., 2009). This literature focuses on the description of those social and natural properties of the system that are hypothesised to foster resilience, like redundancy, stakeholder participation and understanding of the system. The justification for these properties is found in case study research showing how the hypothesised properties enhanced the resilience of a particular outcome of the system to specific disturbances. Nevertheless, this justification is only at a conceptual level and rarely quantifies the impact of actions undertaken on the system, mainly because the way properties are enhanced is not clear. This is a downside in the current literature, since there is still a disconnection between the conceptual relations used to explain resilience and concrete policies, actions and plans to enhance it. The foregoing complicates the usage of resilience in the context of the NPM phenomenon focused on outputs-based performance.

### *2.2. New public management in the public sector and outputs-based performance*

The NPM phenomenon in the public sector has its inceptions in the late 1970s and early 1980s (Pallot, 1999). NPM started in the United Kingdom and the municipal governments in the United States but rapidly expanded to other countries. However, it was only later, in the 1990s, that academics identified the common characteristics of these reforms and organised them under the label of 'new public management' (Dunsire, 1995). NPM assumes that the management tasks in the public sector are not significantly different from the managerial tasks in private sector organisations and therefore that private sector techniques can be usefully applied in public administration (Pallot, 1999). The introduction of private sector techniques in public administration was justified by the aim of enhancing public sector flexibility, accountability and control; a client and service orientation; a strengthened capacity for developing strategy and policy; introducing competition and other market elements; and changed relationships with other levels of government (Laurence, 1998).

NPM was grounded, to a large extent, in the hypothesis that the poor performance of bureaucratic structures could be improved if the public sector would act more like its private counterpart. For instance, performance would improve if the public sector would be more product- instead of function-oriented or if management objectives would become dominant over legal arrangements. Intentionally the NPM phenomenon resulted in a shift from a process-oriented perspective to an outputs-based one focused on results, efficiencies and the value for money (Pallot, 1999; Vries & Nemec, 2013).

Nevertheless, in practice, the public sector faces, by far, more difficult problems than any business in the private sector (Pallot, 1999, p. 22). Many of these problems arise from complex systems, characterised by an underlying causal structure of accumulation processes, the core of any dynamic system, that are interrelated by way of nonlinear feedback structures that cut across sectors and disciplines. The resulting various delays are spread across a system, making the root cause of a problem nearly inaccessible and preventing the identification of the timing and dosage of effective interventions. In addition, circular causality, that is, feedback, leads us into circular arguments, made meaningful only when we recognise the associated delays. Such is the case of building resilience for climate change effects, where the results of the policies implemented are only observable, if so, after long time periods of time and depend on the management of the feedback loop structures influencing the system.

Recognising the complexity of public sector problems is needed in order to understand and effectively act on the dynamics of the SES affected by climate change. Rather than assuming a social system characterised by stability and equilibrium, the analytical focus is placed on understanding processes of change and surprises and on how governance arrangements try to cope with and adapt to a constantly dynamic and evolving environment (Duit et al., 2010).

NPM approaches and their focus on results often fail to capture the dynamic complexity of managerial decisions by underestimating a number of relevant factors influencing policy performance (Arnaboldi et al., 2015; Bianchi, 2010). In fact, by narrowing the measures of policy performance to only the outputs of the system, NPM might constrain the implementation of policies to enhance system resilience, as they do not deliver tangible results measurable in the short term. An additional complication results from the fact that, as mentioned before, the resilience literature is not clear on how to measure resilience or what to measure. This lack of quantification and operationalisation of the concept of resilience is a significant challenge for NPM, because the benefits of policies are hard to assess and there is not a clear framework in the literature to do so.

To summarise, so far, the concept of resilience has been mainly developed in the SES as a metaphor of how systems should behave (Duit, 2015). The idea of resilience in public administration is still awkward mainly due to the discrepancies between NPM perspectives and the inherent complexity of resilience. If resilience is to be used widely in public administration, policymakers need to be able to connect policies with their impact on resilience, compare their effectiveness (e.g., in term of added value for money) and measure their performance. If any progress toward a more active incorporation of resilience perspectives into the public policies were to occur, a new approach for performance management would be required.

## 3. METHODOLOGY: DYNAMIC PERFORMANCE MANAGEMENT APPROACH

This chapter explores DPM as approach to bridge the literature on resilience thinking and the public-sector policymaking world. DPM is a combination of performance management approaches and system dynamics (SD) (Bianchi, 2016). DPM supports policymaking process by modelling organisational systems (in SD models) and using simulation techniques to understand the behaviour of the complex systems public policies deal with (Bianchi & Rivenbark, 2012; Bianchi & Tomaselli, 2015). The contribution of DPM is to help policymakers assess the middle and long-term impacts of their actions in the system outputs by placing the measure of performance in a broader context of the system (Bianchi & Tomaselli, 2015).

In the analysis of resilience, DPM provides a means for discussing the concept of resilience in a more operational manner. Figure 1 shows the three interconnected views of system performance covered by DPM (Bianchi, 2016) and the way they merge with the analysis of resilience. The objective view includes activities and processes influencing the system behaviour, performed by different stakeholders within and outside public administration. The subjective view includes performance goals, performance measures and key indicators defined by higher governmental policies and strategies. While these two views are rather common in traditional performance management, the third one, the instrumental view, is an important addition of the DPM approach. The instrumental view explicitly represents activities, processes, products and their relationships in terms of strategic resources and performance drivers. Performance drivers are the mechanisms conditioning the system outcomes and outputs, while strategic resources are the means supporting the performance drivers. By identifying what the links between the system goals in terms of outcomes and the performance drivers enabling them are, policymakers can identify important performance measures and more effective policies to improve the system responses. The foregoing, represented in an SD model, allows simulation of the behaviour of key elements in the system, to anticipate pitfalls of the policies proposed and to identify opportunities.

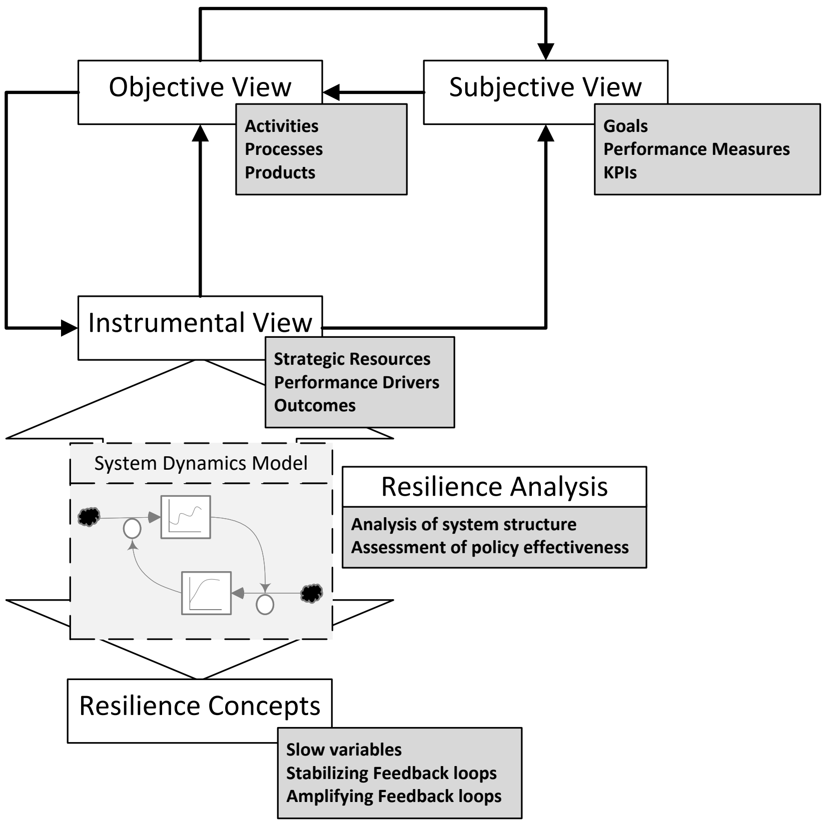



*Figure 1:* Dynamic performance management framework in the context of resilience analysis.

Moreover, the instrumental view is also a very suitable tool to represent key concepts of resilience, qualitative and formal simulation models. Systemic effects described in the resilience literature are easily grasped from the instrumental view. These concepts can be linked back to strategic resources, performance drivers and concrete processes. Then, it is possible to draw concrete action plans, identify key performance indicators and measure performance of policies to enhance resilience. DPM acts here as a bridge between accountable elements needed to manage policies in public administration and abstract concepts needed to describe and interpret the resilience of SES.

### *3.1. Resilience analysis*

The SD model, built within a DPM framework, can be used in the analysis of resilience to (a) analyse the system structure, looking for the mechanisms driving the system resilience and (b) explore in a systematic and quantifiable way the effectiveness of different policies. The analysis of the system structure focuses on identifying slow variables (Chapin III et al., 2009). Slow variables are variables that strongly influence the system but remain relatively constant over time (Chapin III et al., 2009).

While many other analytical frameworks for assessment of resilience require making substantial abstractions, simulation can offer a more practical one (Schattka et al., 2016). Simulations can be used to assess the effect of policies on the resilience of the system by reproducing the behaviour of the system outcomes while affected by a given disturbance. The system outcomes can be represented by a quantifiable and time-dependent outcome function F(x) from which distinctive properties can be measured (Barker et al., 2013; Henry & Emmanuel Ramirez-Marquez, 2012). In this chapter I measure the five characteristics described by Herrera and Kopainsky (2015). These characteristics offer a comprehensive understanding of system resilience and are easily elicited from the simulated behaviour. Table 1 presents the resilient characteristics measured in this chapter to operationalise resilience.

**Table 1.** Characteristics of resilience and how to measure them

| Measure | Description | Equation |
|---|---|---|
| Hardness ($\sigma_H$) | The ability of the system to withstand a disturbance σ without presenting a change in the performance of the outcome function F(x). | $(\sigma_H) = \delta_H \times (t_d - t_c)$ |
| Recover Rapidity ($\bar{R}$) | The average rate at which a system returns to equilibrium after a disturbance σ (Martin et al., 2011; Pimm, 1984) | $(\bar{R}) = \frac{A-B}{t_f - t_d}$ |
| Robustness ($\bar{\rho}$) | The system's ability to withstand big disturbances σ without significant loss of performance (Attoh-Okine et al., 2009) | $(\bar{\rho}) = \frac{\sigma}{A-B}$ |
| Elasticity ($\sigma_E$) | The ability of the system to withstand a disturbance σ without changing to a different steady state (Holling, 1996; Holling & Gunderson, 2002) | $(\sigma_E) = \delta_E \times (t_d - t_c)$ |
| Index of resilience ($I_R$) | The probability of keeping the current steady state or regime (Holling, 1996; Holling & Gunderson, 2002; Martin et al., 2011). | $(I_R) = P(\sigma \leq \sigma_E)$ |

Main parameters needed to calculate the resilience measures described in Table 1 are as follows:

$\delta_H$: amount of disturbance necessary to alter the behaviour of the system

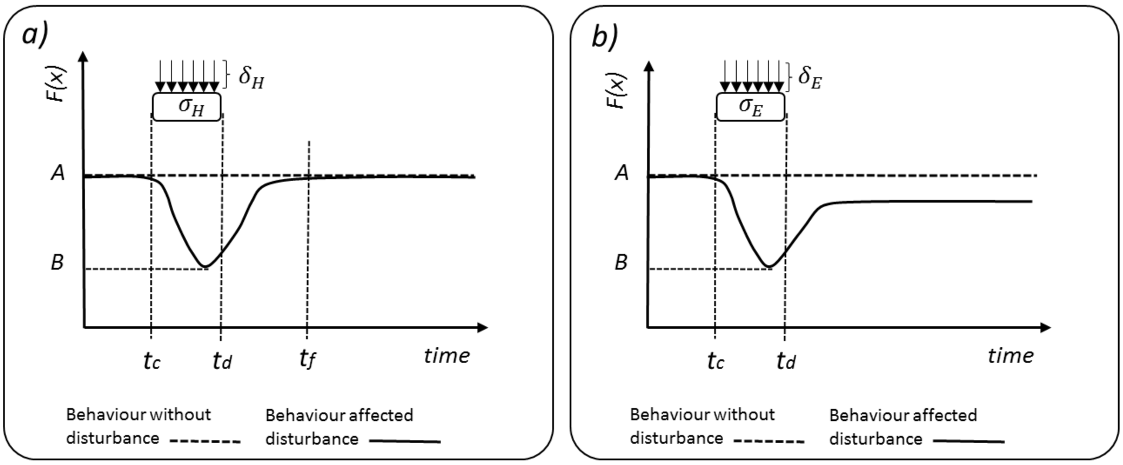
$\delta_E$: amount of disturbance necessary to move the system to a different equilibrium

$t_d$: time when the disturbance starts to affect the system

$t_c$: time when the disturbance stops

$t_f$: time when the system fully recovers

These parameters can be measured from the simulated behaviour of the outcome function F(x) as it is illustrated in Figures 2a and 2b. Since the $\sigma_H$ and $\sigma_E$ represent system thresholds—points or levels at which a significant variation in the behaviour is manifested—it is necessary to simulate the system response to a wide range of disturbances in order to identify them. The first threshold is the smaller σ that produces a change in the behaviour (hardness $\sigma_H$), and the next one is the smaller σ that results in a new equilibrium for the system (elasticity $\sigma_E$). The behaviour produced by disturbances larger than $\sigma_H$ but smaller than $\sigma_E$ are used to calculate the average recovery rapidity and robustness. Finally, the index of resilience ($I_R$) is the probability that σ would be larger than $\sigma_E$, and it can be easily calculated using the probability distribution function of σ.




A: value of the outcome function F(x) for the baseline system
B: lower value of the outcome function F(x) when the system is affected by a disturbance

*Figure 2:* Two, hypothetical pairs of responses to a disturbance and the parameters needed to calculate five characteristics of resilience. a) System affected by a disturbance $\sigma_H$ big enough to change the performance of the outcome function F(x). b) System affected by a disturbance $\sigma_E$ big enough to change the behaviour of outcome function F(x) to a different steady state.

## 4. CASE STUDY: POLICIES TO ENHANCE RESILIENCE OF FOOD AFFORDABILITY IN HUEHUETENANGO, GUATEMALA

The Inter-American Development Bank has identified Guatemala among the top 10 countries most vulnerable to climate change (World Bank, 2003). Guatemala has been severely affected by climate change, mainly experiencing a drastic change in average rainfalls, which have caused both droughts and floods in magnitudes that have not been seen before. Relying on agriculture as its primary economic activity and 26% of its GDP, Guatemala has a vulnerability to climate change that is a high risk to its economy. Additionally, Guatemala is the fourth most susceptible nation to natural disasters and suffers the eight highest incidence of childhood malnutrition in the world, according to UNICEF (2015). Guatemala's chronic malnutrition, an accepted measure of food insecurity, is the third worst in the (World Bank, 2003). This combination of factors places the country's food security at high risk.

Huehuetenango has an area of 7,400 km$^2$ (INE, 2012) and is located in the northwest region of Guatemala, on the border with southern Mexico. Huehuetenango is one of the poorest and most vulnerable districts of Guatemala, with a population estimated at 1.1 million inhabitants in 2014, 67.6% of them under the poverty line (INE, 2011). Huehuetenango's main economic activities are the mining of silver and gold and the production of coffee. The production of maize is, nevertheless, an important activity for self-consumption. The majority of the population is indigenous, of the Mam and Quechi ethnicities, and has a cultural dependence on maize as a main source of calories (71.2% of their basic grains consumption), especially for those in the rural areas, representing around 52% of the total population (Camposeco et al., 2008). Moreover, farming techniques are rudimentary, based on knowledge that has been passed down from previous generations and on the use of simple tools and principles. The effect of these poor conditions and basic techniques became evident in the lowest average yield historically recorded on small farms (between 1.5 and 2.3 tonnes/$km^2$ year). Since yields are low, maize produced is mainly used for self-consumption or local trading, alleviating local food vulnerability. Households' weak purchasing power and poor access by road make the local market less attractive for foreign producers and highly dependent of the local production.

### *4.1 Subjective view*

The policymakers' objective was to identify policies to enhance the resilience of food affordability in maize-based systems to the increasing variation in the rainfall in the district of Huehuetenango. Henceforth, a maize-based system is understood as the system formed by (a) the small farmer producers of maize in the region, (b) the households in poverty who mainly produce and consume that local maize, (c) the local maize supply chain and (d) the ecosystem (soil and water) in which the maize is produced.

The policymakers' objective defines the scope of the analysis by identifying the variables to analyse (a) the outcome function F(x) is food affordability and (b) the disturbance (σ) is the reduction in rainfall. Affordability was measured in the model as an index that reflects the ratio between the theoretical amount of maize required by a household and the actual amount the household can purchase. The units of this index are dimensionless but will be addressed in this chapter as points on the affordability index to avoid confusion. If the affordability is 1.00, it means that, on average, households can buy all the maize they need to cover their daily requirements. Alternatively, 0.50 points on the affordability index means that, on average, households can only buy half of the total maize they need to cover their daily requirements. The reduction of rainfall indirectly causes starvation of many families by destroying the crops of small-scale farmers. There is an estimate is that rainfall has decreased 31% in the last 15 years, and projections expect that 2016 will be the driest year ever in Guatemala (Insivumeh, 2015).

### *4.2 Objective view*

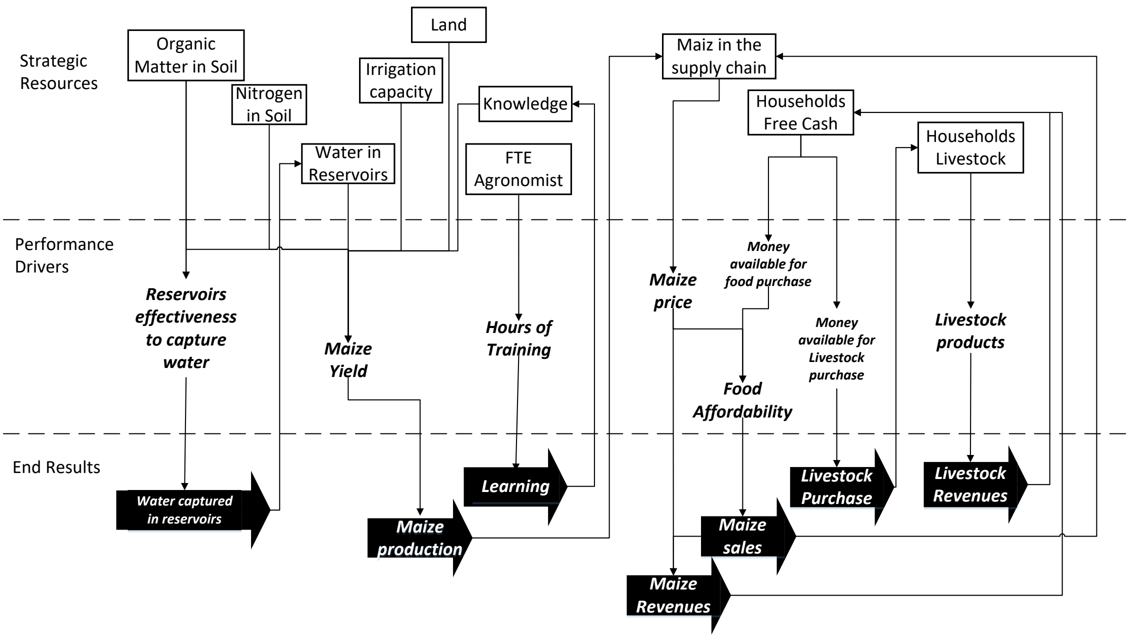
Four stakeholders were identified as the main groups intervening in the maize system of Huehuetenango, Guatemala. In addition to the government and the farmers, the supply chain (big producers and retailers of maize) and NGOs supporting farmers with technical and financial assistance are also important players. The areas of influence, relevant processes and products for each stakeholder group are presented in Table 2.

**Table 2.** Main stakeholders' areas of influence, activities and products

| Stakeholder | Areas of Influence | Activities and processes | Products |
|---|---|---|---|
| **Ministry of Agriculture** | Public policies and public resources | ➢ Policy design and implementation<br>➢ Technical training for farmers<br>➢ Agriculture market regulation. | Technical and economic framework for maize production (recommended seeds, practices, subsidies, technical assistance) |
| **NGO** | Hard and soft resources for supporting farmers | ➢ Technical training for farmers<br>➢ Donations and aids for farmers | Capacitation programmers, donations of seeds and other inputs |
| **Households farmers** | Household economic assets and decisions | ➢ Maize production<br>➢ Maize trade<br>➢ Livestock farming | Allocation of resources (household cash, time, efforts and land) |
| **Supply chain (big producers and retailers of maize)** | Market | ➢ Maize production<br>➢ Maize consumption | Market conditions (price, supply, quality) |

### *4.3 Instrumental view*

The process by which the different stakeholders described in Table 2 interact with the environment is mapped on a diagram using an instrumental view. The purpose of this mapping activity is to make these interactions explicit and to identify the key performance drivers. Key performance drivers are supported by strategic resources. Strategic resources can be part of the ecological dimension (e.g., nitrogen in soil), economic dimension (e.g., households' free cash) or social dimension (e.g., farmers' knowledge) of the maize system. The diagram summarising the system interactions analysed in the instrumental view is presented in Figure 3. Note the relationships in the diagram: strategic resources support performance drivers, performance drivers produce end results and end results (in most cases) build strategic resources in a virtuous circle.

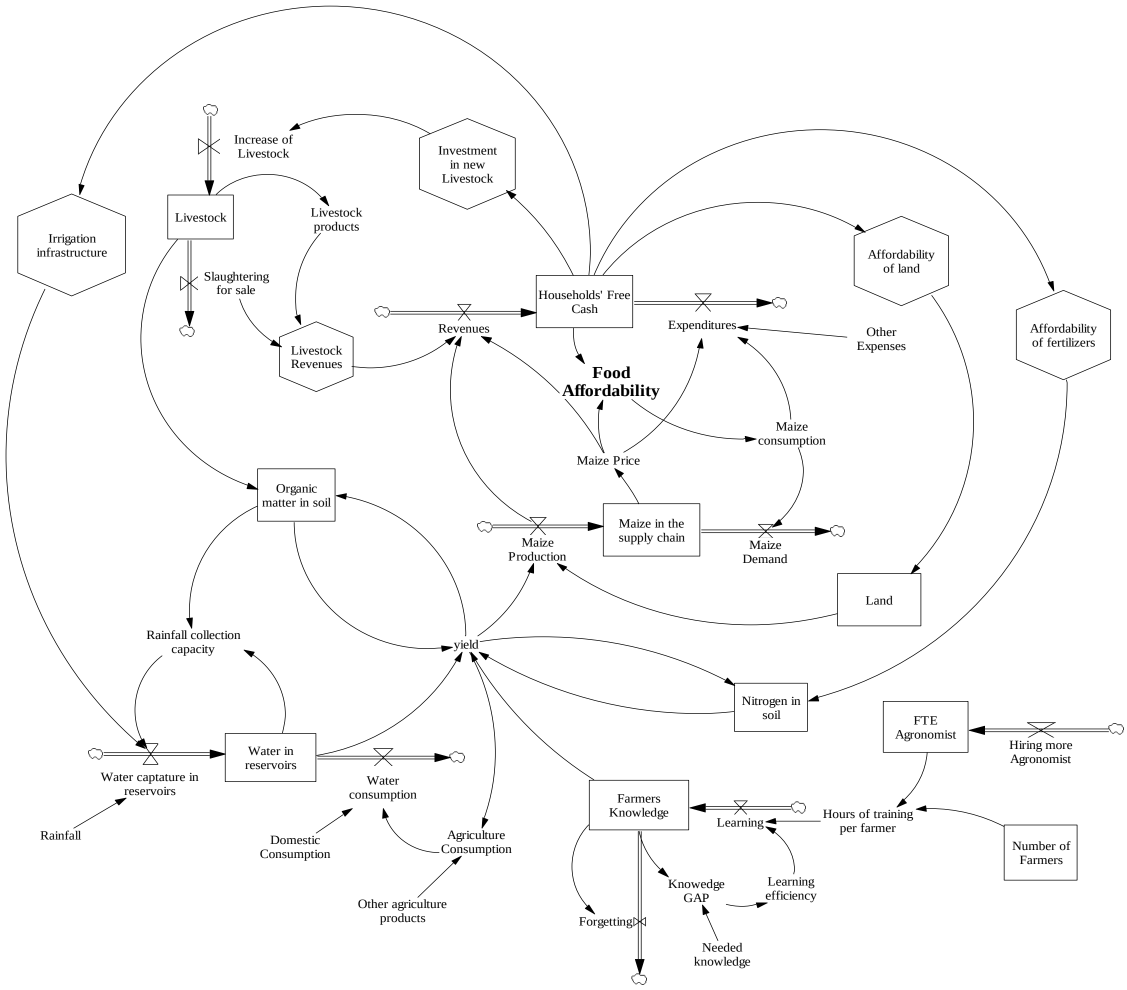



*Note: 1 FTE (full time equivalent) = 42 hours per week*

*Figure 3:* A summarised three-view framework for a dynamic performance management approach to the maize system of Huehuetenango.

### *4.4 System dynamics model*

The relationships captured in Figure 3 were used to produce an SD simulation model. The structure of the model is represented in a stock-and-flow diagram in Figure 4. The strategic resources identified before are represented in the SD model as 'stocks' (the rectangular boxes). Stocks are variables that represent accumulations (Cote & Nightingale, 2011). The 'households' free cash', for instance is an economic strategic resource affected by households' 'revenues' and 'expenditures'. They are represented by double arrows coming in and out of the stock. The double arrows represent the variables increasing or depleting the strategic resources. These variables are the rate at which the strategic resource grows and decreases. The households' free cash defines the 'money available for purchasing food' (the performance driver in Figure 3). Food affordability, the main goal of the system, is the result of the relation between the price of maize and the money available for purchasing food (Figure 4). Food affordability is not only a main goal of the system but also a performance driver by itself, influencing end results like the 'maize demand' and the household's 'expenditures'.



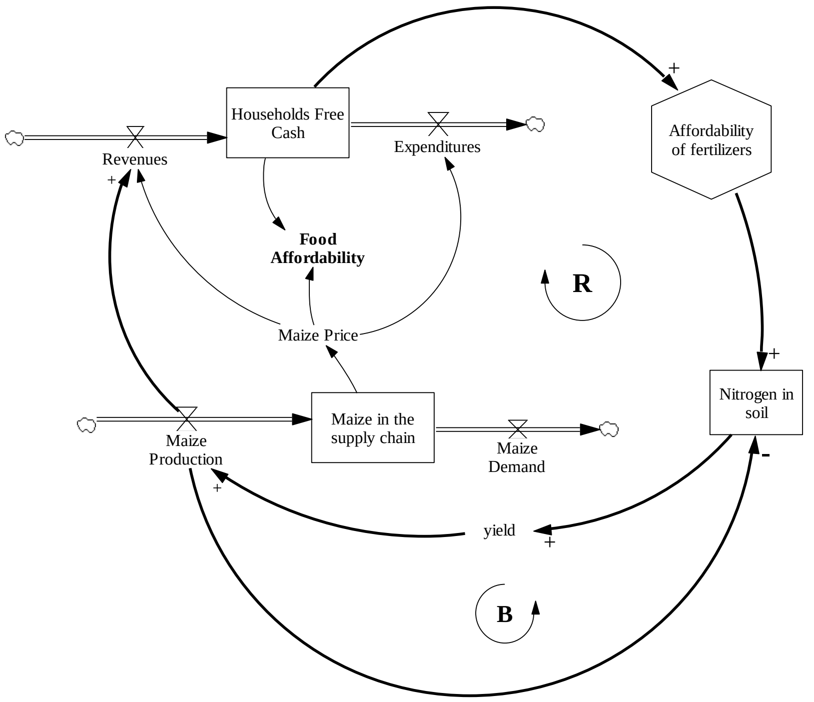

*Note: Hexagons represent structures included in the model but not presented in the figure. FTE= full time equivalent.*

*Figure 4:* Simplified stock-and-flow diagram representing the main structure of the system dynamics model build for the case study.

### *4.5 Resilience analysis*

The resilience analysis focuses on identifying slow variables and feedback loops that have an effect on the resilience of food affordability to reductions in rainfall. It is important to note that even the final goal of the policies is to increase the resilience of food affordability; this cannot increase by simply acting on this variable, but rather by enhancing the strategic resources influencing the performance drivers that define the response of food affordability to a decrease in rainfall.

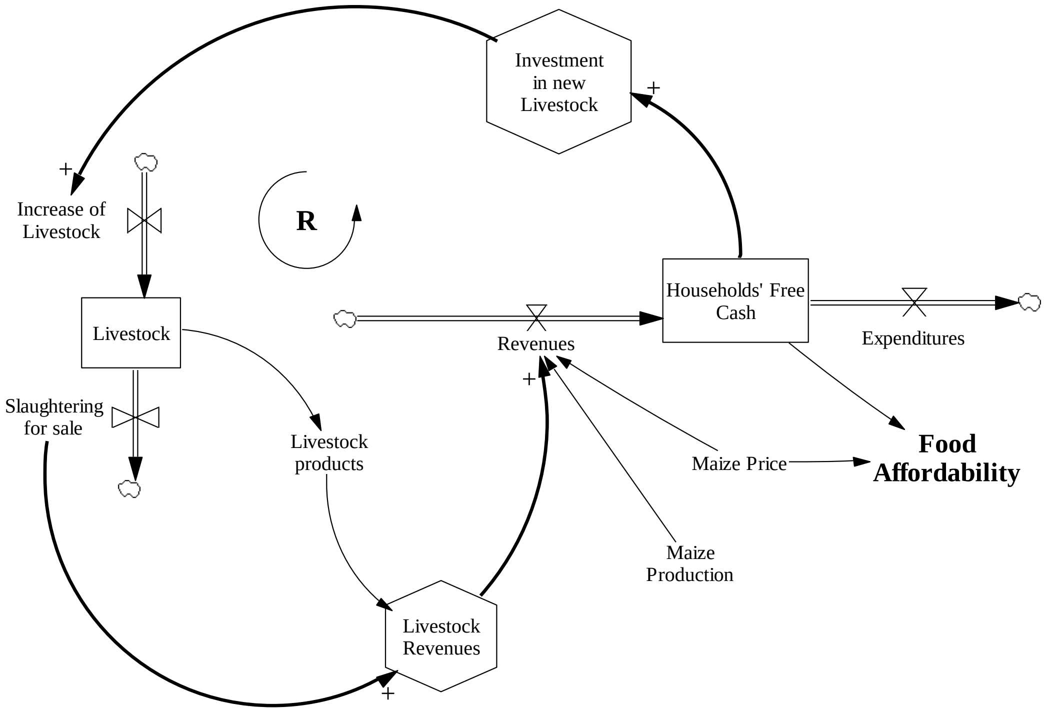
Our analysis focused on three slow variables as points of intervention, 'nitrogen in the soil', 'livestock' and 'water in reservoirs'. The nitrogen coming from organic and artificial fertilisers accumulates in the soil and is depleted by the crops absorbing it and using it to produce standing biomass (see Figure 5). The crop's yield depends to a large extent on the amount of nitrogen in the soil in a nonlinear relationship. Nitrogen in the soil can be increased by adding fertilisers to the soil or some forms of organic matter (e.g., crop residues from leguminous plants). Namely, subsidies for fertilisers were proposed as policy to increase the nitrogen in the soil.




*Note: For presentation purposes, some elements of the structure included in the model are not presented in the diagram.*

*Figure 5:* Stock-and-flow diagram representing the subsection of the model related to nitrogen in the soil.

In Huehuetenango's maize system, livestock is an important resource to generate alternative sources of revenues for households depending on maize production. Livestock can generate revenues through slaughtering then selling the meat and/or by selling products produced by the livestock (e.g., eggs, milk, etc.). The diagram in Figure 6 illustrates how 'livestock revenues', 'households' free cash' and 'livestock' are connected on a virtuous cycle. In the context of resilience, the livestock acts as a buffer in case a disturbance affects the maize production, by providing an alternative source of revenues not directly affected by that disturbance. Policy interventions can provide farmers with incentives to increase the investment in additional livestock. For instance, government can (a) provide subsidies for livestock purchases, (b) donate livestock to the household and (c) provide technical support to improve the management of the current livestock.




*Note: For presentation purposes, some elements of the structure included in the model are not presented in the diagram.*

*Figure 6:* Stock-and-flow diagram representing the performance drivers of the households' free cash.

It is worth mentioning that livestock, especially cattle, is one of the biggest sources of greenhouse gases (namely methane). Greenhouse gases are indirectly responsible for climate change effects. Policies increasing livestock might have counterintuitive consequences, diminishing resilience in the long term. To prevent these unintended results, options like small-scale organic poultry (with low methane emissions) should be prioritised over cattle.

Finally, and closely related to the disturbance, is the water in reservoirs. The water in natural basins (e.g., rivers, lakes and the soil itself) and artificial reservoirs (e.g., tanks) is a key resource for maize production (see Figure 7). Maize, being one of the most water-demanding crops, requires an appropriate and constant supply of it. The water reservoirs depend on (a) the capitation rate (the amount of water captured) and (b) the consumption rate. The capitation rate depends on the amount of rain but also the capitation capacity of the reservoir itself. Eroded soils, for instance, are ineffective at capturing the water that rains on them. In this case, the main uses of water are agriculture and domestic consumption. Considering the time scales modelled (10 years) and with the purpose of simplifying the analysis, domestic consumption is here considered constant. Alternative policies to affect the water in reservoirs are (a) to build water storage capacity to be able to capture more water when the rainfall is abundant, (b) to encourage the utilisation of maize varieties that require less water and (c) to increase the soil's capacity to retain rainfall by adding organic matter to it.

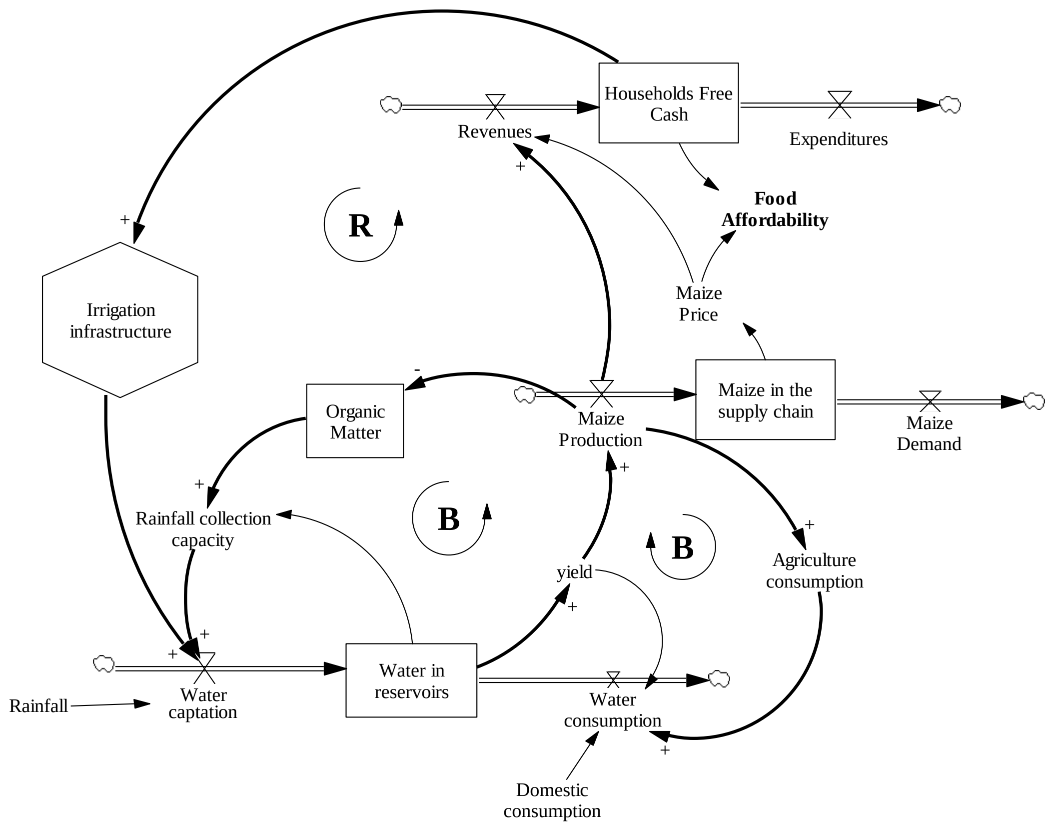



*Figure 7:* Stock-and-flow diagram representing the performance drivers of maize production

In summary, three policies were identified (a) to increase the nitrogen in the soil by encouraging the use of fertilisers (Policy 1), (b) to increase revenues livestock revenues by offering subsidies and training to farmers (Policy 2), and (c) to increase water storage capacity (e.g., cisterns) by offering financial and technical aid to vulnerable farmers (Policy 3). These three policies are simulated to assess their benefits and effectiveness. The current system and the systems including the policies proposed were simulated considering a rainfall reduction with a magnitude between 0 and 35% over a period of 5 years. The simulated behaviour is used to measure the impact of the proposed polies on the resilience as described in Section 3. The calculated values for the baseline scenario (scenario with no policy) and the proposed policies are presented in Table 3.

**Table 3.** Measures of the resilience of food affordability of the maize system in Huehuetenango

| Measure | | Baseline | Policy 1 | Policy 2 | Policy 3 |
|---|---|---|---|---|---|
| Hardness | (% annual rainfall variation) | 12% | 18% | 19% | **21%** |
| Recover rapidity | (Points of affordability index/year) | 4.12 | **6.71** | 6.65 | 5.23 |
| Robustness | (% annual rainfall variation/points of affordability index) | 0.61 | 0.88 | **0.98** | 0.85 |
| Elasticity | (% annual rainfall variation) | 34% | 43% | **73%** | 41% |
| Resilience Index | (% Probability to maintain regime) | 73% | 78% | **95%** | 68% |

*Note: Policy 1: to increase the nitrogen in the soil, Policy 2: to increase livestock revenues, Policy 3: to increase water storage capacity (e.g., cisterns).*

Different policy recommendations can be made when looking at the different performance scores in Table 3. For instance, if the aim is to enable farmers to recover quickly after a drought period, Policy 1 (to increase the nitrogen in the soil) seems more appropriate because has the higher 'recover rapidity'. Alternatively, Policy 2 (increase livestock revenues) is preferable if the aim is to have a flexible system, able to withstand extreme drought without compromising future subsistence of the farmers. Policy 2 is the one with the higher scores for 'elasticity' and 'index of resilience', both indirect measures of the system flexibility. The ambiguity of resilience requires a dialogue about the explicit goals different stakeholders have for the system and their understanding of resilience. DPM might facilitate this dialogue by offering an operational and quantifiable framework.

As good as the analysis might be, it might yield practical benefits only when the proposed policies are transformed into concrete plans. Concrete plans for the policy implementation include activities, timetables and resources needed in the process. These activities are part of the objective view summarised in the DPM diagram summarised in Figure 8. The understanding of the specific activities needed to implement each policy allows for an estimate of how much time, money and resources in general are needed for their implementation (see Figure 8). The original subjective view, including the overall goal of the system, was complemented by adding specific key performance indicators related to the important end results of each policy.

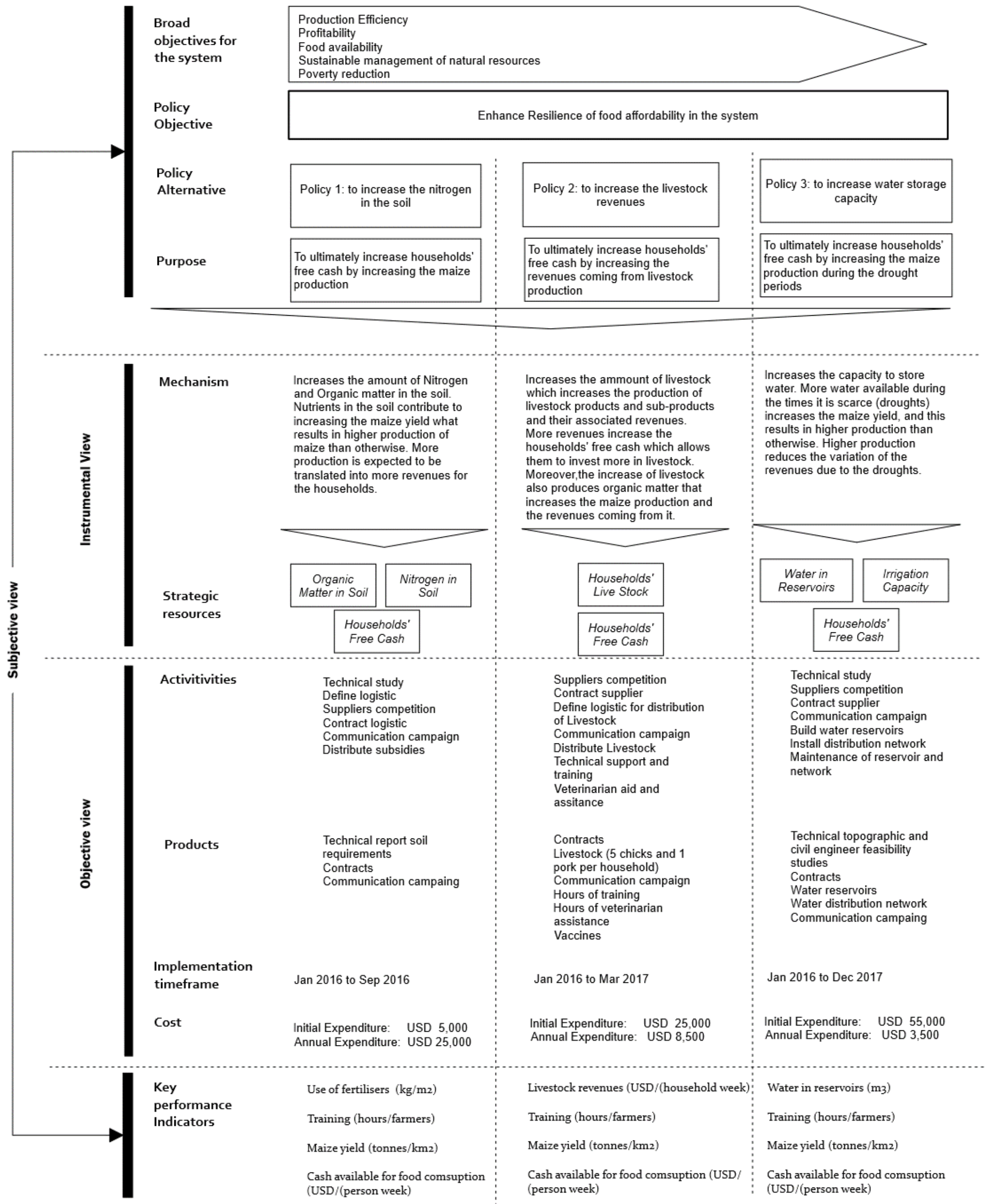



*Figure 8:* A summarised three-view description of the policies to enhance food affordability resilience identified previously in this chapter.

Policy recommendations can also be assessed by evaluating the benefits of each policy against its costs. The high-level plans shown in Figure 8 were used to estimate the costs and the net present value (NPV) of each policy. The NPV is used to account for the cost of different policies in comparable settings. NPV is also used to calculate the value-for-money ratio for each of the policies. Value for money is used as a measure of the benefits delivered by each policy versus its cost in NPV terms. The benefits delivered by each policy are the positive changes observed in the response of the outcome function to the disturbance affecting the system. These changes can be deduced from the differences in the values of each characteristic measured with the policy in place and without it.

Table 4 shows the NPV cost for each one of the three policies analysed and their value-for-money ratio (expressed in benefits per million USD). The results indicate that Policy 2 (increasing livestock reserves) is the one providing higher value for money, because it delivers more benefits per each USD invested.

**Table 4.** Net present values and value-for-money ratio for the policies proposed to enhance the resilience of food affordability in the maize system in Huehuetenango

| | | **Value for Money** (Benefits per millions of USD) | | | | |
|---|---|---|---|---|---|---|
| | **NPV (USD)** | **Hardness** | **Recover rapidity** | **Robustness** | **Elasticity** | **Resilience Index** |
| Policy 1 | 65,000 | 0.92 | **39.85** | 4.15 | 1.38 | 0.77 |
| Policy 2 | 71,000 | **0.99** | 35.63 | **5.21** | **5.49** | **3.10** |
| Policy 3 | 95,000 | 0.95 | 11.68 | 2.53 | 0.74 | *(- 0.53)* |

*Note: Value for money is calculated as the difference in the measure between the policy and the baseline divided by the NPV expended to achieve the difference. NPV calculated using a discount rate of 3.5% per year. Policy 1: to increase the nitrogen in the soil, Policy 2: to increase livestock revenues, Policy 3: to increase water storage capacity (e.g., cisterns).*

## 5. DISCUSSION

While resilience is trending in many academic fields, this chapter focuses on the practical applications of the concept of resilience in public policy design. The case study described above, even if only an example, shows that there are opportunities for bringing together in one single approach the abstraction needed to analyse resilience and the concreteness needed to implement it.

The design and implementation of policies that aim to enhance resilience requires transparent means to connect actions and effects. In a DPM approach, the link between concrete plans and the effects of resilience is transparent, because slow variables, strategic resources, performance drivers and concrete processes harmonically coexist. For instance, the slow variables identified in the analysis of resilience (nitrogen in soil, livestock, and water in reservoirs) correspond to strategic resources supporting processes driving the system's behaviour. Experts and stakeholders can smoothly navigate between concepts through different levels of abstraction. The process moves easily from policy design to implementation to measure of performance, all without risks of losing ownership or accountability in the process.

In this way, the usage of DPM uncovers opportunities to formalise resilience analysis in public administration. DPM acts as transitional tool facilitating dialogue and encouraging policymakers to (a) define resilience in terms of objective and measurable targets, (b) describe policies with regard to intermediate products and services related to concrete activities and processes and (c) analyse the system in terms of strategic resources and performance drivers.

## 6. CONCLUSIONS AND FURTHER RESEARCH

There is potential for resilience to contribute to public policymaking around climate change adaptation. However, the resilience literature so far is too abstract, and the policy recommendations are unfamiliar to the policymaking process and awkward in their implementation. There is still substantial work to do in order to effectively integrate resilience thinking into public administration.

DPM is a promising approach for bridging abstract resilience concepts with the policymaking world and public administration. The instrumental view of the DPM approach connects concrete activities and processes with abstract concepts of resilience. Namely, DPM connects through different levels of analysis, activities, performance drivers, strategic resources and slow variables, allowing navigation back and forth between the concrete policies and abstract mechanisms to enhance resilience. This transparent link between resilience and public policy domains can boost resilience as a sound framework for policymaking and climate change adaptation.

The case study described in this chapter illustrates the potential of DPM and shows how this approach can support a more robust resilience analysis able to withstand the criticism of those in control of public funds. Nevertheless, this case is only one example of the opportunities for the use of DPM, and more research is needed. Further work should include a wider range of applications, different types of stakeholder engagements and follow-up to policies implemented.

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# Interlude C

# An approach to resilience planning

The previous chapters described have discussed specifics about how to engage with stakeholders, manage the diversity of perspectives, measure resilience and link resilience in the public policy world. These are fundamental issues that so far have held back the application of resilience. To address these issues, system dynamics and its different ways to apply it (group model building and dynamic performance management) have been combined with principles described in the socio-ecological resilience with promising results.

It is time now to bring these different applications into a single, organised and coherent approach to resilience planning. Next chapter describes the approach proposed as a whole building on descriptions and conclusions in previous chapters. The chapter focuses on answering the question:

- **How can the different dimensions of resilience (stability, adaptability, transformability) been analysed?**

# Chapter 6

# Resilience planning, a facilitated modelling approach

**Keywords:** Resilience, participation, planning, food systems

**Abstract:** Resilience has emerged as a buzzword among researchers and practitioners. However, despite its popularity, there has been little progress in moving it from an elaborate metaphor describing an idyllic state of the system to a tool for planning and managing adaptation. While case study research is rich with examples of systems that have proven to be resilient or are striving to develop resilience, there is no defined approach that operationalises concepts described in the literature into the planning process. This chapter helps close this gap by illustrating how facilitated modelling can be used for resilience planning in socio-ecological systems. The chapter summarizes our experience using facilitated system dynamics to inform a model-based discussion of food security resilience to climate change in Guatemala. We identify at least three positive outcomes from the intervention, which a) helped to build consensus about the meaning of resilience, b) improved stakeholders understanding of adaptation and c) outlined potential policies to enhance resilience.

## 1. INTRODUCTION

To address climate change effects in socio-ecological systems (SESs), it is necessary to go beyond conventional policymaking approaches, and there is an urgent need to change the way adaptation is approached (Perrings, 1998; Schmidhuber & Tubiello, 2007). In response to this need, resilience has gained popularity as a new framework for planning adaptation (Davoudi, Brooks, & Mehmood, 2013; Tompkins & Adger, 2004). Resilience describes a system's capacity to absorb disturbance and to reorganise in order to adapt to new conditions (Folke, 2006; Walker et al., 2002; Walker, Holling, Carpenter, & Kinzig, 2004).

In simple terms, resilience provides insights into at least three different states of the system. First, resilience provides a useful analytical framework for identifying ways of stabilising the system's outcomes despite the presence of disturbances. Often referred to as system stability or robustness (Herrera, 2017a; Walker et al., 2004), this capacity to withstand disturbances is fundamental for mitigating risk and securing essential system outcomes such as food and water.

Second, the resilience framework can be used to explore the "ability of a system to return to an equilibrium state after a temporary disturbance" (Holling, 1973, p. 17). This ability to persist is a cornerstone for adaptation, and there is a justified interest in understanding the mechanisms that help a system recover and to do it as fast, as feasibly, and as sustainably as possible.

Finally, resilience provides insights into how systems transform when they are pushed beyond their limits (Folke, Carpenter, Walker, Scheffer, & Chapin, 2010). Transformability has been defined by Walker et al. (2004, p. 5) as "the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable". If climate conditions change beyond the system's capacity to adapt, new processes, structures and institutions will be needed for human subsistence.

While the abovementioned versatility of the resilience concept for a holistic approach to adaptation make it appealing to researchers and practitioners, its application continues to be underdeveloped (Davoudi et al., 2012; Pizzo, 2015). The lack of application is at least partially due to the complications associated with operationalising the concept of resilience and the lack of approaches for supporting policymakers in understanding resilience and the complex systems they deal with (Marshall & Marshall, 2007).

By compiling experience documented in case study research, the first steps towards such an approach have been taken. For instance, case study research suggests that planning for resilience should be informed or fully developed with stakeholder input (Walker et al., 2002). The current limited understanding about the social aspects of SESs and the high social and political stakes in these systems means that the discussion of resilience is likely to be contested and that participation is needed to democratise outcomes and reduce conflict (Biggs et al., 2012).

There are also some suggestions in the literature that these processes might involve using mathematical models for supporting resilience analysis (see, for example, Hawes & Reed, 2006; Walker et al., 2002). This assumption is justified by the difficulties in identifying thresholds and adequately anticipating the system's behaviours (Folke et al., 2010; Marshall and Marshall, 2007). Moreover, there is a long history of modelling to help manage natural resources in similar circumstances.

However, despite these first steps towards integrating facilitated modelling and resilience frameworks, there is still a ways to go (Davoudi et al., 2012; Duit, 2015). For example, the practicalities about when and how stakeholders should be involved have not been openly discussed (Duit, 2015). Similarly, while the application of models in natural resource management is extensive, their application in resilience is limited to only a few examples, and the methodological questions about how to conceptualise resilience in mathematical models remain (Davoudi et al., 2012; Marshall & Marshall, 2007).

With the aim to close these gaps in the literature, this chapter takes a step forward in integrating participatory modelling into the resilience framework. Namely, we describe how facilitated system dynamics (SD), also known as group model building (GMB), can support the process of planning for resilience in SES and specifically in food systems. SD is a modelling methodology focused on understanding the circular relationships (feedback loops) driving the outcomes of the system (Richardson, 2011). SD focuses on endogenous behaviour, making this approach an excellent candidate for simulating a system's behaviour, for learning about the system's structure and outcome drivers, and for identifying key resources. In participatory settings, an SD model is not only a realistic representation of the system studied and its outcomes but is also a "socially constructed artefact" that helps stakeholders understand the system (Andersen, Vennix, Richardson, & Rouwette, 2007, p. 692).

GMB is a "bundle of techniques used to construct SD models working directly with client groups on key strategic decisions" (Andersen et al., 2007, p. 691). The GMB intervention per se might end short of the construction of a full simulation model and focus instead on constructing diagrams that are used as social artefacts to facilitate discussion and knowledge creation (Zagonel, 2002, 2004). These diagrams are usually in the form of causal loop diagrams (CLDs) representing the variables, causal relationships and feedback loops of a system (Lane, 2008). In participatory settings, the modelling process turns into a discussion about the theories and hypotheses that explain the system's behaviour. The purpose of the discussion is not to predict behaviour but to gain an understanding about "what happens if?"

Our description and reflections are elaborated within the qualitative paradigm of case study research (Merriam, 2002; Stake, 1995) and are part of an independent model-based discussion of food security resilience to climate change in Guatemala. The purpose of the discussion is to yield practical insights about how to systemically prevent starvation and malnutrition among low-income households facing an increase in the frequency of droughts. With this purpose, different stakeholder groups (farmers, government representatives, and academics) actively collaborated through the GMB process to a) gain practical insights into the adaptive mechanisms of the food system at hand and b) identify ways to improve the resilience of food security.

While our results are exploratory, this case study illustrates how facilitated modelling helps participants carefully unfold the complexity of resilience and to dive into the underlying mechanisms that foster system adaptation. Facilitated modelling offers a road map for the resilience planning process, from defining what resilience means in the specific context to making an informed decision about systemic interventions to enhance it.

The chapter proceeds as follow. First, there is a description of the steps proposed for using GMB and SD in the planning of resilience and how they fit within the framework proposed by Walker et al. (2002). Then, the same steps are carefully described within the context of the case study addressed in this chapter. This case study description is next revised and complemented by feedback from the stakeholders participating in the process and our reflections and insights.

## 2. A FACILITATED MODELLING APPROACH FOR RESILIENCE PLANNING IN SOCIO-ECOLOGICAL SYSTEMS

We use the term "planning for resilience" (or resilience planning) to name the activities needed for analysing and managing a system so that its key outcomes are resilient to disturbances affecting the system. In simple terms, the goal of resilience planning is to prevent a system from moving to an undesired state by creating appropriate adaptation mechanisms within the system to prevent such a state. While resilience planning is embedded in the policymaking process, we do not use it in this context as a normative process. Alternatively, we propose using planning as a means for allowing stakeholders to co-discover how to adapt to and persist in the face of challenges in the environment (Holling & Gunderson, 2002; Walker et al., 2002).

During the planning for the resilience process, it is important to address specific questions such as "resilience of what?" (Carpenter & Gunderson, 2001), "resilience for whom?" (Cretney, 2014; Herrera, 2017b), "resilience to what?" and "what are the ways to build resilience?" (Walker et al., 2002). Consequently, the process is not a linear sequence of steps but a series of iterations between a) eliciting stakeholders' inputs regarding their knowledge about the system, their goals, values and needs and b)confronting them with quantitative data (historical or simulated by the model).

As a starting point for defining a facilitated approach for resilience planning, we used the working hypothesis of Walker et al. (2002) for a participatory approach to managing resilience. In our approach, we combine the steps outlined by Walker et al. (2002) to analyse resilience and standard steps of the SD modelling process (Sterman (2000)). To these steps proposed by Walker et al. (2002), we add a final step specifically focused on discussing policy implementation. The resulting process, as illustrated in Figure 1, consists of five steps: i) answering resilience of what?; ii) defining resilience to what? and developing scenarios; iii) developing a model and analysis; iv) identifying policy alternatives; and v) enacting policy implementation and management. Each of these steps is briefly described next.

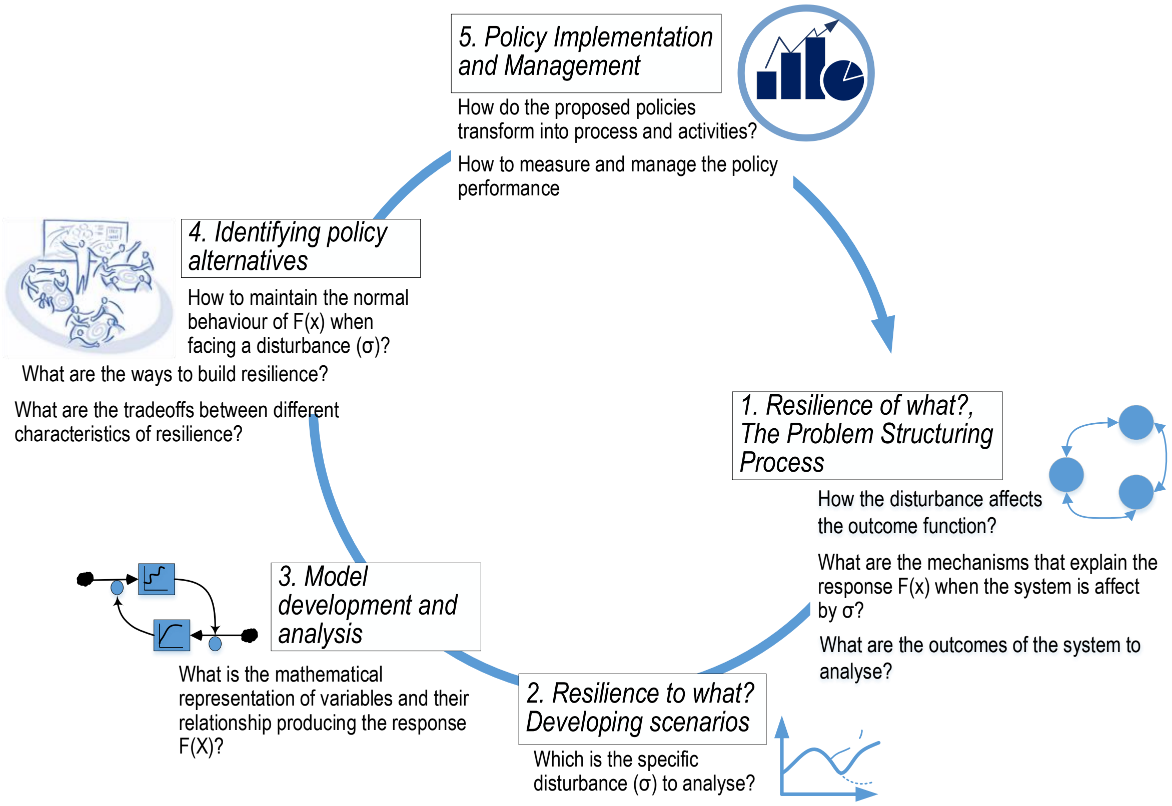


*Figure 1:* System dynamics modelling process tailored to the analysis of resilience. Adapted from (Herrera, 2017a)

### *2.1 Resilience of what? The Problem Structuring Process*

Walker et al. (2002) state that the first step in the process is to develop a "conceptual model of the SES, based strongly on stakeholder inputs". The complexity and contentiousness of resilience imply that definitions of the problem and the system cannot assumed but need to be jointly constructed by stakeholders during a problem structuring process (PSP) (Herrera, 2017b). Since the concept of resilience is flexible and open to interpretation (Duit, 2015; Tendall et al., 2015), it is important to first agree on its interpretation during the scoping of the analysis. Without an explicit discussion and agreement about what outcomes need to be resilient, stakeholders risk talking past each other during subsequent stages of the problem. The purpose of the PSP is to a) conceptualise the analysis regarding the resilience of what? and b) to agree on a causal explanation -dynamic hypothesis (J. D. Sterman, 2000) - of the mechanisms supporting the resilience of the system outcomes.

We propose using GMB as a participatory approach to facilitate the PSP. GMB is a good environment for producing what Walker et al. (2002,14) describe as a "conceptual model embodying what is known about the system regarding issues deemed important to the stakeholders, and what determines them". During the PSP, a GMB workshop offers a suitable setting for eliciting stakeholders' goals, fears and understanding of the system (Stave et al., 2017). To generate these settings, the GMB process uses a neutral facilitator to help moderate the process. It also uses a diagram, or a map, that participants can use to discuss their mental-models (implicit understanding) about resilience and the system. By encouraging the participants to represent their assumptions and knowledge in the diagram, they make these mental-models explicit. Since the explicit knowledge represented in the diagram can be shared, revised and integrated with other types of knowledge (e.g., hard data), it is expected that participants will learn from each other and develop a more robust understanding of the system and resilience in their own context.

### *2.2 Resilience to what? Developing scenarios*

In the second step, Walker et al. (2002) propose focusing on "resilience to what?" This step concerns the analyses the external disturbance to which the system is expected to be resilient. The purpose of this step is to develop a set of plausible scenarios, that is, plausible alternative futures for a system based on different assumptions about what might happen in the future (Mahmoud et al., 2009). In this context, scenarios aim to capture not only the potential behaviour of external disturbances but also the expectations stakeholders might have about the system in general (Walker et al., 2002).

While scenario analysis has become popular in resource management literature (König et al., 2012; Mahmoud et al., 2009; Swart, Raskin, & Robinson, 2004) there is no single method for performing it. There is, however, some agreement that the development of scenarios involves discussions between experts and stakeholders who work together to create a narrative of the future (Mahmoud et al., 2009).

A usual way to elicit scenarios in the GMB workshops is to use graphs-over-time (Randers, 1980). The purpose of the graphs-over-time exercise is to elicit some critical outcomes and performance drivers that will reflect the system performance over a precise time horizon (Andersen & Richardson, 1997). In the case of the analysis of resilience, the exercise can be used to ask the group participating in the workshop to draw the behaviour of a) external variables that might affect the system in a given time (disturbances) and b) key drivers and outcomes that might be affected by these disturbances. For instance, the facilitator might ask the participants about their belief about the future behaviour of rain, plagues, floods or other disruptive events and the expected behaviour of drivers and outcomes such as food production, land usage, food availability or food prices. The expected compatible behaviours drawn by participants are grouped into scenarios and are linked by narratives that describe a potential path for the future of the system.

The scenario narratives are important counterparts of a quantitative model, as they provide a perspective of critical social factors shaping the development of the system, "such as values, behaviours and institutions" (Swart et al., 2004, p. 140). Scenarios also offer an opportunity to explore transformation and how the system might transform as a result of disturbances pushing its nature beyond its limits (Walker et al., 2004, 2002a).

### *2.3 Model development and analysis*

The third steps of the approach consist of assessing the interaction of the system defined in Step 1 in the scenarios defined in Step 2. The assessment of this interaction is not straightforward. Complexity and time delays between cause and effect make it difficult for decision-makers to anticipate what might be the effect of a disturbance in relevant outcomes of the system. Simulation models help mitigate this problem by simulating the behaviour of complex systems and their feedback relationships.

In this context, we propose building the SD models based on the stakeholders' inputs gathered during Steps 1 and 2 and supported with historical data and theories available in the literature about the system. The model might be built partially behind the scenes, but it needs to be validated, fully understood and accepted by the stakeholders participating in the process. The purpose of the model is to offer a simplified but realistic representation of the system and its behaviour when facing external disturbances. Once there is sufficient confidence in the model, it can be used as an aid for identifying "thresholds, their nature, and what determines their positions along the driving variables" (Walker et al., 2002b, p. 14).

### *2.4 Identifying policy alternatives*

The next step in the analysis process is to identify policy alternatives or potential interventions that might enhance the resilience of the desired outcomes of the system to the prioritised disturbances (for the stakeholders involved) (Walker et al., 2002). We propose using the model as a virtual laboratory for testing different policies or changes in the system and to identify points or areas for intervention (Sterman, 2000). Once again, this step in the process should not be mistaken for a predictive or optimisation exercise. This step is not an attempt to identify an optimal solution but is a discussion about the rules (incentives and disincentives) that enhance the system's ability to reorganise and move within some configuration of acceptable states (Walker et al., 2002, p.14).

However, a severe difficulty in analysing and comparing alternatives to build resilience is the lack of operational measures for resilience. While resilience can be, to some extent, inferred from system proxies or the behaviour of the system, observing qualitative behaviour is not enough. When comparing different policies, it is difficult to assess their effectiveness without a quantitative indication of their contributions to resilience or a reference of how resilient the system was before the intervention. In this chapter, we used the set of resilience characteristics identified by (Herrera, 2017a). This set of measures, presented in Table 1, is defined to evaluate the resilience of outcomes in SD models and to offer an effective way to compare different alternatives. It is important to highlight that there might be trade-offs among the various characteristics of resilience, and hence, it is not possible to consider them in isolation.

**Table 1.** Measures of outcomes resilience proposed by Herrera (2017a)

| Measure | Description | Equation |
|---|---|---|
| Hardness ($\sigma_H$) | The ability of the system to withstand a disturbance σ without presenting a change in the performance of the outcome function F(x). | $(\sigma_H) = \delta_H \times (t_d - t_c)$ |
| Recover Rapidity $(\bar{R})$ | The average rate at which a system returns to equilibrium after a disturbance σ (Martin, Deffuant & Calabrese, 2011; Pimm, 1984) | $(\bar{R}) = \frac{A-B}{t_f - t_d}$ |
| Robustness $(\bar{\rho})$ | The system's ability to withstand big disturbances σ without significant loss of performance (Attoh-Okine et al., 2009) | $(\bar{\rho}) = \frac{\sigma}{A-B}$ |
| Elasticity ($\sigma_E$) | The ability of the system to withstand a disturbance σ without changing to a different steady state (Holling, 1996; Holling and Gunderson, 2002) | $(\sigma_E) = \delta_E \times (t_d - t_c)$ |
| Index of resilience ($I_R$) | The probability of keeping the current steady state or regime (Holling, 1996; Holling & Gunderson, 2002; Martin, Deffuant & Calabrese, 2011) | $(I_R) = P(\sigma \leq \sigma_E)$ |

### *2.5 Policy implementation and management*

The final step proposed is to discuss how to transform the proposed policies into implementable projects. Implementation is often one of the most cumbersome aspects of resilience (Duit, 2015). Although some practical insights can be gained using models, the often-abstract nature of the analysis means that these insights still need refinement before being implementable.

Acknowledging this shortcoming, we propose to translate insights from the model into dynamic performance management (DPM) systems that allow policymakers, particularly in the public sector, to link the model insights with concrete activities and measurable outcomes. DPM is an approach for framing the causal mechanisms underlying performance in policymaking settings by combining SD and concepts from performance management (Bianchi, 2016)

The process itself consists of identifying in the model the strategic resources (slow variables that influence the performance of the system), performance drivers (parts of the system that can be influenced) and performance outcomes (measurable outcomes that reflect the status of the system) related to each policy (Bianchi, 2016). Then, this network of strategic resources and performance drivers and outcomes are linked to a) activities and processes in the government system and b) broader goals and indicators. The result is a map that helps policymakers navigate from real processes (objective view) and feedback loop relationships (instrumental view) to high-level goals (subjective view) (Cosenz, 2014). Details about how to outline a DPM system in resilience planning are given in (Herrera, 2017c).

The aim of this step is twofold. First, it helps identify the challenges of implementing the proposed policies. For instance, what resources are needed?, which department will be responsible for what?, what are the links to existent processes?. Simultaneously, it smoothes the implementation by describing concrete performance measures that can be used to assess the realisation of benefits.

## 3. MODEL-BASED DISCUSSION OF FOOD SECURITY RESILIENCE IN GUATEMALA

Guatemala, like other developing countries, faces food security challenges that will only increase as climate change continues to affect small-scale farmers' capabilities to produce food. Guatemala's chronic malnutrition, an accepted measure of food insecurity, is the fourth worst in the world (World Food Programme, 2016), reaching 55% in rural areas (Guardiola, Gonzáles, & Vivero, 2006; World Bank, 2003). Climate change effects, such as severe droughts and increases in average temperatures already compromise the food production in Guatemala, especially among small-scale farmers (Bouroncle et al., 2015). Relying on agriculture as its primary economic activity, comprising 26% of its GDP, Guatemala's vulnerability to climate change poses a high risk to its economic and social activities.

Recognising this as problematic, studies that explore potential means to mitigate climate change effects have separately been commenced by scientists, NGOs and the government (see for example FAO, 2016; WFP, 2016). This research is part of these initiatives. It was independently conducted by the authors with the cooperation of numerous stakeholders in the dry region of the country. The purpose of the study was twofold. First, it aimed to yield practical insights about potential policies for increasing the resilience of food security in the region. Second, the study was a pilot test for the analytical method proposed in this chapter.

Prior to starting the process, with the help of local researchers and practitioners, we identified stakeholder groups that could potentially participate in the study. The groups identified were ranked according to their interest and their degree of influence in the decision-making process (see Figure 2). Regarding time and logistic constraints, of the groups identified, only those with high interest in the problem (stakeholders in quadrants 1 and 2) in Figure 2 were invited to participate in the formal process. These groups were: (a) the Central Government, (b) Jutiapa's Local Government, (c) small-scale farmers and their households and (d) academics.

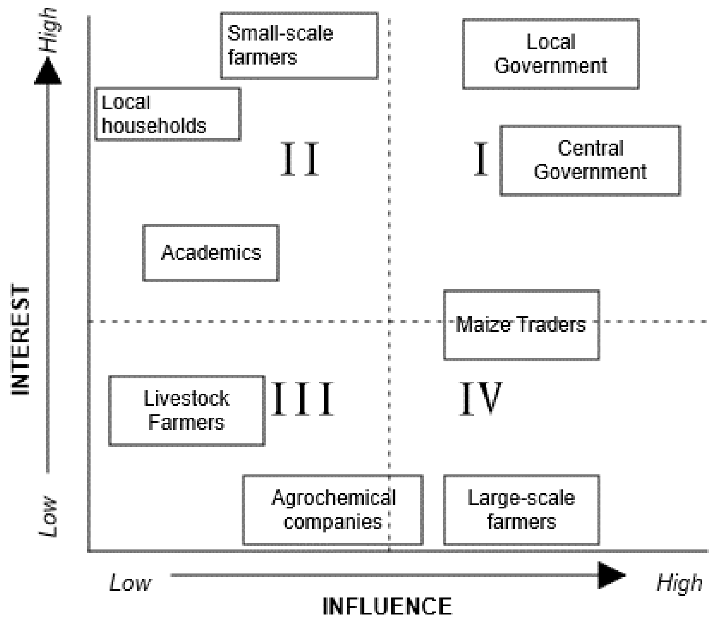


*Figure 2.* Stakeholder influence interest grid for stakeholders in Jutiapa's small-scale maize system.

Table 2 offers an overview of the steps followed during this process and described in Section 2. Next, we briefly describe each step as conducted for this specific case. Since the purpose of this chapter is to offer a replicable approach, we focus our description on the process while presenting tangible and intangible outcomes only to a level of detail needed to understand the benefits and limitations of it. We recognise that a detailed analysis of the discussions that took place during the workshop and the simulation results discussed can yield interesting insights about small-scale farming, food security and climate change adaptation. However, this detailed analysis is outside the scope of this chapter.

**Table 2.** Overview of the steps followed during the model-based analysis process of resilience.

| **Step** | **STEP 1**<br>Resilience to What? The Problem Structuring Process | **STEP 2**<br>Resilience to what? Vision and scenarios | **STEP 3**<br>Model development analysis | **STEP 4**<br>Policy alternatives | **STEP 5**<br>Policy management and implications |
|---|---|---|---|---|---|
| Purpose | To define what resilience means in operational terms. Answer the question resilience of what? | To identify what disturbance might disrupt or diminish the desired outcomes of the system (aka food security) | To produce a simulation model to analyse the system dynamics and identify thresholds, their nature, and potential leverage points. | To discuss potential policies or interventions in the system that might enhance the resilience of its outcomes. | To identify and discuss the implications and challenges of implementing the proposed policies. |
| Concrete activities | Activities in GMB workshop 1:<br>• Elicit variables (resources and drivers)<br>• Elicit causal links among resources, drivers and outcomes of the system.<br>• Discuss how the variables affect the resilience of the desired outcomes | Activities in GMB workshop 1:<br>• Identify disturbances that might affect the system.<br>• Discuss scenarios about the likelihood, magnitude and potential impacts of the identified disturbances in the system. | Build and validate simulation model.<br>Validate model and document its caveats, limitations and purpose. | Activities distributed in two GMB workshops (GMB workshops 2 and 3):<br>• Identify policy alternatives.<br>• Discuss simulation results of alternatives proposed.<br>• Discuss broader implications of policies proposed and trade-offs in other parts of the system. | Develop a performance management system.<br>• Translate the model into an "instrumental" view of the system<br>• Discuss activities and process needed to implement the proposed policies.<br>• Identify key performance indicators. |
| Tangible outcomes | Causal loop diagram describing how resilience "works". | Graphs-over-time Scenarios | Simulation System Dynamics Model | Multicriteria policy assessment | Framework for a performance management system |

*3.1 Resilience of what?*

Prior to the GMB workshop, we conducted a one-to-one session to set the scene, introduce delegates to the issue and gather information regarding different goals for the system, different understandings of resilience for their context and their initial understanding of how the system works. The interviews were followed by a three-hour GMB workshop to discuss food security resilience to climate change. Namely, participants discussed the reasons for the recent decrease (see Figure 3) in food security measured by using the proxy of average kilocalories (kcal) consumed per person per day (Vhurumuku, 2014).

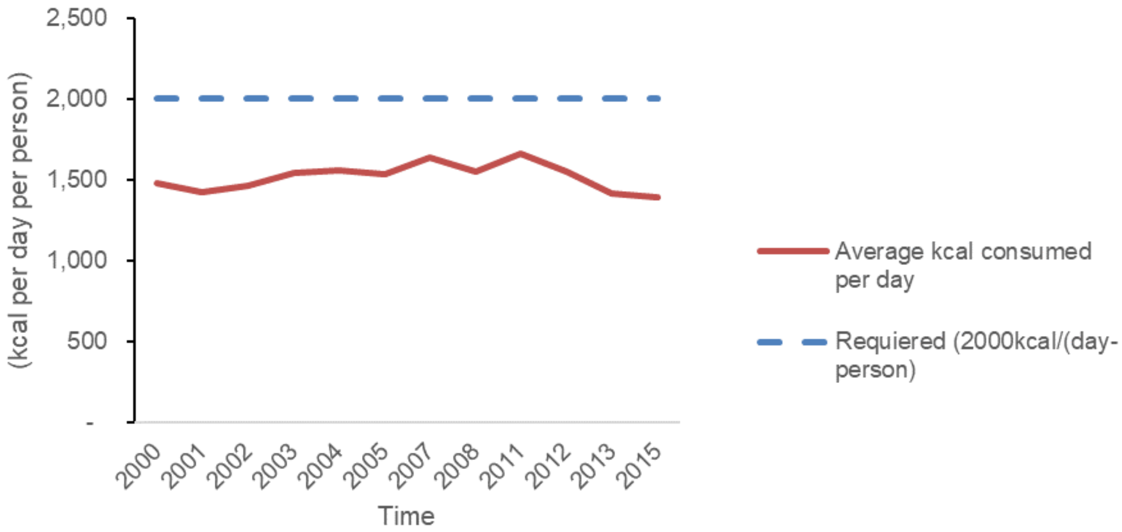


*Figure 3:* Historical behaviour of kcal consumed per capita per day in Jutiapa Guatemala. Source: SEGEPLAN(2016)

The workshops were facilitated by the first author, and they broadly followed scripts widely used in GMB workshops and described by Andersen & Richardson (1997). The workshop started with a round of introductions, presentations of the objectives for the workshop and the overall agenda. As part of the introduction, participants were asked to briefly explain what needed to be resilient and what they understood by resilience.

Next, the facilitator asked participants about the three primary outcomes of the system to achieve food security resilience. The outcomes were captured in the form of variables in a flipchart visible to the whole group. Then, the facilitator led the process of connecting the variables produced in the previous step by linking causes and effects with arrows. The purpose of this step was to use variables proposed by the group to "build an explanation of how climate change affects food security in this case". When needed, participants suggested adding intermediate variables for linking different outcomes. Once most of the variables were interconnected, the participants were asked to describe how different strategic resources were connected to each other and were encouraged to find circular causal relationships (feedback loops).

The tangible outcome of the process described above was a causal loop diagram (CLD) explaining the ways climate change affects the food security of small-scale farmers at a local level. CLDs are diagrams used to capture a broad representation of the causal relationships and feedback loops in a system (Lane, 2008). Causal relationships are represented by arrows connecting the cause with its effects. The “polarity” or nature of the causal relationship is represented by a plus (+), if the cause and effect “move” in the same direction, or a minus (-), if they “move” in opposite directions (Lane, 2008). Similarly, the polarity of the loops is identified by letters, an ‘R’ in the case of reinforcing or self-compounding loops and a ‘B’ in the case of balancing or constraining ones.

The causal relationships discussed and represented in the CLD were used to explain how climate change will affect the system and to answer the question “resilience to what?”. The CLD contains the agreed upon dynamic hypothesis or causal explanation of how the system works and how it reacts, in a structural way, to climate change. This explanation is captured in the CLD presented in Figure 4 and constitutes the initial conceptual model of the system. The thick lines in the figure highlight the main feedback loops discussed during the workshop.

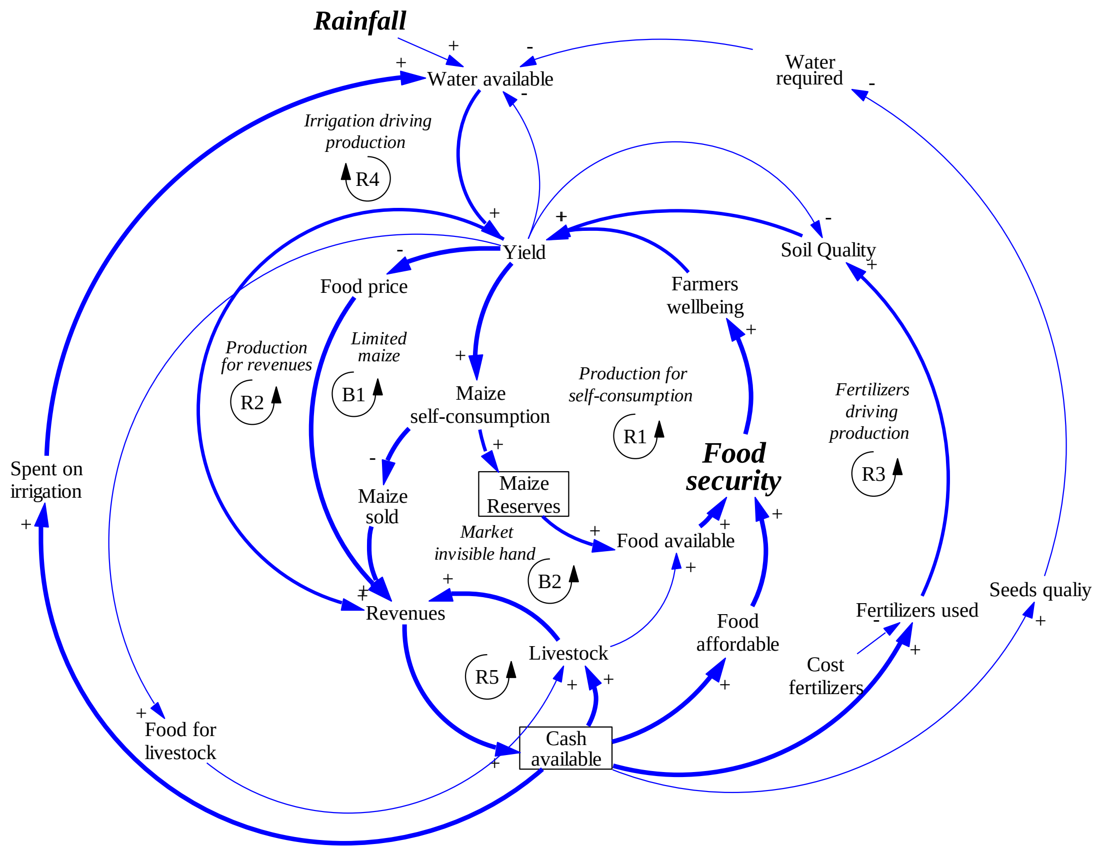


*Figure 4:* Causal loop diagram built by delegates from stakeholders in during the group model building workshop

*Note:* a plus (+) indicates that cause and effect "move" in the same direction, and a minus (-) indicates that they "move" in opposite directions (Lane, 2008). The polarity of the loops is identified by letters, an 'R' in the case of reinforcing or self-compounding loops and a 'B' in the case of balancing or constraining ones.

The resilience of food security was understood by the group as depending on two main feedback loops: *production for self-consumption* (R1) and *production for revenue* (R2), as shown in Figure 4. *Production for self-consumption* describes food security as dependent on how much of the maize produced can be allocated for self-consumption (see R1 in Figure 4). It is important to keep in mind that in rural areas of Guatemala, maize contributes up to 60% of the total calories ingested per person (Fuentes, 2002). Hence, allocating part of the production to self-consumption and being able to build reserves are essential ingredients of resilience and are critical conditions for withstanding variations in the harvests.

Food security also depends on how much food farmers can afford, meaning how much cash they have available for buying food. With a family economy based on the production of maize, cash depends almost entirely on the revenues from maize production. The relationship between revenues and food security is described by the feedback loop production for revenues (R2) in Figure 4.

These two loops (R1 and R2) highlight the importance of two key strategic resources in the resilience of the system: cash available and food reserve (see rectangles in Figure 4). These two strategic resources act as buffers during times when the yields are low, and they help farmers minimise the effect of a bad year in their food security.

Other important feedback loops to consider are those describing alternative mechanisms that (according to the participants in the workshop) might help boost the two key strategic resources identified above. The feedback loop *fertilizers driving production* (R3 in Figure 4) and *irrigation driving production* (R4) describe how cash available can be used to improve production by obtaining a) more fertiliser and b) better irrigation systems. Higher production might translate into higher revenues that eventually increase the cash available for investing in more fertiliser or better irrigation. To a minor extent, cash also depends on the feedback loop *livestock production* (R5 in Figure 4). More cash available means farmers can acquire and maintain more livestock (commonly poultry), which represents an additional source of revenue and food.

The group also identified two significant constraints for building resilience captured in two balancing loops in Figure 4. First, there is a limited amount of maize that can be produced, so farmers need to decide whether to save maize for self-consumption or to sell it in the market. The constraint on the maize produced is captured in the feedback loop *limited maize* (B1 in Figure 4). Second, and related to the previous loop, if more maize is made available to the market, the price decreases and the increase in revenue might be more modest than expected or even negligible. The dynamic between supply and demand is represented by the feedback loop *invisible market hand* (B2 in Figure 4).

### *3.2 Resilience to what? Vision and scenarios*

During the same GMB workshop 1, the facilitator asked the participants to draw graphs-over-time of the expected behaviour of food security and the drivers and outcomes contributing to it. Namely, participants were asked to pick some of these outcomes and drivers and to draw what they thought was the historical behaviour of these variables. Once they had drawn past behaviours for a small group of variables, the facilitator asked them to add to the same graph the trends they expected in the medium-term.

When participants added trends to all the graphs, they were asked to add a line representing the type of future behaviour that would be preferable for each of the variables. An example of the graphs-over-time is shown in Figure 5.

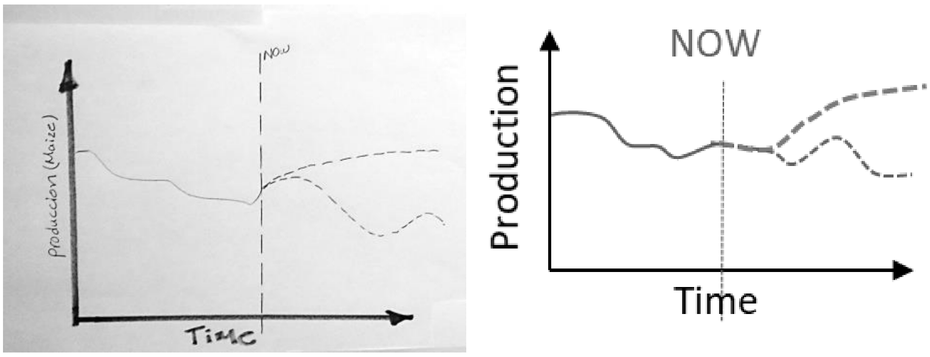


*Figure 5.* a) Picture and b) stylized representation of one of the graphs-over-time produced by the participants during the workshop.

The graphs-over-time were used during the same workshop to describe potential scenarios for the food security of small-scale farmers in the region. The facilitator asked the participants to work in small groups and to describe which disturbance or shock they thought might be responsible for the undesirable trends represented before. In case the disturbance was not already among the drivers for which the participants had drawn a graph-over-time, they were free to draw a new one. After identifying potential disturbances, each group was asked to describe how those disturbances will affect other drivers and the outcomes contributing to food security. To indicate the links between disturbances and outcomes, participants connected graphs-over-time using arrows (see Figure 6). While doing so, the facilitator encourages participants to explain and discuss with others the meaning of each arrow. When the participants concluded the exercise, they presented their diagrams and used them to describe the scenario they had constructed, explaining how a disturbance will affect the future behaviour of the system.

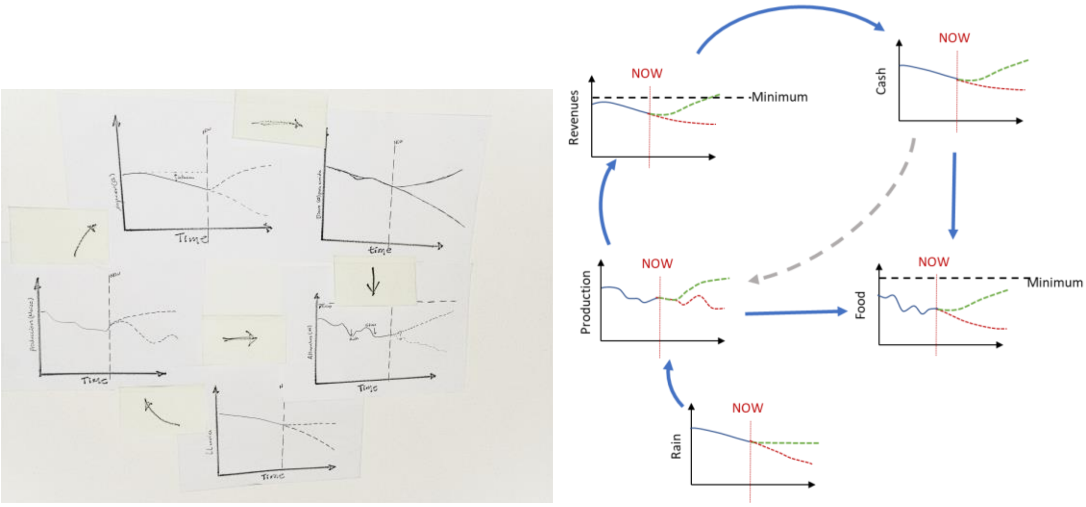


*Figure 6:* Example of the graphs-over-time prepared by the participants.

The scenarios outlined three potential development paths for the system. One alternative, outlined in the Scenario 1, is that the changes in climate conditions have already happened (see Figure 7). If the climate has already changed, from now on, the amount of rainfall will be less than before, but it will not continue to decrease. In this scenario, the farmers think that with government assistance in investing in irrigation systems, they could reorganise their farms and eventually go back to their previous productivities.

Alternatively, Scenario 2 describes a path in which rainfall will continue decreasing, thus increasing the severity of droughts in the region. This scenario would be incredibly challenging for farmers because maize is a water-intensive crop that requires much water to reach high yields (see Figure 7). This is a kind of “doomsday” scenario, and farmers think such conditions will severely threaten their survival.

Finally, Scenario 3 describes a future in which weather conditions are continually changing: severe droughts might be expected, followed by periods with abundant rainfall (probably even floods). This scenario would be challenging because farmers might lose much cash during the bad years (see Figure 7). Planning for such variability was described as a challenge. Increase poverty levels during the bad years will prevent farmers from taking advantage of the good years when yields could be higher.

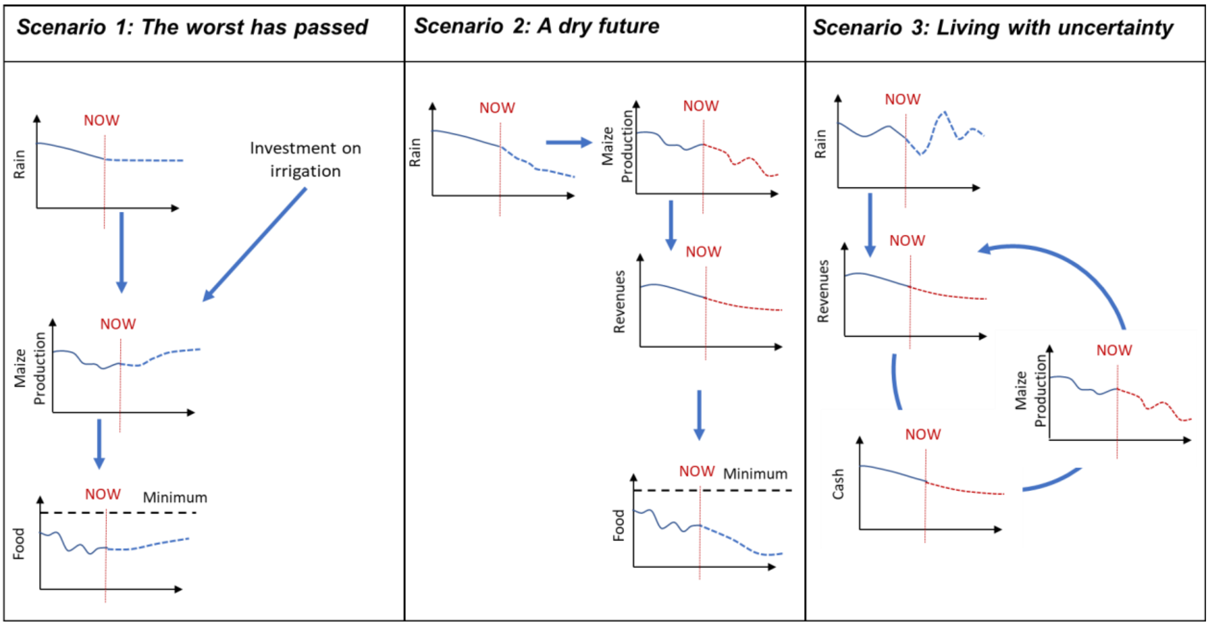


*Figure 7:* Scenarios developed during the GMB workshop using graphs-over-time.

### *3.3 Model development and analysis*

The SD model was built behind the scenes based on the inputs gathered during the first GMB workshop and was supported with statistical data and any literature available on the specific case of Jutiapa and small-scale farm systems in general. The model was built in Vensim DSS and was validated following good SD modelling practices (Barlas, 1996; Morecroft, 2015; J. D. Sterman, 2000). We devoted a considerable amount of time to working with the stakeholder delegates in one-to-one sessions to ensure the model was understood and that the relationships, data and principles included in the model were transparent. The purpose of these sessions was to discuss the following:

a) variables containing assumptions without underlying empirical information
b) simulation results produced and the causal loops producing them
c) results of sensitivity and stress tests performed in the model

The sessions also helped build confidence in the stakeholders that the model was fit for its purpose and that it appropriately represented the information available and their knowledge about the system. The exercise quickly turned into a learning process because the delegates learned about the system by reviewing and interrogating the model. At the same time, they helped to inform and refine the model with insights that were not mentioned during the GMB workshops. A detailed description of the model can be found in Appendix 2.

### *3.4 Identifying policy alternatives*

Once the model was considered fit for its purpose by the modeller and the stakeholders involved, it was used to facilitate the discussion about potential policies to enhance the resilience of food security. The discussion was conducted through two GMB workshops (2 and 3) and was supported by work behind the scenes between the workshops.

GMB workshop 2 focused on identifying policy alternatives for enhancing the resilience of the food security of small-scale farmers. The workshop, facilitated by the first author, lasted 90 minutes and consisted of two main exercises. The first half of the workshop was used to experiment with the model and to assess the effect of changing the value of certain variables on the outcomes that contribute to food security (e.g., maize price and food affordability). Changes in the outcomes were observed over a ten-year period, extending the simulation horizon until 2025. Figure 8 shows some of the simulation results presented in the workshop. It shows the expected effect, everything else remaining the same, of reducing subsidies currently provided by the government for purchasing fertiliser on the calorie intake per capita. While there is a noticeable effect on food security, the effect found was not nearly what they expected. Counterintuitive results like these sparked excited discussions about the question "what is influencing food security?"

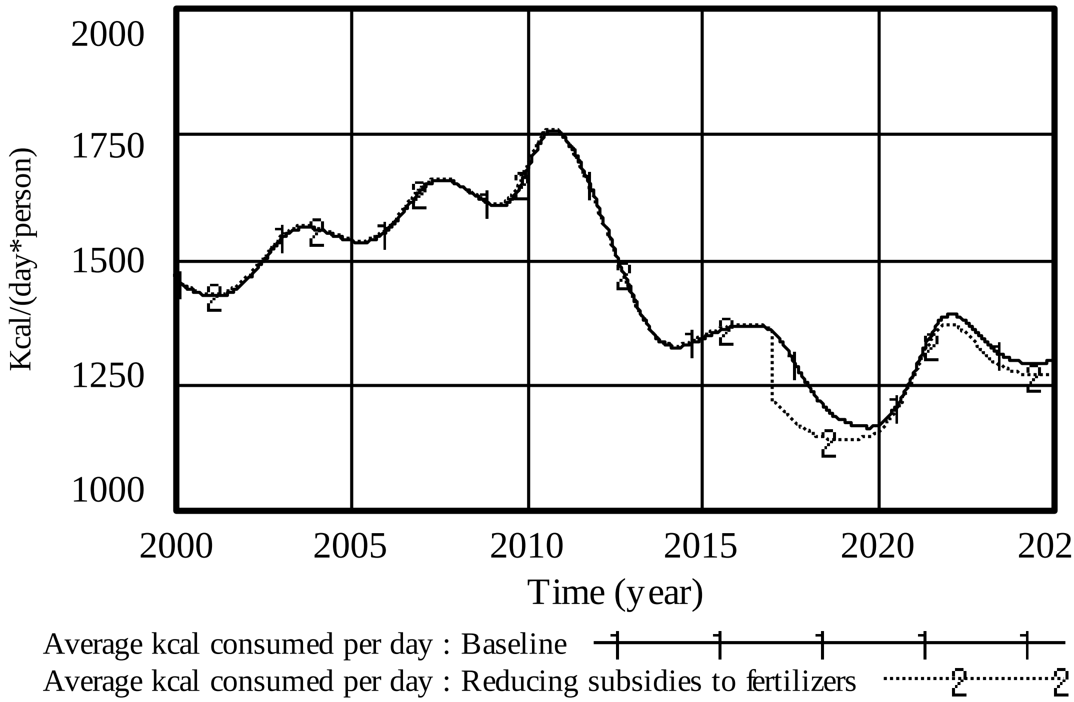


*Figure 8:* example of simulations run in the workshop to assess the effects of reducing subsidies to fertilisers by 25% in food affordability,

The second half of GMB workshop two was used to describe potential policy alternatives to enhance the resilience of food security. Participants worked in small groups for approximately 30 minutes, articulating what might be, based on their experience and the results observed in the model, the best way to enhance the resilience of food security. Then, each group briefly presented a policy they wanted to propose to the whole group. The workshop concluded by identifying a short list of three policies the stakeholders wanted to explore in detail:

1) Support households with direct revenues
2) Support the development of livestock resources
3) Increase subsidies for fertiliser

In-between the workshops and behind the scenes, the three policies proposed were added to the model. The results of introducing the different policies were assessed using simulations and were compared against the original results produced prior to introducing the policies. As described before, the impact of each policy regarding the resilience of food security was quantified using the five measures proposed by Herrera

(2017a). More details about the way each measure is calculated from the simulation results can be found in Herrera (2017a).

Previous to GMB workshop 3, and as part of the behind the scenes work, the authors engaged with the delegates of the different stakeholder groups to discuss the measures used to assess resilience. The purpose of this engagement was to have sufficient time to explain the measures proposed and their meaning in real-world settings. Simple examples were used to illustrate what the specific measures meant and to improve the stakeholders' understanding of the meaning of each measure. For instance, low robustness was compared to the system being a "nervous chicken" moving all over the place in the presence of a disturbance. Alternatively, high robustness values were compared with a "bull", impassive to the changes of the environment.

GMB workshop three was conducted to discuss the policies proposed in the previous workshop and their implications for resilience. Like the previous workshop, it lasted 90 minutes and was facilitated by the first author. The workshop consisted of three parts. During the first part (lasting approximately 45 minutes), the authors presented the impact of the policies on food security resilience regarding the five measures of resilience. When participants had questions about the results or the reasons for a particular value, the facilitator referred back to the model and used simplified CLDs to explain the reasons underlying the results.

The simulation model allowed the participants to explore and to compare the impacts of different policies on the resilience of food security. Figure 9 shows the results for policies when the system is shocked by a severe drought, like that described above in Scenario 2. Figure 9 shows that food security behaves differently when different policies are in place. For instance, granting cash support to farmers (Policy 1) and increasing fertiliser subsidies (Policy 3) improve food security in Scenario 1, while increasing livestock (Policy 2) has almost no effect on the same conditions.

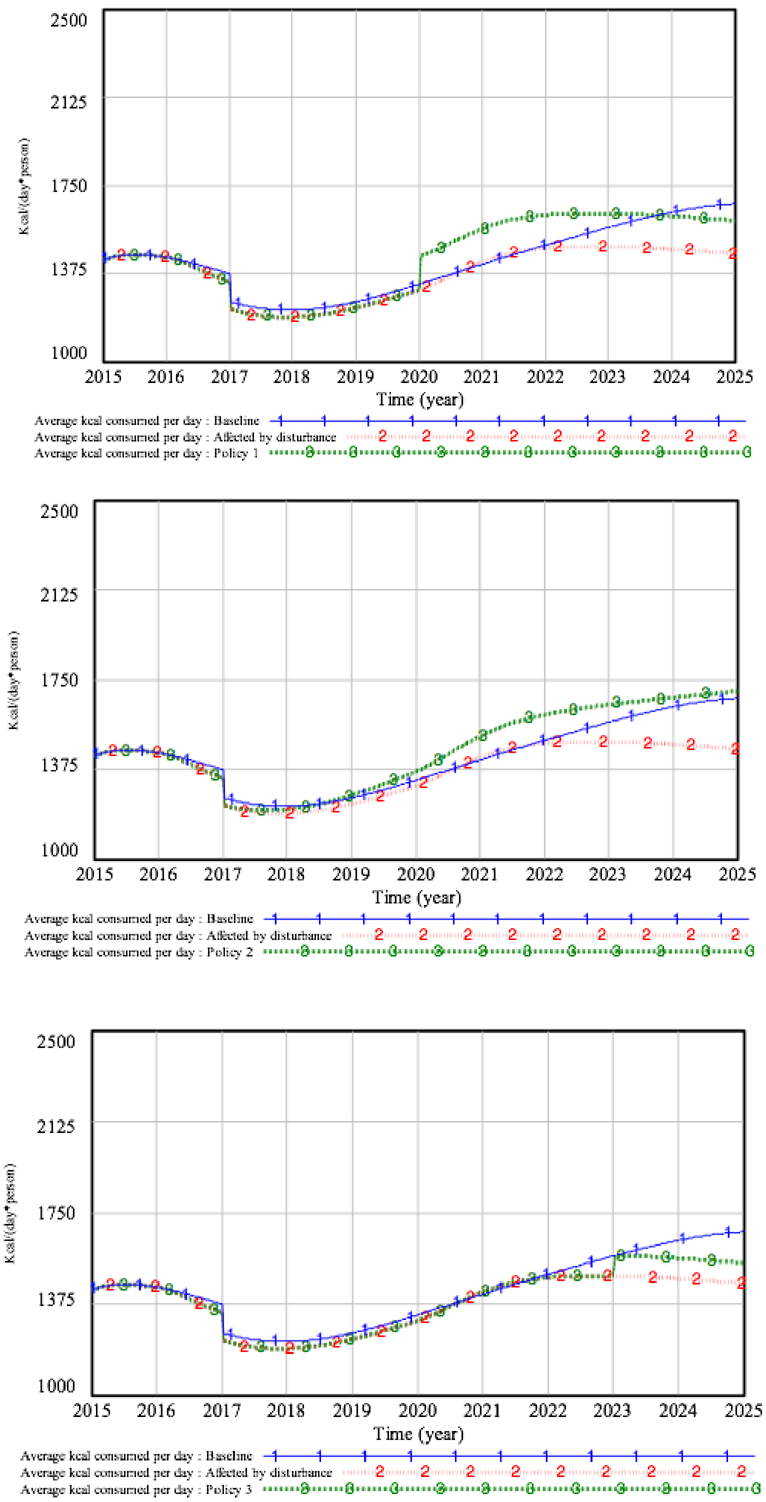


*Figure 9:* Example of simulation results used during the GMB workshop 3 to discuss implications of policies proposed. The charts show the effects of a) Policy 1: Support the households with direct revenues, b) Policy 2: Support the development of livestock resources and c) Policy 3: Increase subsidies to fertilisers, when the system is affected by an extreme drought as described in the Scenario 2 above.

Because it is difficult to compare the policies by merely looking at the simulated behaviour presented above in Figure 9, the results were further analysed and compared regarding the five measures described in Section 2 of this chapter. The results show the impacts of the different policies for a range of rainfall amounts representing the three different scenarios proposed. For this purpose, Monte Carlo simulations were created in Vensim DSS.  For more details about how to calculate the different measures using Monte Carlo simulations, please see Herrera (2017a). Table 3 shows the results of the three policies proposed.

**Table 3**. Measures of resilience

| **Measure** | | **Baseline** | **Policy 1** | **Policy 2** | **Policy 3** |
|---|---|---|---|---|---|
| **Hardness** | (average % rainfall variation) | 4% | 12% | 9% | 5% |
| **Recover rapidity** | (△%diet requirements met/year) | 0.3%/year | 0.6%/year | 0.5%/year | 0.3%/year |
| **Robustness** | (△% annual rainfall variation/(△%diet requirements met) | .04 | .08 | .07 | .06 |
| **Elasticity** | (average % rainfall variation) | 8% | 18% | 22% | 10% |
| **Resilience Index** | (% Probability to maintain regime) | .61 | .90 | .94 | .72 |

*Note:* Policies tested are, Policy 1: Support the households with direct revenues  b) Policy 2: Support the development of livestock resources and c) Policy 3: Increase subsidies to fertilisers.

The second section of the workshop was a facilitated discussion about the broader implications of each policy. For instance, it was noticed that the increase in food security resilience in Policy 3 was overall associated with an increase in the amount of planted land. The limited access to land and the poor quality of the terrain were also discussed.

In the third and final section, the facilitator asked the participants to briefly enumerate the next steps to follow in the process to move the analysis into the planning phase. The list of activities proposed was shared with all the participants and can be picked up in subsequent projects.

### *3.5 Policy implementation and management*

After GMB workshop three, the authors worked with representatives of the central and local governments, outlining DPM systems for each policy proposed. The creation of the diagrams combined work behind the scenes, with the first author drafting DPM maps, will small discussions with representatives from the government. The topics addressed during these discussions were the following:

a) what were the processes and activities needed to implement the policy?
b) how would these process fit in their current organisations and among other projects they currently have?
c) how could they measure progress and performance?
d) how will the proposed policies fit within the broader policy context?

Figure 10 shows the dynamic performance management map drafted for Policy 2. The figure shows, at a very high level, the important activities needed for implementing the policy, estimates for the resources needed and the key performance indicators that can be used to measure the policy performance.

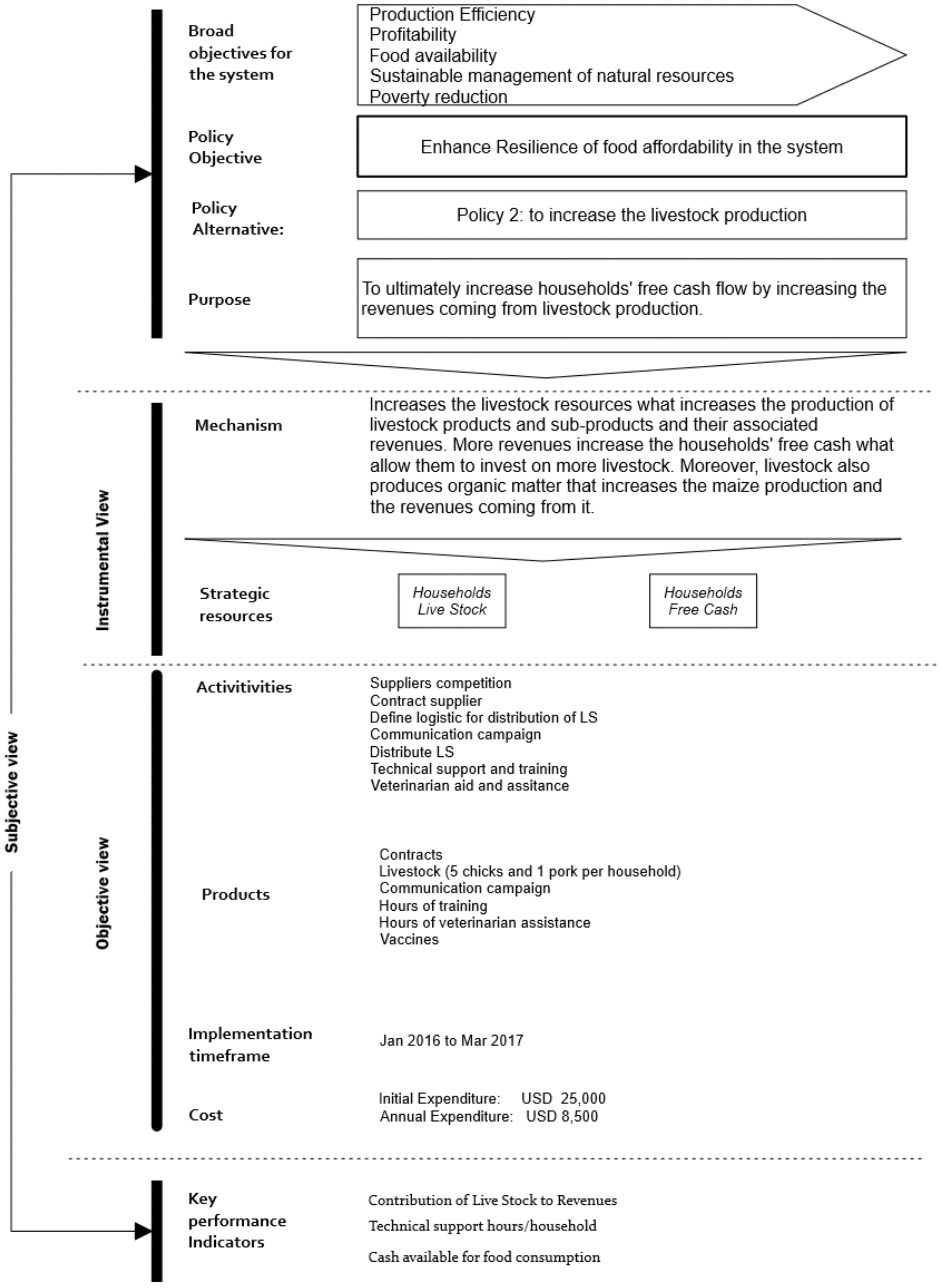


*Figure 10:* Dynamic Performance Map for Policy 2: Support the development of livestock resource

The outcomes of this final step in the process are the basis for preparing concrete project proposals. Even the transition to the implementation stage is often taken for granted; it is important to recognise that implementation is not automatic. The insights gained during the analysis will need to be transformed into concrete and feasible projects before having any impact in the real world. The usefulness of having a DPM diagram such as the one in Figure 10 should not be underestimated.

Preparing the DPM diagram helped the policymakers understand the resources needed and the feasible timescales for implementation. Additionally, the process of building the DPM diagram helped identify additional constraints and potential complications in the implementation. For instance, in the case of Policy 2 (incentivise livestock), providing appropriate veterinary assistance to all the farmers will be nearly impossible due logistical constraints. The logistics needed pose a significant threat to the policy's success, since livestock will need vaccines that have to be kept refrigerated and must be managed and transported appropriately. Without vaccines, the livestock will be susceptible to diseases, jeopardising Policy 2.

## 4. INTANGIBLE OUTCOMES

### *4.1 A joint understanding of the system and resilience*

The approach proposed in this chapter offers a formal framework for engaging with stakeholders and reaching some degree of consensus about what resilience means. The experience in Jutiapa shows that using facilitated modelling smoothed the discussion about the otherwise abstract description of resilience. In particular, building the CLD during GMB workshop one required that the participants a) make their assumptions explicit and b) discuss resilience regarding operational drivers and outcomes. By operationalising their assumptions into variables and links, the participants managed to reach some implicit level of consensus about the answers to questions such as i) what does resilience mean?, ii) what outcomes and drivers contribute to resilience? and iii) what are the boundaries of the system? The CLD and subsequent analysis reflect that to some extent, participants managed to agree on these fundamental questions while still having different opinions about what is the best policy for enhancing resilience.

Simultaneously, the inclusion of stakeholders resulted in a broader description of the system and a more robust representation of how the system works. We hypothesised that the number of feedback loops and the richness of the analysis would probably have been impossible without involving a diverse group. This hypothesis is supported by the participants' feedback regarding how the process helped them broaden their perspectives.

> *"It helped us see the complexity of the farmers' problem. It is not only about adding here or there but about how to make it work" (Delegate from Central Government)*
>
> *"I did not know how important the food reserves are for the farmers" (Delegate from Local Government)*
>
> *"The problem is complex, there are many ways to solve it, and we need to work together more" (Delegate from Central Government)*

Having a more comprehensive and more diverse understanding of the system and its potential developments is helpful in dealing with uncertainty and the always-limited understanding of SESs. By including different perspectives in the causal loop diagram, it is possible to capture relationships and feedback loops that otherwise would have been disregarded. These allow a more comprehensive model of the system that can better represent alternative and unexpected development paths for the system.

### *4.2 A more robust understanding of key resources contributing to food security resilience*

A fundamental purpose of resilience planning is to gain a more robust understanding of the key adaptation mechanisms in the system (Biggs et al., 2012). However, complex systems are cumbersome without the aid of simulations (Diehl & Sterman, 1995; Richardson, 1986; J. Sterman & Sweeney, 2002). Our experience in Jutiapa shows that a qualitative analysis might fail to identify critical strategic resources or might overestimate the impact of certain drivers on the outcomes of the system. For instance, the qualitative analysis undertaken during GMB workshop 1 using the CLD identified two key strategic resources: cash available and maize reserves. The importance of livestock became apparent only after running the simulation results and exploring Policy 2.

Participants also gained insights into the mechanisms driving the system's behaviour. At the beginning of the process, many of the stakeholders believed that revenues alone drove the system. This hypothesis was refined during the process as the other mechanisms in the system became more important to explain the simulated behaviour. The diagram in Figure 11 illustrates one of these mechanisms driving resilience that became obvious during the analysis. When rainfall decreases, less water is available for consumption. Less water has a direct impact on the amount of maize produced. A reduction in the maize produced diminishes the returns farmers will obtain from the cash they have invested in the process, reducing the cash available and simultaneously diminishing the farmers' ability to buy food and invest in the next harvest.

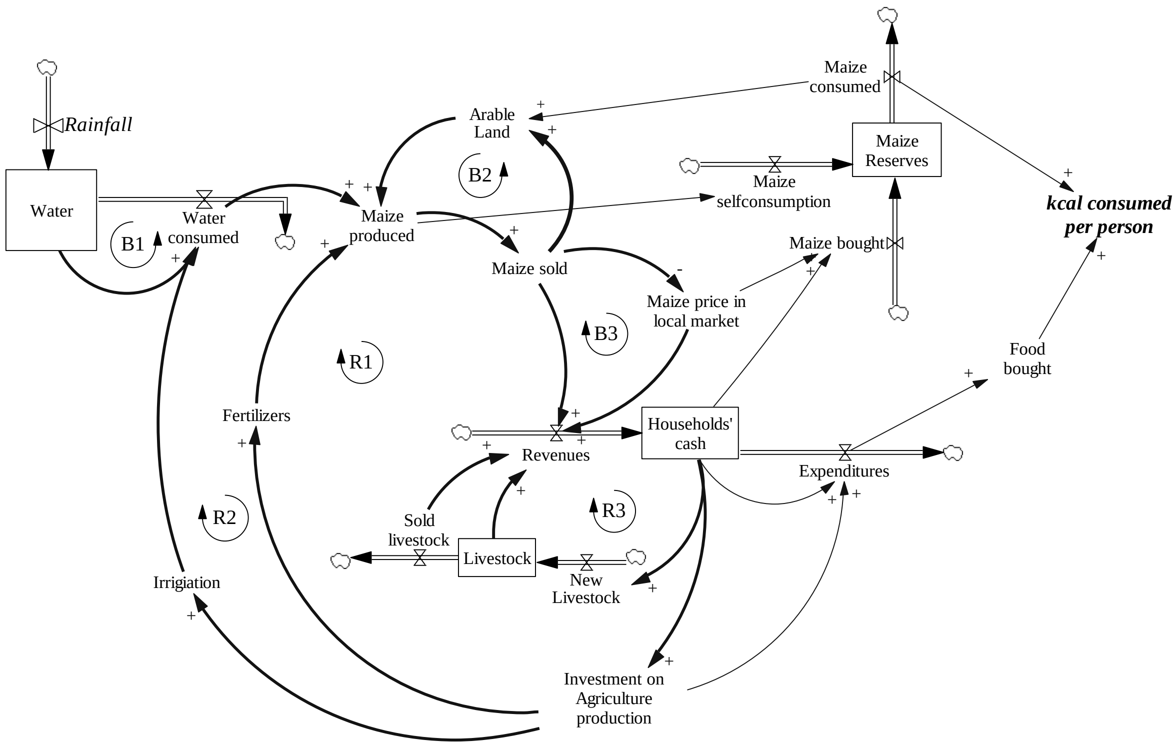


*Figure 11:* Aggregated representation of the model

For farmers, it is difficult to decide where to invest: in future harvests or food today? On the one hand, investing in future harvests compromises their subsistence and wellbeing without the certainty of producing sufficient yields in the future. On the other hand, if farmers only invest in food for the season, they are cut off from their primary source of revenue for the next year.

The implications of this investment decision concern not only the farmers but also the whole community. Since local production is cheaper than maize in the broad market, local households often prefer maize produced by neighbours than maize from other regions. A temporary reduction in cultivated land and reductions in the investment in agriculture supplies have small effects on the supply of maize. These effects are eventually compensated for by the prices in the market. However, if the loss in the harvest is too significant, farmers might be unable, without external help, to restart the production cycle. An extreme loss in the harvest could be expected in Scenarios 2 and 3, and with farmers unable to recover from the disturbances affecting the system, the whole maize system as currently known might disappear.

In the case of Scenarios 2 and 3, a resilience based purely on revenue is insufficient, and non-monetary strategic resources (e.g., maize reserves and livestock) gain importance for maintaining resilience. If these two resources are well developed, they can be used during the dry years either as a source of food (if consumed by the farmers or exchanged by food) or as a source of cash (if sold). Maize reserves and livestock can be accumulated during the good years and can serve as emergency food during rough years.

### *4.3 A conceptual framework for implementing policies*

The ultimate purpose of resilience planning is to identify and implement policies that will ultimately contribute to increasing the resilience of particular outcomes of the system. While we do not intend to use resilience planning as a prescriptive tool, for its outcomes to be meaningful, resilience planning needs to connect with the policymaking and management world. By adding the policy implementation and management step to the approach proposed by Walker et al. (2002), we try to bridge the results of an otherwise abstract analysis with the concrete steps followed in the implementation. The result is a better understanding of the feasibility of policies and the potential challenges that need to be addressed prior to their implementation by public bodies.

In our experience, having a diagram representing, even if at a high level, a DPM system for the policies proposed is a powerful way to engage with public officials and to discuss the practical implications of the process conducted. First, the DPM system translates the policies proposed into concrete actions and process that are meaningful in the public sector's language. Second, the DPM system outlines key performance indicators for measuring the realisation of benefits. It also offers an objective way to assess the value for money of the different alternatives and to select the best policy alternative. Finally, and probably more importantly, we found that the DPM system was a powerful tool to build confidence in public officials about the outcomes of the process. For instance, public officials from the local government in Jutiapa stated the following:

> *"We think we can now see how the whole discussion starts to land on concrete actions we can take to help our communities. It has been a long process, but we are finally there" (Delegate from Local Government)*
>
> *"I did not realise that resilience was such a complex concept. However, I think now we have a very clear direction of travel." (Delegate from Local Government)*

## 5. CONCLUSIONS AND LESSONS LEARNED

Resilience offers a very compelling framework to analyse the adaptive mechanisms an SES needs to adapt to climate change and other rapid and dramatic changes in the environment. Understanding these mechanisms might yield valuable insights for food system management to ensure the food security of vulnerable groups in the short- and mid-term future. However, the analysis of resilience beyond theoretical settings still lags behind, and there are no concrete and replicable analytical methods to move it into policymaking settings.

As an alternative, we have outlined in this chapter an approach for using facilitated SD in the process of planning for resilience. Despite the fact that resilience is context specific (Marshall and Marshall, 2007), we hypothesize that the general steps and activities described in the chapter apply to many contexts and systems. However, further research is needed to validate the usefulness of and improve the approach proposed in this chapter.

Our experience, summarised in this chapter, shows that facilitated SD offers a promising starting point for establishing a resilience planning approach. First, it offers a formal mean for engaging with stakeholders. Having facilitated discussions using diagrams eases the discussion about otherwise abstract concepts and fosters consensus about what resilience means in a particular context and how the system works while incorporating more-comprehensive and diverse perspectives in the analysis. This is fundamental in resilience planning, because including broader perspectives helps enhance the understanding of the system and its potential developments.

Second, a simulation model unlocks the analysis and allows a transition to quantitative comparisons using different characteristics of resilience. While the measures are illustrative, they offer a practical and quantifiable ground for comparing how specific policies affect resilience. As shown in the case discussed in this chapter, different policies excel in different characteristics of resilience under different conditions. The results produced can be used in later stages to inform an economic assessment or a multi-criteria analysis.

Note that even the second benefit is linked to tangible outcomes. The overall benefit of the proposed method is the discussion and learning that springs out of each step of the process. As shown in this chapter, participants can learn from each other and the model as they test their hypotheses about how changes in some parameters might affect the model's behaviour. The effects of these changes are not obscure; on the contrary, they are explicitly represented in the CLDs developed and discussed by and with the group. Rather than a single alternative course of action, the analysis provides policymakers with a more robust understanding of the leverage they have to enhance resilience.

Finally, combining SD and performance management in a DPM map provides a link to further and more-prescriptive steps of the policymaking process. The DPM map reconciles the conceptual discussion about the system as a whole and the policies that can be implemented with the concrete activities that need to be undertaken. While the DPM is still at a very high level, it works as a bridge between analysis and practice and offers a baseline for developing projects and public policies. This extra step towards implementation is, in our experience, helpful to engage with public officials and to build confidence in the feasibility and viability of the policies proposed.

It is important to highlight caveats of the proposed approach that still require further research. First, there is the issue of how to address transformation and changes in the system. In the presence of disturbances, systems might transform, changing their nature in ways that are difficult to anticipate in any model. Second, the method is limited in its means for representing actors in the system and their relationships. While some decisions are represented to some extent in the model, the interaction between actors is often simplified and aggregated in SD models. As an alternative, the socio-ecological literature has suggested using the model in role-play games with different stakeholder groups.

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# Chapter 7

# Conclusions

There is potential for resilience to contribute to public policymaking around climate change adaptation. However, the resilience literature so far is too abstract, and the policy recommendations are unfamiliar to the policymaking process and awkward in their implementation. There is still substantial work to do in order to effectively integrate resilience thinking into public administration.

This study contributes to unlock application of resilience planning as a framework for designing adaptive strategies to climate change in food systems by proposing to use SD as core method. The approach proposed combines simulation SD models, GMB and DPM in different steps of the planning process with the aim of a) engage with stakeholders and manage diversity and plurality of perspectives, b) foster learning about complex adaptive mechanisms in the system and c) link these lessons learned with concrete activities and process in the public administration.

First challenge to overcome in the endeavour for designing such methods is the ambiguity of resilience. Resilience openness is a challenge for practitioners that want to implement it as an analytical and policymaking framework in real life problems. This study addresses the ambiguity of resilience from a cognitive and political perspective by focusing on how resilience is interpreted in practice instead of its theoretical definition. This study argues that the interpretation of what resilience means in a specific context (resilience of what?) and the ways to achieve it are results of the values and beliefs of those with a stake in the system.

The experience working with stakeholders in Guatemala was used to illustrate this issue. To be specific, this study highlights the existence of strategic agendas and mental models as observable expressions of stakeholders' values, beliefs and knowledge about the system. The results discussed in this study, show that in practice different agendas and mental models compete during the PSP to be part of the scope of resilience analysis. The question of what needs to be resilience has many answers (revenues, yield, food supply).

The experiences presented in this thesis show that stakeholders have different understandings of how the system works. Including only a few stakeholders in the process risks leaving many important aspects out of the scope of the analysis undermining its results. Moreover, there is also the role of power shaping and filtering different interpretations of resilience into a formal scope of analysis. It is expected that those with more power will attempt to influence the Problem Structuring Process (PSP) of resilience to reflect their views and agendas. In the cases presented in this study, farmers have little influence in the PSP and their agendas might, intentionally or accidentally, be bypassed by experts (e.g. academics and researchers) and policymakers.

It is also necessary to acknowledge In short, results show that the practical meaning of resilience is socially constructed by those participating in the PSP and the way this process is conducted will affect the result of the analysis. There are at least two practical implications of underestimating resilience ambiguity while structuring the scope of the resilience analysis. First, including only a few stakeholders in the process risks leaving many important aspects of the system out of the scope of the analysis to be undertaken. Second, poor stakeholder management also risks obstructing the implementation of proposed policies and, in the worst case, unintentionally harming those in more vulnerable positions. While literature starts to acknowledge the challenges and contentious implications of power in the resilience analysis, more research is needed toward defining a framework of how to facilitate negotiation during the PSP.

If resilience is to play a significant role in climate change adaptation, policymakers should be careful when structuring the scope of the resilience analysis and should seek for broader participation. Increasing participation is not a normatively uncontroversial route either, but at least it acknowledges that resilience-based policy solutions and institutions will have distributional and, thereby, moral consequences (as most other forms of public policy).

To answer this need for participation, this study proposes to use GMB as facilitated method for managing stakeholder participation. The experience presented in this study using GMB in the PSP of resilience shows that this type of approach offers an ideal framework for including different stakeholders in the discussion. During the process participants learn about each other and become aware of the existence of different agendas and perceptions among the stakeholder groups.

The presence of a neutral facilitator and the use of a jointly built diagram, two of the key elements of any FMM, help those participating in the process to gain a more robust and holistic understanding of the system and increase awareness of the existence of different agendas and perceptions in the group. First, the facilitator set a process where all participants have the same opportunities to voice their perspectives and interpretations of the problem and the system. This prevents the conversation to be steered in a particular direction and brings different, sometimes competing, concepts to the table. Then, the task of building a joint diagram combining and connecting these concepts encourages participants to recognise how different outcomes are linked and to identify the links and overlap among the various explanations. The result is a single joint explanation, wider and more robust than those initially held by individuals.

Moving forward the examples presented in this study shows how SD modelling can be used to understand the system, identify policies and assess their impact. This study describes how to measure five fundamental characteristics of resilient behaviour formulated in the engineering and ecological resilience paradigms. Having a formal set of measures for interpreting resilience using simulated results is necessary to uncover the potential of modelling methods in resilience planning. The characteristics proposed in this study to assess resilience provide a quantitative basis to discuss, compare and select policies to enhance the resilience of SESs.

While measures are illustrative, they offer a practical and quantifiable ground for comparing what is the effect of specific policies in resilience. As shown in the cases discussed in this study, different policies excel in different characteristics of resilience under different conditions. Results produced can be used in later stages to inform an economic assessment or a multi-criteria analysis.

Note that even the this economic assessment is a tangible outcome of the process, the overall benefit of the proposed approach is the discussion and learning that springs out of each step of the process. As shown in the cases presented in this study, participants can learn from each other and the model as they test their hypothesis about how changes in some parameters might affect the model behaviour. The effects of these changes are not obscure, but contrary, they are explicitly represented in the CLDs built and discussed by and with the group. Rather than a single alternative course of action, the analysis provides policymakers with a more robust understanding of the leverages they have to enhance resilience.

Extending the use of resilience from pledges to actions is not straightforward; however, if widely applied, SD modelling can contribute to take resilience from a metaphor into practice, supporting policymakers with the insights needed to successfully adapt SESs to a changing world. Combining SD and performance management in a DPM map links these insights to the subsequent and more prescriptive steps of the policymaking process.

DPM is a promising approach for bridging abstract resilience concepts with the policymaking world and public administration. The instrumental view of the DPM approach connects concrete activities and processes with abstract concepts of resilience. Namely, DPM connects through different levels of analysis, activities, performance drivers, strategic resources and slow variables, allowing navigation back and forth between the concrete policies and abstract mechanisms to enhance resilience. This transparent link between resilience and public policy domains can boost resilience as a sound framework for policymaking and climate change adaptation.

The DPM map reconciles the conceptual discussion about the system as a whole and the policies that can be implemented with concrete activities that need to be undertaken. While the DPM is still at a very high level, it works as a bridge between analysis and practice and offers a baseline for developing projects and public policies. This extra step towards implementation is helpful to engage with public officials and to build confidence on the feasibility and viability of the policies proposed.

More research is needed to validate and better understand the results discussed in this study. For example, further research is required to validate the positive link between

FMM and learning and to identify what particular conditions during the facilitated modelling process are driving knowledge creation. While the results are bound to be exploratory, they suggest that the analysis of and planning for resilience in SES might benefit from using FMM. Having an operational framework for managing participation is a key enabler for unlocking the potential of resilience in the policymaking world, and FMM seems to offer a perfect starting point to develop a formal approach to a participatory analysis of resilience.

# Appendix 1

# Group Model Building Scripts

**SCRIPT 1: VARIABLE ELICITATION**

**Primary nature of group task:** Divergent
**Time:**
Preparation time: 0 minutes
Time required during session: 20 minutes
Follow-up time: 0 minutes
**Materials:**
1. Markers
2. Stacks of plain chapter
3. Chalk/whiteboard markers

**Inputs:** None
**Outputs:** Prioritized list of variables
**Steps:**
1. The facilitator gives each participant sheets of blank chapter and markers.
2. The facilitator writes a task-focusing question such as, "What are the key variables affecting the process and outcomes of the [project name] project?" on the whiteboard or flipchart.
3. The facilitator asks participants to write as many problem-related variables as they can on the sheets of chapter. Participants are given a few minutes to work individually on their lists.
4. Once they have finished the individual exercise, the facilitator uses the same process used in the "Hopes and Fears" script to put all individual variables on the board. When a variable name is open to several interpretations, the facilitator asks for a brief description or definition of the variable, including the units in which the variable can be measured.
5. The facilitator writes the variable name on the board, including any additional information in parenthesis.
6. The facilitator asks the participants to prioritize the variables by simple voting mechanisms. Individuals can vote for as many variables as they want. The number of votes for each variable is also written down on the board.
7. The facilitator makes a summary of the variables on the board, while the recorder captures the products of the process either photographically or in a word processor.

8. The facilitator suggests which variables can be considered stocks as they are mentioned. If the participants agree, the facilitator can add the words "level of" to these variables.

**Evaluation Criteria:** Identification of key variables and stocks

Authors: Andersen and Richardson

History: Originally described in Luna-Reyes et al. (2006).

References:

Luna-Reyes, L. F., Martinez-Moyano, I. J., Pardo, T. A., Cresswell, A. M., Andersen, D. F., & Richardson, G. P. (2006). Anatomy of a group model-building intervention: Building dynamic theory from case study research. *System Dynamics Review, 22*(4), 291-320.

## SCRIPT 2: STRUCTURE ELICITATION

This script is used to capture the key endogenous mechanisms elicited during a discussion that have the potential to explain the observed behaviors or dynamic hypotheses. This script is used after the break which follows the "Reference Mode Elicitation" script.

**Primary nature of group task:** Convergent

**Time:**

Preparation time: 20 minutes
Time required during session: 90 minutes
Follow-up time: 0 minutes

**Materials:**

1. Chalk/whiteboard markers
2. Flip chart/whiteboard

**Outputs:** Basic stock and flow structure

**Roles:**

- Facilitator
- Modeler

**Steps:**

1. During the break that follows the "Reference Mode Elicitation" script, the modeling team selects a couple of key behaviors from the reference mode elicitation exercise.
2. The facilitator starts the structure elicitation by suggesting two stocks. The facilitator explains that these stocks are initial simplifications of the system.
3. The facilitator asks the group to identify the variables that help to open or close the faucet of these two stocks. Participants suggest causal relations linked to these two initial stocks and their corresponding rates.
4. The facilitator clarifies the nature of the causal relationships with the group while drawing them on the board.
5. After adding a couple of variables and causal relations, the facilitator summarizes by telling the story embedded in the model so far. The facilitator then asks the group to add further causal explanations, stressing the importance of selective thinking about causality with the purpose of reaching a powerful and parsimonious explanation of the project success.

**Evaluation Criteria:** A basic stock-flow structure has been produced

**Authors:** Richardson and Andersen

**History:** Originally described in Luna-Reyes et al. (2006) and probably documented by Annaliese Calhoun in 2010.

## References:

Luna-Reyes, L. F., Martinez-Moyano, I. J., Pardo, T. A., Cresswell, A. M., Andersen, D. F., & Richardson, G. P. (2006). Anatomy of a group model-building intervention: Building dynamic theory from case study research. *System Dynamics Review, 22*(4), 291-320.

## Notes:

This script is based entirely on Luna-Reyes, et al.'s article. The main limitation of this script is the risk of having a discussion guided by the group facilitator. The main advantage is that it is flexible and easy to prepare. Initial aggregations can create conflict with the client group.

Usually, the facilitator or the reflector differentiates between detail complexity (many disaggregated processes) and feedback complexity (a rich feedback story with many loops), explaining that system dynamics modelers have found that it is much easier to increase the detail complexity once an appropriate level of feedback complexity has been reached than to increase feedback complexity when the desired level of detail complexity has been reached.

A very important element in the process is to write down (or erase) all group ideas on the board, even if they cannot be included easily as part of the feedback story.

## SCRIPT 3: FEEDBACK LOOP DIRECT ELICITATION

**Primary nature of group task:** Convergent

### Time:

Preparation time: 30 minutes
Time required during session: 10-30 minutes
Follow-up time: 30 minutes

### Materials:

1. Large erasable white surface (cling sheet wall or white board)
2. White board markers
3. Vensim sketch program or camera for the recorder to capture images

### Outputs:

- Feedback loops
- Articulation and mapping of feedback effects

### Steps

1. The modeler picks out a pair of variables of interest to work with first.
2. The facilitator asks the group to sketch causal influences connecting the variables.
3. The facilitator prompts the group to culminating in closed feedback loops.
4. If the participants continue sketching influences without finding a feedback loop, the facilitator might complete by himself one or two "obvious" loops to illustrate the process. This will help participant to grasp how feedback loop works.
5. After couple of iterations the facilitator walk the group through all the loops identified while asking them to add variables or causal influences if they are missing.

### Evaluation Criteria:

- Participants will "get the hang" of what feedback loops are and how they work, and they will start to look for them
- A very good map will have feedback paths that connect to important variables in the system (other than simple, first order loops). These insights that pass through other stocks are especially important.

**Authors:** David F. Andersen and George P. Richardson

### Notes:

Adapted from Andersen and Richardson (1997) with additions based on the authors experience.

## SCRIPT 4: CAPACITY RATIO EXERCISE

This script is used to elicit feedback loops (especially minor loops) and variables within a causal chain.

### Primary nature of group task: Convergent

### Time:

Preparation time: 30 minutes
Time required during session: 10-30 minutes
Follow-up time: 30 minutes

### Materials

1. Large erasable white surface (cling sheet wall or white board)
2. White board markers
3. Vensim sketch program or camera for the recorder to capture images

### Outputs:

- Feedback loops
- Articulation and mapping of feedback effects

### Steps

1. The modeler picks out a pair of stocks to work with first.
2. The facilitator asks the group to name the ratio or difference (caseload, class size, etc.). The facilitator adds the ratio or difference variable using the exact name that the group has suggested.
3. The facilitator maps the ratio (or difference variable) with the incoming arrows marked with "+" or "-" as is causally appropriate.
4. The facilitator asks, "What will happen when these two key levels get far out of alignment? How would the system react?"
5. The participants then start to tell feedback stories about how the system reacts when this key ratio (or difference) gets out of whack. When loops are completed, the facilitator traces them out for the group adding appropriate "+" or "-", telling the stories of the loops. These loops are almost always balancing loops.
6. Steps 2 through 5 are repeated with another set of variables.

### Evaluation Criteria:

- This script will usually fill a white board with lots of feedback loops very quickly
- Participants will "get the hang" of what feedback loops are and how they work, and they will start to look for them
- A very good map will have feedback paths that connect to other important stocks in the system (other than simple, first order loops). These insights that pass through other stocks are especially important.

**Authors:** David F. Andersen and George P. Richardson

**History:** This script was first developed and used by Richardson and Andersen in the 1990s, and described in Richardson and Andersen (1995).

## References:

Richardson, G. P. and Andersen, D. F. (1995), Teamwork in group model building. *System Dynamics Review*, *11*, 113–137.

## Notes

This script typically develops offline when the modeling team realizes that a strong and clear set of stocks and flows exist to under gird this system and that aging chains of usually service loads (students, patients, clients) can be linked to some resource of stocks (teachers, nurses, caseworkers) so that the pairing of related stocks makes sense. Sometimes the modeling team realizes this quite early on, such as when they have a strong hunch before the session even begins. It is a real "work horse" script, yielding lots of feedback in a reliable fashion. This is a gratifying script to use because it so often, consistently, and quickly populates the public diagram with a dense network of feedback loops.

# Appendix 2

# Questionnaire

---

**Date:** **Workshop Code:**

Answers to this questionnaire will be used to evaluate the strengths and weaknesses of the methods we have used in the workshop. You have not been asked for your name on this form, so if you have a specific question for which you want a personal response please ask before leaving today.

Thank you for your contribution to this workshop.

**SECTION 1 –GENERAL ASPECTS OF THE WORKSHOP**

1.1 How useful was this workshop for you? Please tick appropriate box.

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

1.2 What would you like to get out from this system (small scale maize production system)?

________________________________________

________________________________________

________________________________________

1.3 In this context, what resilience of food security to climate change means?

________________________________________

________________________________________

________________________________________

1.4 What are the critical success factors of policies enhancing food security?

________________________________________

________________________________________

________________________________________

## SECTION 2 – PURPOSES ACHIEVED BY THE WORKSHOP

Workshops can achieve a number of different purposes (although no one workshop can achieve all purposes). Please help us to understand what purposes were achieved in this workshop by answering the following questions:

**To what extent do you agree or disagree that the workshop has helped you to …**

Please tick appropriate box.

2.1 Put forward ideas for discussion

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

2.2 Recognise that there are many different points of view

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

2.3 Gain a better idea of the possible options for tackling the initial question of the workshop.

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

2.4 Change your mind on what ought to be done about the initial question of the workshop

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

2.5 Think more creatively about the initial question of the workshop

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

2.6 Learn more about the issues surrounding the initial question of the workshop

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

2.7 Gain a better understanding of how people's values relate to their views on the initial question of the workshop

| | | | | | |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

2.8 Challenge your previous way of thinking about the initial question of the workshop

| | | | | | |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

**SECTION 3 – NEGATIVE ASPECTS OF THE WORKSHOP**

These questions address potential negative aspects of, or things that might have gone wrong, at the workshop.

**To what extent do you agree or disagree with the following statements?**

Please tick appropriate box.

3.1 The purposes of the workshop were clear

| | | | | | |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

3.2 What was expected from me during the workshop was not clear

| | | | | | |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

3.3 There was too much talk

| | | | | | |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

3.4 Workshop discussions were free and open

| | | | | | |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

3.5 My views were not listened to

| ☐ Strongly Agree | ☐ Agree | ☐ Neutral | ☐ Disagree | ☐ Strongly Disagree | ☐ NA |
|---|---|---|---|---|---|

3.6 People worked well in a team

| ☐ Strongly Agree | ☐ Agree | ☐ Neutral | ☐ Disagree | ☐ Strongly Disagree | ☐ NA |
|---|---|---|---|---|---|

3.7 I had sufficient information to take part in workshop discussions

| ☐ Strongly Agree | ☐ Agree | ☐ Neutral | ☐ Disagree | ☐ Strongly Disagree | ☐ NA |
|---|---|---|---|---|---|

3.8 There were issues that could not be discussed

| ☐ Strongly Agree | ☐ Agree | ☐ Neutral | ☐ Disagree | ☐ Strongly Disagree | ☐ NA |
|---|---|---|---|---|---|

3.9 I felt pressured to agree with the group

| ☐ Strongly Agree | ☐ Agree | ☐ Neutral | ☐ Disagree | ☐ Strongly Disagree | ☐ NA |
|---|---|---|---|---|---|

3.10 Significant issue(s) were missed in workshop discussions

| ☐ Strongly Agree | ☐ Agree | ☐ Neutral | ☐ Disagree | ☐ Strongly Disagree | ☐ NA |
|---|---|---|---|---|---|

3.13.a.If you ticked either “strongly agree” or “agree”, please describe the issue(s):

______________________________________________

______________________________________________

______________________________________________

**SECTION 4 – RESULTS OF THE WORKSHOP**

These questions address your opinions about the future decisions to make regarding the problem.

4.1 To which extent did you agree with the final solution of the workshop?

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

4.2 To which extent do you agree with the follow statement: I feel committed with the implementation of the final solution of the workshop

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

4.3 Does the workshop help you to understand better colleagues from other areas of expertise?

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|
| Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | NA |

# Appendix 3

# Model Summary

## SUPPLY AND DEMAND

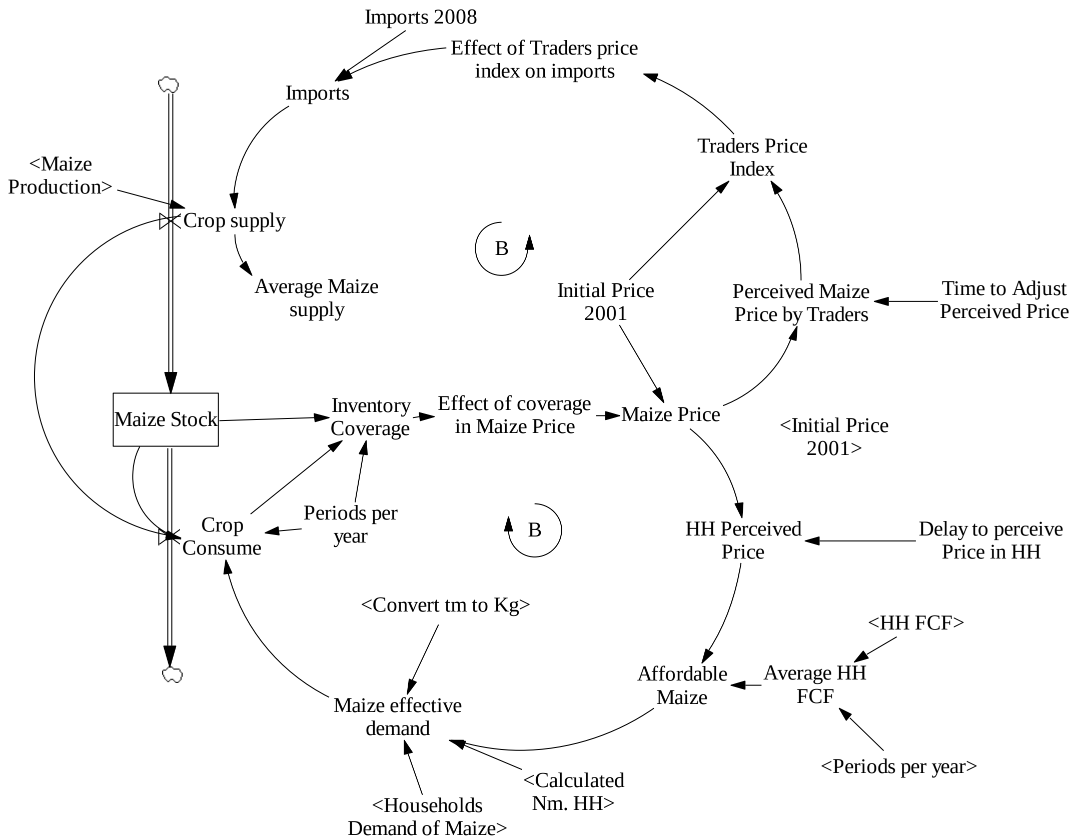

**Table A31.** Validation test applied to the model

| Type | Name | Equation | Units |
|---|---|---|---|
| Stock | Maize Stock | Crop supply-Crop Consume<br>INITIAL: Supply Chain Inventory 2001 | tm |
| Flow | Maize supply | *Maize Production* + Maize Imports | tm/year |
| Flow | Maize consumption | MIN (<br>Maize effective demand,<br>Crop supply + Maize Stock/Periods per year)<br>) | tm/year |
| Auxiliary | Maize Imports | Effect of Traders price index on imports * Imports 2008 | tm/year |
| Auxiliary | Effect of Traders price index on imports | Lookup: Maize stock coverage (<br>[(0,0)-(3,2)],<br>(0,0),(1,0),(1.2,0.25),(1.5,1),(1.75,1.35),(1.86965,1.5),(2.01018,1.6),(2.99389,1.80952)<br>) | Dimensionless |
| Auxiliary | Traders Price Index | Perceived Maize Price by Traders/(Initial Price 2001) | Dimensionless |
| Auxiliary | Perceived Maize Price by Traders | SMOOTH N (<br>Maize Price, Time to Adjust Perceived Price, Initial Price 2001,3<br>) | Q /kg |
| Auxiliary | Maize Price | Initial Price 2001 * Effect of coverage in Maize Price | Q /kg |
| Auxiliary | Effect of coverage in Maize Price | Lookup: Maize stock coverage (<br>[(0,0)(2,15)],(0.25,10),(0.5,3.7),(0.6,2.1),(0.7,1.5),(1,1),(2,0.7) ) | Dimensionless |
| Auxiliary | Maize stock coverage | Maize Stock / (Crop Consume*Periods per year) | % |
| | HH Perceived Price | SMOOTH N (<br>Maize Price, Delay to perceive Price in HH , Initial Price 2001 ,3<br>) | Q /kg |
| Auxiliary | HH Price Index | Average HH FCF in Thousand Q/(HH Perceived Price) | Dimensionless |
| Auxiliary | Average HH FCF | SMOOTH (<br>*HH FCF* , Periods per year) | Q/year |
| Auxiliary | Affordable Maize | Average HH FCF/(HH Perceived Price) | kg/(HH year) |
| Auxiliary | Maize effective demand | MIN(<br>Affordable Maize**Calculated Nm. HH / (Convert kg to tm)*,<br>*Households Demand of Maize*<br>) | tm/year |

*Note:* Variables marked in italic are calculated in a different module indicated in brackets.

## MAIZE PRODUCTION

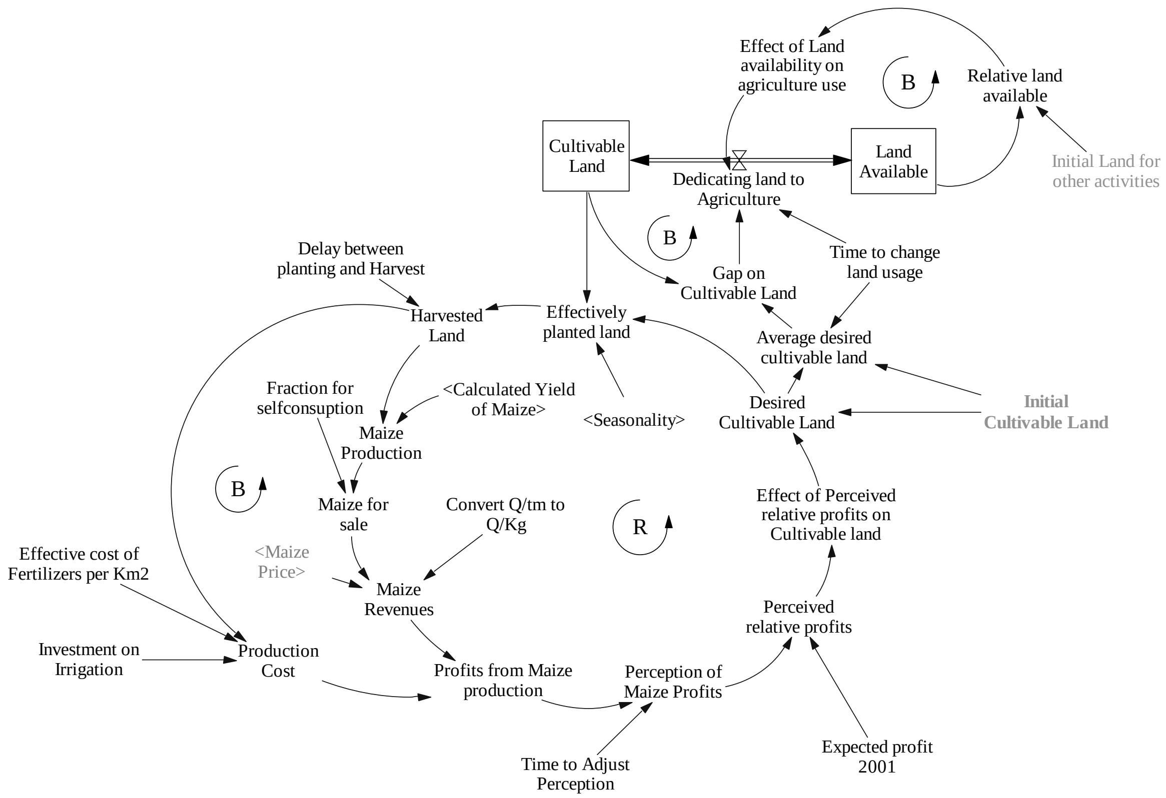


**Table A.3.2:.** Variables in the Maize Production module

| Type | Name | Equation | Units |
|---|---|---|---|
| Stock | Cultivable land | +Dedicating land to Agriculture<br>INITIAL: Cultivable land 2001 | $Km^2$/ |
| Stock | Available Land | -Dedicating land to Agriculture<br>INITIAL: Avialable land 2001 | $Km^2$/ |
| Flow | Dedicating land to Agriculture | (Gap on Cultivable Land/Time to change land usage)*Effect of Land availability on agriculture use | $Km^2$/year |
| Auxiliary | Maize production | Harvested Land**Calculated Yield of Maize* | tm/year |
| Auxiliary | Maize Revenues | Maize Price*Maize Production*Convert_Thousand_Q/tm_to_Q/Kg | Q/year |
| Auxiliary | Profits from Maize production | Maize Revenues-Production Cost | Q/year |

| Type | Name | Equation | Units |
|---|---|---|---|
| Auxiliary | Perception of maize profits | SMOOTH3( Profits from Maize production, Time to Adjust Benefits ) | Q/year |
| Auxiliary | Perceived Relative profits | Perception of Maize Profits/Expected profit 2001 | Dimensionless |
| Auxiliary | Effect of Perceived relative profits on Cultivable land | Lookup: Maize stock coverage ( [(0,0)-(4,2)], (0,0.6),(0.505092,0.819048),(0.75,0.9),(1,1),(1.25,1.25),(1.5,1.3),(2, 1.5),(3,1.75),(4,2)) | Dimensionless |
| Auxiliary | Desired Cultivable Land | Initial Cultivable Land*Effect of Perceived relative profits on Cultivable land*Seasonality | $Km^2$ |
| Auxiliary | Seasonality | Max(SIN(2*Pi*(Time+5)/Period),0) | Dimensionless |
| Auxiliary | Gap on cultivable land | Desired Cultivable Land-Cultivable Land | $Km^2$ |
| Auxiliary | Relative land available | Land Available / Initial Land for other activities | Dimensionless |
| Auxiliary | Effect of Land availability on agriculture use | Lookup: Relative land available ([(0,0)-(6000,1)],(0,0),(0.7,0.1),(0.9,0.6),(0.95,0.9),(1,1),(1.2,1) ) | Dimensionless |
| Constant | Time to change land usage | 2 | year |
| Auxiliary | Effectively cultivated land | MIN (Cultivable Land, Desired Cultivable Land) | $Km^2$ |
| Auxiliary | Harvested land | DELAY MATERIAL (Effectively planted land, Delay between planting and Harvest, Initial Cultivable Land , 0) | $Km^2$ |
| Constant | Delay between planting and Harvest | 0.50 | year |
| Auxiliary | Production cost | Effective cost of Fertilizers per Km2*Harvested Land + Investment on Irrigation | Q/year |
| Auxiliary | Effective cost of Fertilizers per Km2 | Cost of fertilizers per Km2-Subsidies to Fertilizers | Q/( $Km^2$ *year) |
| Auxiliary | Cost of fertilizers per Km2 | Fertilizer application per $Km^2$*_Price of Fertilizer_ Thousand Q per ton | Q/( $Km^2$ *year) |

*Note:* Variables marked in italic are calculated in a different module indicated in brackets

## HOUSEHOLDS MICROECONOMY

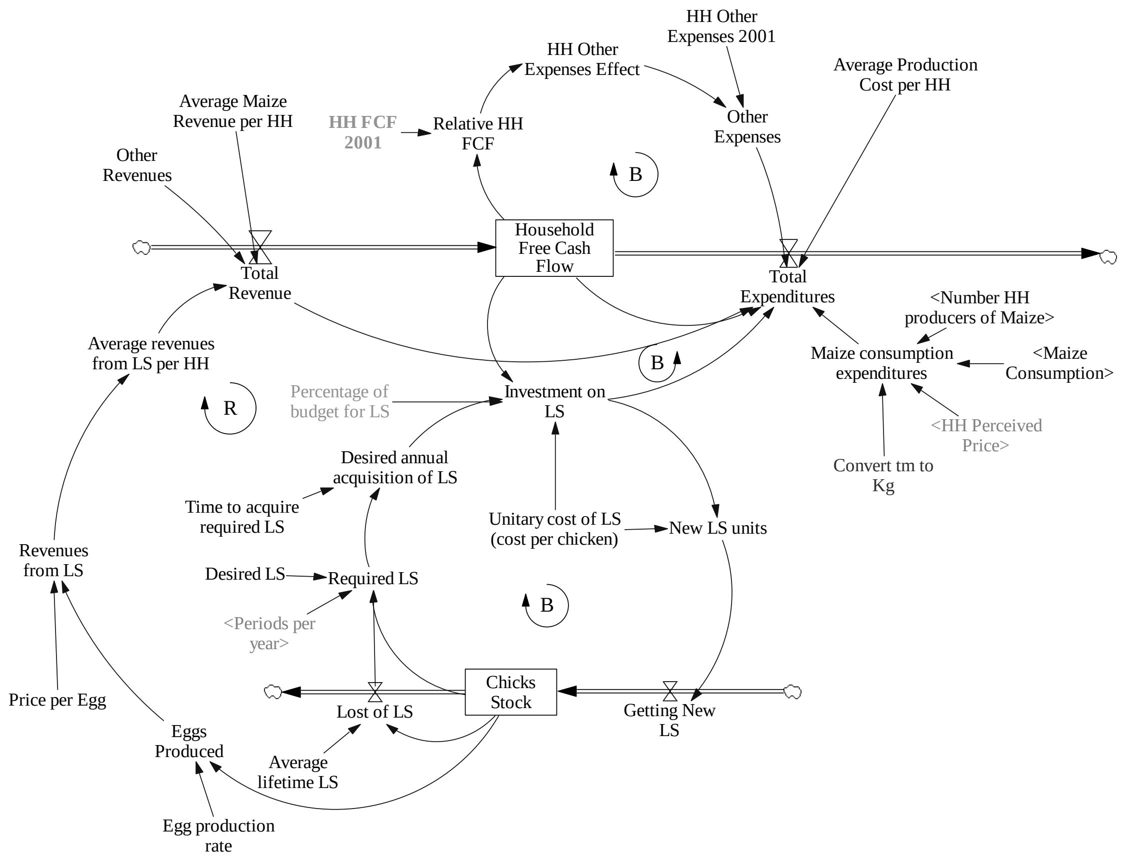


**Table A.3.3:.** Variables in the households microeconomy module

| Type | Name | Equation | Units |
|---|---|---|---|
| Stock | Households Free Cash Flow | Total Revenue-Total Expenditures<br>INITIAL: Households Free Cash Flow 2001 | Q/HH |
| Flow | Total Revenue | Average Maize Revenue per HH+ Other Revenues+ Revenues from Chicks | Q/(year*HH) |
| Flow | Total Expenditure | MIN(Average Production Cost per HH + Maize consumption expenditures+ Other Expenses+ Investment on LS,HH FCF/TIME STEP+<br>Total Revenue) | Q/(year*HH) |
| Auxiliary | Investment on LS | MIN (Desired Investment on LS* Unitary cost of LS (cost per chicken),Percentage of budget for LS*HH FCF) | Q/ HH Year) |

| Type | Name | Equation | Units |
|---|---|---|---|
| Auxiliary | New LS units | Investment on LS/Unitary cost of LS (cost per chicken) | Chicken/<br>(HH Year) |
| Auxiliary | Required LS | Desired LS + Lost of LS*Periods per year - Chicks Stock | Chicken/HH |
| Auxiliary | Desired annual acquisition of LS | Required LS/Time to acquire required LS | Chicken/<br>(HH Year) |
| Constant | Time to acquire required LS | 1 | Year |
| Constant | Desired LS | 12 | Chicken/HH |
| Constant | Unitary cost of LS (cost per chicken) | 12.5 | Q/Chicken |
| Constant | Average lifetime LS | 2 | Year |
| Auxiliary | Egg produced | Egg production rate*Chicks Stock | Egg/(HH Year) |
| Constant | Egg production rate | 42 | Egg/<br>(Chicken Year) |
| Auxiliary | Revenues from Chicks | Eggs Produced*Price per Egg | Q/(HH Year) |
| Auxiliary | Average Maize Revenue per HH | *Maize Revenues* / Number HH producers of Maize | Q/(HH Year) |
| Auxiliary | Number HH producers of Maize | Nm. HH*% HH Producing Maize | HH |
| Auxiliary | Other Revenues | % HH Producing Maize * (1-Seasonality) * Average Incomes other sources +<br>(1-% HH Producing Maize) * Average Incomes other sources | Q/(HH Year) |
| Auxiliary | Relative HH | HH FCF/HH FCF 2001 | Dimensionless |

| Type | Name | Equation | Units |
|---|---|---|---|
| Auxiliary | HH Other Expenses Effect | Lookup: Relative HH FCF<br>([(0,0)-(3,4)],(0,0),(0.75,0.4),(1,1),(2,1.15),(3,1.3) ) | Dimensionless |
| Auxiliary | HH Other Expenses | HH Other Expenses 2001*HH Other Expenses Effect | Q/(HH Year) |
| Constant | HH Other Expenses 2001 | 500 | Q/(HH Year) |
| Auxiliary | Average Production Cost per HH | *Cash Flow Agriculture* / Number HH producers of Maize | Q/(HH Year) |
| Auxiliar y | Maize consumption expenditures | *HH Perceived Price* * *Crop Consume* / Number HH producers of Maize * Convert tm to Kg | Q/(HH Year) |

*Note:* Variables marked in italic are calculated in a different module indicated in brackets

# IRRIGATION AND RAINFALL

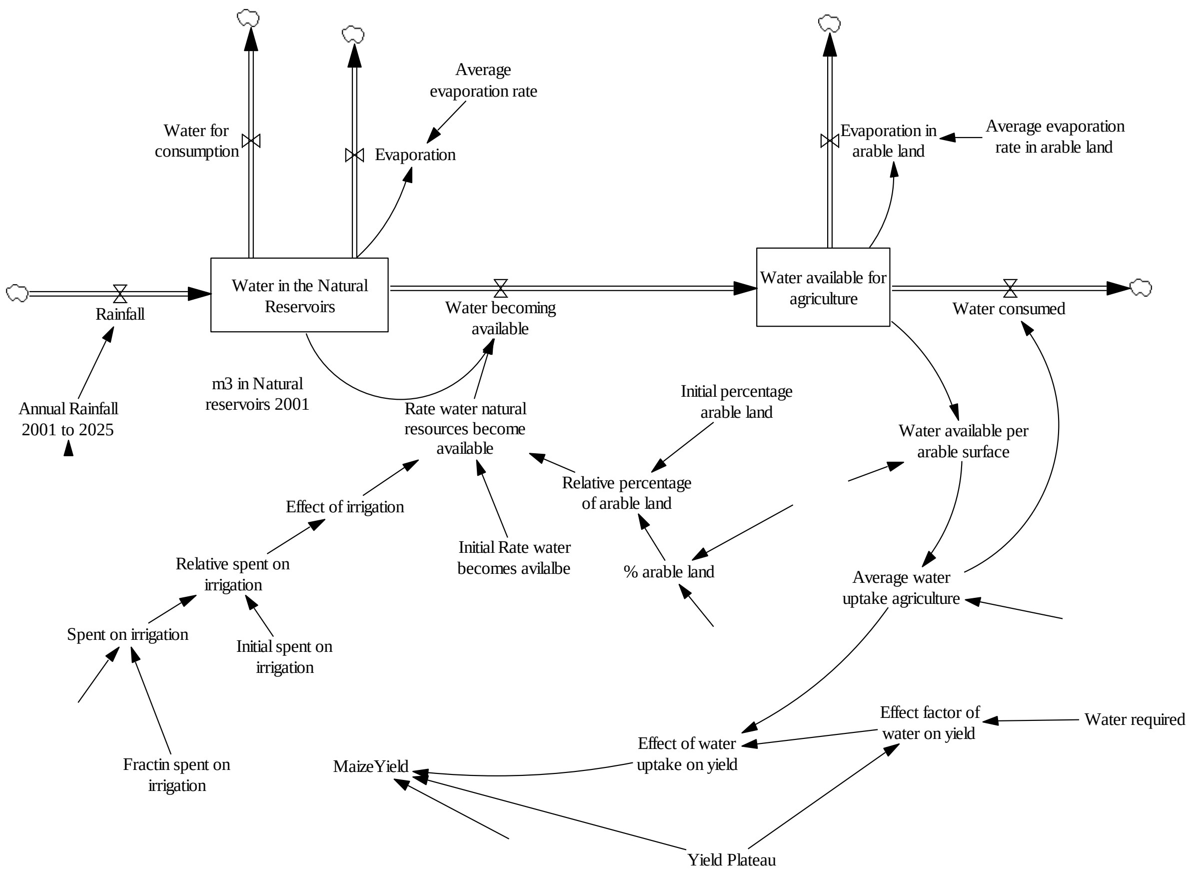


**Table A.3.4:.** Variables in the irrigation and rainfall module

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| Stock | Water in the Natural Reservoirs | Rainfall-Evaporation-Water becoming available-Water for consumption<br>INITIAL: m3 in Natural reservoirs 2001 | $m^3$ |
| Stock | Water available for agriculture | Water becoming available-Evaporation in arable land-Water consumed<br>INITIAL: 3887 | $m^3$ |
| Flow | Rainfall | Annual Rainfall 2001 to 2025 | $m^3$/year |
| DATA | Annual Rainfall 2001 to 2025 | | $m^3$/year |

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| DATA | Water for consumption | | $m^3$/year |
| Flow | Evaporation | Water in the Natural Reservoirs/Average evaporation rate | $m^3$/year |
| Flow | Evaporation in arable land | Water available for agriculture/Average evaporation rate in arable land | $m^3$/year |
| Flow | Water becoming available | Rate water natural resources become available*Water in the Natural Reservoirs | $m^3$/year |
| Auxiliary | Rate water natural resources become available | Initial Rate water becomes available*Relative percentage of arable land*Effect of irrigation | 1/year |
| Auxiliary | Effect on irrigation | Relative spent on irrigation | Dimensionless |
| Auxiliary | Relative spent on irrigation | Spent on irrigation/Initial spent on irrigation | Dimensionless |
| Auxiliary | Spent on irrigation | *Maize production costs**Fraction spent on irrigation | Q/year |
| Constant | Fraction spent on irrigation | 30% | Dimensionless |
| Constant | Initial Rate water becomes available | 0.8 | 1/year |
| Auxiliary | Relative percentage of arable land | *% arable land / Initial percentage arable land* | Dimensionless |
| Auxiliary | "% arable land | *Arable Land*/(*Arable Land*+ *Land other uses*) | Dimensionless |

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| Auxiliary | Water available per arable surface | Water available for agriculture/*Arable Land* | $M^3/Km^2$ |
| Auxiliary | Average water uptake agriculture | Water available per arable surface * *Water uptake* | $m^3$/year |
| Auxiliary | Effect of water uptake on yield | 1-10^(-Effect factor of water on yield*Average water uptake agriculture) | Dimensionless |
| Auxiliary | Effect factor of water on yield | 1/(Water required * Yield Plateau) | year*year*$Km^2$ /$m^3$ |
| Constant | Yield Plateau | 8,000 | Kg/(year*ha) |
| Auxiliary | Maize Yield | Yield Plateau*Effect of water uptake on yield*Effect of Nitrogen on Yield | Kg/( $Km^2$*year) |

*Note:* Variables marked in italic are calculated in a different module indicated in brackets

## SOIL

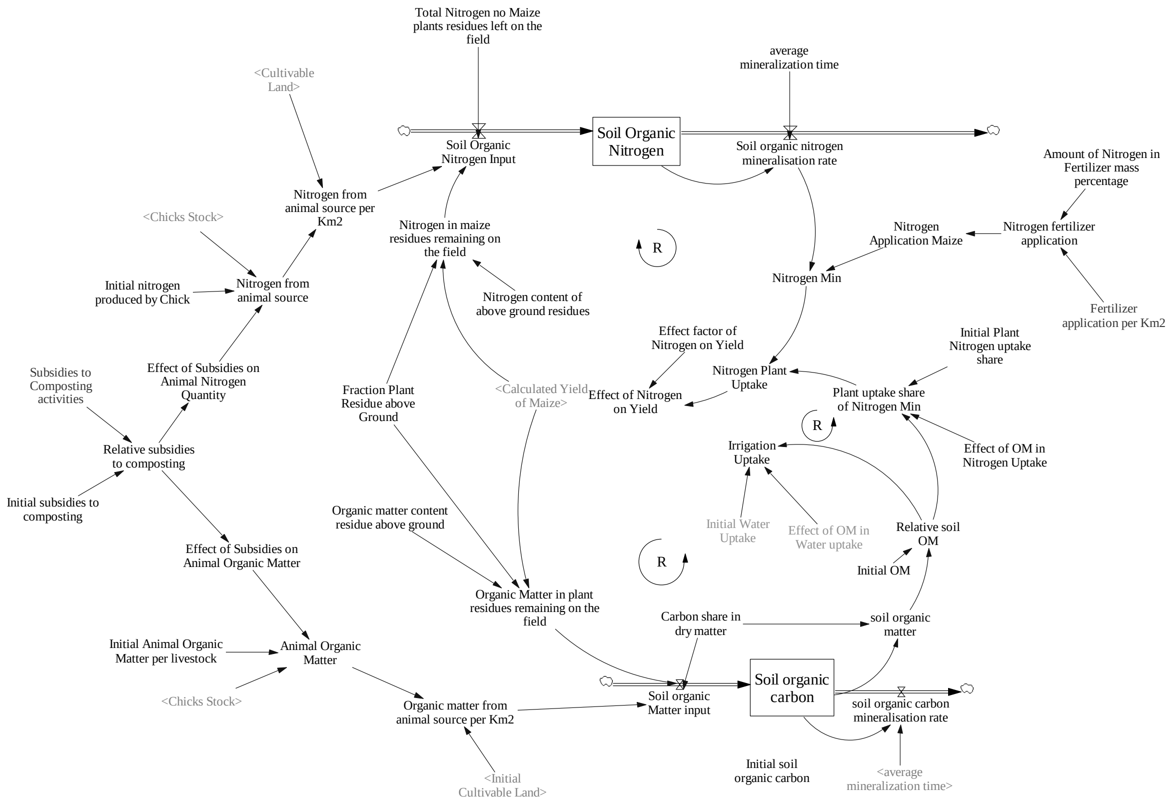


**Table A.3.5:.** Variables in the soil module

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| Stock | Soil Organic Nitrogen | Soil Organic Nitrogen Input-Soil organic nitrogen mineralisation rate<br>INITIAL: Initial Soil Organic Nitrogen | TmN /Km$^2$ |
| Stock | Soil organic carbon | Soil organic Matter input-soil organic carbon mineralisation rate<br>INITIAL: Initial soil organic carbon | |
| Flow | Soil Organic Nitrogen Input | Nitrogen from animal source per Km2<br>+Nitrogen in maize residues remaining on the field<br>+Total Nitrogen no Maize plants residues left on the field | TmN /(Km$^2$ Year) |
| Flow | Soil organic nitrogen mineralisation rate | Soil Organic Nitrogen/average mineralization time | TmN /(Km$^2$ Year) |

| Type | Name | Equation | Dimensions |
| --- | --- | --- | --- |
| Flow | Soil organic matter input | Carbon share in dry matter*(Organic matter from animal source per Km2+Organic Matter in plant residues remaining on the field) | TmC/($Km^2$ Year) |
| Flow | soil organic carbon mineralisation rate | Soil organic carbon/average mineralization time | TmC/($Km^2$ Year) |
| Constant | Average mineralization time | 35 | year |
| Constant | Initial Soil Organic Nitrogen | 5.4 | TmN /$Km^2$ |
| Constant | Total Nitrogen no Maize plants residues left on the field | 0.1 | TmN /($Km^2$ Year) |
| Auxiliary | Nitrogen from animal source per Km2 | Nitrogen from animal source/Cultivable Land | TmN /($Km^2$ Year) |
| Auxiliary | Nitrogen from animal source | Effect of Subsidies on Animal Nitrogen Quantity*<br>Nitrogen produced by Chick**Chicks Stock*Calculated Nm. HH* | TmN /($Km^2$ Year) |
| Constant | Initial nitrogen produced by Chick | 1.83e-005 | TmN /<br>(Chick Year) |
| Auxiliary | Effect of Subsidies on Animal Nitrogen Quantity | Lookup: Relative subsidies to composting<br>([(0,0)-(10,1.5)],(0,1),(1,1),(2.5,1.05),(5,1.2),(7,1.25),(10,1.25) ) | Dimensionless |
| Auxiliary | Relative subsidies to composting | Subsidies to Composting activities/Initial subsidies to composting | Dimensionless |
| Auxiliary | Initial subsidies to composting | 10,000 | Q/year |

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| DATA | Subsidies to Composting activities | | Q/year |
| Auxiliary | Nitrogen Min | Nitrogen Application Maize + Soil organic nitrogen mineralisation rate | TmN /($Km^2$ Year) |
| Auxiliary | Nitrogen Application Maize | Nitrogen fertilizer application | TmN /($Km^2$ Year) |
| Auxiliary | Nitrogen fertilizer application | Amount of Nitrogen in Fertilizer mass percentage* Fertilizer application per Km2 | TmN /($Km^2$ Year) |
| Constant | Amount of Nitrogen in Fertilizer mass percentage | 0.35 | TmN/TMF |
| DATA | Fertilizer application per Km2 | | TmF/($Km^2$ Year) |
| Auxiliary | Nitrogen Plant Uptake | Nitrogen Min*Plant uptake share of Nitrogen Min | TmN /($Km^2$ Year) |
| Auxiliary | Effect of Nitrogen on Yield | 1-10 ^ (-Effect factor of Nitrogen on Yield*Nitrogen Plant Uptake) | Dimensionless |
| Constant | Effect factor of Nitrogen on Yield | 2.5 | ($Km^2$ Year)/ TmN |
| Auxiliary | Nitrogen in maize residues remaining on the field | *Calculated Yield of Maize** Nitrogen content of above ground residues * Plant Residue above Ground | tmN/(Year*Km 2) |
| Constant | Fraction Plant Residue above Ground | 30% | % |

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| Constant | Nitrogen content of above ground residues | 0.006 | TmN/tm |
| Auxiliary | Organic Matter in plant residues remaining on the field | *Calculated Yield of Maize**<br>Organic Matter content Residue above ground*<br>Fraction Plant Residue above Ground | TmOM/<br>(Year*Km2) |
| Constant | Organic matter content residue above ground | 1 | TmOM/tm |
| Constant | Carbon share in dry matter | 0.5 | TmC/tmOM |
| Auxiliary | Organic matter from animal source per Km2 | Animal Organic Matter/*Cultivable Land* | TmOM/<br>(Year*Km2) |
| Auxiliary | Animal Organic Matter | Initial Animal Organic Matter per livestock*<br>Effect of Subsidies on Animal Organic Matter*<br>*Chicks Stock*Calculated Nm. HH* | TmOM/Year |
| Auxiliary | Effect of Subsidies on Animal Organic Matter | Lookup: Relative subsidies to composting<br>([(0,0)-(10,2)],(0,1),(1,1),(2.5,1.1),(5,1.4),(7,1.45),(10,1.5) ) | Dimensionless |
| Auxiliary | Soil organic matter | Soil organic carbon/Carbon share in dry matter | TmOM/$Km^2$ |
| Auxiliary | Relative soil OM | soil organic matter/Initial OM | Dimensionless |
| Auxiliary | Initial OM | Initial soil organic carbon/Carbon share in dry matter | TmOM/$Km^2$ |
| Auxiliary | Irrigation Uptake | Initial Water Uptake*Relative soil OM ^ Effect of OM in Water uptake | % |

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| Constant | Initial Water Uptake | 58% | % |
| Constant | Effect of OM in Water uptake | 0.55 | Dimensionless |
| Auxiliary | Plant uptake share of Nitrogen Min | Initial Plant Nitrogen uptake share* Relative soil OM ^ Effect of OM in Nitrogen Uptake | Dimensionless |
| Constant | Initial Plant Nitrogen uptake share | 0.5 | Dimensionless |
| Constant | Effect of OM in Nitrogen Uptake | 0.25 | Dimensionless |

*Note:* Variables marked in italic are calculated in a different module indicated in brackets

## SEEDS

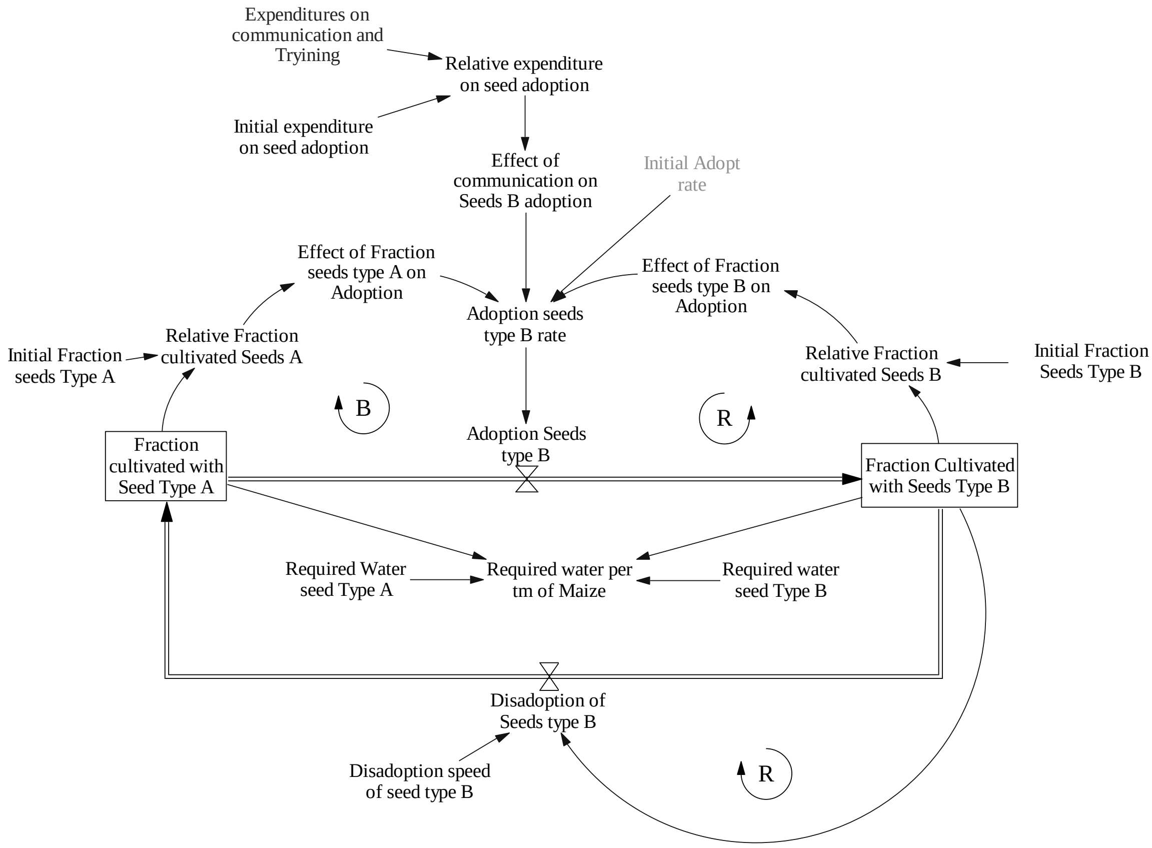


**Table A.3.6:.** Variables in the soil module

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| Stock | Fraction cultivated with Seed Type A | Disadoption of Seeds type B-Adoption Seeds type B<br><br>INITIAL: Initial Fraction seeds Type A | % |
| Stock | Fraction Cultivated with Seeds Type B | Adoption Seeds type B-Disadoption of Seeds type B<br><br>INITIAL: Initial Fraction Seeds Type B | % |
| Flow | Adoption seeds type B | Adoption seeds type B rate | %/year |
| Auxiliary | Adoption seeds type B rate | (Effect of Fraction seeds type B on Adoption-Effect of Fraction seeds type A on Adoption) *<br><br>Initial Adopt rate*Effect of communication on Seeds B adoption | %/year |

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| Constant | Initial Adopt rate | 20 | %/year |
| Auxiliary | Effect of Fraction seeds type A on Adoption | Lookup: Relative Fraction cultivated Seeds A<br>([(0,0)-(2,1)],(0,1),(0.5,0.9),(0.75,0.75),(1,0.4),(1.25,0.2),(2,0) ) | Dimensionless |
| Auxiliary | Relative Fraction cultivated Seeds A | Fraction cultivated with seed type A / Initial fraction seeds type A | Dimensionless |
| Constant | Initial fraction seeds type A | 85% | % |
| Auxiliary | Effect of Fraction seeds type B on Adoption | Lookup: Relative Fraction cultivated Seeds B<br>([(0,0)-(2,2)],(0,0),(0.5,0.1),(1,0.75),(1.5,0.95),(2,1) ) | Dimensionless |
| Auxiliary | Relative Fraction cultivated Seeds B | Fraction Cultivated with Seeds Type B/Initial Fraction Seeds Type B | Dimensionless |
| Constant | Initial Fraction Seeds Type B | 1- Initial fraction seeds type A | % |
| Auxiliary | Effect of communication on Seeds B adoption | Lookup: Relative expenditure on seed adoption<br>([(0,0)-10,3)],<br>(0,0.71),(0.275229,0.723684),(0.764526,0.789474),(1,1),(1.2844,1.17105),(1.68196,1.35526),(3.5,1.8),(5,2.15),(10,2.15) ) | Dimensionless |
| Auxiliary | Relative expenditure on seed adoption | Expenditures on communication and Training / Initial expenditure on seed adoption | Dimensionless |
| Constant | Initial expenditure on seed adoption | 56,000 | Q/year |

| Type | Name | Equation | Dimensions |
|---|---|---|---|
| DATA | Expenditures on communication and Tryining | | Q/year |
| Auxiliary | Required water per tm of Maize | Required Water seed Type A*Fraction cultivated with Seed Type A+ Fraction Cultivated with Seeds Type B*Required water seed Type B | $m^3$/tm |

*Note:* Variables marked in italic are calculated in a different module indicated in brackets