Earth's Future

RESEARCH ARTICLE
10.1029/2020EF001506

Key Points:
- This research responds to the need for identifying clear pathways to enhance subnational capacity for climate change adaptation
- Two research approaches have been combined, one for measuring the state of governance systems and one for identifying pathways

Supporting Information:
- Supporting Information S1

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Citation:
Williams, D. S., Celliers, L., Unverzagt, K., Videira, N., Máñez Costa, M., & Giordano, R. (2020). A method for enhancing capacity of local governance for climate change adaptation. *Earth's Future*, *8*, e2020EF001506. https://doi.org/10.1029/2020EF001506

Received 31 JAN 2020
Accepted 4 MAY 2020
Accepted article online 11 MAY 2020

A Method for Enhancing Capacity of Local Governance for Climate Change Adaptation

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Abstract The lack of capacity for climate change adaptation at the subnational level has been highlighted as a key barrier to implementing the UNFCCC National Adaptation Plans. At the same time, the adaptive capacity of local governance is highly context sensitive, making a "one-size fits all" approach inappropriate. Thus, a versatile methodological approach for application in various local contexts is required. There are several indicator-based local governance assessment methods for evaluating the effectiveness of local governance for climate change adaptation. However, they fall short of identifying and prioritizing between key factors within local governance for enhancing adaptive capacity and driving positive change. Building on adaptation theory, the authors propose combining two methodological approaches, the Capital Approach Framework for evaluating the adaptive capacity of local governance and Fuzzy Cognitive Mapping for identifying leverage points, into one integrated modeling approach, which can be applied by local researchers. This paper describes the process and benefits of combining the methodological approaches, with an example provided as supporting information. Assisting decision-makers and policy planners from subnational governance in identifying leverage points to focus and maximize impact of capacity-enhancing measures would make a key contribution for successful implementation of the UNFCCC National Adaptation Plans.

1. Introduction

The current and projected impacts of global warming emphasize the urgency of enhancing governance systems for responding to climate change (The Intergovernmental Panel on Climate Change, IPCC, 2018; Hoegh-Guldberg et al., 2019). Understanding and supporting governance processes for responding to the environmental and societal impacts of climate change is therefore a key challenge to be addressed in the 21st century (Brasseur & Van Der Pluijm, 2013). The UNFCCC National Adaptation Plans (NAPs) are viewed as one of the key drivers for advancing this global response, particularly in low-income regions disproportionately affected by climate change impacts.

The NAPs are a mechanism for guiding the implementation of climate change adaptation (The Intergovernmental Panel on Climate Change, 2018) by "enhancing adaptive capacity, strengthening resilience, and reducing vulnerability with a view to contributing to sustainable development and ensuring an adequate adaptation response" in line with Article 7 of the Paris Agreement (United Nations Framework Convention on Climate Change, UNFCCC, 2015a, 2015b). Specifically, the NAP process aims at facilitating effective implementation of climate change adaptation actions at the national and subnational level (UNFCCC, 2012). It further intends to enable national and subnational stakeholders to identify and address medium- and long-term priorities for responding to climate change (UNFCCC, 2015a, 2015b).

During the negotiations at COP25 in Madrid, the idea of utilizing the NAPs for enhancing NDC adaptation commitments, allowing to mainstream adaptation targets across national and subnational levels was discussed (NAP Global Network, 2019). However, when country delegations were asked to name the key barriers to NAP implementation, they highlighted the lack of capacity at the subnational level. Furthermore, the need for developing efficient and community-driven approaches or methods to enhance adaptive capacity at the subnational level was emphasized.

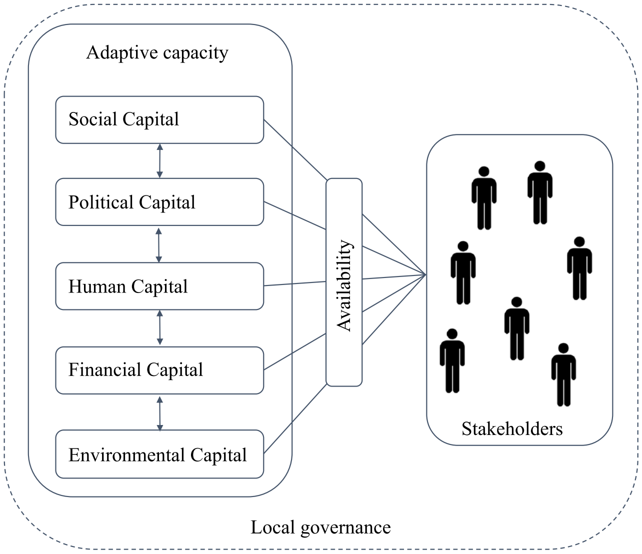

Figure 1. The five capitals, adaptive capacity, and stakeholders composing local governance for climate change adaptation.

The lack of adaptive capacity at subnational level can prevent the implementation of climate change adaptation because the NAP process uses the concept of multilevel governance to enable systematic transformation and effective governance (Di Gregorio et al., 2019). Hence, each tier of the multilevel governance system must be equipped with significant capacity to implement climate change adaptation actions (IPCC, 2018). Local governance, defined as the political and institutional processes through which decisions are taken and implemented in a specific subnational geographic region (UCLG, 2019), has been found to be a significant determinant of effective adaptation policy (IPCC, 2018; Williams et al., 2019). This structural decentralization of power is also known as polycentric governance, without which multilevel governance would not be able to function (Ostrom, 2011). Enhancing the autonomy of local governance has shown to significantly improve the response to climate change (Forsyth & Evans, 2013). The scope of local governance includes all actors involved in decision-making and policy planning processes, including networks, informal institutions, and communities (IPCC, 2018).

The level of local governance forms the focus of this research as it is best situated to coordinate and develop place-based responses to climate change, to enable participatory decision-making, and to involve local communities (Corfee-Morlot et al., 2011; Gray et al., 2014; IPCC, 2018). Setting clear boundaries and isolating those deemed as local governance stakeholders is tricky, as the execution of decision-making and policy planning processes, including networks, informal institutions, and communities (IPCC, 2018) constitutes a necessary move from unipolar government to multipolar governance to reflect the cross-cutting dynamics of climate change adaptation (Renn et al., 2011; Vogel et al., 2016). This explains why local governance has been described by some as complex, diffuse, and context dependent (Celliers et al., 2020). However, it is important for climate change adaptation scholars to not let context dependency impede research at the local level, as this would deprive the field of generalizing and providing theoretical insight at the local level (Siders, 2019).

In this research, local governance stakeholders are referred to as those who affect or are affected by a climate change adaptation-related decision (Scheffran, 2006). Research has found that local governance can be and heavily constrained by institutional barriers and resource limitations (Ojwang et al., 2017; Rosendo et al., 2018). Strengthening the ability of local governance for climate change is therefore an urgent necessity in an attempt to cope with the impacts of 1.5°C, 2°C, and more severe global warming (Baker et al., 2012; Rosendo et al., 2018; IPCC, 2018).

The ability of local governance stakeholders in responding to climate change by implementing the NAPs is determined by adaptive capacity, in turn conditional on the availability of different forms of capital (Figure 1) (Adger et al., 2011; Lemos et al., 2013; Scoones, 1998; Serrat, 2017). Numerous indicator-based governance assessment methods have applied this concept to evaluate adaptive capacity (Siders, 2019). To capture a holistic representation of a governance baseline, the capitals span across five dimensions, including social, political, human, financial, and environmental capital (Carmona et al., 2017; Goodwin, 2003; Gupta et al., 2010; Ojwang et al., 2017; Olsen et al., 2009; Ostrom, 2011; Williams et al., 2018).

A recent review of adaptation frameworks however revealed that while indicator-based governance assessment methods are apt at revealing the strengths and weaknesses of adaptive capacity, they fall short of identifying priority intervention areas to affect system-wide change (Siders, 2019). This was confirmed at COP25, where country delegates acknowledged the challenge of low adaptive capacity in their respective regions but also lamented the lack of approaches or methods to identify clear pathways or suggestions for enhancement. Assessment results disseminated through reports were not having a positive effect, and because each local context is different, the indicators signifying successful adaptation in one region may not necessarily be appropriate in another (Dilling et al., 2019).

This illustrates the potential added value of a method for examining relationships between the capitals, establishing synergies and trade-offs to identify leverage points, defined as instances in which an inflow of energy into a system affects a greater outflow (Meadows, 1999). This is because small shifts in certain variables can lead to fundamental changes throughout complex systems for realizing positive change (Meadows, 1999). Identifying leverage points in complex systems for affecting positive change has been highlighted as a key opportunity for genuinely transformational sustainability science (Abson et al., 2017).

Strengthening the capitals could therefore improve the ability of local governance to implement the NAPs in line with the Paris Agreement, as the availability of different forms of capital determines the ability of local governance in responding to climate change (Adger et al., 2011; Lemos et al., 2013; Scoones, 1998; Serrat, 2017). This research proposes a new method for identifying leverage points for local governance stakeholders to focus and maximize impact of capacity-enhancing measures. To achieve this aim, we further develop and combine an indicator-based governance assessment method (Capital Approach Framework [CAF]) with a participatory modeling technique (Fuzzy Cognitive Mapping [FCM]). The proposed method has been empirically tested in laboratory settings, and example results are provided in the supporting information.

2. The CAF, FCM, and the Identification of Leverage Points

The challenge of assessing and enhancing adaptive capacity of local governance as key for societies to respond to climate change has long been acknowledged in the climate community (Brooks & Adger, 2004). Out of the wide array of indicator-based governance assessment methods, the CAF (Máñez Costa et al., 2014; Siders, 2019) was selected. As an assessment approach, the CAF has shown to be highly valuable (Carmona et al., 2017). Created in an extensive codevelopment process with local stakeholders, it has been proven apt at identifying strengths and weaknesses in the ability of local governance to respond to climate change, while at the same time showing significant versatility in terms of context-sensitive application (Carmona et al., 2017; Máñez Costa et al., 2014; Ojwang et al., 2017; Williams et al., 2018). However, similarly to the alternative indicator-based governance assessment methods available, it does not prioritize between strengths and weaknesses or identify leverage points to affect virtuous system-wide change across local governance systems. FCM, a form of participatory modeling, is proposed to bridge this analytical gap.

2.1. Capital Approach Framework

The CAF identifies strengths and weaknesses in local governance and establishes a governance baseline (Olsen et al., 2011) as a reference point for monitoring and evaluation through longitudinal analysis (Gupta et al., 2010; Williams et al., 2019). With its theoretical and conceptual roots in sustainable livelihood resources, a capital can be understood as a capability, resource, property, or other valuable upon which the ability of local governance to respond, adapt, and adjust to climate change depends (Goodwin, 2003; Scoones, 1998). Constraints in the capacity of local governance for climate change adaptation most commonly arise from the lack of access to these capitals (Esteve et al., 2018). For a more detailed exploration of each capital, as well as practical applications of the CAF, please refer to (among others) Carmona et al. (2017), Celliers et al. (2020), Máñez Costa et al. (2014), Ojwang et al. (2017), Williams et al. (2018), and Williams et al. (2019).

A capital is measured by a factor, which is in turn evaluated by an indicator. Evaluative questions are devised pertaining to each indicator, and questionnaire-led interviews are conducted with selected stakeholders from local governance to qualitatively evaluate each indicator. The individual evaluations of each indicator are subsequently aggregated to factor and capital level, respectively. This forms a governance baseline reflecting the functioning of the current governance system through the perspective of its stakeholders (Carmona et al., 2017; Williams et al., 2018). Though the capitals stay the same for each case study, the factors and indicators can be adjusted to the local context in an iterative process through extensive literature reviews (governance reports, policy briefs, and written communication), as well as semistructured interviews and focus group discussions with local governance stakeholders and experts.

2.2. Fuzzy Cognitive Mapping

Adaptation is highly context sensitive and heavily dependent on place-based knowledge, and effective research must be carried out with the participation of local stakeholders (IPCC, 2018). At the same time, interdisciplinary approaches are necessary for the coproduction of knowledge with diverse representation (Brasseur & Van Der Pluijm, 2013; Norström et al., 2020). Originating out of System Dynamics, participatory modeling is an umbrella term for stakeholder engagement in simulation modeling (Kok, 2009; Videira et al., 2010, 2014; Voinov & Bousquet, 2010). There are various forms of participatory modeling, including but not limited to Group Model Building, Mediated Modeling, Companion Modeling, Participatory Simulation, Shared Vision Planning, Collaborative Learning, and FCM (Özesmi & Özesmi, 2004; Voinov & Bousquet, 2010). For an in-depth review of each technique, please refer to Voinov and Bousquet (2010).

In general, participatory modeling techniques can be applied to enhance understanding of complex dynamic systems under various conditions and to identify and clarify the behavior of the system under impacts of management options and solutions (Kok, 2009; Voinov & Bousquet, 2010; Williams et al., 2019). During this process, stakeholder knowledge is integrated in an interactive and iterative manner, which is seen as essential for effective adaptation planning (Allington et al., 2018; Hedelin et al., 2017).

Where modeling is constrained by a lack of data, FCMs are particularly valuable (Kok, 2009; Özesmi & Özesmi, 2004), and they have been underutilized in brokering a shared conception of climate change adaptation, as well as for coproducing knowledge in transdisciplinary settings (Gray et al., 2014). First introduced in 1970, FCMs were developed for depicting social scientific knowledge and have since become an established approach in soft knowledge domains (Gray et al., 2015; Kok, 2009; Kosko, 1986). More recently, FCMs have been applied to represent thought processes and belief systems in relation to a given problem and to construct participatory models for analyzing and elucidating the "messy" reality around decision-making and policy planning for adaptive responses (Gray et al., 2014; Kok, 2009; Shakya et al., 2018). Acknowledging the importance of beliefs as sources of human thinking and understanding is key for improving the management of the environment (Glynn et al., 2017).

The hazy degree of causality between variables composing complex systems is mediated through applying the concept of "fuzziness" (Kosko, 1986). FCMs are thus a graphical representation of systems composed of driving variables, along with the weighted relationships explaining the causal dependencies between variables (Kok, 2009). The variables and weighted relationships are defined semantically (e.g., assigning values to certain words) by participating stakeholders (Gray et al., 2015). The FCM is then simulated by transforming the cumulative impact of weighted relationships on the different variables via a nonlinear transformation function, meaning FCMs are nonlinear models (Salmeron & Froelich, 2016). The degree of influence can then be calculated for each variable across the system under examination, facilitating the identification of leverage points (Leclerc, 2014; Meadows, 1999). The simplicity of algorithms used for computing a cumulative strength of connections between variables is seen as a key advantage in the applicability of FCMs (Gray et al., 2015). The quantification of drivers and their causal relationships can only be interpreted in relative terms, and FCMs are thus "semiquantitative" (Kok, 2009). For a more detailed description of the computation formulae behind FCMs, please refer to Cole and Persichitte (2000), Felix et al. (2017), Gray et al. (2013, 2015), Kok (2009), and Özesmi and Özesmi (2004).

3. Integrated Modeling Approach for Assessing Adaptive Capacity and Identifying Leverage Points

Since the Fourth Assessment Report of the IPCC highlighted the lack of approaches for prioritizing between adaptation options, a range of criteria-based adaptation assessments, including cost-benefit analysis and decision-support tools, have been developed and utilized (De Bruin et al., 2009; Guillén Bolaños et al., 2018; IPCC, 2007). However, these approaches do not fulfill the need for community-driven approaches articulated at COP25. Table 1 lists 15 examples of FCM applications prioritizing between management options in diverse sets of fields, as a bottom-up alternative to conventional cost-benefit analysis and decision-support tools. These applications show promise in contributing to efficient and community-driven approaches or methods that identify clear pathways or suggestions for enhancing adaptive capacity at the local level for the implementation of the NAPs.

Henly-Shepard et al. (2015) use FCM for community disaster planning in a coastal area. The FCM was developed through iterative participatory modeling and scenario building. The outputs were then drawn upon as a basis for identifying the key risks, assets, values, and dynamics of social, economic, and environmental aspects of disaster planning and climate change adaptation (Henly-Shepard et al., 2015). In Pagano et al. (2019), FCM is applied to elucidate and structure the risk perceptions of stakeholders and to assess

Table 1
Examples of 15 Previous Applications of FCM

Sociogeographic context	Research topic	Data collection method	Participants	Disciplinary background	Reference
Educational institutions	Learner's understanding	Individual interviews and participatory modeling workshops	Local experts	Education	Cole and Persichitte (2000)
River basin	Displacement from large-scale infrastructure development	Individual interviews	Local community affected by displacement	Environmental conflict	Özesmi and Özesmi (2004)
River basin	Issue identification, stakeholder dialog and stakeholder mediation	Individual interviews and participatory modeling workshops	Local stakeholders	Water resources management	Giordano et al. (2005)
Rural area in subtropics	Socioecological systems analysis	Individual interviews and participatory modeling workshops	Local community	Environmental management	Rajaram and Das (2010)
Mid-Atlantic	Flounder fisheries	Participatory modeling workshops	Managers, scientists, harvesters, environmental NGOs	Marine ecology	Gray et al. (2012)
Marine environments	Stakeholder risk perception	Individual interviews	Local stakeholders	Risk management	Papageorgiou and Kontogianni (2012)
Retail	Quality management	Individual interviews	Local experts	Information management	Can Kutlu and Kadaifci (2014)
Coastal areas	Stakeholder perception of climate vulnerability	Individual interviews and participatory modeling workshops	Coastal stakeholders	Coastal management	Gray et al. (2014)
Rural areas in High Mountain Zones	Agricultural development project	Individual interviews	Farmers	Rural development	Halbrendt et al. (2014)
Forest communities	Identifying leverage points for management options	Conceptual group mapping	Local experts	International development	Leclerc (2014)
Rural areas in Grasslands	Bushmeat Trade	Participatory modeling workshop	Local rural communities	Conservation management	Nyaki et al. (2014)
Rural areas in Grasslands	Rural socioecological system resilience	Participatory modeling workshop	Local stakeholders from bushmeat trade	Conservation management	Gray et al. (2015)
Coastal areas	Community disaster planning	Participatory modeling workshops	Local coastal communities	Environmental management	Henly-Shepard et al. (2015)
Urban areas	Decarbonization strategies for urban resilience and transformation	Individual interviews	Representatives of civil administration, NGOs, general public, academics and private sector	Governance	Olazabal and Pascual (2016)
River Basin	Effectiveness of nature-based solutions	Individual interviews and group sessions	Local stakeholders	Risk management	Pagano et al. (2019)

	Phase 1: Stakeholder selection and identification of key factors	Phase 2: FCM coproduction and CAF evaluation	Phase 3: Desktop analysis	Phase 4: Feedback
Objective	Stakeholder selection and identification of key factors	FCM co-production and evaluation of CAF	Desktop analysis for identification of leverage points	Feedback and dissemination
Methods and tools	Stakeholder mapping, expert interviews, Venn diagram, social network analysis, snowball sampling, document analysis	Individual interviews, participatory modelling workshops	FCM Modeler, FCM Expert, Java Fuzzy Cognitive Maps, Mental Modeler	Participatory workshop, report, policy briefs, webinar
Output	List of stakeholders, list of preliminary factors	Fuzzy Cognitive Map	Leverage points for intervention	Policy recommendations for improving leverage points
Further reading	(Carmona et al., 2017; Esteve et al., 2018; Noy, 2008; Pacheco & Garcia, 2012; Prell et al., 2009)	(Giordano et al., 2005; S. A. Gray et al., 2015; S. R. J. Gray et al., 2014; Kok, 2009; Özesmi & Özesmi, 2004)	(Felix et al., 2017; Giordano et al., 2018; Leclerc, 2014)	(Williams et al., 2019)

Figure 2. Integrated modeling approach for identifying leverage points to enhance the adaptive capacity of local governance.

the multidimensional impacts of Nature-Based Solutions in decreasing flood risk. The application of FCM in combination with other modeling techniques helped identify economic productivity and community safety, as well as a decrease in damages to the built environment as primary impacts of the proposed Nature-Based Solution. Halbrendt et al. (2014) utilize FCM in an agricultural development project to examine the relationships between development technology and perceptions of rural farmers and forecasts in conservation agriculture practices. This was done by using FCM to identify the weight of different social, cultural, and ecological factors, which influenced the perceptions of farmers and the decision (Halbrendt et al., 2014).

The successful application of FCM shows promise for bridging the identified research gap in providing a framework within which to identify leverage points for enhancing adaptive capacity (Siders, 2019). FCM can be seen as an appropriate method for integrating stakeholder knowledge to establish concepts, which are prioritized as key factors and are then be fed into FCMs as variables.

Figure 2 proposes a combination of the CAF and FCM into an integrated modeling approach for assessing adaptive capacity and identifying leverage points of local governance for climate change in four phases. This approach will enable local governance to prioritize actions for improving the response to climate change impacts and implementation of the NAPs. This approach has been applied successfully in controlled conditions with a transdisciplinary research group at the Climate Service Center Germany (GERICS). The step-by-step approach and outcome can be found in the supporting information.

3.1. Stakeholder Selection and Identification of Key Factors (Phase 1)

The first phase of the integrated modeling approach is local governance stakeholder selection, that is, those who affect or are affected by a climate change adaptation-related decision. However, due to the broadness of this definition, compounded by the cross-cutting and multisectoral nature of climate change, the list of stakeholders must be prioritized according to importance. This is why it is necessary to consult with local experts to identify those stakeholders with the most significant influence to affect decisions and those that are most affected by those decisions.

Generally, those most affected by decisions are also those most vulnerable to climate change impacts. Because marginality, often caused by social and economic exclusion, are key determinants of vulnerability (Chu & Michael, 2018), justice and equity concerns need to be considered carefully. Participatory research methods should encourage counter-hegemonic action by highlighting the mechanisms for producing, maintaining, and legitimizing social injustice and inequality (van der Riet, 2008). Participatory modeling techniques should therefore be applied to reflect the priorities and amplify the voice of vulnerable stakeholder groups (Williams et al., 2019), the inclusion of which has been found to be crucial for encouraging positive climate-resilient outcomes (GIZ, 2014; Satterthwaite et al., 2018; Sutherland et al., 2015). There are various methods for stakeholder selection, including but not limited to, stakeholder mapping, vulnerability assessments, expert interviews, Venn diagram techniques, social network analysis, or snowball sampling (Esteve et al., 2018; Noy, 2008; Pacheco & Garcia, 2012; Prell et al., 2009).

During the stakeholder selection process, an insight into the functioning of local governance needs to be established. As relevant issues relating to the adaptive capacity of local governance for climate change begin to emerge during the expert interviews, the key factors of the system can be preliminarily identified. Key factors are defined as those elements that drive or constrain the adaptive capacity of local governance and are thus inherently relevant (Barranquero et al., 2015). Further methods appropriate for identifying key factors include focus group consultations or analysis of key documents, such as policy papers, public communications, or adaptation frameworks, and toolkits (GIZ, 2014; Vennix, 1996).

3.2. FCM Coproduction and CAF Evaluation (Phase 2)

As shown in Table 1, FCMs can either be coproduced by synthesizing individually constructed models (Özesmi & Özesmi, 2004) or coproduced collaboratively in interactive participatory modeling workshops (Nyaki et al., 2014). In either approach, participants need to be familiarized with the project objectives and expected outcomes. For some stakeholders, the concepts used in this research may be abstract. To prevent this from posing a barrier to effective facilitation, a thorough and clear presentation of the methodological approach, including an example of previous applications of FCMs (Table 1), is crucial to enhance stakeholder comprehension (Özesmi & Özesmi, 2004). For stakeholders to build trust on the scientific results emanating from the process, they need to understand the method.

In this integrative modeling approach, the key factors driving or constraining the capitals for adaptive capacity of local governance preliminarily identified in Phase 1 need to be validated with the stakeholders. When presenting the key factors, it is important to provide a precise definition of each key factor. Referring to the possible indicators for evaluation will assist the stakeholders in grasping the concepts (Supporting Information). If stakeholders identify factors that are missing, these need to be added to the list. If stakeholders deem previously identified factors irrelevant, these need to be excluded. Previous applications of FCMs show that modeling with approximately 15 variables is appropriate (Kok, 2009).

To explore models of dynamic systems and identify causal dependencies, a formal representation of causality (cause and effect) needs to be established (Cole & Persichitte, 2000). Thus, after validating the key factors and translating them into variables, participants are asked to explain the causal dependencies between the variables (Özesmi & Özesmi, 2004). For FCMs, there are two types of causal dependencies, either positive polarity (e.g., if one variable increases, so does the other) or negative polarity (if one variable increases, the other decreases, or vice versa) (Felix et al., 2017; Williams et al., 2019).

Then the degree of causal dependency between variables needs to be established by quantifying the strength of the relationship (Kok, 2009). Stakeholders need to establish the significance of relationship between two variables, either numerically (e.g., to a degree of between 1 [least significant] and 5 [most significant]) or through linguistic modifiers, which can then be converted into fuzzy functions (Cole & Persichitte, 2000).

Phase 2 also includes the evaluation of the factors in line with the CAF. The current level of effectiveness of the variables of influence determining the adaptive capacity of local governance is established (Williams et al., 2018). Thus, participants will be asked to qualitatively evaluate the effectiveness of each variable as either "effective," "moderately effective," or "ineffective." Either this can be carried out in a consensus-building collaborative group exercise or individual evaluations can be gathered and aggregated. Stakeholders are encouraged to use the table provided in Appendix 1 to support the comprehension for abstract concepts to assist the evaluation process.

3.3. Desktop Analysis (Phase 3)

After completion of the interactive participatory workshop, the FCM needs to be translated using one of the available FCM software packages (Figure 2). Once all key factors have been translated into variables, along with the causal dependencies and their weight, as well as the evaluation of the functioning of the key factors, the software can calculate several dimensions of interest for FCM interpretation (Gray & Cox, 2009).

Complexity indicates the degree of resolution and is determined by the ratio of receiving variables compared to transmitting variables. A FCM is highly complex when it has many receiving variables, which is an indication of several possible outcomes and implications resulting from the system. On the other hand, a FCM with a high number of transmitting variables indicates more unidirectional hierarchical knowledge structure, and more potential management policies (Özesmi & Özesmi, 2004). The higher the complexity, the higher the outcomes of driving forces that need to be considered. The density of multisectoral institutional relationships also gives an indication of the need for systems thinking when dealing with local governance (Lemos et al., 2013; Özesmi & Özesmi, 2004).

Centrality is the absolute value of the influence of variables and is determined by the nature of relationship between variables and the weighting of connections (Gray & Cox, 2009). By showing how a variable is connected to other variables, and the weighting of those connections, the significance in contribution of a variable can be determined (Özesmi & Özesmi, 2004). Essentially, centrality reveals the degree of importance of a variable in the model (Özesmi & Özesmi, 2004). The higher the value, the greater the influence of the variable on the dynamic behavior of the model. It is important to note that the degree of centrality is not the sole determinant of a leverage point, as the effort required for improving the variable is yet unknown.

The variable evaluation however reveals crucial participant perspectives on the current functioning of the variables, indicating the amount of required effort for improving the variable (Meadows, 1999). If a variable with a high degree of centrality is evaluated as "highly effective," then the effort required for improvement is comparatively high. If a variable with a high degree of centrality is evaluated as "ineffective," then the effort required for improvement is comparatively low, and thus highly appropriate for concentrating intervention efforts. This is why the factors are ranked by the degree of centrality divided in three columns labeled "effective," "moderately effective," and "ineffective." The variable in the "ineffective" column with the highest degree of centrality is the leverage point with the highest potential for positive change relative to the energy needed for improving the effectiveness of that variable (Meadows, 1999) (see supporting information for more information).

The benchmark for model verification is therefore to assess whether it adequately describes perceptions, necessitating the involvement of stakeholders in the verification process. The complexity of the model however may challenge cognitive limitations, meaning that while a FCM adequately describes perceptions, the dynamic behavior is counter to the inference of stakeholders (Jetter & Kok, 2014). Therefore, verification can be supplemented by some statistical analysis, such as stabilizing the value of the state vector, using standard matrix calculations to analyze the adjacency matrix, or standard sensitivity analyses (Kok, 2009).

3.4. Feedback (Phase 4)

Scenario building allows for the demonstration of system behavior through increased effectiveness of certain variables. These "what-if" scenarios can be simulated jointly with stakeholders in real-time, fostering dialog and learning. When presenting the outcomes, it is important to clearly communicate that FCMs do not convey a "truth" and do not represent accurate forecasting systems with real values. Rather, FCMs convey formalized descriptions of perceptions and can be applied as powerful tools for negotiation (Jetter & Kok, 2014).

Running plausible scenarios can indicate the amount of relative change in the other variables included in the model. Artificial scenario building therefore allows a comparison of system states under different conditions of management and policy intervention (Özesmi & Özesmi, 2004). By simulating an improvement in the effectiveness of specific variables, synergistic interactions and trade-offs between management and policy interventions can be identified (Özesmi & Özesmi, 2004). This is useful for assessing management and policy interventions for strengthening adaptive capacity, and recommendations for policy formulation according to the needs of the local stakeholders can then be devised for enhancing local governance.

4. Discussion

Climate change adaptation policies such as NAPs have rapidly reached political agendas in recent decades (Preston et al., 2011). As an essential element of the NAPs, identifying and assessing capacities for overall coordination and leadership on adaptation is a priority at the subnational level (United Nations Framework Convention on Climate Change, 2017). The innovative combination of a capitals approach with FCM is designed to facilitate the identification of leverage points for decision-makers and policy planners from local governance to focus and maximize impact of capacity-enhancing measures for responding to climate change and implement the NAPs. This demands a different set of requirements in each region and governance setting. It calls for a versatile and flexible approach. While the integrated modeling approach fulfills these criteria, there are also some more advantages, as well as limitations, which need to be considered.

4.1. Added Value of Integrated Approach

The approach proposed in this paper not only integrates information on climate change impacts with development needs but also contributes to current limitations in the availability of empirical data on the interactions that determine the adaptive capacity of local governance (Adger & Vincent, 2005; Lemos et al., 2013). The inability to model systems with multiple intangible dimensions has served as a significant barrier to enhancing the adaptive capacity of local governance (Nelson et al., 2010; Siders, 2019). Using simple mathematical relationships and software, this approach opens up the possibility of modeling intangible dimensions semiquantitatively (Gray et al., 2014). Furthermore, the integrated modeling approach reflects the high level of contextual sensitivity required for enhancing the adaptive capacity of local governance to climate change and implementing the NAPs (Ojwang et al., 2017; Rosendo et al., 2018).

The primary added value of the proposed integrated approach is in guiding decision-making and policy planning processes at the local level. Identifying effective measures for local governance stakeholders to enhance the capacity for climate change adaptation has been highlighted as a priority for adaptation (Siders, 2019). At the same time, approaches need to reflect the context sensitive and place-based characteristics of local adaptation arenas (Dilling et al., 2019). There are a number of alternative theoretical and practical tools for supporting adaptation processes at the local level, including the adaptive capacity wheel (Gupta et al., 2010; Hurlbert & Gupta, 2017), several resilience frameworks (Maru et al., 2014; Nelson et al., 2007; Pahl-Wostl, 2009), The Shared Learning Dialogue (Institute for Social and Environmental Transition, 2010), or Resilience Dialogues (Resilience Dialogues, 2016). Similarities include the representation of diverse values and management objectives, as well as location and context sensitivity. Local place-based planning, referring to a set of spatially distinct interactions of biophysical and social conditions in which global and local drivers manifest, should play an important role in adaptation planning processes (Measham et al., 2011).

Not only is there a need for generating local place-based knowledge for assessing vulnerability to climate change impacts but also the generated knowledge needs to bridge the assessment-action gap by being integrated into top-down policy planning processes (Conway et al., 2019; Conway & Mustelin, 2014). Hence, one core attribute distinguishing the integrated modeling approach from alternative theoretical and practical tools for supporting adaptation processes at the local level is that it refers specifically to the local implementation of NAPs. In addition, through the use of participatory methods not only for issue identification but also for during the modeling phase itself, transparency and trust are enhanced among participating stakeholders, creating a sense of ownership and increasing the likelihood of bridging the assessment-action gap through knowledge uptake in decision-making and policy planning processes (Moyson et al., 2017).

When working with local stakeholders, in particular government officials and administrators, resource limitations in terms of time and commitment become immediately apparent (Yang & Callahan, 2007). Identifying synergies and trade-offs between adaptation options is of particular value to resource-constrained local governance (Guillén Bolaños et al., 2018). The importance of feasibility and efficiency is underestimated in climate change adaptation research. It is not realistic, nor appropriate, to occupy the little time local managers and decision-makers with noncore research and analysis. Also, in terms of pragmatism and practicality, two further important prerequisites for stakeholder engagement processes, which are commonly overlooked (Garard & Kowarsch, 2017), the integrated modeling approach offers significant value as FCM is one of the easier to use participatory modeling methods and not beset by as many barriers as other participatory method techniques (Jordan et al., 2018).

The participation necessary in Phase 1 is flexible and can be adjusted according to the stakeholder requirements. The participatory workshop in Phase 2 is realistically achievable in one morning or one afternoon session. While stakeholder participation in Phase 4 is preferable, it is not a requirement. Material costs, beyond logistical meeting means and travel costs, are minimal; the skills required by facilitators are easily learned; and the software for data analysis is open access, free of charge, and intuitively understandable to laypersons and requires minimal computer processing power (Gray & Cox, 2009). Overall, the approach is cost and time efficient. This makes it particularly suitable for resource-constrained applications in which the amount of available time and resources of local adaptation managers are limited (Williams, 2019).

4.2. Benefit of Identifying Leverage Points

Resource constraints, as well as socioeconomic and political inequalities, are common at local administrative levels. Therefore, efforts to measure and enhance adaptation capacity must aim to address climate change impacts and development needs in synergy (Lemos et al., 2013). The integrated modeling approach of this paper recognizes this by identifying leverage points at which the impact of capacity-enhancing measures is maximized. This allows resource-constrained local managers to focus on the improvement of specific factors with the aim of improving the response and enhancing societal resilience to climate change impacts.

While applying the integrative modeling approach is within the remit of researchers, translating its results into action is within the remit of local decision-makers and policy planners. This reveals a further key advantage of the proposed approach. The indicators of the factor identified as a leverage point provide a direct indication of possible measures to enhance the respective factor. If the factor "internal and external communication" has been identified as a factor for intervention, then decision-makers and policy planners may consider formulating their response based on improving the indicators, that is, "transparency of communication processes" or "availability of reports in local languages" to enhance the effectiveness of that factor (Appendix 1) (Williams et al., 2018).

4.3. Participatory Processes

The integrative modeling approach constitutes an alternative to unidirectional or transmissive modes of science-society interaction (Shaw et al., 2009). It is a systematic and simple and process for involving local knowledge in decision-making and policy planning for climate change issues (Brugnach et al., 2017). Besides improving the quality of knowledge and policy, a participatory assessment process also enhances adaptive capacity. A participatory approach lays a foundation for improving the capitals by strengthening stakeholder cohesion and cooperation and more broadly by nurturing a more inclusive mode of governing.

Participation inherently creates an opportunity to foster dialog between stakeholders. It also encourages positive attitudes toward cooperation, promotes consensus, provides opportunity for voicing concern and discontent, nurtures team learning, and provides new insight into strengthening adaptive capacity (Antunes et al., 2006; Shaw et al., 2009). It is a fundamentally important response to establish "bottom-up" approaches to climate change adaptation, and for aligning local with national and international objectives, as recommended in the NAPs (Gray et al., 2014; UNFCCC, 2017). Codeveloping mental models with stakeholders also has the potential to create a sense of ownership, meaning the outcomes are more likely to enter decision-making and policy-planning processes (Antunes et al., 2006; Moyson et al., 2017).

Engaging with stakeholders from diverging sectors and with various interests, for whom differences in problem-framing and ambiguous problem definitions are inevitable, can pose a challenge (Giordano et al., 2017). High stakeholder diversity always brings with it the risk of hierarchy, power, and language influencing deliberative outcomes (UNDP, 2010). As yet, there is no clear pathway for participatory modelers to mitigate issues around advocacy, justice, equity, and ethics (Jordan et al., 2018). It has been shown that successful participatory processes do not institutionally predefine deliberative outcomes, as such engineering can only serve to alienate stakeholders (Few et al., 2007).

4.4. Consensus Building and Interpreting Model Results

The integrative modeling approach is inherently reliant on consensus building. The process of agreeing on the inclusion of key factors to include into the model, the relationships between factors, their weights, and the evaluation of model outputs is dependent on stakeholders building consensus. This has been demonstrated by the many applications of these approaches listed in Table 1. Consensus is achieved through debate. The success of the participatory process is therefore dependent on the quality of debate among stakeholders (Eun, 2016). Facilitators need to mediate a deliberative process that encourages learning, exchange, understanding, and sympathy of viewpoints of other stakeholders (Eun, 2016). Participatory theorists have supported the view that a consensus-building approach increases the likelihood of compliance with policies resulting from the process. It can also build trust, create new dialogs and partnerships, and promote joint learning (van de Kerkhof, 2006). There are several frameworks available for assisting facilitators in reaching consensus in participatory processes (EPA, 2019; The Jefferson Center, 2004; Nielsen et al., 2006).

However, consensus-building approaches can also lead to outcomes that are most tractable rather than important. They can depend on agreeing to generalized and imprecise principles rather than concrete results and oversimplify complex relations and overlook rich contextuality in the search for a lowest common denominator of the participating interests (van de Kerkhof, 2006). There may be situations in which reaching consensus poses an insurmountable challenge and establishing a lowest common denominator would be to the detriment of the rich and important contextuality; it may be necessary to separate interest and combine shared ambiguity, in order to form more homogeneous stakeholder groups. Situations in which stakeholder groups are too diverse with a high likelihood or potential for conflict may also require the development of several individual iterations of the model. These individual iterations can then be aggregated to form a synthesized group FCM (Table 1) (Özesmi & Özesmi, 2004).

4.5. Verification and Interpretation of Model Results

The semiquantitative characteristics of FCMs makes standard verification methods used for quantitative methods inappropriate (Kok, 2009). There is lack of historical data or collectively accepted truths against which to test and "calibrate" the model (Jetter & Kok, 2014). As FCMs are constructed to represent formalized descriptions of perceptions, and not to create an accurate forecasting model, the motivation behind verifying a model as "true" is, at best, misguided (Jetter & Kok, 2014).

Scholars in critical theory and philosophy of social science have argued that research generating knowledge on human action needs to be assessed against concepts of validity that deviate from conventional verification processes, which rely on a correspondence theory of truth. According to the notion of "catalytic validity" (Lather, 1986), the validity of social knowledge rests to an extent on its ability to afford social change. "Pragmatic validity" (Kvale, 1996) is therefore the usefulness of knowledge within a particular context. Last but not least, moving beyond the political imperative of participation, philosophers of social science have argued for a reconceptualization of validity by recognizing the particular nature of knowledge on human action (Lather, 1986). Postpositivists recognize that one needs to understand meanings in order to study human action. In this sense, participatory approaches may be better suited epistemologically to producing knowledge on adaptation.

According to this line of argument, participatory research is a methodological response to the participative, relational, and social nature of human action. The idea of correspondence of knowledge to reality loses its usefulness in a social reality under construction. Participatory research processes may be able to account for this due to their dialogic nature. The resulting notion of validity is based on the concept of intersubjectively valid knowledge beyond individual truth. Validity thus resides in the situatedness of the research process and the way in which it accounts for the intersubjectively emergent nature of meanings that guide human action (van der Riet, 2008).

As an easy-to-use participatory modeling technique, there is a risk that FCM does not adequately reflect the complexity of a particular problem (Jordan et al., 2018). The translation of concepts into factors and variables is problematic and in themselves highly complicated. This can be mitigated however by clear communication to stakeholders in Phases 2 and 4. Another limitation of FCMs in terms of complexity is the lack of consideration for spatial and temporal scales. Applying delay factors or dummy variables to incorporate the speed of process could improve the semidynamic nature of FCMs (Kok, 2009). There is a growing body of research on combining and integrating FCMs with other models using System Dynamics (Pagano et al., 2019; Salmeron & Froelich, 2016). Using this methodological approach to supplement vulnerability, impact, and risk assessments could also yield potential for supporting adaptation decisions (Corfee-Morlot et al., 2011).

Further research is also necessary to understand how the determinants of adaptive capacity at the local level are embedded within a multilevel governance system. Local decision-making and policy planning for the NAPs is enabled and constrained by regional, national, and international tiers of governance (Bulkeley & Betsill, 2013; Corfee-Morlot et al., 2011; IPCC 2018). The optimal scale of participation in the modeling process should ensure the possibility of acknowledging multiple goals and combining multiple scales and sectors of governance. Further clarity in this regard is required to achieve the greatest impact for enhancing the adaptive capacity of local governance for climate change.

A further risk of this approach is the depoliticization of local governance arenas through reducing local governance for climate adaptation into measurable criteria, capitals, factors, and indicators. Previous research has found that adaptation problems rendered technical are prone to becoming depoliticized by extracting local issues from socioecological and politico-historical contexts (Scoville-Simonds et al., 2020; Webber, 2019). A potential consequence of depoliticization is the concealment of hegemonic relations between actors and the pervasion of social discourse (Remling, 2018). This risks to cover up the fact that many local governance systems are themselves inherently nonpluralistic in terms of representation and participation.

The key here would be to strike the right balance, as politicization of climate change adaptation has conversely shown to increase inertia by hindering public engagement and policy action (Pepermans & Maeseele, 2016). In this approach, they key factors are place based, developed in a participatory process with local experts and stakeholders, therefore reflecting socioecological and politico-historical contexts. Hence, certain inequities of local governance would be reflected in the outcome of the results, as illustrated in previous applications of the CAF (Williams et al., 2018, 2020).

While this approach has been empirically tested under laboratory conditions, the real-world application is sure to reveal unforeseen dilemmas and inadequacies. Additionally, there may be a need for facilitation and training to bridge the gap from assessment to action (Conway & Mustelin, 2014). Nonetheless, the authors believe this integrative modeling approach shows great methodological potential for guiding resource-constrained local governance in identifying resilience-enhancing pathways for reducing climate change impacts and improving their ability to implement the NAPs. It is currently being tested in a coastal setting in South Africa, and outcomes will be published as soon as possible.

5. Conclusions

This study has successfully demonstrated how the combination of two research approaches, one for measuring the state of governance systems and one for modeling the relationships within such systems, can be used to identify leverage points for decision-makers and policy planners from local governance. Stakeholder participation forms the basis of both research processes and is a critical success factor. The leverage points can be used to focus and maximize impact of any capacity-enhancing measures needed to respond to climate change and implementing the NAPs. The proposed integrative modeling approach is intended as a response to calls from states represented in the COP25 for an acknowledgment of the challenge of low adaptive capacity in their respective regions. They also lamented the lack of approaches or methods to identify clear pathways or suggestions for capacity enhancement. This integrative modeling approach supports the development of context-sensitive measures while adequately reflecting the diversity of local governance. It is a simple and efficient method to reduce the complexity of local governance without "burning out" the limited human resources and capacity that often limits adaptation at the local scale. It offers a solution for prioritizing adaptation actions that is inherently acceptable and trustworthy to stakeholders as coming from "within."

Data Availability Statement

An application of the proposed integrated modeling approach can be found in the supporting information under Williams (2019): Supporting_Information_EF_16.04.20.pdf. figshare (online resource: https://doi.org/10.6084/m9.figshare.12136494.v1).

Acknowledgments

The authors would like to thank various colleagues within the Climate Service Center Germany (GERICS) for their time and valuable inputs contributing to the development of the methodological approach and the Helmholtz-Zentrum Geesthacht (HZG) for covering publication fees. In addition, CENSE is financed by Fundação para a Ciência e Tecnologia, I.P., Portugal (UID/AMB/04085/2019). Finally, the authors would like to express their gratitude to the reviewers and editor, whose work has improved the paper significantly. The authors declare no conflict of interest.

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