Regional Environmental Change (2022) 22:110
https://doi.org/10.1007/s10113-022-01958-4

ORIGINAL ARTICLE

Cross-scale collaboration for adaptation to climate change: a two-mode network analysis of bridging actors in Switzerland

Dominik Braunschweiger[1]

Received: 8 March 2021 / Accepted: 15 July 2022 / Published online: 3 September 2022
© The Author(s) 2022

Abstract

Adaptation to the impacts of climate change has become an increasingly important policy field in recent years, but it is complicated due to ambiguous responsibilities. To ensure the coherence of adaptation policies, cooperation is necessary between sectors as well as between administrative levels. As such, fragmentation between both sectors and levels is a huge challenge for the successful formulation and implementation of climate change adaptation policies. Bridging actors who coordinate actions across levels and sectors play an important role in overcoming this challenge. Through means of social network analysis, I investigate which actors occupy key bridging roles in the multi-level and federalist arrangement of Swiss climate change adaptation governance. I analyse a two-mode network of actors and climate change adaptation measures, conducting a complete inventory of all measures and policies carried out in the context of the Swiss adaptation strategy as well as all actors involved in their design, funding and implementation. I find that federal governmental actors occupy the most important bridging roles. However, for the most part, they seem more focused on building cross-sectoral ties than on building cross-level ties. The Swiss Federal Office for the Environment (FOEN) stands out as the one national authority that managed to establish almost as many cross-level ties as cross-sectoral ties through the coordination of an adaptation funding programme. Thus, while adaptation measures will primarily be implemented on the municipal level, higher level actors still have a vital role to play in promoting municipal efforts, fostering collaboration and reducing fragmentation.

Keywords Climate change adaptation · Governance · Environmental policy · Social network analysis · Bipartite networks · Bridging · Fragmentation

Introduction

After decades of climate change, mitigation efforts failed to constrain global greenhouse gas emissions to sustainable levels, many impacts of climate change are now inevitable or already happening (IPCC 2018). Thus, adaptation efforts aimed at preparing for climate change impacts and reducing vulnerability to climate change have become increasingly important in recent years (Bauer et al. 2012). Climate change adaptation has emerged as a second, complementary field of policy to climate change mitigation in handling the climate crisis (Biesbroek et al. 2011). However, climate change impacts come in a broad variety that transcends the domains of traditional policy sectors and cuts across governmental levels. Thus, adaptation efforts must similarly transcend sectoral boundaries and administrative levels. This poses a significant challenge from a governance perspective, as different institutions share overlapping responsibilities or work independently on connected issues (Jasny and Lubell 2015). Such interdependencies can be problematic, as governing bodies may fail to take into account how their actions affect other actors during decision-making processes (Jasny and Lubell 2015). Furthermore, when multiple actors are involved in efforts to provide a service or protect a resource without clearly defined jurisdictions, collective action problems can quickly become system-threatening (Berardo 2014; Feiock 2009; Rhinard 2013). As such situations may enable free-riding, individual actors may adopt non-cooperative

---

Communicated by Alta de Vos

Dominik Braunschweiger
dominik.braunschweiger@wsl.ch

[1] Economics and Social Sciences, Eidgenössische Forschungsanstalt Für Wald Schnee Und Landschaft, Zürcherstrasse 111, 8903 Birmensdorf, CH, Switzerland

strategies, rather than allowing themselves to be taken advantage of (Berardo 2014; Feiock 2013). Consequently, institutional fragmentation and the problems resulting therefrom have been identified as some of the most important barriers to adaptation (Biesbroek et al. 2011; Ekstrom and Moser 2014).

Fragmentation is also directly related to another major barrier to adaptation: uncertainty. Climate change and its impacts are incredibly complex issues surrounded by many uncertainties. Actors are subject to uncertainties about exact climate change impacts and uncertainties about human handling of and reactions to climate change as well as uncertainties about the extent of human knowledge on climate change (Biesbroek et al. 2011). Many of these uncertainties are caused or exacerbated by fragmentation issues, such as a lack of institutionalised channels of exchange between relevant actors, insufficient exchange of information or a disconnection amongst the expectations of different actors. For example, Kiem and Austin (2013) find a significant gap between 'the information that end-users need (or think they need)' (p. 29) in rural Australia and the information produced by existing research on climate change impacts and adaptation.

Brokerage institutions reduce the challenges posed by fragmentation and uncertainties by connecting different actors and institutions, providing opportunities to negotiate terms of coordination and distributing information (Berkes 2002; Carlsson and Sandström 2007; Crona and Parker 2012; Jasny and Lubell 2015). Brokers spread information and facilitate cooperation amongst actors who otherwise lack either access to one another or trust in each other (Marsden 1982). Brokerage may also pave the way towards more collaborative governance approaches and may thus reduce the odds of policy failure (Ansell et al. 2017).

The advantages provided by brokerage are widely recognised (Carlsson and Sandström 2007; Crona and Parker 2012; Stovel and Shaw 2012; Tanaka et al. 1980) and many institutions aiming to function as brokers for various aspects of environmental policy have evolved in recent decades (Schneider et al. 2003). Specific instances of brokerage, sometimes also called bridging, are the subject of many empirical investigations (Aldrich and Herker 1977; Brown 1998; Chaskin 2001; Collins-Dogrul 2012; Friedman and Podolny 1992; Hahn et al. 2006). Identifying which actors or which types of actors are most likely to take on such bridging roles in natural resource governance allows for targeted measures to support key bridging actors in their endeavours (Angst et al. 2018; Vignola et al. 2013). Thus, identifying important bridging actors in adaptation governance may contribute to overcoming key barriers to adaptation, such as fragmentation and uncertainty. My analysis aims to identify which actors take on bridging roles in adaptation governance based on the case of the Swiss federal strategy and action plan for adaptation to climate change. My goal is to answer the following two research questions:

1) *Which actors take on bridging roles amongst different sectors regarding adaptation to climate change?*
2) *Which actors take on bridging roles amongst administrative levels regarding adaptation to climate change?*

Today's political challenges are mostly cross-sectoral and multi-level in nature. One way to overcome such challenges is through key actors who take on bridging roles between different sectors and administrative levels. By answering these research questions, I contribute to the brokerage literature and the multi-level governance literature by applying established conceptualizations of brokerage to pinpoint those actors that bridge boundaries between different sectors and administrative levels, thereby reducing fragmentation at two of its main sources, particularly when it comes to multi-level challenges such as adaptation to climate change. This is particularly relevant in the case of the federalist Swiss political system that delegates a lot of power and responsibilities to the subnational levels (Ladner 2010) exacerbating the detrimental effects of fragmentation. Switzerland is also highly vulnerable to the impacts of climate change (Brönnimann et al. 2014) while simultaneously boasting high adaptive capacity due to its wealth and technological capacities (Westerhoff et al. 2011). Nevertheless, climate change adaptation in Switzerland has so far been largely limited to strategic mainstreaming activities at the federal level while concrete adaptation at the municipal level is rare (Braunschweiger and Pütz 2021, Widmer 2018). This study aims to contribute to the resolution of this adaptation implementation gap by identifying important actors to support in their adaptation brokering endeavours. These results may also be relevant beyond the Swiss case for other wealthy industrialised countries subject to similarly lacking implementation of concrete adaptation measures (Dupuis and Knoepfel 2013).

Methodologically, the paper contributes to the literature by showing how established operationalizations of different types of bridging actors may be applied to the analysis of two-mode network data. Empirically, I provide new insight into the governance of the highly fragmented field of Swiss climate change adaptation policy.

I first lay out the relevant theory and analytical framework for the paper by discussing climate change adaptation and the importance of bridging actors therein through the lens of the multilevel and polycentric governance framework as well as the literature on collaborative governance. From this framework and the literature discussed, I derive three hypotheses regarding the distribution of bridging positions and test them using social network analysis. I find that national level authorities as well as research institutions take on the most important bridging roles but national authorities generally focus on building cross-sectoral ties rather than cross-level ties.

Theory and analytical framework

Adaptation to anthropogenic climate change entered international and domestic policy agendas in recent decades as a consequence of both rising climate change impacts and the gradually spreading realisation that climate change mitigation efforts will most likely fail to completely prevent further escalation of said impacts (Bauer et al. 2012). Some researchers conceptualise adaptation to climate change as merely a new policy issue or even an increased focus on existing issues such as natural hazard management (Birkmann and Mechler 2015; Leitner et al. 2020). However, while Switzerland has a long history of managing adaptation relevant issues such as flood prevention (Ingold and Gavilano 2020), comprehensive national adaptation policies have only begun development in the last 13 years (Braunschweiger et al. 2018). Based on their assessment of governmental and non-governmental actors concerned with adaptation as well as the number of sectors covered by the national adaptation strategy and action plan, Massey and Huitema (2016) classify adaptation to climate change in Switzerland as a newly emergent policy field.

Different types of uncertainty are one of the main barriers to adaptation: Substantive uncertainties stem from the inherent complexity of anticipating and preparing for climate change impacts as well as uncertainties about how humans will handle climate change. They are exacerbated by strategic uncertainties stemming from the unique perceptions and strategies of individual actors and by institutional uncertainties stemming from the different institutional backgrounds of the actors involved (Koppenjan and Klijn 2004). Fragmentation between actors exacerbates these uncertainties as it impedes them in anticipating how others will behave and in comprehending their interpretations of human–environment relations, their strategies and their institutional guidelines (Ingold et al. 2019). However, uncertainty also stems from the lack of established substantive expertise due to the novelty of the field (Massey and Huitema 2013, 2016). As such, the development of said expertise should be a priority during the early stages of adaptation policy. Indeed, there is ample empirical evidence that the development and communication of knowledge is a cornerstone of current adaptation policy in Europe (Bauer and Steurer 2015; Biesbroek et al. 2010; Braunschweiger et al. 2018; Massey and Huitema 2016). Brokers are of key importance to reduce these issues of fragmentation and uncertainty, to distribute knowledge amongst relevant actors and to coordinate adaptation measures. However, current adaptation literature is vague on which actors exactly are taking on this vital role.

Climate change adaptation — a multi-level governance challenge

Adaptation to climate change is also a multi-level challenge. While climate change is a global development, its impacts vary drastically, and adaptation needs vary accordingly across regional and local levels (Bauer and Steurer 2014). Thus, municipalities and other actors at subnational levels are commonly expected to take charge of the design and implementation of concrete adaptation measures while national and supranational level actors raise awareness, conduct basic research, disseminate knowledge and provide funding and guidance (Galarraga et al. 2011; Keskitalo 2010). Additionally, since climate change adaptation concerns private business and individuals as well, governmental actors are expected to facilitate exchanges with and between non-state actors (Cimato and Mullan 2010). Thus, effective adaptation governance must be able to bridge the gap between administrative levels and governmental and non-state actors (Adger et al. 2005; Bauer and Steurer 2014). A multi-level governance system capable of addressing complex, long-term problems such as climate change must transfer power from central governments to local governments and from governmental to non-state actors to allow room for the growth of local initiatives while also fostering networks to improve coordination and disseminate information on best practices (Di Gregorio et al. 2019; Underdal 2010). The multi-level governance framework thus clearly states the importance of bridging actors who serve these functions in adaptation governance networks.

Recognising the multi-levelled nature of climate change adaptation challenges, most member states of the Organisation for Economic Cooperation and Development (OECD) are trying to reach adaptation goals by integrating them into the mandates and duties of those pre-existing state departments and agencies that are most closely affected by climate change impacts (Bauer and Steurer 2015; Eisenack et al. 2014). Thus, adaptation policy is a prime example of polycentric governance (Ostrom 2010). Polycentric governance arrangements where actors engage in simultaneous collective decision-making processes regarding interconnected issues force actors to ‘learn, coordinate and cooperate’ (Berardo and Lubell 2019, p. 11). Systems that encompass ties to connect distant actors allow their members to quickly learn about new information or outstanding issues within the network (Berardo and Scholz 2010). Thus, bridging actors are an important facilitator of learning in addition to coordination. Berardo (2014) and Bodin et al. (2017) show that actors belonging to more heterogenous networks are better able to learn and share information on how to handle complex problems. It follows that bridging configurations are of key importance to climate change adaptation governance systems, as climate change adaptation is an emergent policy field with actor constellations and policy guidelines still in flux across all administrative levels (Braunschweiger and Pütz 2021).

Improving climate change adaptation through collaborative governance

The importance of bridging actors for climate change adaptation is also reflected in the literature on collaborative governance. Collaborative governance approaches play an important role in the resolution of the so-called wicked societal problems such as climate change. They offer better coordination amongst governmental authorities (Bingham and O'Leary 2014; Emerson and Gerlak 2014) as well as improved public participation and stakeholder involvement (Leach and Sabatier 2005). Collaborative governance enables political adversaries to find common ground, enables governmental actors to develop constructive relationships with non-governmental stakeholders and allows for advanced forms of collective learning and problem-solving (Ansell and Gash 2008). Multi-actor collaboration during both the policy design and policy implementation phases reduces the odds of policy failure significantly (Ansell et al. 2017). Collaborating with the actors who are directly involved in and affected by the implementation of a policy allows important knowledge to be shared during the policy design process and helps to generate the political and administrative support necessary to ensure successful implementation (Ansell et al. 2017; Terman and Feiock 2015). Collaborative policy design also 'facilitates a joint exploration of policy problems' (Ansell et al. 2017, p. 476) by fostering mutual trust between the actors involved and enabling them to develop new and creative policy solutions together. Collaboration continues to play an important role during the policy implementation process, as ongoing communication between policymakers and implementers allows policies to be updated and adapted to emerging problems and opportunities as well as local and regional conditions (Ernstson et al. 2010; Hartley et al. 2013; McAllister et al. 2014; Pahl-Wostl 2009; Torfing 2019; Vignola et al. 2013). This substantiates the importance of bridging actors, who are necessary for collaboration to happen in the first place.

Types of bridging actors

Social network researchers differentiate between different types of bridging actors. Berardo and Scholz (2010) identify central coordinators as an important source of bridging capital. The idealised version of the central coordinator forms the centre of a star-structured network where every other actor is connected to him and only him. This way, the shortest path between any two members of the network will always go through the central coordinator, making them integral for efficient coordination. Of course, idealised versions of central coordinators rarely exist in practice, but some form of core-periphery structure has been observed in many empirical studies, demonstrating the importance of the role (Ernstson et al. 2010; Hirschi et al. 2013; Luthe et al. 2012). Others specifically analyse actors that form bridging ties across levels (Rathwell and Peterson 2012), actor types (McAllister et al. 2015) or ecological scales (Ernstson et al. 2010). Angst et al. (2018) propose a classification building on the two strengths of bridging ties that Berardo and Scholz (2010) identify: distribution of knowledge and coordination. They discuss two types of bridging ties that contribute to these strengths in slightly different ways: central coordinators and periphery connectors.

Central coordinators form connections to many others and represent the shortest path between many other pairs of actors that are not directly linked. They are thus very valuable when coordination needs to be strengthened or when information needs to be disseminated across the network as efficiently as possible. Periphery connectors, on the other hand, connect actors to the network that have no other connection to it. Thus, they increase the heterogeneity of the network and its access to non-redundant information and increase its capacity for learning (Fig. 1).

Hypotheses

The literature on polycentric and collaborative governance emphasises that both governmental and non-governmental actors form important, independent decision-making entities at different scales (Ostrom 2010, 2014). As their respective decisions affect one another, actors in such governance systems develop mechanisms to coordinate their actions, to cooperate and to resolve conflicts. But which actors are most likely to take on bridging positions? As Fliervoet et al. (2016) explain, collaborative governance may be a shift away from traditional conceptions of hierarchical governance, but governmental actors still have important roles to play. Governmental actors generally have the highest capacity for coordination and facilitation and may thus be more likely to occupy bridging roles. While Berardo and Lubell (2016) contend that governmental actors generally have more resources available to participate in policy forums and build ties than non-governmental actors. Similarly, Klijn and Koppenjan (2000) show how governmental actors are uniquely capable of coordinating networks even in polycentric governance settings by engineering venues for interactions and strategically allocating government resources. Ingold et al. (2017) also show that governmental actors may be more likely to play important coordinating roles especially in nascent policy subsystems. When actors

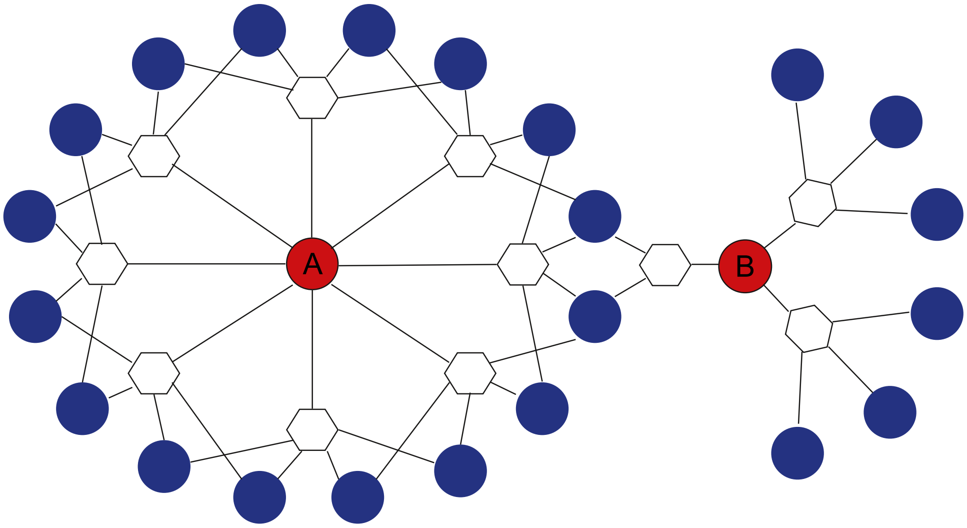

Fig. 1 Illustration of central coordinator position (**A**) and periphery connector position (**B**) in a bipartite network (actors are represented as circles, and policies and measures are represented as hexagons)

are yet uncertain about their policy preferences, allies and enemies, formal decision makers or structurally particularly well-embedded actors serve as important role models and knowledge providers. This brings me to my first hypothesis:

> **Hypothesis 1** Governmental actors are more likely to take on cross-level and cross-sectoral bridging roles than non-governmental actors.

In a similar vein, it can be argued that national authorities generally have more resources at their disposal and greater capacities for coordination and facilitation than their sub-national counterparts. Angst and Hirschi (2017) argue that higher level governmental actors play important bridging roles due to their superior ability to build stable and long-lasting ties. Angst et al. (2018) show that higher-level governmental actors are more likely to take on bridging roles than their counterparts at the municipal level since their activities typically encompass a broader range of actors. This leads me to my second hypothesis:

> **Hypothesis 2** Higher level governmental actors are more likely to take on cross-level and cross-sectoral bridging roles than lower level governmental actors.

These hypotheses are in line with the current state of research: Swart et al. (2009) find that coordinating actors, organising the development and distribution of knowledge and coordinating sectoral activities for climate change adaptation in Europe, are usually governmental actors. Lorenz et al. (2019) show that most key climate change adaptation actors in the UK are governmental actors. National-level authorities dominate the top 10% of the ranking, demonstrating how responsibility for climate change adaptation has been spread amongst sectors and that national authorities play important coordinating roles. Multiple studies on Swiss climate change adaptation governance also found the FOEN to occupy an important central coordinator role (Christopoulos and Ingold 2015; Braunschweiger et al. 2018; Braunschweiger and Pütz 2021).

Lastly, due to the nature of climate change adaptation as an emergent policy field and the many uncertainties surrounding it, I expect adaptation actors to seek ties to actors capable of reducing said uncertainties by producing and disseminating knowledge. Thus, I expect research organisations to play a central role during these early stages of adaptation policy, as suggested by an early assessment of the state of adaptation in Europe (Swart et al. 2009). With various heterogeneous actors poised to seek out knowledge, large research organisations are perfectly positioned to take on bridging roles amongst their different clients.

> **Hypothesis 3** Research organisations are more likely to take on cross-level and cross-sectoral bridging roles than other non-governmental actors.

Case, data collection and method of analysis

The case of climate change adaptation in Switzerland

Many longstanding policies and measures exist across different sectors, such as natural hazard management, water governance, forest management or agriculture that increase resilience to the impacts of climate change. However, policies and measures that explicitly and primarily aim to adapt to climate change have only started appearing during the last decade (Braunschweiger et al. 2018; Kruse and Pütz 2014). The field is also subject to heavy fragmentation as different climate change impacts fall under the purview of different sectoral authorities (Bauer et al. 2012). This fragmentation is further exacerbated in the case of Switzerland, with its federal system that delegates a large amount of political authority and responsibility to the subnational cantonal and municipal levels (Ladner 2010). In Switzerland, national climate change adaptation policy began in 2008 with the foundation of the interdepartmental climate committee, which aimed to coordinate the activities of all the federal agencies involved in climate politics, including adaptation. The work of the committee resulted in the creation of the Swiss adaptation strategy of the federal council in 2012 and its second part, the national action plan adaptation, in 2014 (Widmer 2018). The strategy is primarily meant to foster inter-sectoral cooperation regarding climate change adaptation at the federal level, while the action plan defines 63 measures to implement the strategy (Braunschweiger and Pütz 2021). The action plan has since been reworked, and an updated version was released in 2020. One of the more prominent measures contained within the action plan is the pilot programme adaptation, which sponsored 31 adaptation projects on the cantonal and municipal level. The pilot programme is significant in so far as it marks the national-level adaptation policies' first departure from the exclusive focus on federal agencies and instead aims to foster initiatives on the subnational levels (Braunschweiger and Pütz 2021). The legal basis for Swiss climate change adaptation is the CO2-law, which mandates the FOEN to coordinate adaptation measures while accounting for the measures of the cantons. The cantons are mandated to report to the FOEN on their adaptation measures. This lack of a clear legal adaptation mandate for cantons or municipalities has led to a very heterogenous adaptation progress at the subnational level (Braunschweiger and Pütz 2021).

Data collection

My data collection process began with an expert workshop attended by the members of the INTERREG (European Territorial Cooperation) project GoApply,[1] which aimed to analyse climate change adaptation governance in the Alpine space. The project team included both scientists and members of the federal administrations from the four Alpine countries Austria, Germany, Italy and Switzerland (a full list of participants can be found in the annex). Workshop attendees worked together to identify the most important climate change adaptation policies, measures and actors in all four countries. I started the analysis by reviewing all publicly available documentation and progress reports on the Swiss adaptation policies and measures identified during the workshop (a full list of all reviewed documents can be found in the annex). I reviewed these documents for the information on any actors mentioned as being involved in the design, the implementation or the financing of said policies and measures. Strategic policy documents usually mentioned the actors responsible for their design while documents more directly concerned with implementation such as action plans or project reports usually mentioned who would be responsible for the implementation process. This is how I identified the actors included in my network analysis. If policy documents mentioned any subsequent policies or measures deriving from or involved in the implementation of the superordinate policies and measures, I continued by finding any available documentation on those subordinate policies and measures and likewise analysing them. The collection of policies and measures identified through this process form the second mode of my network. I only included policies and measures explicitly defined as pertaining to climate change adaptation. This data was then validated based on 24 interviews with members of the federal, cantonal and municipal administrations as well as employees of NGOs and private companies involved in the implementation of adaptation measures. The documentation on any additional policies and measures identified during these interviews was likewise analysed. Through this process, I identified 125 actors involved in the design, financing or implementation of a total of 110 adaptation policies and measures included in or derived from the Swiss national adaptation strategy. These policies, measures and actors form the nodes of my network. Actors are tied to all the policies and measures they were involved in.

The data collection process took place from July 2017 to April 2018. It included documents starting in 2018 and dating back to 2009, although most analysed documents were published after the adoption of the national adaptation strategy in 2012.

Method of analysis

My data structure links actors with all the policies and measures that they were involved in rather than directly with each other. In network analysis, this type of data is called two-mode data. Nodes belong to one of two groups or modes, and ties always connect two nodes that do not belong to the same group (Thiétart et al. 2012). I considered policies and measures as one group of nodes and actors as the second group. I consider two actors to have co-participated in a policy or measure if they share a direct tie to at least one policy or measure.

Two-mode data can be analysed either by converting the data into one-mode data or representing two-mode data in a bipartite network (Thiétart et al. 2012). However, conversion to one-mode data leads to a loss of information on the original structure of the dataset (Borgatti and Everett 1997). For example, if I was to convert my data, I would no longer be able to retrace which policies and measures had played an especially important role as they established a markedly high number of ties between actors and connected actors that had not worked together on any other policies and measures. While this disadvantage can be avoided by employing a dual-projection conversion approach (Everett and Borgatti 2013), such an approach would be just as complex as working with bipartite networks. The primary disadvantage of working with bipartite networks is that the methods employed to calculate certain characteristics need to be adjusted or may not be applicable at all. Thus, whether I follow a conversion approach or not depends on how I operationalise bridging actors and whether those operationalisation methods can be applied to two-mode networks or not.

---

[1] https://www.alpine-space.org/projects/goapply/en/home

The analysis of two-mode data rests on the assumption that co-participation in a policy or measure by two actors is comparable to the direct ties measured by one-mode network analysis. However, Borg et al. (2015) validated this assumption by showing that ties of trust between actors are primarily established through working together rather than exchanging information or sharing common goals.

A common indicator for the centrality of an actor is betweenness centrality (Christopoulos and Ingold 2015; Freeman 1977; Ingold 2011). Betweenness centrality measures how often any given node in a network lies on the shortest possible path between two other nodes, indicating how well-positioned the said actor is to take on a coordinating role within the network (Borgatti and Everett 2006; Thiétart et al. 2012). Betweenness centrality can be calculated for two-mode networks by following the method introduced by Borgatti and Everett (1997). Thus, following Angst et al. (2018) who first proposed to categorise bridging actors as central coordinators and periphery connectors, I operationalise central coordinators by calculating the betweenness centrality for all actors and identifying those actors that show the highest results.

Periphery connectors connect actors to the network that have little or no other connection to it. As the method employed to identify periphery connectors by Angst et al. (2018) is not well suited for analysing two-mode networks, I instead use network modularity to operationalise periphery connectors. Network modularity is an indicator of the extent to which a network is divided into separate modules or clusters. Higher modularity indicates more dense connections between actors within the same module but less well-developed connections between different modules (Guimerà and Amaral 2005; Newman 2006; Olesen et al. 2007). Thus, the removal of a periphery connector from the network results in higher modularity as connections between separate modules disappear with them. Whereas for more peripheral actors, their removal from the network results in lower network modularity as the separate modules they form disappear with them and the remaining modules are on average more well-connected than before. For any given actor, I calculate the difference in modularity between the network without that actor and the original network. Any actor whose removal leads to an increase in network modularity is considered a periphery connector. This new method of identifying periphery connectors allows for more nuanced assessments of how the presence or absence of specific nodes influences the heterogeneity of a network and is easily applicable to two-mode as well as one-mode networks.

Table 1 Distribution of actors in the network across administrative levels

Administrative Level	Number of actors
Federal	36
Cantonal	33
Municipal	8
Private Sector	14
Miscellaneous	34
Total	125

I calculate betweenness centrality scores and modularity scores using the R packages statnet (Handcock et al. 2008) and igraph (Pemberton 1975). Arguably, all actors with a betweenness centrality score above zero are coordinators, as they constitute the shortest path between at least two other actors. However, I am specifically interested in those actors playing the most important coordinating roles within the network. Thus, I consider actors central coordinators if their betweenness centrality scores lie both above zero and within the top 10% of betweenness scores.

Each actor in the network is assigned two variables denoting the administrative level and the sector to which they belong as shown in Tables 1 and 2. Governmental actors are assigned to the federal, cantonal or municipal level depending on their level of jurisdiction while profit-oriented private business is assigned to the private sector. The remaining non-state, non-private actors such as research institutions or non-profit organisations (NPO) are assigned the label miscellaneous. Sectoral affiliations are assigned based on official designation for state actors, based on the closest fit of their primary product or service for private businesses or based on my assessment of their thematic focal point in the case of non-profit organisation. For each identified bridging actor, I then calculate the total number of co-participants operating at different administrative levels (cross-level ties) and from different policy sectors (cross-sectoral ties).

Results and discussion

Figure 2 shows the climate change adaptation actor network in Switzerland. As is immediately apparent, the FOEN plays an extremely important coordinating role with a betweenness

Table 2 Distribution of actors in the network across policy sectors

Sector	Number of actors
Agriculture	10
Construction	3
Economy	10
Energy	3
Environment	33
Health	2
Hunting	1
Meteorology	1
Military and civil protection	5
Natural hazards	9
Research	24
Spatial planning	3
Traffic and transport	5
Water	11
Miscellaneous	5
Total	125

centrality score that is almost five times as high as that of the runner-up. The federal offices involved in the design and implementation of the adaptation strategy, as well as their primary partners at the cantonal level, form a core structure with well-developed ties amongst each other. Municipal and non-governmental actors largely form various peripheral clusters. Similar core-periphery structures have been recognised in many empirical studies of natural resource governance networks (Angst et al. 2018; Ernstson et al. 2008; Hirschi et al. 2013; Luthe et al. 2012). One small cluster around the municipal adaptation strategy for Zurich turns out not to be connected to the overall network.

Distribution of bridging positions

Out of 125 actors, three were eliminated from the analysis, as they have no connection to the larger overall network. Amongst the remaining 122, I identified thirteen central coordinators and ten periphery connectors. Table 3 details how bridging positions are distributed

Fig. 2 Climate change adaptation actor network in Switzerland and important bridging actors—Federal actors are visualised by octagons, cantonal actors by hexagons, municipal governmental actors by quadrangles, private businesses by triangles and miscellaneous actors such as research institutions or NPOs by circles. Vertex size correlates to betweenness centrality. Important bridging actors are labelled and marked by colour: central coordinators in yellow, periphery connectors in red and actors that fulfil both roles in orange. Policies and measures are not pictured to improve visual clarity

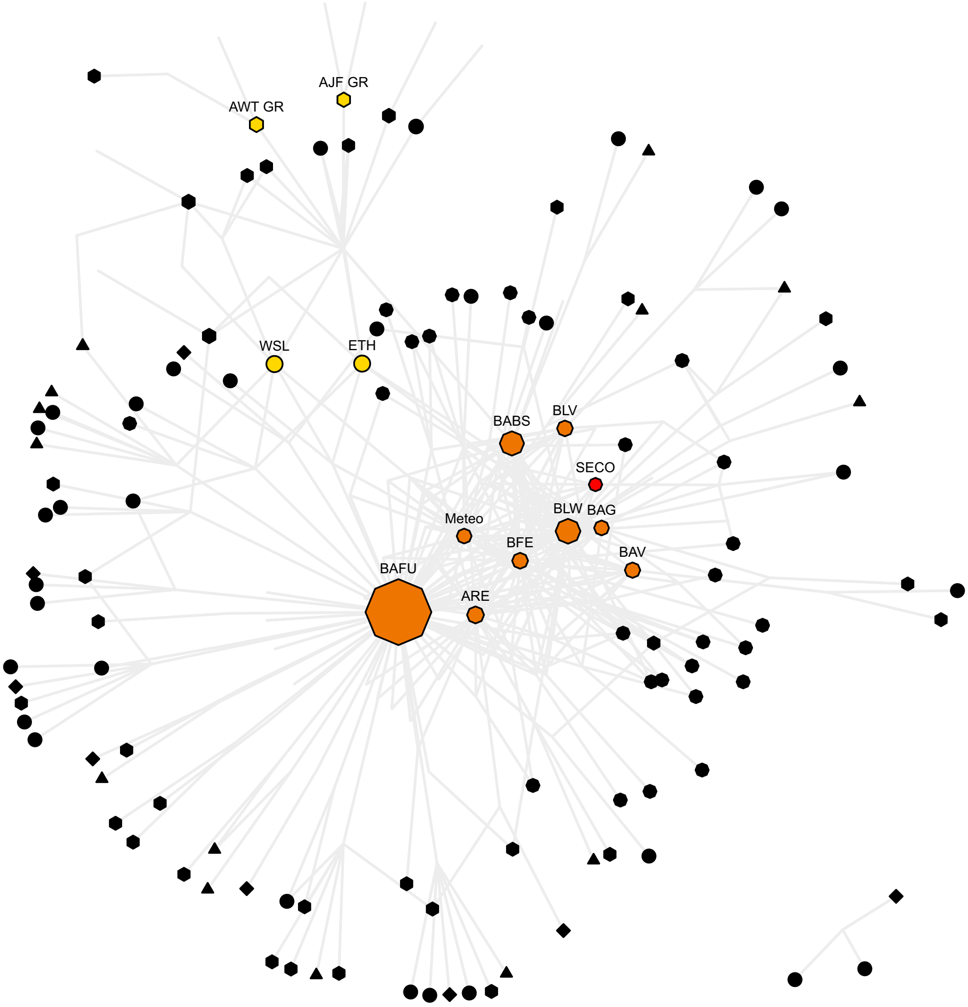

Table 3 Distribution of bridging positions across administrative levels as well as governmental and non-governmental actors

Actor attributes	Central coordinators	Periphery connectors
Federal level	9	10
Cantonal level	2	0
Municipal level	0	0
Private sector	0	0
Miscellaneous	2	0
Total	13	10

amongst administrative levels as well as amongst governmental and non-governmental actors. Most central coordinators are governmental actors, with the two exceptions being a federally funded university and research institution, respectively. The federal authorities are very well represented amongst central coordinators, making up nine out of thirteen of them, with the FOEN, the Federal Office for Agriculture (FOAG) and the Federal Office for Civil Protection (FOCP) occupying the three most prominent coordinating roles. The last two central coordinator positions are occupied by the cantonal agency for the Economy and Tourism (AWT) as well as the cantonal agency for Hunting and Fishing (AJF) Grisons.

Periphery connector positions are exclusively occupied by federal level authorities. This may be evidence of the fact that governmental actors are more inclined to seek out new information than non-governmental actors. Nine out of ten identified periphery connectors are also central coordinators, while nine out of thirteen central coordinators are also periphery connectors. This degree of overlapping between the two bridging types is yet more evidence of the important bridging and coordinating roles the federal authorities play in the governance of adaptation to climate change in Switzerland.

Cross-level and cross-sectoral ties of bridging actors

Due to the high amount of overlap between central coordinators and periphery connectors, I identified only fourteen unique bridging actors in total. Table 4 shows all bridging actors with their respective betweenness centrality and delta modularity scores, whether they are central coordinators or periphery connectors or both, their number of ties to other actors and their respective proportions of cross-level ties and cross-sectoral ties.

Overall, I observe considerably more cross-sectoral ties than cross-level ties. The reasons for this are twofold. Firstly, there is a lot more variation regarding policy sectors than there is regarding administrative level. Secondly, the Swiss adaptation strategy primarily aims to improve inter-sectoral cooperation at the federal level. This is readily apparent in the scores of the federal offices, which mostly boast proportions of cross-sectoral ties from 85 to 100% but cross-level proportions below 40%, and in many cases even below 20%. The one exception to this trend amongst federal offices is the FOEN with 64% cross-level ties and 69% cross-sectoral ties. Presumably, the reason for this deviation is that the FOEN takes on a coordinating role amongst federal offices for the adaptation strategy and action plan in general and, in particular, for the pilot programme adaptation, which aims to foster adaptation initiatives at subnational levels. This special role of the FOEN is also reflected in its high number of ties in general and its betweenness centrality score.

In addition to the ten federal offices, I find that two cantonal offices, the AWT and the AJW, as well as two research institutions, the ETH and the WSL, also play important bridging roles. The fact that two cantonal offices from Grisons occupy bridging roles demonstrates the progress achieved by the cantonal climate strategy Grisons. Said strategy mirrors the federal adaptation strategy insofar as it primarily aims to foster intersectoral coordination within the canton. This is reflected by the fact that both cantonal offices established considerably more cross-sectoral ties than cross-level ties. The two research institutions on the other hand show remarkably high proportions of cross-level ties with 76.67% and 69.23%, respectively, surpassing even the FOEN.

I hypothesised that higher-level actors and governmental actors are more likely to take on both cross-level and cross-sectoral bridging roles. The network contains a total of 122 actors. 44 out of those 122 are federal level actors, and 58 are governmental actors. Thus, if bridging role distribution were independent from the administrative level or governmental status and, federal-level actors should make up 30–40% of bridging roles and governmental actors should make up 45–55% of bridging roles.

I find that amongst a total of fourteen identified bridging actors, ten are federal authorities, with the remaining four being two cantonal authorities and two research organisations. The FOEN, despite its role as the primary central coordinator for Swiss climate change adaptation, has a significantly lower proportion of cross-sectoral ties than the other federal offices. The reason for this discrepancy is that the FOEN plays an important coordinating role in the pilot project adaptation, which aims to foster adaptation at subnational levels. Thus, the FOEN also built a high number of cross-level ties to actors from within the same sector of environmental policy,

Table 4 Identified bridging actors and their respective proportions of cross-level and cross-sectoral ties

Actor	Administrative level	Ties	Cross-level ties	Cross-sector Ties	Cross-level ties [%]	Cross-sector ties [%]	Betweenness centrality (scaled)	Delta modularity	Central coordinator	Periphery connector
Federal Office for the Environment	Federal	97	62	68	63.92	70.10	10.512	0.0824	1	1
Federal Office for Agriculture	Federal	47	15	40	31.91	85.11	2.198	0.0303	1	1
Federal Office for Civil Protection	Federal	40	16	36	40.00	90.00	2.083	0.0149	1	1
Federal Office for Spatial Planning	Federal	36	9	35	25.00	97.22	0.610	0.0256	1	1
Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)	Misc	26	18	16	69.23	61.54	0.444	−0.0160	1	0
Swiss Federal Institute of Technology Zurich (ETH)	Misc	30	23	25	76.67	83.33	0.424	−0.0187	1	0
Swiss Federal Office of Energy	Federal	32	4	31	12.50	96.88	0.392	0.0138	1	1
Federal Food Safety and Veterinary Office	Federal	24	6	22	25.00	91.67	0.368	0.0106	1	1
Federal Office of Transport	Federal	25	5	23	20.00	92.00	0.295	0.0019	1	1
Office for the Economy and Tourism Grisons	Cantonal	13	5	13	38.46	100.00	0.248	−0.0105	1	0
Federal Office of Public Health	Federal	22	4	22	18.18	100.00	0.185	0.0042	1	1
Federal Office of Meteorology and Climatology	Federal	32	6	32	18.75	100.00	0.176	0.0193	1	1
Office for Hunting and Fishing Grisons	Cantonal	12	5	12	41.67	100.00	0.109	−0.0111	1	0
State Secretariat for Economic Affairs	Federal	17	3	15	17.65	88.24	−0.107	0.0043	0	1

consequently lowering the proportion of cross-sectoral ties. All the other federal agencies are particularly active in building cross-sectoral ties to other federal actors. Comparing the total number of ties shows that the FOEN is more successful in building both cross-level and cross-sectoral ties than any other actor.

The federal government is much better represented amongst the most important bridging actors than what would be expected if administrative level or governmental status did not matter regarding bridging roles. Thus, the data supports my first two hypotheses.

Lastly, I expected research organisations to be more likely to take on bridging roles than other non-governmental actors due to the importance of developing and disseminating knowledge during the early stage of adaptation policies characterised by countless uncertainties. I find strong support for this hypothesis, with the two only non-governmental actors identified as important bridging actors being research organisations.

Conclusions

My results show that federal governmental actors are most likely to take on bridging roles both amongst administrative levels and amongst policy sectors. This result departs from similar analyses of other multi-level governance issues such as environmental policy or land-use and water governance, which find that regional actors generally play more important coordinating roles than federal authorities (Angst et al. 2018; Hamilton et al. 2021; Henry et al. 2011; K. Ingold 2014). While these differences may partially be attributed to different research designs, the difference in policy fields is certainly another important factor. Whereas environmental policy, land-use planning or water governance are well-established fields, climate change adaptation has only recently begun to develop into a full-fledged policy field of its own (Massey and Huitema 2016). The special status of climate change adaptation as an emerging policy field is further exemplified by the central role played by two research institutions. Accessing and distributing new information are well accepted as one of the key functions and benefits of central coordinators in policy networks (Berardo and Scholz 2010). However, it is rather uncommon for research institutions to occupy a central coordinator position themselves. Thus, my results demonstrate how the relative prioritisation of different governance functions and the actors providing them may vary depending on how well established a given field of policy is, lending credence to Massey and Huitema's (2013, 2016) call on policy researchers to pay more attention to how policy fields as a whole form and change to better understand policy change and the role different actors play therein.

The FOEN is by far the most important bridging actor in Swiss climate change adaptation. This is not surprising, as the FOEN was supposed to take on a coordinating role amongst sectors for the design and implementation of the Swiss adaptation strategy. Nevertheless, it is remarkable that the federal government plays such an important role even in the Swiss system, which focuses on delegating power and responsibility to the subnational levels. Comparable multi-level governance issues in Switzerland such as land-use or water governance are highly decentralised. Cantonal authorities take on the most important bridging roles with specific tasks commonly being delegated to municipalities (Angst et al. 2018; K. Ingold 2014). In comparison, Swiss adaptation policy at the federal level has so far been focused on mainstreaming and cross-sectoral cooperation and many cantons and municipalities still lack formal adaptation policies or strategies (Braunschweiger and Pütz 2021). Thus, the efforts at the federal level dominate the adaptation field so far. Many cantons have only recently appointed adaptation contact points, and many municipal adaptation initiatives have been fostered by the federal level rather than the cantonal level. The Swiss federal authorities have so far mostly built cross-sectoral ties, while cross-level ties are rarer. This result is in line with empirical studies on the implementation of adaptation, which find that many European nations struggle to translate national-level adaptation policies and coordination efforts into concrete adaptation efforts at subnational levels (Bednar et al. 2019; Braunschweiger and Pütz 2021; Runhaar et al. 2018). The high number of cross-level ties the FOEN established through the coordination of the pilot programme adaptation which demonstrates the importance of these efforts to foster adaptation on the cantonal and municipal levels. However, if the federal government is to continue playing this key coordinating role in Swiss adaptation policy, it may require more funds dedicated to adaptation to finance measures such as the pilot programme and to reach a broader audience at the municipal level. On the other hand, if cantonal governmental actors are to systematically take on more important roles in Swiss adaptation governance as they do for comparable multi-level governance issues, a clearer legal mandate may be required to force even the stragglers to do so. The present lack of both dedicated funds for the current most important adaptation bridging actors to fulfil their roles more effectively and of a legal mandate for other potentially important bridging actors to take over may be one of the most important reasons for the Swiss adaptation implementation gap.

My empirical analysis is limited to the case of Switzerland. Switzerland is a wealthy country well-known in political science for its focus on consensual politics as well as its effective and well-trusted government agencies (Kriesi and Trechsel 2008; Sciarini et al. 2015). Thus, some of my results, especially those relating to the central role played by governmental actors, may not be perfectly applicable beyond the Swiss context. However, I expect federal government actors to play an important coordinating role during the emergence of adaptation as a new policy field in most countries with similarly well-established governmental institutions.

One possible disadvantage of my methodological approach was that I relied on the completeness of my initial sample to define the network boundaries. Additional policies and measures were only included if they either had a well-documented connection to the initial sample or were mentioned by my interview partners. Thus, it is possible that I missed some important bottom-up adaptation initiatives originating at the municipal or cantonal level that had no link to the national adaptation strategy or action plan. It is unlikely, that this caused me to miss any truly important initiatives as they should have been caught during the expert interviews. Nevertheless, my methodological approach was centred on national adaptation policies and the policies and measures resulting therefrom, which may be a part of the reason why most of the bridging actors I identified were federal agencies and few municipal governmental actors are represented in my sample. Another flaw of my research design is that it cannot account for how actor constellations change over time. However, limiting the analysis to a relatively short period of time as I did increases the likelihood that actor constellations have remained stable throughout the observed period. As my data collection process finished in 2018, the empirical analysis also did not take the updated version of the national action plan adaptation or the second round of the pilot programme adaptation into account.

Additionally, my methodological approach, especially the betweenness centrality and change in network modularity thresholds chosen to identify central coordinators and periphery connectors, could benefit from further examination and empirical testing to ascertain how well suited they are to this purpose.

Lastly, my reasoning for researching bridging actors is based on the idea that reducing fragmentation and improving collaboration through bridging will lead to improved policy outcomes. However, as I have gathered no data on actual outcomes, I have not empirically tested this assumption. Future research aiming to improve our understanding of how ties amongst actors influence policy outcomes should strive to address this research gap.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10113-022-01958-4.

Funding Open Access funding provided by Lib4RI – Library for the Research Institutes within the ETH Domain: Eawag, Empa, PSI & WSL. This work was supported by the Swiss Federal Office for the Environment (FOEN) [grant number 16.0144.PJ/Q074-1254].

Data Availability An interactive visualisation of the data on Swiss climate change adaptation governance that served as the basis for this social network analysis can be accessed at https://www.wsl.ch/gov-vis-cca/#switzerland.

Declarations

Conflict of interest The author declares no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Adger WN, Arnell NW, Tompkins EL (2005) Successful adaptation to climate change across scales. Glob Environ Chang 15(2):77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005

Aldrich H, Herker D (1977) Boundary spanning roles and organization structure. Acad Manag Rev 2(2):217. https://doi.org/10.2307/257905

Angst M, Widmer A, Fischer M, Ingold K (2018) Connectors and coordinators in natural resource governance: insights from swiss water supply. Ecol Soc 23(2). https://doi.org/10.5751/ES-10030-230201

Angst M, Hirschi C (2017) Network dynamics in natural resource governance: a case study of swiss landscape management. Policy Stud J 45(2):315–336. https://doi.org/10.1111/psj.12145

Ansell C, Gash A (2008) Collaborative governance in theory and practice. J Public Adm Res Theory 18(4):543–571. https://doi.org/10.1093/jopart/mum032

Ansell C, Sørensen E, Torfing J (2017) Improving policy implementation through collaborative policymaking. Policy Polit 45(3):467–486. https://doi.org/10.1332/030557317X14972799760260

Bauer A, Steurer R (2014) Multi-level governance of climate change adaptation through regional partnerships in Canada and England. Geoforum 51:121–129. https://doi.org/10.1016/j.geoforum.2013.10.006

Bauer A, Steurer R (2015) National adaptation strategies, what else? Comparing adaptation mainstreaming in German and Dutch water management. Reg Environ Change 15(2):341–352. https://doi.org/10.1007/s10113-014-0655-3

Bauer A, Feichtinger J, Steurer R (2012) The governance of climate change adaptation in 10 OECD countries: challenges and approaches. J Environ Planning Policy Manage 14(3):279–304. https://doi.org/10.1080/1523908X.2012.707406

Bednar D, Henstra D, McBean G (2019) The governance of climate change adaptation: are networks to blame for the implementation deficit? J Environ Planning Policy Manage 21(6):702–717. https://doi.org/10.1080/1523908X.2019.1670050

Berardo R (2014) The evolution of self-organizing communication networks in high-risk social-ecological systems. Int J Commons 8(1):236–258. https://doi.org/10.18352/ijc.463

Berardo R, Lubell M (2016) Understanding what shapes a polycentric governance system. Public Adm Rev 76(5):738–751. https://doi.org/10.1111/puar.12532

Berardo R, Lubell M (2019) The ecology of games as a theory of polycentricity: recent advances and future challenges. Policy Stud J 47(1):6–26. https://doi.org/10.1111/psj.12313

Berardo R, Scholz JT (2010) Self-organizing policy networks: risk, partner selection, and cooperation in estuaries. Am J Polit Sci 54(3):632–649. https://doi.org/10.1111/j.1540-5907.2010.00451.x

Berkes F (2002) Cross-scale institutional linkages: perspectives from the bottom up. The Drama of the Commons. pp 293–321

Biesbroek GR, Swart RJ, Carter TR, Cowan C, Henrichs T, et al. (2010) Europe adapts to climate change: comparing National Adaptation Strategies. Glob Environ Chang 20(3):440–450. https://doi.org/10.1016/j.gloenvcha.2010.03.005

Biesbroek R, Klostermann J, Termeer C, Kabat P (2011) Barriers to climate change adaptation in the Netherlands. Climate Law 2(2):181–199. https://doi.org/10.3233/CL-2011-033

Bingham LB, O'Leary R (2014) Big ideas in collaborative public management. Big ideas in collaborative public management. ME Sharpe, New York. https://doi.org/10.4324/9781315706146

Birkmann J, Mechler R (2015) Advancing climate adaptation and risk management. New insights, concepts and approaches: what have we learned from the SREX and the AR5 processes? Clim Chang 133(1):1–6. https://doi.org/10.1007/s10584-015-1515-y

Bodin Ö, Sandström A, Crona B (2017) Collaborative networks for effective ecosystem-based management: a set of working hypotheses. Policy Stud J 45(2):289–314. https://doi.org/10.1111/psj.12146

Borg R, Toikka A, Primmer E (2015) Social capital and governance: a social network analysis of forest biodiversity collaboration in Central Finland. Forest Policy Econ 50:90–97. https://doi.org/10.1016/j.forpol.2014.06.008

Borgatti SP, Everett MG (1997) Network analysis of 2-mode data. Soc Networks 19(3):243–269. https://doi.org/10.1016/S0378-8733(96)00301-2

Borgatti SP, Everett MG (2006) A Graph-theoretic perspective on centrality. Soc Networks 28(4):466–484. https://doi.org/10.1016/j.socnet.2005.11.005

Braunschweiger D, Pütz M (2021) Climate adaptation in practice: how mainstreaming strategies matter for policy integration. Environ Policy Gov. https://doi.org/10.1002/eet.1936

Braunschweiger D, Pütz M, Heidmann F, Bludau MJ (2018) Mapping governance of adaptation to climate change in Switzerland. Reg Stud Reg Sci 5(1):398–401. https://doi.org/10.1080/21681376.2018.1549507

Brönnimann S, Appenzeller C, Croci-Maspoli M, Fuhrer J, Grosjean M, et al. (2014) Climate change in Switzerland: a review of physical, institutional, and political aspects. Wires Clim Change 5(4):461–481. https://doi.org/10.1002/wcc.280

Brown LD (1998) Creating social capital: nongovernmental development organizations and intersectoral problem solving. Private Action and the Public Good. pp 228–241

Carlsson LG, Sandström AC (2007) Network governance of the commons. Int J Commons 2(1):33. https://doi.org/10.18352/ijc.20

Chaskin RJ (2001) Organizational infrastructure and community capacity: the role of broker organizations. Res Soc Prob Public Policy 8:143–166. https://doi.org/10.1016/s0196-1152(01)80009-0

Christopoulos D, Ingold K (2015) Exceptional or just well connected? Political entrepreneurs and brokers in policy making. Eur Polit Sci Rev 7(3):475–498. https://doi.org/10.1017/S1755773914000277

Cimato F, Mullan M (2010) Adapting to climate change: analysing the role of government. london: department for environment, food and rural affairs.https://research.fit.edu/media/site-specific/researchfitedu/coast-climate-adaptation-library/europe/united-kingdom-amp-ireland/DEFRA.-2010.-Adapting-to-CC-Analysing-the-Role-of-Government.pdf. Accessed 02.08.2022

Collins-Dogrul J (2012) Tertius iungens brokerage and transnational intersectoral cooperation. Organ Stud 33(8):989–1014. https://doi.org/10.1177/0170840612445118

Crona BI, Parker JN (2012) Learning in support of governance: theories, methods, and a framework to assess how bridging organizations contribute to adaptive resource governance. Ecol Soc 17(1). https://doi.org/10.5751/ES-04534-170132

Di Gregorio M, Fatorelli L, Paavola J, Locatelli B, Pramova E, et al. (2019) Multi-level governance and power in climate change policy networks. Glob Environ Change 54(November 2018):64–77. https://doi.org/10.1016/j.gloenvcha.2018.10.003

Dupuis J, Knoepfel P (2013) The adaptation policy paradox: the implementation deficit of policies framed as climate change adaptation. Ecol Soc 18(4). https://doi.org/10.5751/ES-05965-180431

Eisenack K, Moser SC, Hoffmann E, Klein RJT, Oberlack C, et al. (2014) Explaining and overcoming barriers to climate change adaptation. Nat Clim Chang 4(10):867–872. https://doi.org/10.1038/nclimate2350

Ekstrom JA, Moser SC (2014) Identifying and overcoming barriers in urban climate adaptation: case study findings from the San Francisco Bay Area, California, USA. Urban Climate 9:54–74. https://doi.org/10.1016/j.uclim.2014.06.002

Emerson K, Gerlak AK (2014) Adaptation in collaborative governance regimes. Environ Manage 54(4):768–781. https://doi.org/10.1007/s00267-014-0334-7

Ernstson H, Barthel S, Andersson E, Borgström ST (2010) Scale-crossing brokers and network governance of urban ecosystem services: the case of stockholm. Ecol Soc 15(4):Art28. https://doi.org/10.5751/ES-03692-150428

Ernstson H, Sörlin S, Elmqvist T (2008) Social movements and ecosystem services - the role of social network structure in protecting and managing urban green areas in Stockholm. Ecol Soc 13(2). https://doi.org/10.5751/es-02589-130239

Everett M, Borgatti S (2013) The dual-projection approach for two-mode networks. Soc Networks 35:204–210. https://doi.org/10.1016/j.socnet.2012.05.004

Feiock RC (2009) Metropolitan governance and institutional collective action. Urban Aff Rev 44(3):356–377. https://doi.org/10.1177/1078087408324000

Feiock RC (2013) The institutional collective action framework. Policy Stud J 41(3):397–425. https://doi.org/10.1111/psj.12023

Fliervoet JM, Geerling GW, Mostert E, Smits AJM (2016) Analyzing collaborative governance through social network analysis: a case study of river management along the waal river in The Netherlands. Environ Manage 57(2):355–367. https://doi.org/10.1007/s00267-015-0606-x

Freeman LC (1977) A set of measures of centrality based on betweenness. Sociometry 40:35–41

Friedman RA, Podolny J (1992) Differentiation of boundary spanning roles: labor negotiations and implications for role conflict. Adm Sci Q 37(1):28. https://doi.org/10.2307/2393532

Galarraga I, Gonzalez-Eguino M, Markandya A (2011) The role of regional governments in climate change policy. Environ Policy Gov 21(3):164–182. https://doi.org/10.1002/eet.572

Guimerà R, Amaral LAN (2005) Functional cartography of complex metabolic networks. Nature 433(7028):895–900. https://doi.org/10.1038/nature03288

Hahn T, Olsson P, Folke C, Johansson K (2006) Trust-building, knowledge generation and organizational innovations: the role of a bridging organization for adaptive comanagement of a wetland landscape around Kristianstad, Sweden. Hum Ecol 34(4):573–592. https://doi.org/10.1007/s10745-006-9035-z

Hamilton M, Fischer AP, Jasny L (2021) Bridging collaboration gaps in fragmented environmental governance systems. Environ Sci Policy 124:461–470. https://doi.org/10.1016/j.envsci.2021.07.014

Handcock MS, Hunter DR, Butts CT, Goodreau SM, Morris M (2008) statnet: software tools for the representation, visualization, analysis and simulation of network data. J Stat Softw 24(1):1548–7660. https://doi.org/10.18637/jss.v024.i01

Hartley J, Sørensen E, Torfing J (2013) Collaborative innovation: a viable alternative to market competition and organizational entrepreneurship. Public Adm Rev 73(6):821–830. https://doi.org/10.1111/puar.12136

Henry AD, Lubell M, McCoy M (2011) Belief systems and social capital as drivers of policy network structure: the case of california regional planning. J Public Adm Res Theory 21(3):419–444. https://doi.org/10.1093/jopart/muq042

Hirschi C, Widmer A, Briner S, Huber R (2013) Combining policy network and model-based scenario analyses: an assessment of future ecosystem goods and services in Swiss mountain regions. Ecol Soc 18(2). https://doi.org/10.5751/ES-05480-180242

Ingold K (2011) Network structures within policy processes: coalitions, power, and brokerage in swiss climate policy. Policy Stud J 39(3):435–459. https://doi.org/10.1111/j.1541-0072.2011.00416.x

Ingold K (2014) How involved are they really? A comparative network analysis of the institutional drivers of local actor inclusion. Land Use Policy 39:376–387. https://doi.org/10.1016/j.landusepol.2014.01.013

Ingold K, Fischer M, Cairney P (2017) Drivers for policy agreement in nascent subsystems: an application of the advocacy coalition framework to fracking policy in Switzerland and the UK. Policy Stud J 45(3):442–463. https://doi.org/10.1111/psj.12173

Ingold K, Driessen PPJ, Runhaar HAC, Widmer A (2019) On the necessity of connectivity: linking key characteristics of environmental problems with governance modes. J Environ Planning Manage 62(11):1821–1844. https://doi.org/10.1080/09640568.2018.1486700

Ingold KM, Gavilano A (2020) Under what conditions does an extreme event deploy its focal power?: toward collaborative governance in Swiss flood risk management. Collaborative Crisis Management. Routledge, London, pp 132–147

IPCC (2018) Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte V, Zhai P, et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–24. https://doi.org/10.1017/9781009157940.001

Jasny L, Lubell M (2015) Two-mode brokerage in policy networks. Soc Networks 41:36–47. https://doi.org/10.1016/j.socnet.2014.11.005

Keskitalo ECH (2010) Introduction-adaptation to climate change in Europe: theoretical framework and study design. Developing Adaptation Policy and Practice in Europe: Multi-level Governance of Climate Change. Springer, Berlin, pp 1–38

Kiem AS, Austin EK (2013) Disconnect between science and end-users as a barrier to climate change adaptation. Clim Res 58(1):29–41. https://doi.org/10.3354/cr01181

Klijn EH, Koppenjan JFM (2000) Public management and policy networks. Public Manag: Int J Res Theory 2(2):135–158. https://doi.org/10.1080/14719030000000007

Koppenjan JFM, Klijn E-H (2004) Managing uncertainties in networks: a network approach to problem solving and decision making. Psychology Press, London

Kriesi H, Trechsel AH (2008) The politics of Switzerland continuity and change in a consensus democracy. The Politics of Switzerland Continuity and Change in a Consensus Democracy. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511790676

Kruse S, Pütz M (2014) Adaptive capacities of spatial planning in the context of climate change in the European alps. Eur Plan Stud 22(12):2620–2638. https://doi.org/10.1080/09654313.2013.860516

Ladner A (2010) Switzerland: subsidiarity, power-sharing, and direct democracy. Oxford University Press, Oxford. https://doi.org/10.1093/oxfordhb/9780199562978.003.0009

Leach WD, Sabatier PA (2005) To trust an adversary: integrating rational and psychological models of collaborative policymaking. Am Polit Sci Rev 99(4):491–503. https://doi.org/10.1017/S000305540505183X

Leitner M, Buschmann D, Capela Lourenco T, Coninx I, Schmidt A (2020) Bonding CCA and DRR: recommendations for strengthening institutional collaboration and capacities. PLACARD project, FC.ID, Lisbon. https://www.placard-network.eu/wp-content/PDFs/PLACARD-Insitutional-strengthening-May2020.pdf

Lorenz S, Porter JJ, Dessai S (2019) Identifying and tracking key climate adaptation actors in the UK. Reg Environ Change 19(7):2125–2138. https://doi.org/10.1007/s10113-019-01551-2

Luthe T, Wyss R, Schuckert M (2012) Network governance and regional resilience to climate change: empirical evidence from mountain tourism communities in the Swiss Gotthard region. Reg Environ Change 12(4):839–854. https://doi.org/10.1007/s10113-012-0294-5

Marsden PV (1982) Brokerage behavior in restricted exchange networks. "Pp. 201—18 in Social structure and networkanalysis. edited by PV Marsden and N. Lin. Beverly Hills, CA: Sage. 1983. Restricted access in networks and models of power." Am J Sociol 88(4):686–717

Massey E, Huitema D (2013) The emergence of climate change adaptation as a policy field: the case of England. Reg Environ Change 13(2):341–352. https://doi.org/10.1007/s10113-012-0341-2

Massey E, Huitema D (2016) The emergence of climate change adaptation as a new field of public policy in Europe. Reg Environ Change 16(2):553–564. https://doi.org/10.1007/s10113-015-0771-8

McAllister RRJ, McCrea R, Lubell MN (2014) Policy networks, stakeholder interactions and climate adaptation in the region of South East Queensland, Australia. Reg Environ Change 14(2):527–539. https://doi.org/10.1007/s10113-013-0489-4

McAllister RRJ, Taylor BM, Harman BP (2015) Partnership networks for urban development: how structure is shaped by risk. Policy Stud J 43(3):379–398. https://doi.org/10.1111/psj.12103

Newman MEJ (2006) Modularity and community structure in networks. Proc Natl Acad Sci USA 103(23):8577–8582. https://doi.org/10.1073/pnas.0601602103

Olesen JM, Bascompte J, Dupont YL, Jordano P (2007) The modularity of pollination networks. Proc Natl Acad Sci USA 104(50):19891–19896. https://doi.org/10.1073/pnas.0706375104

Ostrom E (2010) Polycentric systems for coping with collective action and global environmental change. Glob Environ Chang 20(4):550–557. https://doi.org/10.1016/j.gloenvcha.2010.07.004

Ostrom E (2014) A polycentric approach for coping with climate change. Ann Econ Financ 15(1):97–134. https://doi.org/10.2139/ssrn.1934353

Pahl-Wostl C (2009) A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Glob Environ Chang 19(3):354–365. https://doi.org/10.1016/j.gloenvcha.2009.06.001

Pemberton JR (1975) Retention of mercurial preservatives in desiccated biological products. J Clin Microbiol 2(6):549–551 (http://igraph.sf.net) Last accessed 04.03.2021

Rathwell KJ, Peterson GD (2012) Connecting social networks with ecosystem services for watershed governance: a social-ecological network perspective highlights the critical role of bridging organizations. Ecol Soc 17(2):Art24. https://doi.org/10.5751/ES-04810-170224

Rhinard M (2013) Self-organizing federalism: Collaborative mechanisms to mitigate institutional collective action dilemmas - edited by Richard C. Feiock and John T. Scholz. Public Adm 91(2):517–519. https://doi.org/10.1111/padm.12023

Runhaar H, Wilk B, Persson Å, Uittenbroek C, Wamsler C (2018) Mainstreaming climate adaptation: taking stock about "what works" from empirical research worldwide. Reg Environ Change 18(4):1201–1210. https://doi.org/10.1007/s10113-017-1259-5

Schneider M, Scholz J, Lubell M, Mindruta D, Edwardsen M (2003) Building consensual institutions: networks and the National Estuary Program. Am J Polit Sci 47(1):143–158. https://doi.org/10.1111/1540-5907.00010

Sciarini P, Fischer M, Traber D (2015) Political decision-making in Switzerland. Political decision-making in Switzerland. Palgrave Macmillan UK, London

Stovel K, Shaw L (2012) Brokerage. Ann Rev Sociol 38(1):139–158. https://doi.org/10.1146/annurev-soc-081309-150054

Swart R, Biesbroek R, Binnerup S, Carter TR, Cowan C, Henrichs T, Loquen S, Mela H, Morecroft M, Reese M, Rey D (2009) Europe adapts to climate change adaptation strategies. http://www.peer.eu/publications/europe-adapts-to-climate-change/. Accessed 22.10.2021

Tanaka M, Nishigaki T, Nakajima E, Totsuka S, Nakamura K (1980) Distribution, excretion, and metabolism of 3-[(4-amino-2-methyl-5-pyrimidinyl)methyl]-1-(2-chloroethyl)-1-nitrosourea(ACNU) in rats and mice after IV administration. Cancer Treat Rep 64(4–5):575–580

Terman JN, Feiock RC (2015) Improving outcomes in fiscal federalism: local political leadership and administrative capacity. J Public Adm Res Theory 25(4):1059–1080. https://doi.org/10.1093/jopart/muu027

Thiétart R-A, Angot J, Josserand E (2012) Analyzing social networks. Doing Manag Res. https://doi.org/10.4135/9781849208970.n14

Torfing J (2019) Collaborative innovation in the public sector: the argument. Public Manag Rev 21(1):1–11. https://doi.org/10.1080/14719037.2018.1430248

Underdal A (2010) Complexity and challenges of long-term environmental governance. Glob Environ Chang 20:386–393. https://doi.org/10.1016/j.gloenvcha.2010.02.005

Vignola R, McDaniels TL, Scholz RW (2013) Governance structures for ecosystem-based adaptation: using policy-network analysis to identify key organizations for bridging information across scales and policy areas. Environ Sci Policy 31:71–84. https://doi.org/10.1016/j.envsci.2013.03.004

Westerhoff L, Keskitalo ECH, Juhola S (2011) Capacities across scales: local to national adaptation policy in four European countries. Clim Pol 11(4):1071–1085. https://doi.org/10.1080/14693062.2011.579258

Widmer A (2018) Mainstreaming climate adaptation in Switzerland: how the national adaptation strategy is implemented differently across sectors. Environ Sci Policy 82:71–78. https://doi.org/10.1016/j.envsci.2018.01.007

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.