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# Bottom-up identification of subsystems in complex governance systems

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# Abstract

Theories of policymaking often focus on subsystems within a larger, overarching governance system. However, subsystem identification is complicated by the complexity of governance systems, characterized by multiple, interrelated issues, multi-level interactions, and a diverse set of organizations. This study suggests an empirical, bottom-up methodology to identify subsystems. Subsystems are identified based on bundles of similar observed organizational activity. The study further suggests a set of three elementary criteria to classify individual subsystems. In order to prove the value of the methodology, subsystems are identified through cluster analysis, and subsequently classified in a study of Swiss water governance. Results suggest that Swiss water governance can be understood as a network of overlapping subsystems connected by boundary penetrating organizations, with high-conflict and quiet politics subgroups. The study shows that a principled analysis of subsystems as the interconnected, constituent parts of complex governance systems offers insights into important contextual factors shaping outcomes. Such insights are prerequisite knowledge in order to understand and navigate complex systems for researchers and practitioners alike.

KEYWORDS: natural resource governance, governance, policy subsystems, networks, cluster analysis

# Introduction

Theories of policymaking often focus on an analysis of subsystems within a larger political system (Cairney and Heikkila 2017, 305). Depending on the theoretical background they have been labeled differently. Prominent concepts include the policy subsystem in the advocacy coalition framework (Weible and Sabatier 2007), policy areas in applications of punctuated equilibrium theory (True, Jones, and Baumgartner 2007), or policy domains (Laumann and Knoke 1987; Burstein 1991).

While conceptualizations of policy subsystems differ and serve different theoretical needs, they have in common that the empirical identification of subsystems is a complicated task. Subsystems are primarily meant to simplify the study of a complex policy area, but are themselves ambiguous, nested, dynamic, and interdependent constructs containing multiple components (Nohrstedt and Weible 2010). This study suggests a widely applicable, systematic procedure for subsystem identification to inform the application of policy process theories, with specific advantages in identifying different types of subsystems. In the light of the complex diversity in actors, activities, and issues, which characterizes modern governance (Rhodes 1996), the identification of subsystems is treated as an empirical question (Weible, Sabatier, and McQueen 2009). Thus, subsystems are not defined a priori but are identified given an observed empirical reality, based on a generalizable, systematic procedure. Subsystems are defined as bundles of similar observed organizational activity, and approached from a bottom-up, data-driven perspective.

The focus of policy analysis on the conduct of analyses within well-defined subsystems has long been challenged to incorporate more adequate representations of the complex empirical reality of governance. To do so, some have proposed to extend subsystem approaches. Proposed extensions include detailed concepts of sector-subsector relationships (Rayner et al. 2001), linked subsystems with trans-subsystem dynamics (Jones 2009) or the possibility of nested or overlapping subsystems (Zafonte and Sabatier 1998; Nohrstedt and Weible 2010). These extensions all implicitly reflect some of the complex system properties (Byrne and Callaghan 2014) of governance systems.

This article contends that the study of subsystems still provides a useful focal point for the application and development of governance theory. Subsystems provide a comparable frame of reference within which the predictions of different theoretical frameworks can be tested and compared across studies. As context-rich, meso-level constructs, they represent one of the most powerful ways to inform policy analysis approaches (Cairney and Weible 2017, 624). Similarly, public management that harnesses complex systems thinking, which depends on developing an understanding of the interaction of constituent parts of an overall system (Haynes 2015), can profit from knowledge about subsystem properties.

This makes it all the more essential that the way in which subsystems as a common frame of reference are identified and conceptualized reflects the reality of complex modern governance systems. Otherwise, studies based on the study of subsystems risk to draw invalid, or at least incomplete conclusions. A bottom-up identification of subsystems based on the observed activity of actors mitigates this risk. Subsystems that are identified inductively based on observed empirical patterns within a common methodology are more likely to allow comparison and allow for valid statements about single subsystems and their interconnections. This encourages cross-fertilization and comparison between theories, which is increasingly important, not least due to the proliferation of policy process theories (Weible 2017).

Besides systematizing the empirical task of subsystem identification or boundary setting, the complexity of governance also suggests that subsystems should be conceptually classified according to a set of criteria that allows to differentiate different types of subsystems. A classification of subsystems provides information about a crucial element of the all-important context within which policy choices take place (Cairney and Weible 2017). Predictions from some policy process theories might better apply to specific types of subsystems. For example, theories such as the Advocacy Coalition Framework (ACF) have mostly been applied and proven useful in adversarial subsystems (Weible 2017, 13), but to a lesser extent in collaborative ones (although exceptions exists, see Weible and Sabatier (2009)). Fitting the scope of a policy process theory to a specific type of subsystems thus increases the theory's explanatory power.

Thus, there are two main research aims of this study. First, it aims to develop a systematic, broadly applicable procedure for subsystem identification within a complex governance system. Second, the study aims to develop a starting set of criteria to classify subsystems, which are generally applicable and relevant to governance outcomes.

The methodology for subsystem identification is based on three dimensions of organizational activity. Substantive issues that organizations deal with, the levels on which they are active, and the type of activity they engage in draw up a three-dimensional space where organizations can be active at every possible junction. The space each individual organization occupies within these three dimensions represents its specific organizational activity profile. Comparing different activity profiles makes it possible to identify clusters of similar organizational activity profiles, in order to identify subsystems. The methodology's distinct advantage lies in its minimalist definition, which focuses solely on organizational activity. This allows for the identification of a broad range of different subsystems, as subsystems can be identified in any case where some sort of organizational activity exists.

To characterize different types of subsystems, the study makes use of three criteria. These relate to substantial properties of modern governance systems that have the potential to influence processes within the subsystem. First, areas of substantial overlap between subsystems are highlighted as an important criterion, which measures the extent to which organizations in a subsystem are also present in other subsystems. Interlinkages and spill-over effects, which can be gauged by subsystem overlap, are essential knowledge for organizations navigating a complex landscape. They can also help in assessing potential and need for cross-sectoral policy coordination. Second, the degree of conflict within subsystems is compared, distinguishing adversarial and collaborative subsystems. The degree of conflict can play a crucial role in shaping outcomes in a subsystem. High conflict can lead to blockages and low problem-solving capacity, but also to implementation problems, if outcomes are not considered legitimate by a large portion of organizations in the subsystem. Third, issue multidimensionality classifies subsystems based on the extent to which they contain multiple, substantially different issues. This basic feature is crucial as it is a direct reflection of the complexity of the issue configuration within a given subsystem, which influences the potential for change and collective problem-solving.

To prove the value of both the methodology for identification and the criteria for classification of subsystems, they are utilized to analyze subsystems of the Swiss water governance system. The analysis demonstrates how a bottom-up identification of subsystems can reveal insights into the structure of governance, which would not have been possible otherwise. It also reveals the extent to which different types of subsystems are present in Swiss water governance. The results provide evidence for the validity of a theoretical conception of governance systems as networks of subsystems, and the focus of trans-subsystem dynamics that comes with it (Jones 2009).

# Theoretical background

## Subsystems in policy theory

Empirical case studies of a policy process and applications of policy theory usually feature some variant of subsystem identification. The development of theories about the policy process has rested on studies of subsystems for a long time. Laumann and Knoke (1987) studied how policies were made in health and energy policy domains in an influential study that emphasized the importance of organizational networks for the modern state. Theirs and further explorations of organizational activity in politics focused on policy domains as parts of a larger political system that revolve around substantive political issues (Burstein 1991).

Current state-of-the-art theories of the policy process, which evolved from such earlier work, also rest on highlighting processes and patterns within subsystems. The advocacy coalition framework (ACF) is the foremost example in this regard, as it focuses exclusively on statements about subsystem dynamics. It generally defines a policy subsystem by a territorial boundary, a substantive topic, and the organizations that are part of it. Acknowledging the vagueness of this definition, Weible and Sabatier (2007) recommend to identify subsystem boundaries empirically through preliminary interviews with policymakers to identify the relevant the territorial and substantive boundaries of an issue as well as the set of other relevant organizations within a subsystem. The ACF thus treats the definition of subsystems as an empirical question. Still, in a review of ACF applications, Weible, Sabatier, and McQueen (2009) found that a large proportion of studies relied on unsystematic data collection and did not specify methods clearly. This indicates that subsystem definition is unlikely to have followed a rigorous procedure. Further, exploratory interviews with policymakers, if thoroughly applied, are likely to be useful in defining valid subsystem boundaries as perceived by participants within the subsystem, as many ACF applications show. However, interviews may not suffice to understand subsystem interdependencies, which are an important area of theory development regarding the ACF (Weible, Sabatier, and McQueen 2009). Also, exploratory interviews risk to neglect the diversity in issues and levels that may characterize a subsystem, if they focus on single issues that are specified by the researcher in advance.

Another theoretical development, which focuses heavily on subsystems, is punctuated equilibrium (PE) theory (True, Jones, and Baumgartner 2007). PE theory studies how changes in policy originate in policy subsystems, or sometimes policy areas (Epp and Baumgartner 2017) or niches (Givel 2010). Subsystem identification in PE theory is not as extensively discussed as in the ACF, and mostly rests on identifying a single issue and observing policy change over time based on the tone of media coverage or policy output (Givel 2010; Mortensen 2007).

As the ACF and PE theory examples demonstrate, a key advantage of the focus of policy theories on subsystems is that in doing so, they can generate statements relating to a well defined scope. As such, hypotheses derived from a theory are transferable. They can be tested in different contexts by referring to the intended scope of the original theory. The focus on subsystems further generates immediate substantive context to an application of policy theory. Studies can be compared within similar subsystems, such as floodwater protection in different countries. Similarly, studies can compare substantively different subsystems, asking, for example, if results obtained from studying processes of public health policymaking transfer to energy policymaking.

Theoretical models which aim to give structure to the social space in which policymaking happens have to achieve a certain level of abstraction in doing so. The various subsystem concepts applied in practice thus disregard some of the complexity in empirically observed governance (Nohrstedt and Weible 2010). This is necessary as it in turn enables these theoretical concepts to serve as a stepping stone from which to posit more general principles governing the policy process.

However, the abstraction of policy systems into subsystems becomes problematic if it does fail to capture key aspects of the complexity of these systems. On the one hand, this can result in missing important processes, which characterize a policy process but happen across the boundaries of subsystems. On the other hand, analyses of interactions between subsystems (Jones 2009) can also be compromised, if these interaction do not actually represent a genuine interaction between different parts of a governance system, but should rather be seen as a misspecification of boundaries between subsystems, which should be considered a single subsystem.

This problematic becomes even more pressing in the the study of modern governance structures, which have been described as becoming increasingly more complex, fragmented and dynamic (Torfing 2005). Broadly, such systems satisfy the definition of complex systems in Simon (1962, 468), in that they are "made up of a large number of parts that interact in a nonsimple way". More specifically, complexity in policy systems manifests itself in systemic behaviour that emerges from interdependent, interacting parts that are hard to predict, path dependence, local level interactions that lead to global changes and periods of punctuated equilibria (Cairney 2012). Faced with this, scientific inquiry into governance needs to acknowledge the differing explanatory roles of multiple theoretical approaches (Byrne and Callaghan 2014), depending on the context in which choices are made, of which subsystems are an essential part (Cairney and Weible 2017). Given the oftentimes singular complexity of subsystem settings, a generalized methodology to identify them can also be the basis for further qualitative inquiry based on methods such as process tracing (Beach and Pedersen 2013), which are uniquely suited to understand the peculiarities of a single subsystem in more depth.

The value in organizing governance systems along the lines of subsystem concepts that reflect their complex nature goes beyond the provision of a common reference for research alone. For practitioners in the public sector, the lack of clear relationships of cause and effects in the complex governance systems they face call for a holistic understanding of the environment they operate in. Understanding patterns and influences permeating system boundaries is needed to arrive at management decisions with improved outcomes over such based on overly simplified understandings inappropriate to complex systems (Haynes 2015). Illuminating the properties of subsystems, together with their interrelations within a complex governance system provides essential knowledge needed in this task.

## Criteria for subsystem classification

Subsystems can differ in substantial ways. These differences affect the processes within them. In the following, three crucial, although not exhaustive criteria for subsystem classification are introduced, which have been shown to influence subsystem dynamics. These are subsystem overlap, the degree of conflict, and issue multidimensionality.

Overlap between subsystems is a key component complicating the study of governance. A given subsystem is unlikely to exist in a vacuum. Instead it is embedded in a nested and overlapping structure of larger, as well as smaller subsystems. In the ACF framework, Zafonte and Sabatier (1998) already built upon a long tradition of research stressing the various ways in which subsystems can influence each other. For example, minority organizations in one subsystem may seek allies in another subsystem to make their voices heard. Another interesting example combining a multi-level conceptualization of governance and subsystem interdependency is they way in which subsystems far removed on higher political levels and addressed by specialized organizations can substantially overlap on the local level, where generalist administrators typically cover a broader variety of issues. Some authors conceptualize a network of linked subsystems, where links between subsystems allow changes to ripple through different subsystems. Subsystems can be linked in various ways, including communication or transaction links between actors from different subsystems, or actual boundary penetration, wherein actors are present in multiple subsystems (Jones 2009, 46). Subsystem interaction can therefore play an important role in explaining change in subsystems. Interaction can also explain blockages in subsystems, as (Rayner et al. 2001) highlight in a discussion of so-called critical subsectors, which have an outsize influence on whole sectors.

The degree of conflict in a subsystem is a key differentiating factor among subsystems and influences decisionmaking processes (Fischer 2014). Theories of the policy process differ in the degree to which they incorporate conflict. Applications of the ACF framework often focus on subsystems with a high degree of conflict, which is understandable since the ACF-inherent notion of coalitions implies a set of competing interests within a subsystem. However, the ACF does not in itself predetermine this, as the distinction between collaborative and adversarial subsystems in an ACF application regarding Lake Tahoe water quality policy shows, which also outlines a number of ways in which a predominantly adversarial or collaborative subsystem setting can influence overall processes within the subsystem (Weible and Sabatier 2009). For example, in collaborative subsystems, the role of science in informing the policy process is likely to be different, as science is less likely to be used as a weapon and more likely as a tool for policy learning. PE theory as another example of a policy process theory is characterized by its explicit differentiation of common, stable and low-conflict, and rare, high-conflict subsystems where punctuated equilibria may occur (Baumgartner 2006). Generally, a high degree of conflict raises the profile of a subsystem and profoundly shapes the way in which rules are negotiated within it. In low conflict, low salience subsystems, “quiet politics”, shaped by experts and private interests, and less touched by public contestation, is much more likely (Culpepper 2011).

Issue multidimensionality characterizes the extent to which a subsystem revolves around multiple, substantially differing issues. The presence of multiple issues increases the internal complexity of a subsystem. Issue multidimensionality has been recently highlighted as a key contributing factor for the instability of a subsystem (Epp and Baumgartner 2017). In simple subsystems dominated by single issues, problems can be solved by incremental adjustments. Epp and Baumgartner (2017) cite snow removal as a prime example, where agreement on the solution for solving a recurring problem is the straightforward and widely understood and agreed upon deployment of snow plows. A snow removal subsystem is therefore unlikely to undergo drastic changes. On the other hand, in complex, multidimensional subsystems, the demands on the information processing capabilities of subsystem members are often too high for them to deal in detail with all subsystem dimensions. This makes them more likely to focus on a single aspect of a problem. However, if attention then switches to a different aspect, subsystem members are more likely to undertake drastic changes to accommodate it.

## Research design and methodology for subsystem identification

A bottom-up identification of subsystems within a governance system requires a clear definition of the scope of a governance system itself. In the following, a governance system is defined as a system of governmental and non-governmental organizations, which engage in the formation, application, interpretation and reformation of rules (McGinnis 2011, 171) concerning one or multiple policy issues within a geographic boundary (Lubell 2013).

Further, the definition of subsystems as bundles of similar organizational activity introduced in this study requires that the dimensions of the conceptual space in which organizational activity takes place need to be established. In order to characterize activity of organizations involved in governance, three dimensions are utilized. These are issues, levels and the type of rule-oriented activity.

First, policy issues, defined as substantive collective action problems (Lubell 2013, 541), define the varying substantive content that activity in governance is related to. For example, this might be floodwater protection.

Second, a number of levels that are involved in a governance system can be defined. Multi-level governance has been extensively studied as a normative concept, suggesting that multi-level structures increase the flexibility of governance, but also as a descriptive tool to understand modern governance (Scharpf 1997; Hooghe and Marks 2003; Bache and Flinders 2004). It suggests that modern governance is ever more removed from command-and-control systems and distributed across multiple centers or levels of authority. As this is an important dimension structuring the space where governance happens, a definition and partition of a governance system should therefore take multi-level structures into account. To continue the example, organizational activity in floodwater protection might be differentiated between activity located at the national level (such as the planning of national strategy) or the local level (such as the building of a dam by a municipality).

Third, organizational activity can be divided into different activity types, approximately based on distinct phases of governance processes. This is not to return to a strict cyclic model of the policy process that is descriptively inaccurate, but simply to acknowledge that there are different distinct types of activity in policymaking in the lived experiences of policymakers (Howard 2005), as well as other types of actors not usually considered policymakers (Cairney and Weible 2017, 621). Phases are therefore used as a starting point to typify organizational activity, but without an implication of temporal order. Activity types should be seen as distinct sets of similar substantive organizational activity, which are related to each other in multiple path-dependent ways. For example, the application of rules (such as the implementation of a law) governing the use of a natural resource implies a set of activities that is sufficiently distinct from the formation of these rules to constitute a different activity type. To illustrate path-dependency, the implementation of rules is in most cases dependent on their crafting. Concluding the example, the type of organizational activity in floodwater protection on the local level might range from application of rules (building a dam based on legal requirements) to their formation (if local stakeholders are involved in the crafting of laws).

The activities of organizations within a governance system can be summarized as the properties of the space they occupy within the resulting three-dimensional matrix. Figure 1 illustrates this for a single organization. The overall distribution of occupied space within this matrix for all organizations structures the governance system as a whole. For a bottom-up identification of subsystems, related organizational activity within this matrix can be grouped together. Subsystems can thus be multidimensional in issues, include various levels, and cover multiple types of activity, if this reflects observed patterns in the activity of organizations.

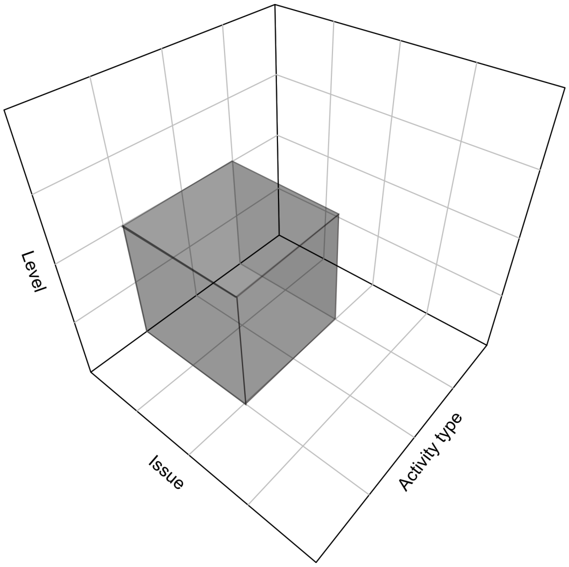


Figure 1: Simplified example of organizational activity of a single organization, summarized as the space taken up by it within a three-dimensional matrix, drawn up by the dimensions issues, levels and type of activity. The grey cuboid indicates that the exemplary organization is active on two issues, two levels and involved in two types of activity.

# Data Collection and Methods

## Case

The governance of water resources makes for a compelling case of a complex governance system. Most systems of even small-scale natural resource governance are characterized by a complex interplay of biophysical and social parts (Ostrom 2009). Water governance is no exception. Institutional fragmentation indicated by interconnected issues that are dealt with separately by different institutions, has been called one of its defining characteristics (Jasny and Lubell 2015, 37).

To gather empirical data on the overall make-up of Swiss water governance, 467 organizations in water governance were surveyed through an online-survey about water issues they regularly work on. 326 organizations responded, resulting in an overall response rate of 68 percent. A logistic regression model used to model total non-response (Sax, Gilmartin, and Bryant 2003) as a function of the type of respondent organization only identified the organizational types politics (mostly political parties) and private sector organizations as statistically significant predictors of non-response (compared to interest groups as a baseline, see model results in table A1 in the appendix). Thus, even while the differences in non-response rates are not drastic, it is still worth noting that the subsystem identification undertaken in the study could potentially be biased if a group of private sector organizations or political parties with distinct activity profiles were missing from the analysis. However, based on the relatively large number of respondents, as well as to the best knowledge of the organizational landscape of the author, this seems unlikely.

The issues and organizations included in the survey were identified based on an extensive manual content analysis of newspaper articles and parliamentary hearings related to water topics in a companion study (BLINDED). The content analysis used to identify issues and organizations followed a bottom-up model. It started with the delimitation of water as the only common concept that the documents analyzed in the manual content analysis had to share. Beyond this, all possible organizations and issues were considered. This increased that chance that the sets of organizations and issues were representative of Swiss water governance as a whole. Also, sources from the national level (a national-level newspaper and the federal parliament), as well as on the level of a constituent state, called canton (a cantonal newspaper and parliament), were used. This ensured that the set of organizations and issues also reflects the multi-level structure of Swiss water governance.

The subsequent survey asked organizations whether they had regularly been involved in projects in the three years prior to 2016 regarding 26 issues aggregated from the content analysis. For every issue chosen, the survey presented organizations with a list of levels within the federal setting (municipal, cross-municipal, state, cross-state and national). The survey then asked organizations to indicate on which of these levels they normally dealt with each issue. Some organizations were, for example, involved in the protection of aquatic ecosystems exclusively on the municipal level, such as a local nature protection interest groups. Other organizations, such as state nature protection agencies, were involved in projects on all levels ranging from working with municipal stakeholders to providing input on national regulation. Similarly, the survey asked organizations to indicate the phases where they normally would engage with each issue. Phases included initiation, planning, decision-making, implementation and evaluation. Of these phases, the initiation and decision-making phases relate to the formation, planning to the interpretation, implementation and evaluation to the reformation of rules governing organizational activity (McGinnis 2011, 171). Finally, for every issue chosen by an organization, a name generator question (Bien, Marbach, and Neyer 1991) asked organizations to provide a list of other organizations they considered allies or opponents regarding each issue.

## Identification of subsystems

The technical procedure to identify subsystems based on organizational activity can be summarized in four steps. Figure A1 in the appendix provides an illustrated overview over all steps, starting from an example of the initial survey questions used. To further encourage reproducibility the (anonymized) dataset of organizational activity in Swiss water governance used in the analysis for this study, as well as a set of scripts to replicate the clustering procedures used can be found in a public online repository under BLINDED.

First, the data gathered in the survey was formally represented in a two-dimensional binary incidence matrix with organizations as rows and the set of all observed unique triplet combinations of issues, levels and activity type (called triplets in the following) as columns. Cell entries specify for each organization if it is involved in a given unique triplet.

Second, the identification of subsystems is based on identifying clusters of triplets in the transposed incidence matrix in terms of common organizations. In other words, this means that triplets become observations, while the indications of organizational activity become features of each triplet. Every unique triplet is thus characterized by a binary vector specifying organizational activity. In this binary vector, a one indicates that a given organization is active in the given triplet. The similarity between two such vectors indicates the degree to which the corresponding triplets share organizations, a measure of their relation in terms of organizational activity.

Third, to identify clusters of triplets, a k-medoids algorithm from the family of k-means clustering procedures (Lloyd 1982) implemented in the R package cluster is used (Maechler et al. 2017; R Core Team 2017). The resulting clusters of triplets represent the patterns of organizational activity that characterize different subsystems.

Clustering is an inherently subjective procedure as the choice of clustering algorithm as well as the choice of parameters for clustering algorithms determines the clustering results. This subjectivity however also has advantages as it forces the researcher to substantively consider the clustering problem and evaluate the results. With regard to the clustering problem in the present study, the first difficulty lies in choosing a suitable clustering algorithm. The k-medoids procedure was chosen due to its simplicity, speed and the widespread use of k-means based clustering, which facilitates replication of the analytical procedure. The binary, relatively sparse incidence matrix, which is clustered in this application, is not an ideal case for simple k-means clustering as k-means clustering relies on minimizing the euclidean distance between observations and cluster centroids (means of features). For binary vectors these means do have a substantive meaning (the proportion of a given feature) but are not means on the scale of the input data, as intended by the algorithm.

The k-medoids procedure mitigates these problems by operating directly on a similarity matrix, which can be constructed using an adequate similarity measure for binary vectors (for an overview, see Seung-Seok, Sung-Hyuk, and Tappert (2010)). Sokal-Michener similarity was chosen to represent the similarity between triplet vectors, as it includes matches in the absence of attributes between vectors, which includes additional information about organizational activity. The k-medoids procedure further minimizes distances to medians, instead of means, which is more adequate for binary vectors. As an additional robustness check, density-based spatial clustering of applications with noise (DBSCAN) (Ester et al. 1996) implemented in the R package dbscan (Hahsler and Piekenbrock 2017) was also used on the data, to see if results would be approximately similar using an alternative, starkly differing clustering approach.

Besides the choice of clustering algorithm, the choice of parameter settings for the algorithm is equally important. The main challenge for k-means and k-medoids algorithms lies in choosing a sensible value for k, which determines the number of subsystems. The difficulty lies in the fact that there is no objectively correct choice for k. Instead, to an extent, different values for k allow to probe for different aspects of the structure of the governance system, providing more general, but coarse-grained, or more fine-grained results.

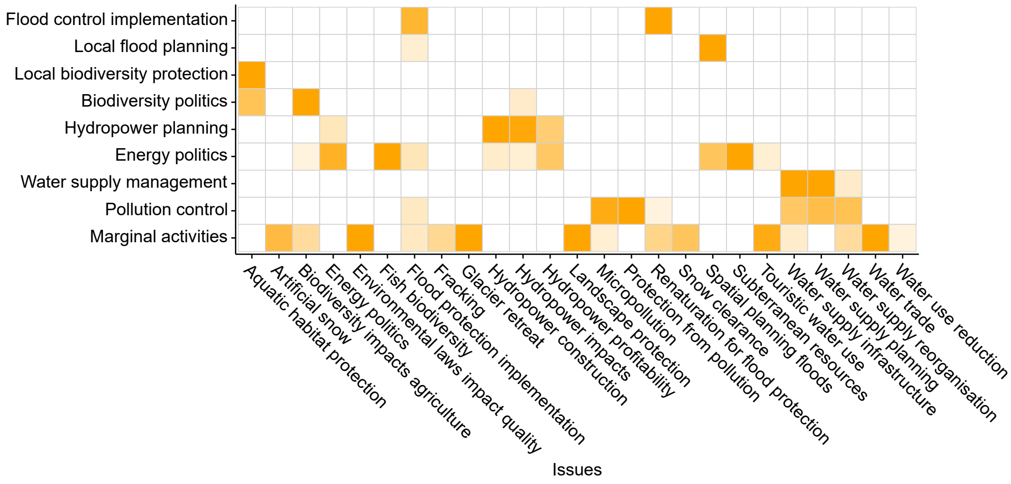
In this study, the optimal number of clusters k was identified based on the data, by calculating the gap statistics (Tibshirani, Walther, and Hastie 2001) for different numbers of clusters. The optimal number is chosen by identifying the smallest k such that the value of the gap statistic function for k is not more than one standard error removed from the first local maximum of the function, as implemented in the R package cluster (Maechler et al. 2017). This procedure formalizes the intuitive notion of the optimal number of clusters as the point from which the marginal improvement in the fit of clustering to the data through the addition of a new cluster decreases significantly.

In a fourth and final step, organizations that were active in one of the triplets contained in a subsystem were assigned to the respective subsystem, leading to a list of subsystems containing disjoint sets of triplets and partially overlapping sets of actors for each subsystem. It should be noted that clustering triplets into disjoint sets is not strictly necessary, but in this case a result of the clustering procedure chosen. However, depending on the application, a fuzzy clustering method, which can assign triplets to multiple clusters, might be deemed more appropriate. This could for example be the case for studies where some triplets are believed to be highly crosscutting throughout most subsystems.

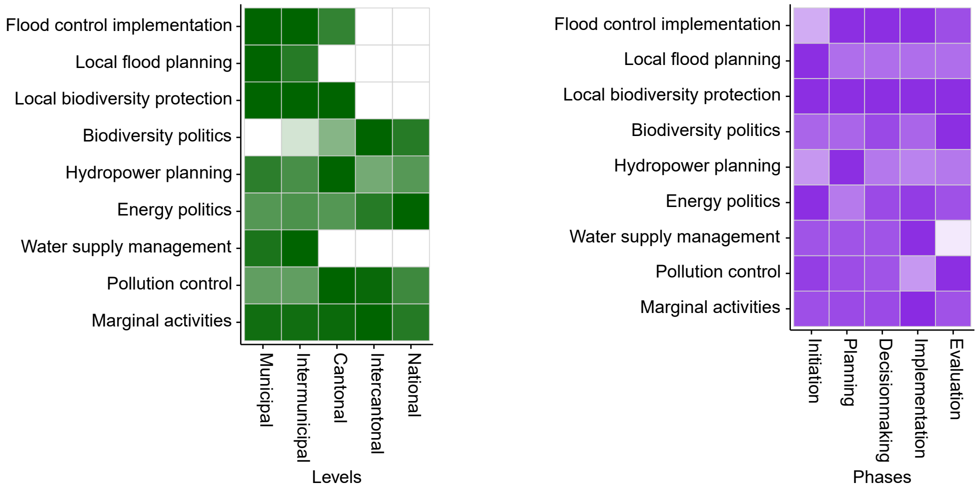
# Results

The k-medoids clustering procedure resulted in 9 subsystems. Figure A2 in the appendix displays the results of gap statistic calculations leading to this number. The k-medoids procedure starts from a random draw, which means that clustering results vary slightly between successive runs. In order to check for large variations between results, the procedure was run multiple times and results compared. While small variations occured, no changes in the broad overall pattern of results could be detected.

Figure 2 graphically illustrates the composition of each subsystem, based on the issues, levels and activity types present within it. Eight subsystems identify meaningful and nuanced clusters of organizational activity in Swiss water governance. A ninth can be seen as a residual category, which clusters together a broader set of diverse, mostly marginal activities, which are grouped into a common subsystem mainly not due to their similarity but dissimilarity to all other clusters. This conclusion is further justified by the fact that DBSCAN clustering either classifies most of these activities as outliers or groups them into individual clusters (see figure A5 in the appendix). Results from the DBSCAN algorithm were substantially very similar to k-medoids clustering, which illustrates the validity of the general statements that can be derived from the clustering procedure. In the following, all subsystems are shortly discussed.



(a) Issue incidence



(b) Level incidence

(c) Phase incidence

Figure 2: Composition of subsystems derived from k-medoids clustering illustrated in three incidence matrices. Non-white colors indicate the prevalence of issues, levels and activity types in a subsystems. The strength of colors indicates the relative frequency of a given issue, level or activity type in organizational activity characterizing the subsystem. Reading example: In the level incidence matrix, if some cells are white, one is light green and two dark green (such as the flood control implementation subsystem), this implies that the two white levels are not present, there is a small amount of activity triplets that include the level indicated by the light green color, and most subsystem activity focuses on the three levels indicated by dark green level to the same extent.

The flood control implementation subsystem contains organizational activity regarding the implementation of technical flood protection measures as well as renaturation measures for flood control. Activities in the subsystem focus primarily on the local (municipal and intermunicipal) and cantonal levels, and on planning, decisionmaking and implementation of measures. The subsystem is heavily dominated by local and cantonal administrative agencies (mostly municipalities and local associations set up to implement flood control measures), and engineering firms.

The local flood planning subsystem is the conjoint part to the flood control implementation subsystem. It is however sufficiently different to be categorized as its own subsystem. This is mostly evident in the fact that it does not contain any activity on the cantonal level. The subsystem also almost exclusively contains activities regarding spatial planning for flood protection, especially on the municipal level. It is dominated by local municipalities. This reflects the fact that spatial planning is a task undertaken at the municipal level in the setting of Swiss federalism. The federation only sets general guidelines, which are implemented by the cantons, which in turn often delegate a large proportion of responsibilities to municipalities.

The local biodiversity protection subsystem concerns projects regarding aquatic biodiversity on the sub-national level. It is shaped mostly by local municipalities, cantonal agencies, and a mix of mostly local nature protection interest groups. Beyond this, scientific actors, such as research groups at universities, are most prevalent in this subsystem, compared to all other subsystems. This is most likely due to the fact that projects regarding nature protection often require expert input concentrated at research institutes and that scientific groups conduct research projects themselves on the local level.

The biodiversity politics subsystem includes predominantly evaluative activities regarding the issue of general protection of aquatic habitats and two main threats to aquatic biodiversity in Switzerland. These are the impacts of hydropower operations and the construction of new hydropower plants on biodiversity, as well as the impacts of agricultural practices on biodiversity. The intercantonal level is the most important level in this subsystem. This reflects the fact that nature protection in Switzerland is mostly carried out by the cantons, with incentives set by the national government. The subsystem is much more politicized than other subsystems, as it contains a large number of political parties, as well as interest groups representing different views on aquatic biodiversity. These are mostly national level organizations such as the largest Swiss nature protection organization Pro Natura, Aqua Viva (an interest group specializing in water topics), the Swiss farmer's association, or industry associations.

The hydropower planning subsystem is centered on the planning stage in the construction of hydropower facilities. This includes explicit construction issues, but also biodiversity impacts of hydropower, cantonal energy politics and the profitability of hydropower. The fact that activity in the subsystem mostly takes place on the cantonal level illustrates the important role of the cantons in Swiss hydropower. Cantons (and sometimes municipalities) need to approve new hydropower construction, but also own many facilities themselves.

The energy politics subsystem is the second subsystem besides biodiversity politics, which is heavily focused on the highest political level. It mainly revolves around the two main issues in the political discussions regarding water and energy, which are the regulation of hydropower and the use of subterranean resources (geothermal energy and fracking). The political discussion regarding hydropower regulation have been dominated by the call for subsidies due to decreased profitability of hydropower and to a lesser extent by the influence of hydropower construction on biodiversity associated issues such as fish biodiversity, which is evident in the issues present in the subsystem. Hydropower dams may block migration routes of fish, and the operation of hydropower plants directly affects the dynamics of aquatic ecosystems and the health of fish populations. Activities in the subsystems take place on the national level, where the general guidelines regarding regulation in the energy domain are set. They mostly involve the initiation phase, which reflects that the subsystems contains a large number of interest groups, which aim to influence the political agenda.

The water supply management subsystem is exclusively focused on the local (municipal and intermunicipal) level and contains all issues directly related to water supply. This subsystem is comparable to the flood control implementation subsystem in its focus on implementation of a specific task on the local level, which is mostly carried out by local level administrators.

The pollution control subsystem mostly contains organizational activity related to protection against pollution. To a lesser extent, it also contains activities regarding water supply management. Most of the activity takes place on the cantonal level and regards evaluative activity. The proportion of activities that relate to implementation is remarkably low. Thus, this subsystem is about controlling the framework within which rules regarding pollution control and water supply are implemented, but not the implementation itself. As to be expected in a subsystem focused on regulative overview of activities carried out by municipalities, the subsystem contains a large number of local and cantonal administrative agencies.

The marginal activities subsystem on the one hand contains issues which are treated by small groups of focused organizations and are not high or only emerging on the political agenda (such as glacier retreat, artificial snow production, trade in water, or touristic water use). On the other hand, it contains outlier combinations of issues, levels and activity types, which were only rarely chosen by organizations (such as energy politics on the municipal level or water supply planning on the national level). These outliers either represent genuine outliers in that they represent unique activities of some organizations, but could also be erroneous entries. Based on the results of alternative clustering approaches, the first possibility seems more likely.

# Discussion

In the following, the eight identified meaningful subsystems are classified based on the initially introduced three criteria issue multidimensionality, overlap, degree and conflict. Much as evoked by Jones (2009), the overall system of Swiss water governance can be seen as a network of partially overlapping subsystems. This is graphically illustrated in figure 3, which displays both the overlap among subsystems and their respective degree of conflict.

Subsystem overlap was measured for every pair of subsystems as the proportion of actors present in both subsystems compared to the total number of actors in both subsystems. This captures the boundary penetration types of ties between subsystems introduced in Jones (2009, 46).

Overlap between subsystems ranges from six to sixty percent (exact proportions for every pair of issues can be found in figure A3 in the appendix). A certain amount of baseline overlap should be assumed due to the fact that the set of organizations contains a number of organizations that are active in a wide variety of water issues, such as cantonal and national government agencies, large environmental interest groups, but also local municipalities, which often manage all issues related to water on their territory. High amounts of overlap are also generally found in thematically similar subsystems. The highest amount of overlap exists between the flood control implementation and local flood planning subsystems. Therefore, many organizations who participate in flood control implementation are also involved in planning and vice versa. This indicates a high level of coordination between these two activities. The high respective overlap between the higher-level pollution control and the lower-level water supply management subsystems, and the higher-level biodiversity politics and lower-level biodiversity protection subsystems are similar in this regard. However, they also further indicate a high amount of cross-level interaction in these issues.

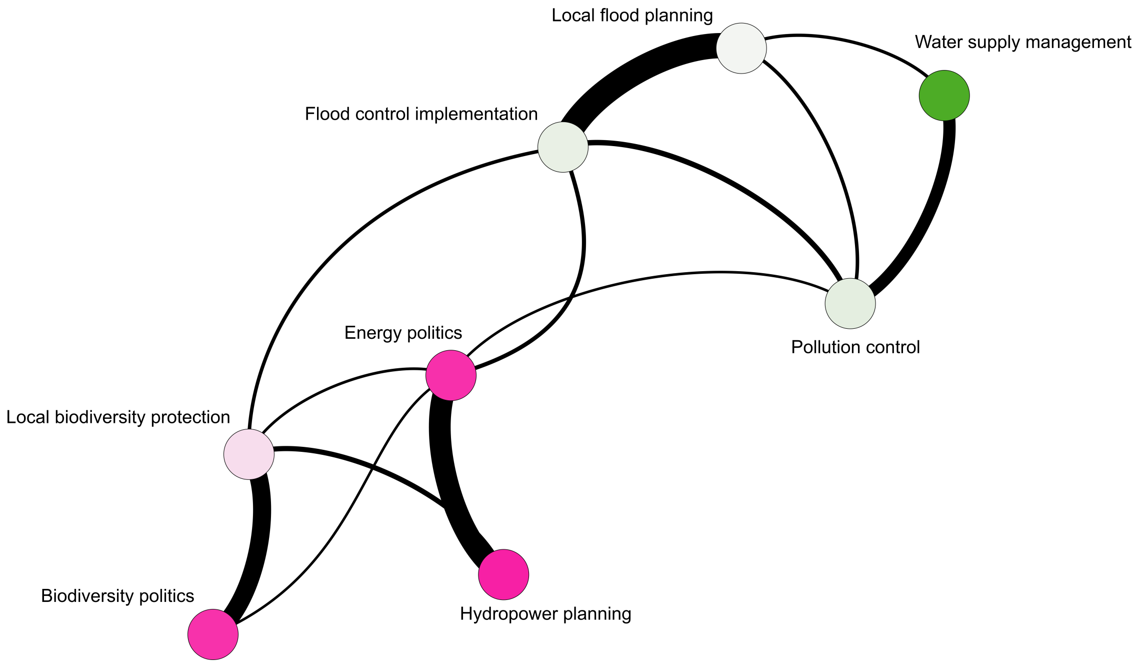


Figure 3: Subsystem network of Swiss water governance. Circles indicate subsystems. Overlap between subsystems is indicated by links. Links indicate that more than 30 percent of actors between subsystems are shared. The size of links is proportional to the number of actors shared. The color of circles indicates the degree of conflict within a subsystem. Red circles indicate high, green circles low conflict.

In general, the overlap between subsystems matches functional interdependencies between issues. For example, biodiversity subsystems overlap with hydropower planning and energy politics, which represent factors strongly influencing aquatic biodiversity, to a relatively high degree. However, biodiversity politics almost has no overlap with water supply management, which is not directly related to aquatic biodiversity in a way other subsystems are. One area where the amount of overlap is surprisingly low, based on what would have been expected due to functional interdependence, is between pollution control and biodiversity subsystems. This could however be a reflection of the fact that discussions around impacts of pollution on biodiversity have recently been more focused on the impact of agricultural practices, and much less on waste water treatment, which makes up a large proportion of the pollution control subsystem.

The different levels of overlap serve to illustrate a further more general point about subsystems in complex governance systems. These subsystems are likely to overlap to a large extent due to the nature of complex functional relations between issues. A bottom-up identification of subsystems can highlight the nature of this overlap and indicate related subsystems that need to be taken into account in the analysis of a given subsystem. For example, studying processes of biodiversity regulation should also analyze consequences on energy politics and flood control subsystems.

The level of conflict in each subsystem was measured as the ratio of opponents to allies indicated by members of a subsystem regarding issues that were part of the subsystem. Figure 3 points out the main differences among subsystems in terms of conflict (exact numbers can be found in table A2 in the appendix). The three most conflictive subsystems are biodiversity politics, hydropower planning and energy politics. The fact that energy and biodiversity politics are among the most conflictive is not surprising and illustrates the validity of the partition. These subsystems contain the most salient discussions in Swiss water politics and are both centered on higher levels, focusing on rule-making, where different interests clash. The planning of hydropower facilities has also been particularly contentious in Switzerland. One of the most relevant examples in this regard is the proposed extension of the large Grimsel hydropower facility, which would inundate an area of disputed protected status, and has subsequently been fought by nature protection organizations for years.

Combining the classification criteria overlap and conflict as illustrated in figure 3 shows that Swiss water governance can be conceptualized as consisting of two parts, which are similar in their degree of conflict and also represent network subgroups, in that they are more strongly connected internally than between them. On the one hand, the four subsystems dealing with water supply, pollution and flood control issues form an area of 'quiet politics", dominated by administrative organizations and low levels of conflict (Culpepper 2011). On the other hand the two most contentious issues in Swiss water governance, biodiversity and hydropower engender their own subgroup of four subsystems, which is characterized by higher levels of conflict, high issue salience, and the presence of a higher number of non-administrative organizations.

Subsystems in Swiss water governance are multidimensional in issues (in that they feature very dissimilar issues) to a varying degree. The eight meaningful subsystems center around around four common overarching themes. These are flood control, aquatic biodiversity, hydropower and water supply/ pollution. Among those, aquatic biodiversity is the most multidimensional. Besides habitat protection, the aquatic biodiversity subsystem touches on issues related to hydropower and farming, two topics which would not readily be grouped together at the first sight. Their presence in the same subsystems shows that both are essential factors influencing aquatic biodiversity in Switzerland and organizations active in this topic reflect this in their activity. Further, the hydropower subsystem also includes the issue of fish biodiversity, which further reflects the intricate interconnections between nature protection and most other issues in water governance. The subsystems revolving around flood control are relatively focused on these topics, but also include renaturation as an issue related to nature protection. The two water supply/ pollution subsystems are relatively unidimensional but give different weights to water supply and protection against pollution respectively.

Generally, higher issue multidimensionality of subsystems is associated with increased conflict, which is in line with recent findings in the literature (Epp and Baumgartner 2017). For example, the biodiversity politics subsystem involves different sets of organizations, which have substantially different interests. These range from hydropower firms, over nature protection groups to farmer's associations. These organizations are affected by biodiversity protection in different ways. While nature protection groups generally favor strict regulation of residual flows, hydropower companies may face reduced production capacity due to this. Similarly farmers can be restricted in their operations due to limitations on pesticide use advocated by nature protection groups. Conversely, unidimensional subsystems, such as water supply management, consist mostly of organizations that implement existing rules on a given, narrowly defined issue. This reduces the chance for conflict.

The subsystems demonstrate that Swiss water governance is heavily influenced by multi-level structures. Activity broadly differs between higher (cantonal, intercantonal and national) and lower (municipal and intermunicipal) levels. This is also apparent in the alternative clustering solution (see figure A5b in the appendix). This separation of some governance issues into distinct higher and lower level subsystems illuminates a key feature of Swiss water governance. Swiss water governance is characterized in many areas by strong decentralization and local autonomy (Hill Clarvis and Engle 2015).

The split between lower and higher levels is most apparent in the relatively unidimensional subsystem that revolves around water supply/ pollution. The aquatic biodiversity and hydropower subsystems include a broader variety of levels but nonetheless show a tendency toward a similar structure. The pollution control, biodiversity politics and hydropower planning subsystems are further strongly dominated by a focus of activities on the cantonal level. This illustrates the key position of this level as a hub of activities in Swiss water governance. Lower level subsystems tend to focus on implementation, while higher level subsystems bundle more evaluative and initiative activities. However, the subsystems are not as clearly split on activity type as they are on levels, which is also likewise repeated in the alternative clustering solutions. This is substantially interesting, as it shows that subsystems are generally bundling most types of organizational activities regarding the issues they contain. A special case in this regard is the water supply management subsystem, which does not contain any activity regarding evaluation. The energy politics and biodiversity politics subsystems are also interesting cases. Judging by the organizations, as well as the levels and issue-specific activities they contain, these subsystems are the most political subsystems identified in this study, containing the highest numbers of political parties and interest groups, and mostly concerned with rule-making and the crafting of higher-level legislation. Theories of the policy process that focus on political decision-making are therefore most likely to apply directly to these subsystems.

These observations regarding the predominant levels and types of activity across subsystems are empirical evidence illustrating that care needs to be taken in studying subsystems in two further ways, beyond taking into account issue multidimensionality, conflict, and subsystem overlap. First, governance subsystems are likely to be heavily influenced by multi-level structures. On different levels, different dynamics are therefore likely shape outcomes, which is further evidenced by the differences in activity type between subsystems. Identifying subsystems without taking account of multi-level structure thus risks to disregard a key feature of organizational activity. Second, the fact that many subsystems contain a broad variety of different types of activity suggests that further care needs to be taken if studies of subsystems focus on only a single type of activity, such as decision-making, as there is a high likelihood that organizations in a subsystem also engage in various other activities. This is relevant as actions of organizations during initial stages of a project, for example, may influence their considerations in later stages.

The subsystem partition based on the methodology presented in this study resulted in a nuanced set of subsystems. These subsystem differ along the criteria proposed for their classification. This shows the added value of a bottom-up identification of subsystems, based on a minimal criterion for subsystem identification (distinct groups of organizations with similar activity profiles). A procedure based on this type of empirical data can pick up patterns that might have been ignored otherwise. One such example is the differentiation between subsystems which involve the same issues, but on different levels. The fact that the methodology for identification only makes minimal initial presumptions about what should be considered a subsystem, enables it to pick up subsystem of vastly differing types. As the empirical results show, these range from conflictive, high-level to local, ‘quiet politics“ subsystems, providing an adequate representation for the complex, messy reality of governance.

## Conclusion

The identification of subsystems in complex governance systems has many advantages. It provides a clear scope for the application of theoretical concepts, makes results comparable across cases and simplifies the sometimes bewildering complexity of governance to manageable proportions. Especially the last aspect is an essential prerequisite for public management concerned about the likely results of actions reverberating within complex system structures (Haynes 2015). However, these advantages rest on a valid procedure to identify and classify subsystems. This article has suggested a bottom-up way to identify and classify subsystems in complex governance systems, based on similar patterns of observed organizational activity.

The suggested methodology to identify subsystems proceeds in three general steps. First, relevant issues and organizations pertaining to a certain governance topic are identified based on document analysis. Second, data on organizational activity in three dimensions is gathered. The resulting information specifies for each issue an organization is active in the levels and types of activity the organization focuses on. Third, the resulting data structure can be clustered to identify subsystems as patterns of organizational activity.

A key advantage of identifying subsystems based on minimal initial presumptions regarding the grouping criterion (similar organizational activity) is that they can then be more easily classified according to a wide-ranging set of criteria. In this study, issue multidimensionality, overlap, degree of conflict and predominant type and level of organizational activity have been highlighted as key criteria, based on the fact that they have been shown as influential in shaping subsystem processes and outcomes in the past. However, depending on the substantive interest of the researcher, other criteria, such as the maturity of a subsystem (Nohrstedt and Weible 2010; Ingold, Fischer, and Cairney 2017) can easily be envisioned.

This article has applied this procedure to identify subsystems in Swiss water governance. The resulting partition of Swiss water governance is substantially interesting in its own right in illuminating three main characteristics of the complex system of Swiss water governance. First, the subsystems in Swiss water governance can be thought of as a network connected by boundary penetrating organizations. This network broadly consists of two subgroups. In a first subgroup, issues of biodiversity and energy politics are addressed in conflictive subsystems, while a second subgroup of "quiet politics" dominated by administrative agencies, contains issues of water supply, pollution and flood control. Second, this "quiet politics" subgroup shows that there are a number of subsystems, generally perceived to be well-functioning, which feature only moderate or little conflict. Such subsystems are less likely to be noticed by analysts, but are likely to be as crucial for governance outcomes as conflictive ones. Third, there is a clear difference between local and higher-level (cantonal and national) activity in almost all issues. The level at which organizations are active therefore emerges as an influential dimension partitioning Swiss water governance. The existence of clear local-level subsystems in most governance issues highlights one of the most crucial points in order to understand Swiss water governance. Processes of implementation and interpretation of rules at the local level are absolutely important in order to understand how governance works in a given area. Analyses and policy design should therefore not only account for the most visible, high-level subsystems, but also consider their conjoint parts at lower levels and the interaction between the two.

These empirical results illustrate more general properties of subsystems in complex governance systems, which become apparent through the use of a bottom-up procedure. The analysis suggests that governance subsystems are likely to be more multidimensional and more interdependent than often conceived. The identified subsystems in Swiss water politics are mostly not centered around a single issue, level, or activity type. As the complex nature of large-scale governance systems implies, subsystems of organizations who engage in similar governance activities revolve around unique configurations of multiple issues, multiple levels, and multiple types of governance activities. This is a stark reminder for analyses that focus on the analysis of individual subsystems to carefully specify the delimitation of subsystem boundaries and beware of potential bias regarding the overall structure these subsystems are situated in. Further, the network-like structure between subsystems supports analytical efforts that try to assess the influence of between- and trans-subsystem dynamics (Jones and Jenkins-Smith 2009).

The variance in the degree of conflict between subsystems and the existence of unidimensional and low-conflict, or less politicized subsystems further points toward a need for theory that focuses more explicitly on such subsystems. Most concepts in policy theory apply most fruitfully to subsystems focused on rulemaking on higher governmental levels. Two instances of such subsystems could empirically be found in the case of Swiss water politics. However, the results reported in this article suggest that the interplay of such political subsystems with other types more strongly focused on implementation, or the local level, should be more extensively researched, in order to gain a more detailed understanding of governance processes.

The extensive overview of a large-scale governance system undertaken in this article is likely not feasible in many applications. A study trying to focus in more depth on a given policy subsystem, where a large-scale system overview is not available from previous research, would face unresolvable challenges in balancing a large overview of a governance system with the analytical depth required for a thorough study of a single subsystem. However, in many cases, subsystem research undertaken with an increased awareness of multi-level structures, local level implementation, and adjacent, overlapping subsystems should already strongly mitigate the danger of inadequately determining subsystem boundaries and neglecting important contextual conditions. Even the sole exercise of more precisely situating the activities of organizations in a given policy area within the three dimensions outlined in this study alone has merit. On the one hand, it should provide an appreciation for how appropriate it is to treat the policy area as single subsystem. On the other hand, it can illuminate the extent to which comparisons with other subsystems are possible.

This study suggests a way forward to establish a common subsystem procedure identification procedure to serve the needs of different theoretical frameworks as a shared frame of reference. While it demonstrates a methodology that yields viable results, further research should explore the implications that arise from implementations in different contexts. Be it as an entrance door for in-depth qualitative studies of single subsystems, as a way to relate features of a multitude of subsystems to policy outcomes, or to inform policymakers about the structure of the ecosystem they are active in, the possibilities of a shared subsystem identification procedure should be exploited and debated.

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# Appendix

| | |
|---|---|
| Intercept | $-1.10^{***}$ |
| | $(0.25)$ |
| Local Administration | $-0.07$ |
| | $(0.36)$ |
| Other actors | $-1.20$ |
| | $(0.78)$ |
| Politics | $1.66^{***}$ |
| | $(0.40)$ |
| Private sector | $0.82^{*}$ |
| | $(0.33)$ |
| Science | $-0.64$ |
| | $(0.68)$ |
| Service Providers | $-0.00$ |
| | $(0.43)$ |
| State and national administration | $0.50$ |
| | $(0.34)$ |
| BIC | 595.68 |
| Num. obs. | 464 |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table A1: Logit model of total nonresponse in survey as a function of organizational type. Baseline category: Interest groups

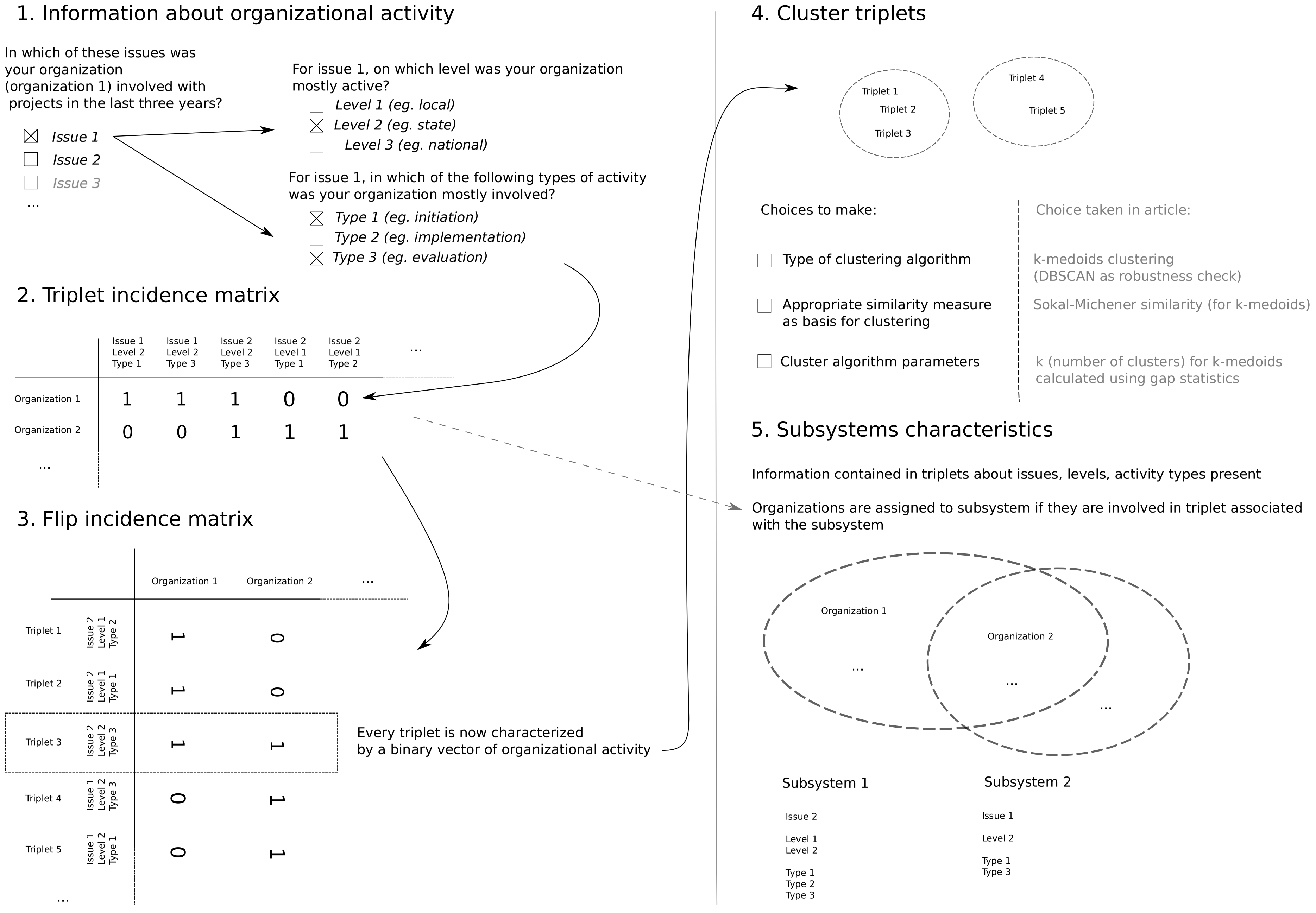


Figure A1: Overview over data gathering and clustering steps for bottom-up subsystem identification based on organizational activity

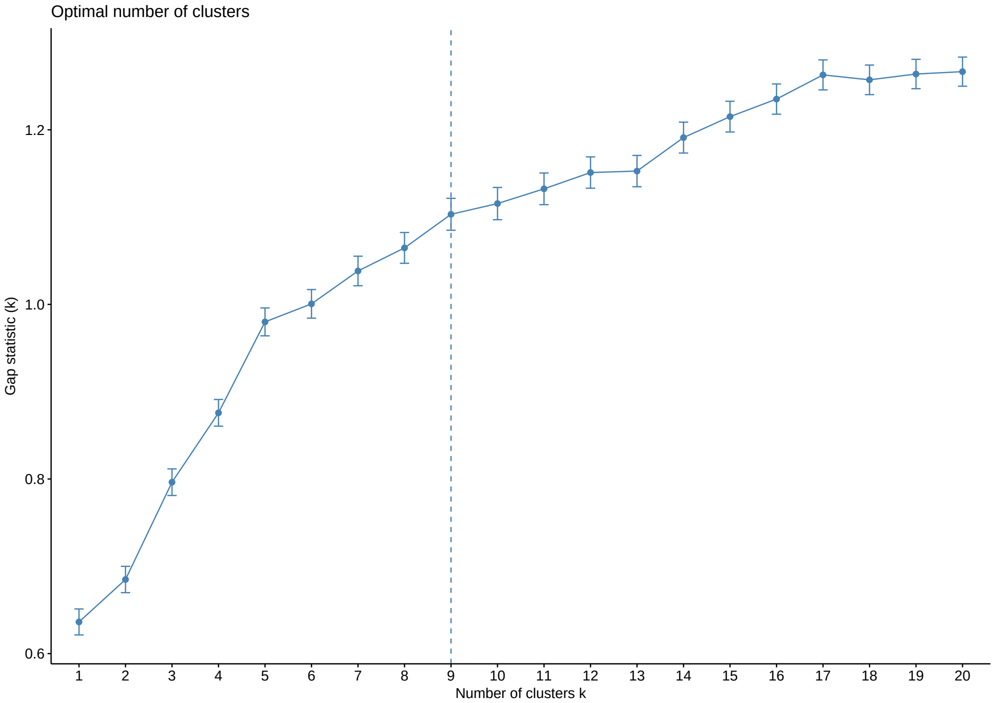
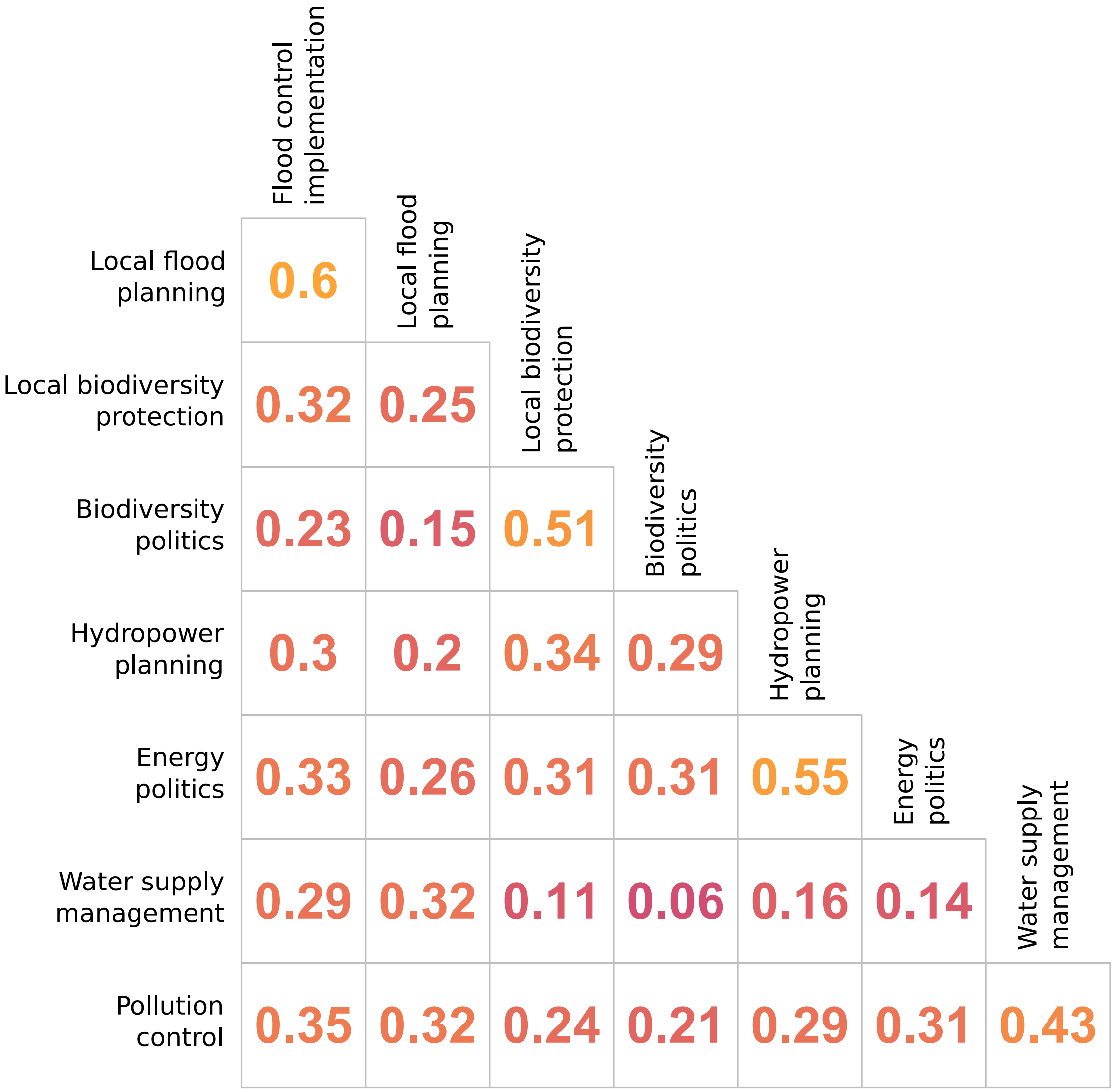


Figure A2: Plot of gap statistic depending on the number of clusters for k-medoids algorithm operating directly on a similarity matrix based on Sokal-Michener (simple matching) similarity. The dashed line indicates the optimal number of clusters based on the criterion proposed in Tibshirani, Walther, and Hastie (2001).



| | Flood control implementation | Local flood planning | Local biodiversity protection | Biodiversity politics | Hydropower planning | Energy politics | Water supply management |
|---|---|---|---|---|---|---|---|
| Local flood planning | 0.6 | | | | | | |
| Local biodiversity protection | 0.32 | 0.25 | | | | | |
| Biodiversity politics | 0.23 | 0.15 | 0.51 | | | | |
| Hydropower planning | 0.3 | 0.2 | 0.34 | 0.29 | | | |
| Energy politics | 0.33 | 0.26 | 0.31 | 0.31 | 0.55 | | |
| Water supply management | 0.29 | 0.32 | 0.11 | 0.06 | 0.16 | 0.14 | |
| Pollution control | 0.35 | 0.32 | 0.24 | 0.21 | 0.29 | 0.31 | 0.43 |

Figure A3: Overlap between subsystems as percentage of shared organizations

| Subsystem | Most prevalent issues | Conflict level |
|---|---|---|
| Flood control implementation | Flood protection implementation, Renaturation for flood protection | 0.27 |
| Local flood planning | Spatial planning floods | 0.28 |
| Local biodiversity protection | Aquatic habitat protection | 0.29 |
| Biodiversity politics | Aquatic habitat protection, Biodiversity impacts agriculture | 0.36 |
| Hydropower planning | Hydropower impacts, Hydropower construction, Hydropower profitability | 0.42 |
| Energy politics | Spatial planning floods, Hydropower profitability, Energy politics, Subterranean resources, Fish biodiversity | 0.37 |
| Water supply management | Water supply infrastructure, Water supply planning | 0.11 |
| Pollution control | Water supply reorganisation, Water supply planning, Water supply infrastructure, Protection from pollution, Micropollution | 0.26 |

Table A2: Level of conflict of subsystems in Swiss water governance as the ratio of opponents to allies reported by all organizations in the subsystem regarding issues in the respective subsystem

## Density-based clustering with noise (DBSCAN)

DBSCAN is substantially different from k-medoids clustering as it groups together points based on their location in space, depending on a minimum number of points set as required per cluster and an epsilon value specifying the minimal distance to reach the points. It has the fundamental advantages of disregarding outliers (not grouping them), and is also much more flexible in detecting clusters of different sizes and shapes. It can also operate directly on a similarity matrix appropriate to a binary data structure, for which in this case Ochiai similarity was chosen, to add another point of deviation from the k-medoids procedure. Ochai similarity results in similar results to the widely used Jaccard similarity but does punish dissimilarity slightly less.

For DBSCAN, parameters for the minimum number of points per cluster and epsilon values, which can be thought of as specifying the breadth of clusters, need to be chosen. The minimum number of points was set to 12, requiring each cluster to contain at least 12 triplets, which is about half of all possible unique triplets that can be associated with an issue. Epsilon was set to 0.4 based on visual inspection and identification of the "knee" in the k-nearest neighbor plot (see figure A4).

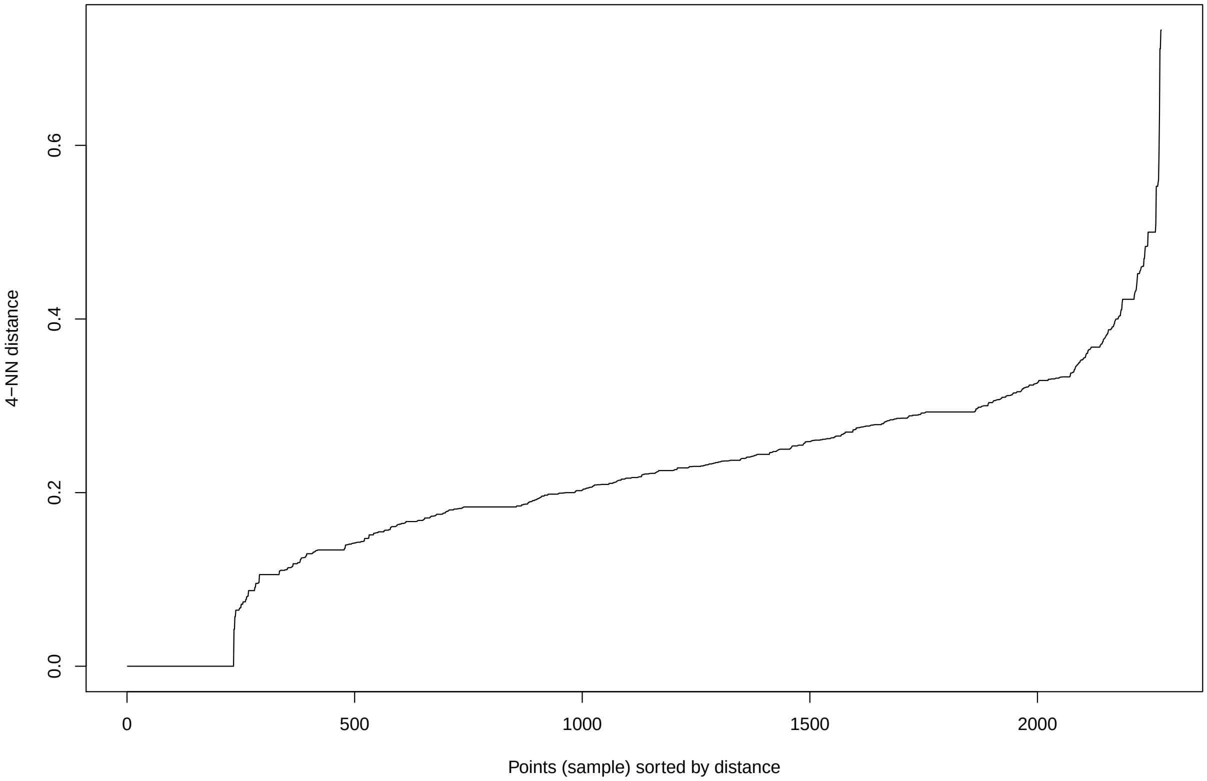
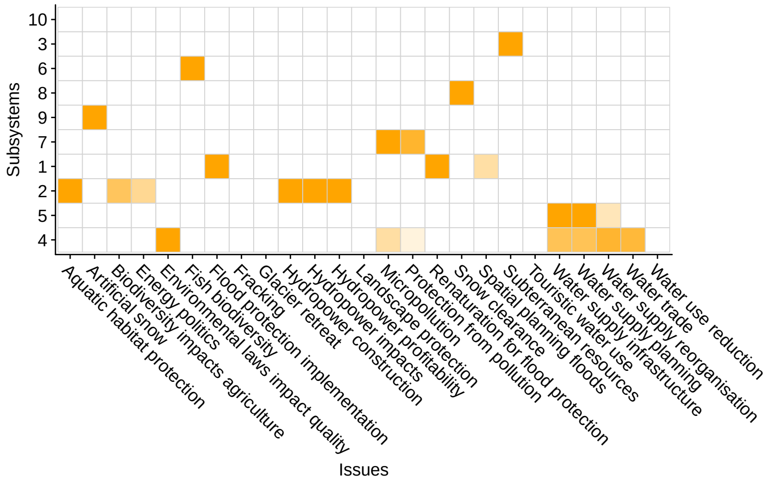
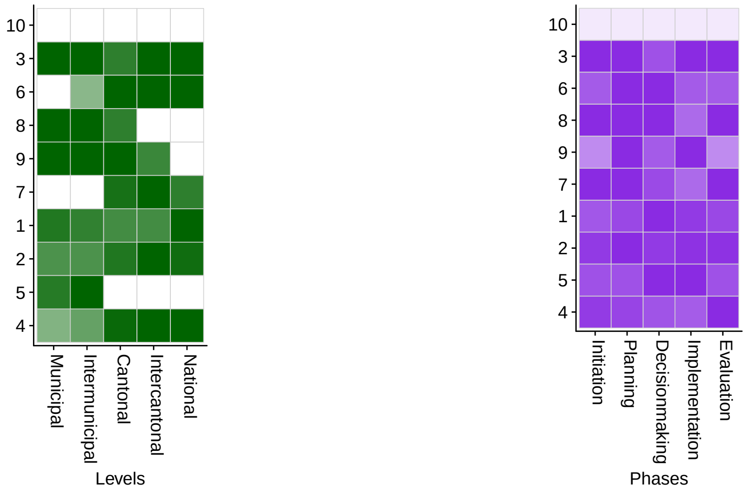


Figure A4: k-nearest neighbors plot based on Ochiai similarity between triplets used in determing epsilon values for the DBSCAN clustering algorithm.



(a) Issue incidence



(b) Level incidence

(c) Phase incidence

Figure A5: Composition of subsystems derived from clustering based on DBSCAN.