# Article "Adapting water governance in river basins to climate change: Archetypical barriers"

## Supplementary Online Material

## Stylised example for archetypes

Suppose the fictive data in Fig. S1 is given, with case studies in rows and attributes in columns. The diagnostic attributes a1 (upstream and downstream users present), a2 (water use conflicts), a3 (collective choice arrangements for water distribution) may correspond to those in the main text's example.

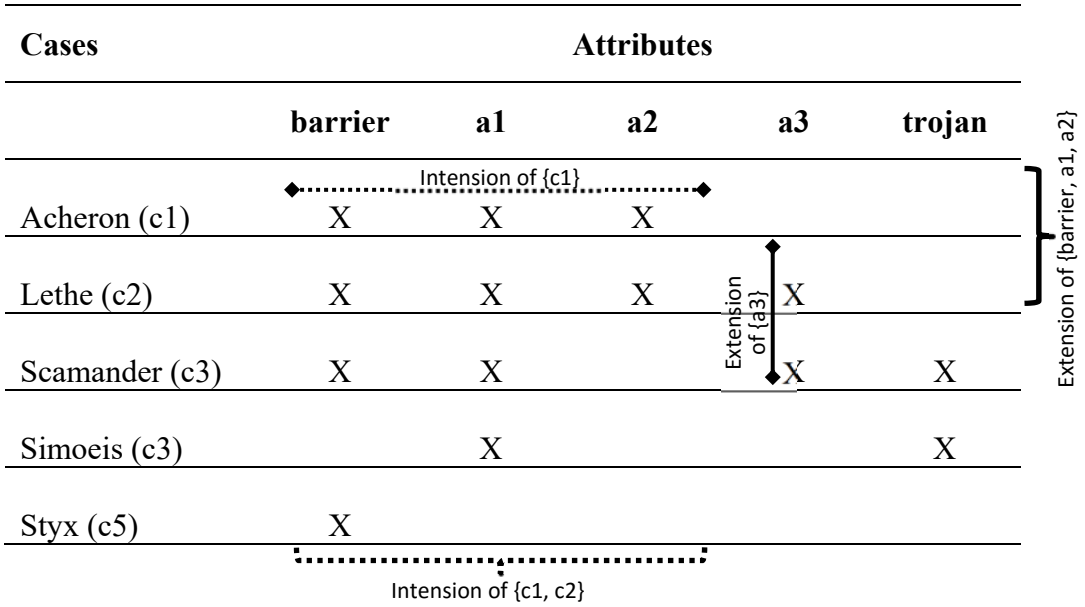


**Figure S1**: Data for stylised example.

In the example, the vertical solid bar represents the extension of the single attribute {a3}, which is the set of cases {c2, c3}. The horizontal dotted bar represents the intension of the single case {c1}, which is the set of attributes {barrier, a1, a2}. The extension of the set of attributes {barrier, a1, a2}, i.e. all cases that jointly have all these attributes (and possibly more individually), is {c1, c2}, denoted by the solid bracket at the right side. The intension of the set of cases {c1, c2}, i.e. all attributes that are common to all of them, is {barrier, a1, a2}, denoted by the dotted bracket at the bottom side. Obviously, the extension or intension can be determined for any set of cases or attributes, respectively.

An archetype requires closure with respect to extension and intension. Take, for example, the cases {c1, c2}. The intension of this set are the attributes {barrier, a1, a2}. Now determine the extension of {barrier, a1, a2} to obtain the cases {c1, c2} – exactly the set of cases that we started from. So, {c1, c2} in combination with {barrier, a1, a2} is closed, such that this combination qualifies for an archetypes.

Obviously not all combinations of cases and attributes are closed. For example, the combination of {c2, c3} with {a1} cannot be an archetype in the example. The extension of the attribute would add further cases (c1 and c4), and the intension of the cases would add further attributes (barrier and a3). The idea is to require archetypes to be maximal in a specific sense: no further attributes and cases can be added without making the combination inconsistent.

A total of 8 closed combinations of cases and attributes can be found in Fig. S1. Some of them are characterized by just one attribute or one case. In addition to closure, it is reasonable to require (i) that archetypes appear repeatedly, i.e. to hold for at least two cases, and (ii) that they are characterized by at least one diagnostic attribute (barrier is an outcome attribute here). With this additional criteria, the example yields the archetypes shown in Tab. T1.

| Archetype | Cases | Diagnostic Attributes | Outcome Attributes |
|---|---|---|---|
| 1 | {c1, c2} | {a1, a2} | {barrier} |
| 2 | {c2, c3} | {a1, a3} | {barrier} |
| 3 | {c1, c2, c3} | {a1} | {barrier} |

**Table T1**: Archetypes in the example.

Note: In the full meta-study, rows are not cases, but 'models', i.e. empirically justified causal statements made in a case study (see Section 3.2.2). We will also tighten the additional criteria to require at least two diagnostic attributes and at least three 'models' for an archetype (see Section 3.2.3).

## Codebook

This codebook (Tab. T2) contains the variables used in this meta-analysis. It comprises a multi-tiered map of variables (Ostrom, 2005; 2009): Higher-tier variables are decomposed into more specific variables at lower tiers. The codes with more digits denote sub-variables of codes with fewer digits, e.g. RS21 is a sub-variable of RS2. Starting with the first-tier variables of Ostrom's (2009) SES Framework, the codebook was developed through the iterative procedure that is described in the methods section of the article. Therefore, the sub-tier variables reflect the factors inductively coded from the case studies rather than the sub-tier variables of the original Ostrom (2009) paper. The variables were coded as "present" in a "model", if they were part of the case study's explanation how and why a barrier emerged.

| Code | | Description |
|---|---|---|
| **Outcome** | | |
| O1 | Barrier to adaptation is reported. | The case study reports and explains the occurrence of a barriers to climate adaptation. |
| **Interactions** | | |
| I1 | Insufficient reason | Problems of insufficient reason characterize a situation in which a potential operator prioritises alternatives over an adaptation option based on her/his preferences, decision heuristics, and mental models or beliefs, i.e. the actor does not have sufficient reason for the adaptation option(s) in question. There are multiple, more specific sub-types I11, I12, etc. |
| I11 | Limited adaptation incentives | Potential operators place low priority on the considered adaptation options in their preference order. |
| I12 | Maladaptation incentives | Actors act operate under incentives that guide them to prioritize maladaptive activities and objectives. |
| I13 | Short time horizon | Potential operators act upon a short-term horizon which makes them to disregard longer-term challenges and implications. |
| I14 | Fear of shifting power during institutional reform | Actors expect shifting control during an institutional reform, which entices them to opose that reform. |
| I15 | Unconvinced veto players | A set of veto players has insufficient reason to support the considered adaptation option. Two aspects:<br>- game structure ("aggregation technology") includes players with sufficient veto-power. |

| | | |
|---|---|---|
| | | - those veto players expect higher costs than benefits from the adaptation options.<br><br>The focal operator is willing to realize adaptation options. Approval or support by other actors is necessary to realize the adaptation option. However, the focal operator cannot convince those veto players about the net benefits of the respective adaptation options. |
| | | |
| I2 | Constrained capacity | Potential operators of adaptation are present and aware of adaptation needs, but their limited action space during a given time period hampers them to effectuate the considered adaptation option(s). Multiple subtypes (I21 etc.). |
| I21 | Missing means | Potential operators of adaptation are present, but have limited action space because the means for the considered adaptations are severely limited or even absent in the considered time period. |
| I22 | Rare windows of opportunity | Windows of opportunities during which supportive decision-making or implementation of the considered adaptation options would become feasible are rare. Windows of opportunities characterize a limited period of time during which the considered adaptations would become feasible in economic, political, technical, ecological, and/or social terms. |
| I23 | Enforcement deficits | Deficits in rule enforcement limit capacity for collective action. |
| I24 | Decision-making upon poor data | Decision-making in the face of large uncertainty due to data gaps. |
| | | |
| I3 | High transaction costs, low cooperation benefits | Transaction costs are defined here as the costs that actors need to incur to engage in social interactions, including peaceful cooperation (e.g. costs for communication, monitoring, enforcement) as well as the costs incurred by destructive effects of social conflict (Schmid 2004), including lost productivity in collective action (e.g. rent seeking, Tullock 1980). Problems of I3 arise due to high transaction costs or low benefits from cooperation and coordination, or a combination of both. Multiple sub-types. |
| I31 | high cost of coordination | High transaction costs, including costs of complexity (confusion) and slow processes. |
| I32 | limited benefits of coordination | Low benefits of coordinating among involved actors, incl. latent conflicts of interest (no perception of any possible benefits from agreeing). |
| I33 | Rent seeking | Dilemma structure and strategies among involved actors about the capture of rents of collective decision-making. |
| I34 | Costs of conflict | Social conflict (e.g. political, violent) about control over the RS or RUs lingers on unresolved, hampers collective decision-making, and entices individual actors to incur monetary and non-monetary costs to engage in conflict activities (e.g. individual resistance, organized resistance), including organized resistance. |
| I35 | Endogenous creation of special interests | An adaptation option creates new interests (e.g. due to new entitlements or new actor constellations) which limit flexibility to adapt in the long term (e.g. should high-end impact scenarios come true). |
| | | |
| I4 | Asymmetric control | An actor's control is defined as her/his influence on aggregate outcomes of a situation (Ostrom 2005; 2011).<br>Asymmetric control enables specific participants of an adaptation situation to shape the outcomes of interdependent decision-making particularly strong according to their particular interests. |
| | | |
| I5 | Stalled social learning | Learning in a social network is stalled. Learning in the sense of updating (generating, communicating, accepting): new information used in decision-making, mental models, values and preferences. |
| I51 | Lagged information uptake | Operators delay the use of available information on climate change impacts and adaptation. |

| | | |
|---|---|---|
| I52 | Restricted uptake of information and knowledge | Operators do not make use of available information on climate change impacts and adaptation. |
| I53 | insufficient reason to learn | Operator face insufficient reason to learn. |
| | | |
| **Governance System** (adapted from Oberlack 2016) | | |
| GS1 | Actor eligibility | Attributes of boundary rules that regulate the set of actors who are eligible to participate in an adaptation situation |
| GS11 | Limited stakeholder participation | Eligibility of stakeholders to participate in decision-making is limited. |
| GS12 | Inclusive approach | Eligibility of stakeholders to participate in decision-making is broad. |
| | | |
| GS2 | Responsibilities | attributes of position and choice rules that regulate the positions available to participants and the required, prohibited and allowed actions assigned to positions; |
| GS21 | Fragmented responsibilities | Multiple interdependent actors or arenas of decision-making co-exist without sufficient coordination among them |
| GS22 | Clarity of rights and responsibilities | |
| GS221 | Unclear rights and responsibilities | Rights and responsibilities are unclear. |
| GS222 | Missing standards | Technical, administrative or procedural standards are missing. |
| GS23 | Institutional incentives and priorities | |
| GS231 | … incentivize high resource use | Operational rules incentivize high resource use. |
| GS232 | … focus on the short term | Operational rules incentivize short-term planning. |
| GS233 | … priority to particular water services | Operational rules (e.g. organizational mandates) prioritize provision of a particular water service over other water services. |
| GS234 | Organizational imperatives | An organizational mandate or fundamental strategy (institutions for operational decision-making of organization members). |
| GS234a | ... is present | … is present. |
| GS234b | Rules based on historical hydrology | Operational rules for water supply or use are based on historic hydrologic conditions. |
| GS24 | Property rights | |
| GS241 | Secure property rights | Security of water rights is high. |
| GS241a | Secure property rights with fixed allocations | Security of water rights is high, and they provide rights holders with a right to a fixed amount of water per time unit. |
| GS241b | Frictions in transfer of property rights | Frictions occur in the transfer of water rights. |
| GS241c | Insurance and compensation claims | An actor has legally sanctioned insurance claims against the public in case of damages. Damage (e.g. flood damage) would imply compensation through public budgets. |
| GS242 | Changed property rights | Property rights about water have changes. |
| GS243 | Wide-spread private water rights | Private water rights are widespread in the study region. |
| GS244 | Intransparency about water rights | Distribution of water rights is intransparent. |
| | | |
| GS3 | Control | attributes of aggregation rules that regulate the control that a participant has<br>over the aggregate outcomes of an adaptation situation |
| GS31 | Limited control in polycentric system | The focal operator has limited control in a polycentric system. For instance, the focal potential operator(s) (e.g. operational public agencies) in the focal SES lack the control over water management, because |

| | | |
|---|---|---|
| | | control is located with actors at other governance levels (e.g. regulator). Including missing mandate in a polycentric system. |
| GS32 | Concentrated control | Rules and procedures concentrate control in the focal AS. Control over water management is concentrated within a few actors in the focal SES. |
| | | |
| GS4 | Social connectivity | attributes of institutionalised procedures (i.e. chains of actions, events and outcomes) and networks (i.e. connections between multiple positions and actors) that connect actors within and across tiers of social organisation |
| GS41 | Limited vertical coordination | Limited coordination/cooperation between actors within the focal SES and other governance levels. |
| GS42 | Limited horizontal coordination | Limited horizontal coordination/cooperation within the focal SES, e.g. between different departments of same-level public organizations. |
| GS421 | Poor coordination of data and knowledge | Limited horizontal coordination/cooperation within the focal SES, e.g. between different departments of same-level public organizations, with regard to data and knowledge coordination. |
| GS43 | Efficient interest group organization | An interest group is very efficient in organizing themselves. |
| GS44 | Top-down decision-making | Agenda-setting and decision-making is driven in a hierarchical, top-down manner. |
| GS45 | Lack of higher level regulation | Regulation from higher levels of a hierarchy is missing. |
| GS46 | Decentralized governance system | The GS is a decentralized one. |
| GS47 | Competition between public organization | Public organizations within one jurisdiction compete with each other. |
| GS48 | Water market failure | Market failure in a water market. |
| | | |
| GS5 | Conflict mechanisms | institutional attributes that shape how conflicting interests and actions among actors are resolved, transformed, or prevented; |
| GS51 | Slow procedures for conflict resolution | Procedures for conflict resolution are slow. |
| | | |
| GS6 | Social learning | institutional attributes that shape how information, knowledge, values and preferences are constructed, communicated and accepted among participants |
| GS61 | Ineffective science-policy interface | The science-policy interface is ineffective in terms of social learning. |
| | | |
| GS7 | Accountability mechanisms | institutional provisions for monitoring, evaluating, rewarding and enforcing responsibilities. |
| GS71 | Lack of accountability | Decision-makers are not sufficiently held accountable towards the public. |
| | | |
| GS8 | Scale of institutions | The spatial and temporal boundaries of institutions |
| GS81 | Short period of office | Potential operators have a short period of office. |
| GS82 | Time scale mismatch | Institutional time-scale implications have a misfit with the temporal scale of the AO and/or the RS functioning. |
| | | |
| GS9 | Adaptiveness of institutions | The extent to which change of the rules-in-use is constrained by higher-order rules, path dependence and transaction costs; |
| GS91 | Slow procedures for institutional change | Established procedures for changing formal rules and plans imply slow pace (e.g. many iterations). |
| GS92 | Overcomplex GS | The GS is perceived as overcomplex by its actors. |
| GS93 | Emergency plans. | Emergency plans exist which allow, in case of an extreme event, for temporary adjustments of operational and collective choice rules. |
| GS94 | Institutional persistance | The institution in question persists over a long timeframe with no significant changes |
| | | |

| | | |
|---|---|---|
| GS10 | Formality of institutions | The degree to which the rules-in-use are embedded in written laws, plans or documents. |
| GS101 | High degree of informality | Social interaction is dominantly governed by informality. |
| | | |
| | | |
| **Actors** | | |
| A1 | Individual knowledge, beliefs and preferences | |
| A11 | Awareness | Attributes of awareness among operators. |
| A111 | Low awareness | Operators have low awareness of local impacts of climate change. |
| A112 | Awareness hype | After an event, potential operators have high awareness of impacts and risks. This awareness decreases soon after the event is over. |
| A12 | Limited understanding SES | The potential operator has limited understanding of the system of concern at which to act. |
| A13 | Limited understanding climatic stimulus | The potential operator has limited understanding of the climatic stimulus that affects the system of concern. |
| A14 | High risk aversion | The potential operator acts upon high risk aversion. |
| A15 | Low priority because climate change is future problem | Operators perceive climate change as a problem to be tackled in the distant future. |
| | | |
| A2 | Heterogenous beliefs, interests and priorities | |
| A21 | Heterogenous interests about water vs. other priorities | Different actors prioritize water services vs. other public goods differently, e.g. water service provision vs. industrial development vs. financial crisis management (e.g. in allocating scarce time and resources to alternative public goods) |
| A22 | Heterogenous interests about water services | Different actors prioritize different water services (e.g. shipping vs. freshwater vs. fishery vs. recreation), including ethical interests & values. |
| A23 | Heterogenous interests about priority of adaptation | Different actors prioritize different adaptation options. |
| A24 | Divergent beliefs | Different actors hold divergent beliefs about climate change and impacts or about the SES of concern. |
| A25 | Limited trust among actors | Trust = expectation of actor A that other actors would choose cooperative strategies instead of defective/conflictive strategies. |
| | | |
| A3 | Access to material resources | |
| A31 | Financial constraints | Operators face tangible financial constraints for adaptation. |
| A32 | Technological constraints | Operators face tangible technological constraints in adaptation. |
| | | |
| A4 | Access to information resources | |
| A41 | Limited information | |
| A411 | Limited information on impact | Operators have limited access to information about local impacts of climate change. |
| A412 | Limited information on SES | Operators have limited access to information about the functioning of the social-ecological system of concern. |
| | | |
| A5 | Staff resources | |
| A51 | Constrained staff capacity | The organization that could act as an operator faces tangible constraints in terms of staff capacity (e.g. number, fluctuation, qualification, experience of staff). |
| A52 | Reliance on volunteer work | The organization that could act as an operator relies on volunteer work. |

| | | |
|---|---|---|
| **Resource System and Resource Units** | | |
| RS1 | Size and scale of RS | |
| RS11 | Focal RS is embedded in larger water system | The focal RS of a study is embedded in larger water system, and the study reports this as an explanatory factor for an adaptation barrier. |
| RS12 | Upstream-downstream effects | The natural flow of the river (from up- to downstream) implies a specific positioning of actors in collective decisionmaking, contributing to an impasse. |
| RS2 | Climate stimuli and exposure | |
| RS21 | Current stimuli | Current stimuli that affect the focal resource system. |
| RS211 | Drought | |
| RS212 | Flood | |
| RS213 | High variability | |
| RS214 | Low variability | |
| RS215 | Other | |
| RS22 | Climate stimuli not (yet) experienced | potential operators did not experience significant climate stimuli, according to their memory. |
| RS221 | Flood | |
| RS222 | Drought | |
| RS223 | Other | |
| RS3 | Current state of RS | |
| RS31 | Ecosystem adaptation deficit | The ecosystem that underpins the focal RS has an adaptation deficit. |
| RS4 | Built infrastructure | |
| RS41 | Infrastructure adaptation deficit | Built infrastructure has an adaptation deficit in the status quo. |
| RS42 | Long-lived infrastructure | Built infrastructure has been built long time ago (long in relation to usual lifetime of the infrastructure, as assessed in the primary study). |
| RS5 | Concurrent stimuli | The RS is affected by concurrent stimuli, e.g. population growth, industrial development, macroeconomic crisis. |
| | | |
| **Adaptation Option** | | |
| AO1 | Leads to conflicts or externalities | The adaptation option generates winners and losers, leads to conflicts or externalities. |
| AO2 | Uncertain consequences | Uncertain consequences of an adaptation option, e.g. with regard to costs and benefits. |
| AO3 | Long lead times | It takes a long time to implement the adaptation option. |
| AO4 | High costs | The adaptation option implies high financial costs. |
| AO5 | Reliance on technical measures | The adaptation option is a purely technical option. |

**Table T2**: Codebook.