Paper for ICPP6, T14 P12

Future water conflicts in Germany: Serious gaming for policy design under future uncertainty

Hannah Kosow[1], Simon Brauner[2], Fabian Hölzlberger[3], Janina Moschner[1], Stefan Vögele[2], Wolfgang Weimer-Jehle[1], Anja Brumme[3], Dirk Rübbelke[3]

[1] Center for interdisciplinary Risk and Innovation Studies, University of Stuttgart Germany (ZIRIUS)

[2] Forschungszentrum Jülich (FZJ)

[3] Technische Universität Bergakademie Freiberg (TUBAF)

Abstract

Heat waves, drought, but also heavy rainfall events are already being felt in Germany today as a consequence of climate change. These phenomena will intensify in the future. For this reason, we expect water stress at least locally and seasonally in Germany, originally water-rich, due to potentially decreasing groundwater and surface water levels with constant or rising consumption. This may exacerbate existing conflicts between industry, water providers, private households, agriculture, and ecosystems, or create new conflicts over the protection, use, and distribution of surface and groundwater resources.

What influence will future contexts such as climate change have on water conflicts and their governance in Germany? How will future strategies and decisions of various actors – and the interplay of these policies – affect conflict situations? Which combinations of policies (policy mixes) could exacerbate or mitigate future water conflicts in different scenarios? We will explore these questions around possible future water conflicts in Germany with potentially affected as well as interested actors in an inter- and transdisciplinary approach. To make the uncertainty and complexity linked to the issue tangible, semi-qualitative system analysis is applied. We have chosen cross-impact balance analysis (CIB) because it supports both, the construction of qualitative future scenarios as well as policy design. We apply CIB, and this is an innovation, in the form of participatory modeling and develop a serious game (web application) that supports actors in anticipating conflicts and forming coherent strategies under future uncertainty. Currently, three modular case studies are carried out: Module A 'conflicting objectives in a river basin' (focus on industry, urban development, and reservoirs); module B 'conflicts of irrigation' (focus on rising water demand of viticulture, field cultivation and urban green); module C 'conflicts in large-scale mining projects' (focus on operation and flooding of open-cast coal mining in a transboundary setting). In all three cases, we develop qualitative models of possible future water conflicts together with local and external experts. In a second step we use these models as a serious gaming tool to illustrate the consequences of one's own and others' decisions. This supports the development of conflict-reducing strategies and policy mixes that are robust to a range of possible future developments.

Expected results comprise, first, three modular and participatory CIB models of future water conflicts in Germany i) representing possible context scenarios as well as possible strategies and options for action of different actors, and ii) uncovering the extent and nature of linkages between affected parties. The play sessions with experts will result in potential policy mixes for the investigated conflict fields under different scenarios (policy-mix scenarios). Second, we will prepare a shareable workshop version of the co-designed web application for this use of CIB for local and external experts and academic teaching. Finally, we will carry out cross-case system analyses on future water conflicts in Germany and on possible strategies for conflict mitigation under different scenarios of climate change and other uncertain contexts.

Our paper reports about the early phases of ongoing research in the project ZuWaKo (www.zuwako.en). We would like to use the opportunity of the session T14 P12 to discuss our overall approach.

1. Introduction

While Germany has long been seen as a country with extensive water resources, the last years have shown that water can become increasingly scarce – at least regionally and seasonally. The main reason is climate change, resulting in hotter and dryer summers, changed precipitation patterns throughout the year (dry summers and heavy rainfalls in winter) (e.g., DWD 2023, DVGW 2022, 2023) poor infiltration, and high outflow rates, at times producing floods. These climate change effects pressure freshwater reserves, groundwater renewal and soil moisture (e.g., LAWA 2017, DVGW 2022, Wunsch et al. 2022). At the same time, hot and dry springs and summers lead to increased water demand by households, industry, agriculture, and water related ecosystems, affecting water quantity and quality. Such developments will change the water balance in Germany (LAWA 2023). In the future, water extremes such as droughts and floods associated with climate change as well as water-related conflicts between different water users such as private households, industry, agriculture and ecosystems are expected to increase (Diemel 2022, Tröltzsch 2021, LAWA 2022).

Preparing for this potentially conflictive and still uncertain future is a current challenge for practice. Potential water scarcity and water conflicts have already found their way to political agendas as indicates the national water strategy (BMUV 2023), approved by the German Federal Parliament this year. Still, much uncertainty can be observed among different actors regarding the current[1] and future water situation in Germany as well as regarding (future) actors' decisions and their interplay. This uncertainty challenges not only political decision makers in designing and voting for regulations, but also administrations on local and regional levels. These administrations are historically responsible to manage the water rights, normally issued to private and public actors for rather longer time periods of 10-20 years. Uncertainty also challenges water providers (public or private companies), who are facing very important investment decision regarding future water infrastructures (with effects and path-dependencies for multiple decades or even more than half of centuries to come).

Water conflicts in Germany are an emerging issue not only for politics but also for research and so far, have hardly been the subject of social science or public policy research in particular (for an exception see WADKLIM, in press, and LAWA 2023). Future water conflicts in Germany can be

[1] Notably, the actual water withdrawal in Germany, in particular by agriculture, remains a black box. Although State ministries are now seeking to ameliorate the data situation (e.g. Masterplan Wasser BW).

conceptualized as a wicked problem (e.g. Head 2022). Literature on wicked problems (Head 2022, e.g.) provides us with a conceptual framework to better understand its three dimensions, namely uncertainty (Dewulf & Biesbroek 2018 for detail), complexity (Kirschke 2019 for detail) and conflict, at times labeled “divergence” (Head 2022) or “ambivalence” (Renn et al. 2011) or, and in the focus in our study, “goal conflict” (Kirschke 2019, Kirschke et al. 2022).

Future water conflicts refer to the fields of *adaptive governance* (Folke et al. 2005, e.g.) and even more to *anticipatory governance* and its methods of futures-thinking (Alexandra 2023), in particular to the tool scenario analysis (e.g. ElSawah et al. 2020) to address and deal with future uncertainty and complexity. While research has pointed out that today's’ scenarios of water extremes need to better address complexity and uncertainty (Kosow et al. 2022a), with this study, we additionally propose an explicit focus on the aspect of *conflicts*, which always resonates in water governance research but does not necessarily become the central perspective.

A report by the German working group on water issues of the Federal States and the Federal Government (LAWA 2022) already points to conflicting goals and possible synergies in adapting water management to climate change. Still, comprehensive combinations of measures (policy mixes) have not been examined yet. In particular, there are still no systematic analyses and no prospective studies, i.e., studies that anticipate possible futures, that focus on both, effects of climate change and other context developments such as land use, demographic change, economic development etc., but also on actor decisions, their interplay and possible conflicts between actor strategies. There is also a lack of offers for professionals from science, administration and practice to systematically explore future water scenarios as well as options for action and their consequences and to support the development of coherent strategies. Although there are already a number of simulation games or serious games in the field of water governance, they do not yet focus on the complexity, i.e., the complex interactions between uncertain future context factors, actors’ goals, strategies and decisions in (anticipated) water conflicts (Brauner et al. 2023).

In order to systematically analyze the interplay between policies to reach multiple goals, a new approach was recently developed (Kosow 2022b) that uses a qualitative but systematic form of systems analysis, cross-impact balances (CIB) (Weimer-Jehle 2006) for policy-interaction modeling. This approach allows i) the evaluation of status quo policy-mixes ex post, ii) designing of alternative policy mixes, and iii) their ex ante evaluation regarding their internal consistency and degree of synergy. This approach was developed in the field of water management (Kosow 2022b) and also successfully tested in the field of land use (Kosow 2022c). The CIB approach has been originally developed to construct future scenarios and has been applied to build 'big picture scenarios' in multiple fields, amongst others, of water governance (Lazurko et al. 2023, e.g.) and climate change (e.g. Schweizer/O'Neill 2014). However, CIB has so far not been applied for a systematic combination of comprehensive context scenarios and policy-interaction models, in short, to build policy-mix scenarios with CIB, nor has CIB been considered as a 'game engine' yet. This is where our research project comes in.

The overall research questions of our project are: What influence will future contexts such as climate change and other uncertain developments have on water conflicts and their governance in Germany? How will future strategies and decisions of various actors – and the interplay of these policies – affect conflict situations? Which combinations of policies (policy mixes) could exacerbate or mitigate (or more neutrally: transform) future water conflicts under different scenarios? And, from a method-angle, what role can policy-mix scenarios play for policy design under uncertainty? How can we use CIB, a semi-quantitative form of systems analysis, in form of participatory modeling and for serious gaming for this purpose?

In the following, we give an introduction into our project and build the grounds towards answering the overall questions. We clarify key concepts and basic assumptions of our work (section 2). We introduce our empirical basis, consisting of three modular case studies (section 3), detail our methods based on CIB for constructing and analyzing policy-mix scenarios in form of participatory modeling and serious gaming (section 4); provide first results on future uncertainty, actor complexity, and potential water conflict types in Germany (section 5) and provide an outlook (section 6).

2. Definitions and assumptions

We briefly introduce our overall perspective on wicked problems and problem structuring (2.1.), then dive deeper into three dimensions conflicts (2.2), complexity (2.3), and uncertainty (2.4) as we understand them in our study.

2.1 Wicked problems and problem structuring

We choose to analyze water conflicts through the lens of "wicked problems" (Rittel/Webber 1973, Head 2014, Hou et al. 2022) and of "problem structuring" (Simon 1973, Hoppe 2010). This conceptual lens focuses on the structure of policy problems and the effects of these on policy responses Issues become policy problems when groups demand action and when plausible stories are advanced comprising not only causes but also remedies of these problems (cf. Stone 1989: 299). "[…] divergent 'framing' of policy problems generates conflict about the nature of these problems and about how to address them." (Head 2022: 8). How problems are defined - or structured - matters for the solutions that are proposed, decided and implemented to address them (Head 2022: 10). Wicked problems literature distinguishes between "simple" (unanimous) vs. "complex" (controversial) problems (Head 2022), or "tame" problems with clear boundaries and agreed solutions (Rittel/Webber 1973) vs. "wicked" problems with disagreement on a) nature, b) solutions and c) values/principles that should guide improvements (Head 2022: 21, for detailed characteristics what a wicked problem consists of, see Rittel/Webber 1973: 161-167). Literature on problem structuring turns the focus on the processes of transforming "ill-structured problems" with high uncertainty and high ambivalence into "well-structured ones" while designing their policy solutions (Hoppe, 2011). In the literature on wicked problems, conflict is often associated with "ambivalence" (Renn et al., 2011) or "divergence" (Head 2022) – and (more or less) analytically separated from the two other key characteristics, namely uncertainty and complexity (Head 2022, Dewulf/Biesbroek 2018, Kirschke 2019, Kirschke/Kosow 2021, Kirschke et al. 2022)[2]. Structuring or framing problems as conflictual (or not!), has consequences for the possible solutions - and thus for policy design (Hoppe/Turnbull 2022). Structuring problems as certain types of conflict (and not others.) also has consequences for possible solutions and the policy mixes that are developed and implemented.

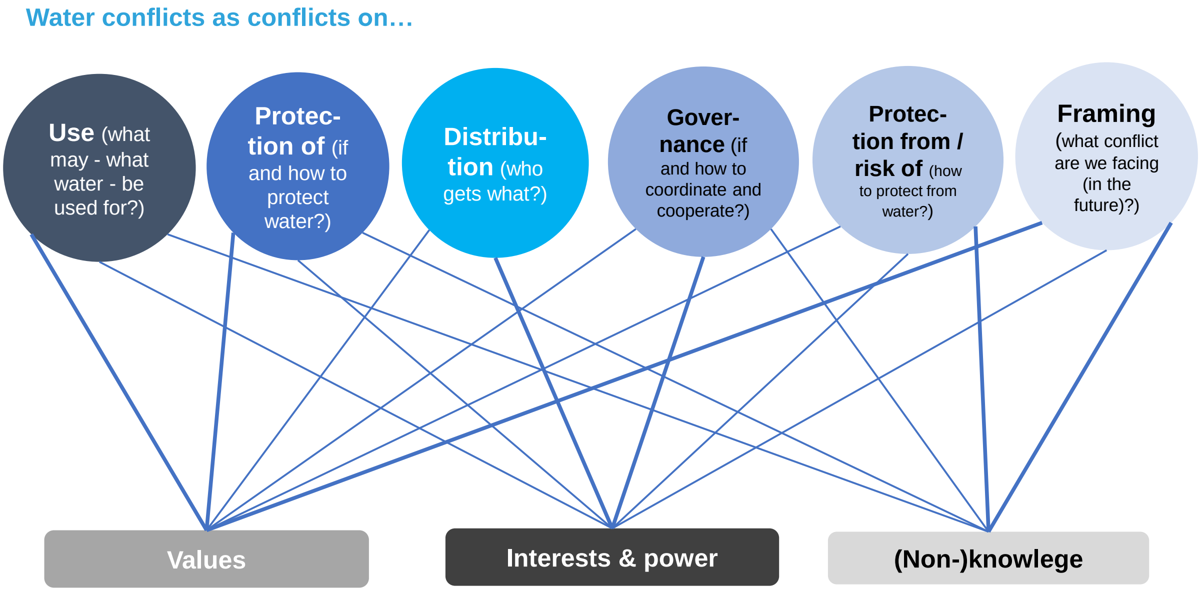
2.2 Water conflicts

We understand conflict very broadly as "a relationship between two or more parties (individuals or groups) who have, or think they have, incompatible goals" (Fischer et al. 2000: 4). These different actors are referred to as conflict parties. Regarding water conflict, we consider different types of conflicts, see also Figure 1: These include conflicts over the *use*, *distribution*, and *protection* of surface water (SW) and groundwater (GW), as well as conflicts over the *protection from and risks of water* (e.g. heavy rains, floods, flooding of disused mines etc.). Both *water resource conflicts* and conflicts over *water governance* (understood as the horizontal and vertical coordination and cooperation of various actors, s. Pahl-Wostl et al. 2020) are considered. Conflicting perceptions and expectations of whether a conflict exists today, or is anticipated for the future at all, and if so, what type of conflict, are considered by our study as *framing conflicts* (or meta-conflict, s. Saretzki/Feindt 2010). In terms of the classical conceptualization of conflicts of interest vs. conflicts of values vs.

[2] Kirschke (2019) subsumes uncertainty and conflict under the overall category of complexity, Dewulf & Biesbroek (2018) subsume conflict and complexity under the overall category of uncertainty.

conflicts of (non-) knowledge (e.g., Saretzki/Feindt 2010), we observe that in the water conflicts considered by our study, these three dimensions are nested and interlocked but no independent features, see figure 1. Instead, water conflict may be considered under a main angle (be it values, interest or knowledge), but not isolated, as the other dimensions play a role, too. In addition, it seems necessary to distinguish between latent and manifest as well as between singular vs. multiple, interlocking conflicts (e.g., historical political conflicts behind water conflicts).

Figure 1: Types of water conflicts considered in our study and their relation to conflicts of values, interests & power, and (non-)knowledge



Water conflicts do not need to be seen as negative per se and thus to be avoided at all costs, but from an analytical perspective also provide an opportunity for change in water governance (e.g., Houdret 2011, Taylor/Sonnenfeld 2008). While in general conflict theory (for an overview see Bonacker 2005 and Axt et al. 2006), early approaches of conflict management focussed on “conflict settlement” in a neo-realist perspective considering conflict as zero-sum games (e.g., Bercovitch 2019, Zartman 1985). Competing approaches focused on “conflict resolution” (e.g., Burton 1990) in a social-psychological perspective, considering synergetic solutions, fostering several goals at the same time. Currently, the focus often is on “conflict transformation” (based on fundamental work by Lederach 1996 and Galtung 1999), where all solutions to conflicts are considered as being only temporary. This approach follows sociological perspectives (e.g. Coser 1965, Darendorf 1965) emphasizing the role of conflict for social change and governance as a central means for conflict transformation. We assume that in water governance, conflict and transformation have a complex relationship: Conflict can enable transformation, as (new) policy solutions must or can be sought or (finally) implemented (e.g., "window of opportunity" (Kingdon 1984)). Depending on the degree of escalation or the way in which the conflict is handled, however, conflicts can also prevent change. At the same time, transformation triggers (new) (side) effects and, in turn, new - or transformed - conflicts. Finally, we choose a moderate constructivist perspective in order not to lose sight of material and social structures and processes behind water conflicts and to understand their social construction at the same time. While water issues have been subject to political regulation in Germany since a while (see, e. g., the Federal Water Act (WHG) since the year 1960, following State water acts from the 19th century, the European Water Framework Directive since 2000), *conflicts* around water are to a large extent "emerging problems" representing a new topic of the public and political debate on the federal and national level, i.e. issues that are just in the process of becoming urgent public policy problems in Germany.

2.3 Complexity of policy-interactions

Water conflicts relate to potentially conflicting goals of various actors as households, industry, water companies, agriculture, and water related ecosystems. These goals translate into various actions as strategies and measures (here broadly understood as policies) by these actors. In their interplay, these policies can aggravate, remedy or transform conflicting situations. The complexity of policy interactions is object of policy-mix and policy design research. Research on policy combinations has been performed in various fields, such as development policy, innovation policy (Rogge/Reichardt 2016, Reichardt et al. 2016, Kern et al. 2016), and mobility policy (Feitelson 2003, Givoni 2014, Scheer et al. 2022). It analyzes interactions, goal conflicts, temporal logics of (old and newly implemented) strategies, and measures and policy instruments within or between policy fields and between levels of governance. The literature illustrates that consistent bundles of measures are rare. In contrast, a policy patching of different measures is frequently observed, which is often inconsistent in their interactions (Kivimaa/Kern 2016, Kern et al. 2017). Public policy analysis provides a rich body of literature on policy mixes (Rogge/Reichardt 2016, Howlett/Rayner 2013, Howlett 2014), i.e., combinations of policies (tools, instruments, and measures) and their interaction. The main hypothesis that we can draw from the literature is that policies must be considered in their interplay; focusing on individual approaches neglects the interplay of new and old policies as well as policies within and between sectors and on different scales (e.g., municipal, inter-municipal, regional, state). Combinations require to be considered to avoid trade-offs and generate synergies. Regarding future water management and governance in Germany, strategies and lists of individual policies for different governance levels in Germany have been or are currently developed (on the Federal level by BMUV 2023, as well as water use concepts on the state level, e.g. Niedersächsisches Ministerium für Umwelt, Energie, Bauen und Klimaschutz 2022). A first analysis on synergies and conflicts of individual approaches and policies has been carried out by the German working group on water issues of the Federal States and the Federal Government LAWA (2022). However, we lack a systematic analysis of their interplay and the effects of their overall combination. Such analysis is required to design approaches for a more coherent (and more sustainable) governance of water in Germany in the future.

2.4 (Future) uncertainty, scenarios, and robustness

The future of water in Germany is not only potentially conflictual and complex, but these water conflicts are ridden with uncertainty, too. There are several proposals to further distinguish types of uncertainty (e.g., Walker et al. 2003, Dewulf/Biesbroek 2018). Walker et al. (2003) distinguish locations, levels and types of uncertainty in modeling and decision support. For our study, their understanding of "scenario uncertainty" (Walker et al. 2003: 12) is particularly relevant:

> **"The use of scenarios is one approach used in policy analysis to deal with uncertainty related to the external environment of a system (usually its future environment) and its effects on the system. A scenario is a plausible description of how the system and or its driving forces may develop in the future. To be plausible, it should be based on a coherent and internally consistent set of assumptions about key relationships and driving forces." (Walker et al, 2003: 12**).

Please note that scenarios do not predict the future but rather indicate what might happen in form of what-if thought experiments (ElSawah et al. 2021) – and can be considered today's expectations of possible future situations ("present futures" and not "future presents", in the terms of Grunwald 2013). Scenarios typically come in form of multiple, alternative scenarios to represent this openness of the future.

Building on Walker et al. (2003), Dewulf & Biesbroek (2018) specifiy "nine lives of uncertainty" in decision-making to specify strategies for dealing with uncertainty in environmental governance. They distinguish three types of uncertainty, namely i) epistemic uncertainty (involving the lack of knowledge about a particular system) , for instant missing data on the current water situation, especially regarding levels of ground water (and its renewal rate) or the effective water use by agriculture; ii) ontological uncertainty (irreducible unpredictability due to inherently complex system behavior), where complexity and future uncertainty come into play, and iii) ambiguity, referring to conflicts between fundamentally different frames about the issue at hand, e.g. in form of different interpretations and causal models, for instance of groundwater and land lowering in mining areas. In addition, they distinguish between three objects of uncertainty, namely a) substantive uncertainty, i.e. uncertainty about the content of decisions or policy issues, i.e. uncertainty of what to do, what policy to opt for and how to decide; b) strategic uncertainty, i.e. uncertainty about the actions of other actors in the strategic game of decision-making and finally c) institutional uncertainty, i.e. uncertainty about the rules of the game in decision-making. Regarding the objects of uncertainty, especially substantive and strategic uncertainty are relevant to our study. In particular, the concept of *robustness* (Dryzek 1983), i.e. what policies are effective under various different possible future contexts, plays a role. Here, the question arises, how to consider uncertain contexts in decision making and policy design.

3. The empirical base: three modular case studies

For our study, we have selected three modular case studies: A) goal conflicts in a river basin, B) irrigation conflicts and C) water conflicts in the mining sector. These three modules can be understood as spotlights on different aspects of the overall issue of future water conflicts in Germany.

3.1 Module A: Goal conflicts in a river basin

An abstracted case of conflicts between industry, households, reservoir management and others is developed with the help of actors and associations from the Eifel-Ruhr (also known as Maas-South) catchment area. What are typical conflicts in this (sub)catchment area and which ones are expected in the future? What are the actors who are (or could be) facing each other at this point or in the future? How can these conflicts be overcome? Additional questions in this case are: To what extent are water conflicts more than distributional conflicts? What roles do actors and their knowledge play in conflicts?

3.2 Module B: Irrigation conflicts

The case focuses on conflicts that may arise due to changes in irrigation demand in both urban and rural areas. In the urban context, the focus is on water use in urban green spaces for cooling and recreation, as well as on concepts for dealing with heavy rainfall events (keywords heat, sealing, "sponge city"). In the rural context, the focus is on yield and quality assurance of cultivated crops (in particular potatoes and viticulture), as well as on securing good soil conditions (keywords drought, compaction/erosion, biodiversity), in addition to landscape management. A potential conflict line between irrigation of agricultural land and restoration and preservation of water related ecosystems is considered, too. Urban and rural irrigation are hydro-connected through the use of the same drinking water provided by a regional and a remote water provider and by the same river water. Specific questions of this case study are: What perceptions regarding (future) water scarcity exist and arise among different irrigation (related) actors and what influence do these perceptions have on (possible) actor strategies?

3.3 Module C: Water conflicts in the mining sector (ligate mining)

Based on the case study of an opencast lignite mine in a tri-state area, current water problems during operation and those expected in the future are analyzed. The cross-border perspective is particularly interesting. Specific questions of this case study are, which water-related conflicts can already be observed during the operating period of an opencast mine and which conflicts arise after decommissioning - and flooding? What can we learn from the past and from thought experiments about future conflicts and their possible resolution, prevention or transformation?

4. Methods: Policy-mix scenarios with CIB

We use cross-impact balance analysis to build policy mix scenarios (4.1) in form of participatory modeling (4.2) for and through serious gaming (4.3.).

4.1 CIB for policy design under uncertainty (policy-mix scenarios)

The methodological core of our project is cross-impact balances, CIB (Weimer-Jehle 2006). CIB is a qualitative yet semi-formalized form of systems analysis (Weimer-Jehle 2006). This conceptual modeling method requires identifying system elements and allows exploring the interrelations found between them. A brief introduction to CIB is given in Supplement A. Initially, CIB was developed and used to construct future scenarios and CIB has proved its usefulness in the field of inter and transdisciplinary water (governance) (e.g., Schütze et al. 2019; Motschmann et al. 2023) and also climate change studies (Schweizer/Kriegler 2012; Schweizer/O'Neill 2014; Ruth et al. 2015), in particular to provide big picture scenarios of societal, socio-technical and socio-environmental systems.[3] It has also been applied to design societal context scenarios for numerical modeling (Weimer-Jehle et al. 2016; Weimer-Jehle et al. 2020, e.g.).

However, CIB also proved useful for qualitative forms of systems analysis (Renn et al. 2009. Weimer-Jehle et al. 2012, e.g.) and recently, CIB has been transferred to the realm of policy design (Kosow et al. 2022b&c) to assess internal contradictions of status quo policy mixes and to support the design of alternative policy combinations. The main idea of this application consists of considering goal

[3] For a bibliography of CIB studies, please visit: https://www.cross-impact.org/english/CIB_e_Pub.htm

conflicts on the level of policies to reach these goals and using the CIB balance algorithm to optimize all goals at the same time. The approach as initially proposed comprises four steps:

> Step 1: Identify and define central objectives of different actors as well as alternative policies to reach these goals;
> Step 2: Assess directed hindering and fostering impacts between policies (pairwise) through expert or stakeholder judgments;
> Step 3: Identify policy mixes with a high level of internal consistency;
> Step 4: Assess policy mixes, e.g., regarding their synergy, goal attainment, or other criteria.[4]

Leon et al. (2021) and Kosow et al. (2022) have already shown that the combination of context scenarios and policy-mix design in one and the same CIB analysis is possible, but integrated two uncertain context factors only (namely governance and climate change) into their policy-interaction modeling with CIB. We would like to further develop this combined "policy-mix scenario"- approach and use CIB to combine comprehensive context scenarios representing future (socio-environmental) uncertainty with policy-interaction modeling, representing impacts of contexts on policies as well as interaction effects between policies of different actors (i.e., potential conflict parties) to achieve different goals. This should support the design of context sensitive and robust policy mixes. These CIB models will be built in form of participatory modeling (3.2) and be used for qualitative simulation of conflict interdependence in form of serious games (3.3.) to anticipate and transform potentially conflictual situations.

4.2 Participatory modeling with CIB

Through actor analysis, relevant actors affecting and affected by future water conflicts have been identified in the three case studies. Through informal meetings and a first round of interviews, each module has built a group of local and external experts representing the different central actors' perspectives. These experts will be involved into the further course of the project. In the next phase, these actors will contribute as co-modelers to build the respective CIB models.

The models of the three modules A-C are formulated in terms of cross-impact matrices. The participatory modeling process (s. Voinov/Bousquet 2010) comprises the joint definition of the scope of the model as well as decisions about future contexts, actors, goals, policies and system indicators to be included. Figure 2 shows different options to specify a CIB policy-mix scenario

[4] For the CIB definition of internal consistency and synergy (and their relation), please consider supplement B.

matrix, which are currently explored and discussed. These will be specified for each of the three modules in the next months.

Figure 2: Different options to design a CIB policy-mix scenario matrix (first ideas)

Option I (Kosow et al. 2022b)		**Option II** (FZJ, in prep)		**Option III** (Ecologic, in prep)	
Descriptors	**Variants**	**Descriptors**	**Variants**	**Descriptors**	**Variants**
Context	Variants 1-n	Context	Variant 1-n	Context	Variant 1-n
Goal	Policy 1-n	Actor	Policy 1-n	Policy	On/off
System indicator	/ (passive)	Effect	Higher, status quo, lower	Goal attainment	/ (passive)
Interrelation	*Fostering or hindering effect (effectiveness)*	*Interrelation*	*Fostering or hindering effect*	*Interrelation*	*Fostering or hindering effect (implementation)*
Policy-policy interactions are directly assessed through cross-impacts (verbal justification stored); Goals are anlytically separated from actors (external to model)		Interaction effects between policies are explicitly coded via effect descriptors (no direct policy-policy interaction); Actors are explicit in the model as agents behind policies		In contrast to type I an II, policies are not alternatives to reach individual goals but are considered in free combinations. Contribution of policies to different goals ist assessed through goal attainment indicators	

During the model construction, additional methods of data collection and analysis are necessary. Overall, these iterate between desk research as literature review and participatory formats as interviews, group interviews, focus groups, workshops, and are tailored to the specific needs of the three modules, for an overview see table 1.

Table 1: Participatory formats in the three modules (design and expected effects).

	Module A	**Module B**	**Module C**
Degree of abstraction	High, chosen case and participants as a blueprint	Low, very specific case and respective actors	Low, case and actors according to historical events
Participatory methods and *intensities* during: a) modeling	Interviews (*selective consultation)*	Interviews, workshops, focus groups (*regular consultation and collaboration*)	Interviews and focus groups (selective *consultation and collaboration*)
b) co-design of web application	Interviews, surveys, focus groups, cross-module working group (researchers & stakeholders) (*consultation and collaboration*)		
c) serious gaming	Gaming sessions (with feedback loops to model building, esp. in module A) (*information, consultation and collaboration*)		
Degree of effective policy involvement	Low, participants as ideal-type representatives	Medium, specific actors but with differing ability to design and implement policies	Medium, specific actors but with differing ability to design and implement policies
Key challenges	Transfer to practice and decision making	Abstraction to generally applicable results	Separation from yet conflictual case

4.3 Serious gaming with CIB

Serious games are teaching and exercise methods in which the participating persons playfully take on roles in a reality-based but model-like decision-making task and are told the effect of their decisions through a simulation. The goal of a serious game is to provide the participating persons with a deeper understanding of the decision-making task. Role reversal and dialogue based on the simulation can also improve decision-making competence for the task in question ("action learning").

In the field of water governance, serious gaming has become increasingly important in recent years (e.g. Bathke et al. 2019, see also examples for the school sector). Medema et al. (2019) cite the following functions of games in water governance: games as change agents, complexity mediators, negotiation arenas for social values, and sites of social learning. In a review of 12 serious games in water governance, Hockaday et al. (2017) found 3 board games, 8 role-playing games, 2 Excel-based games, and 2 online games, including overlaps, and thus a focus on easy-to-follow but low-complexity game mechanisms. Our project promises two new impulses for this field: a) the explicit focus on the aspect of water conflicts, and b) the special chances of using the CIB as a 'game engine'. These lie in the ability of the CIB to process qualitative causal models semi-quantitatively (i.e., avoiding full-quantitative simulation approaches), thus opening up a middle ground between transparency and complexity capability. We can build on the freely available software of cross-impact balance analysis, *ScenarioWizard*. Our serious game will explicitly be developed in co-design with actual policy actors in order to be tangible for real world developments. As such, we strive to balance the inevitable simplifications that occur in serious gaming by the real world actors, bringing their nuanced, diverse and complex perspectives (see Brauner et al. 2023).

The CIB game is implemented in a web-based simulation interface so that the application can be run online, independent of location and system. This makes it possible for actors to come together and exchange in a low-threshold way. The serious games are used to work through the qualitative conflict models developed in the modules together with the actors involved. In doing so, the interdependencies of the actors caused by side effects of actions are to be made visible and the complexity of the conflict situations is to be made tangible. In this way, future scenarios in their various manifestations are specifically set as framework conditions within which the players can experimentally decide about their (desired) policies and reflect on them through the reactions in the overall system.

The web application will first be developed in a preliminary version and then elaborated for practical use in a participatory co-design process together with the participating actors in the three modules. Within the project, a workshop version that can be used in the context of serious gaming is aimed for. In addition to the use with the participating actors in the case studies, the game is also to be used in the university teaching of the project partners. On the basis of the experiences gained in both use cases, the application will be revised and accompanying materials developed for independent use of the serious game by third parties. The game and the accompanying materials developed are to be kept freely available online even after the end of the project and provide an offer for research and practice for the participatory management of interdependent (water) conflicts under future uncertainty.

5. First results

In the following we share first results regarding assumptions on future uncertainty (5.1), the complexity of actor constellations (5.2) and the variety of (emerging) water conflicts (5.3.) across modules.

5.1. Future uncertainty: Joint assumptions on possible context developments

Together with experts from various disciplines and from practice a well as based on literature review on existing scenarios, we have identified key factors (or drivers) that might influence future water conflicts in Germany and have defined possible alternative development for each factor (see Table 2). This preliminary selection will be refined and used to define joint context assumptions and context scenarios for the overall project. To build scenarios, interrelations between alternative key factor developments are assessed and analyzed with the CIB method by the project team, including issue experts. The individual modules will – together with their respective local and external expert groups – select relevant variants, descriptors and/or scenarios for their specific CIB models. This methodological approach is inspired by Tori et al. (2023). The approach assures at the same time i) joint context assumptions on future uncertainty across the project and ii) tailored context assumptions for the individual situations in the three modules.

Table 2: Future uncertainty until the year 2050 - Context developments potentially influencing future water conflicts in Germany (water related measures and strategies excluded; geographical reference: Germany, unless otherwise specified, preliminary selection of variants)

Area	Key factor	Variant 1	Variant 2	Variant 3	Variant 4	Variant 5
Climate change	Precipitation	Decrease in annual average, up to -60% in summer	Shift to the colder seasons, average remains or increases slightly	High variability between years (extremes alternate between years		
	Temperature	Significant increase of annual average temperature (RCP 8,5)	High variability within years (significant increase of extremes within the course of the year)	High variability between years (cold and hot years -average temperature- alternate)	Annual average temperature tends to remain stable (level of 2023). (RCP2,6)	
Land use	Type of agriculture	Agriculture loses significantly in importance as economic sector and in terms of land use	Extensification of agriculture with increase in organic farming (up to 30%)	Intensification of agriculture	Intensification of agriculture (as in 3) with approximately unchanged resource use through high-tech	Hardly any change in agriculture
	Urban settlement and soil sealing	Expand	Remain	Decrease		
Gover-nance	Cooperation in water governance (also transboundary)	No meaningful cooperation, transboundary conflicts.	Temporary and/or goal-specific cooperation among some (not all) actors	Cooperation as needed, cross-border tensions possible. Regular, i.e. institutionalized cooperation	Close and stable collaboration, also across borders.	
	Political (esp. regulatory) framework (EU and Federal level)	Deliberate circumvention of regulations	Water as an economic good	EU regulations are implemented 1:1 in German law	WEF approach (Water-Energy-Food)	WEFE Nexus Approach (Water-Energy-Food-Ecosystem).
Economy	General economic situation, esp. investment propensity and behavior, sustainability orientation	Decline in investment, failure to meet climate targets and falling GDP	Business as usual	Eco-investing	Green liberation (decoupling) / paradigm shift	
	Structure of water intense industry	*Potential variant (TBD):* Slight increase in highly water intense industries, high reliance on fossil energy production	Business as usual - water needs of the industry are slowly decreasing until 2050	Energy turnaround - water needs of industry decrease drastically until 2050		
Society/ Culture	Perception and cultural value of water, (including prioritization of water using sectors)	Low water awareness in population, agriculture and industry and low priority of (water connected) ecosystems in scarcity (last priority after public supply, non-public supply and agriculture)	Enhanced valorization of water, but acceptance of measures only in case of acute threat. Medium overall priority of water connected ecosystems (priority after public and non-public supply, but before agriculture)	High water awareness in population, agriculture and industry and high priority of (water related) ecosystems in scarcity (second priority after public supply).		
	Demographic development	Population tends to decline (decrease)	Population remains stable (stagnation)	Population tends to increase (increase)		

5.2 Complexity of actor constellations

Across modules, we observe a high complexity of actor constellations. This means, per case, we see many actors with multiple interests, diverging perceptions and assessments of the situations as well as different strategies and policy options.

In Module A, nine interviews with a focus on the constellations in a river basin showed that there are many different actors with varying perceptions of current and future water conflicts. Some actors expressed more concern about future uncertainty, others less. But all actors mentioned that changes, induced by climate change and human behavior, will affect the way they deal with water and its management in the future. Key actors – and potential conflict parties – that will be considered and involved in the following model building process are the industries, agriculture and households. They are to some degree influenced by the city government (another actor) and the general political context as well as others of the mentioned context variables such as climate change or economy.

In Module B, an inventory of reported conflicts about irrigation in agriculture in Germany was build up (Perillieux 2023). For this purpose, court cases and press articles were evaluated. In addition, the actorscape in our example region was analyzed. The results clearly show the high complexity of the water situation in agriculture, which results from the interaction of availability (natural conditions and infrastructure), water rights, interests, pricing and climate impacts. The empirical analysis finds, so far, in Germany, only isolated and mainly latent/quiet conflicts related to irrigation, but these show complex conflict situations with many actors, long conflict duration and path dependencies. Second, a first round of interviews with eight different actor groups (15 persons) in the case study area revealed a shared vision of water becoming scarcer with increasing future demand, and hence the need to reconsider distribution processes. Clearly, study participants see the complexity and the network character of water resources; however so far only little and selective exchange has been established. Actors' goals related to water and irrigation differ, but also their personal (emotional) connections, which have widely differing implications for the future and will hence affect conceivable policy options.

In Module C, the transboundary nature of the open-pit mine case study entails a comprehensive and diverse actorscape (Hölzlberger 2023). In a first row of nine semi-structured interviews with a focus on Germany, a total of 26 related actor groups were identified. The interviewees included representatives of environmental NGOs, a state parliament member, a state authority, water management, local media, a local town and a member of the European Parliament. Next to the mining operator, the governments of the three riparian states and the European Commission were perceived as the most influential actors by the interviewees. The German side mostly struggles with GW loss and the following land subsidence, the other country drinking water scarcity. For the operating country the open-cast mine is a valuable source of energy and work places. Although it became quieter around the water conflicts after their peak in 2020/21, governmental changes and the flooding and renaturation of the mine have the potential to re-aggravate the conflicts or to create new ones.

Overall, rather high – but diverging – degrees of future uncertainty and in particular, a high *strategic* uncertainty (i.e. what will the others do) are experienced. Therefore, many actors strongly resonate with the projects' idea to build scenarios and to exchange with the other actors on possible policies and to do so now. Otherwise, as expressed mutatis mutandis by different actors, 'every stakeholder assures as much water as they can for themselves now, as long as there are no clear regulations yet - and then future conflict is inevitable'.

5.3 Variety of emerging conflicts

The first round of interviews has revealed a multitude of different potential future water conflicts in the three modules. Table 3 summarizes our preliminary results on different conflict objects and respective conflict parties.

Table 3: (Potential) water conflict objects and conflict parties in the three different modules (preliminary results)

		Conflict parties		
Conflict object	*Explanation*	**Module A**	**Module B**	**Module C**
Usage	*What may - what water - be used for?*	Supplying the stakeholders of the river basin: e.g. Households the drinking water, industry the process water	Irrigation of wine: Luxury vs. regional identity (NGOs vs. locals & farmers) Water for irrigation vs for ecosystems (especially in small rivers) (farmers vs NGO)	During operation: Mining vs regional GW levels (land subsidence, drinking water) Flooding period: Flooding vs. downstream usage of rivers (fast flooding necessary, water for downstream usage also necessary)
Protection	*If and how to protect water resources?*	*To be explored*	Protection of water bodies: Water provider vs. Farmers (quantity and quality)	*To be explored*
Distribution	*Who gets what (quantity and quality)?*	Industry vs. private households vs. agriculture vs. ecosystem	(Urban) Public vs. private green; Farmers vs. Farmers; Households vs. Agriculture; Agriculture vs. Industry; Ecosystems vs. Agriculture; Distribution of max water amount for irrigation on "peaks" Priorization in case of withdrawal limits: agriculture vs industry	Open-cast mine vs. residents vs. ecosystem (environmental NGOs) vs. downstream water users
Governance	*If and how to coordinate and cooperate?)*	Horizontal (between farmers, households and industries)	Horizontal (between municipalities; between administrative units in one municipality/county) and vertical conflict lines (municipal vs. Land level)	Horizontal (between the three riparian states) and vertical (municipal vs state level)
Protection from/ risk of	*How to assess the risk of/ protect from water?*	Ensuring sufficient water access/supply of the actors (e.g. households, industries)	Assure safe drain (urban) and increase infiltration, vs. build reservoirs (rural) Drought and heat protection vs sealing	Mitigate GW drainage, ensure fast enough flooding and sufficient water for downstream users and ecosystems
Framing	*If and what conflict(s) are we facing (in the future)?*	*To be explored*	Environmental NGOs (dramatic, radical change in use, monitoring and regulation necessary) vs. Farmers and water providers (manageable)	State vs. state (upstream vs downstream), Environmental NGOs & local actors vs. operator

6. Next steps

Over the coming months, the participatory modelling will enable the definition and selection of joint and module specific context scenarios. In the three modules, the most suitable type of CIB matrix will be decided for each case (see 3.2.). Then, alternative strategies and measures (policies) of the actors involved will be identified, selected and combined in the form of a CIB matrix. Fostering and hindering interactions between polices as well as the effects of context developments are assessed. Once the three CIB matrices are constructed, policy mixes can be analyzed under different context scenarios within and across modules. The web application of the serious game will be refined through co-design with the local experts. Game sessions in the three modules as well as in academic teaching are carried out with at least three purposes: first, let participants experience the consequences of own and other's decisions and thereby prepare the handling of uncertainty and complexity, and second, support the development of conflict-reducing strategies and policy mixes. Third, building on these experiences, the game engine is prepared for transfer to professionals in the field of water governance and to academic teaching as a tool to encourage anticipatory collaboration in potential water-conflict settings.

Finally, we reflect our use of CIB to explore policy-mix scenarios through serious games on a methodological level. Currently, hypotheses on effects of our serious game design on the perceived wickedness of water conflicts are developed. The three dimensions uncertainty, complexity and conflict are operationalized. A short survey with approx. nine items is prepared that will ask involved actors for perceived wickedness - during participatory modelling (t0) as well as right before (t1) and shortly after (t2) playing the game in the three modules and in the teaching applications.

Overall, although the approach of using CIB based serious games for exploring policy-mix scenarios is being developed in the context of water conflicts, we expect that it will also be applicable in the context of other (environmental) governance fields with a high degree of (future) goal conflict, uncertainty and complexity.

Literature

Alexandra, C., Wyborn, C., Roldan, C. M., & van Kerkhoff, L. (2023). Futures-thinking: concepts, methods and capacities for adaptive governance. In *Handbook on Adaptive Governance* (pp. 76-98). Edward Elgar Publishing.

Axt, H.-J., Milososki, A., & Schwarz, O. (2006). Conflict - A literature review. https://www.researchgate.net/publication/323847788_Conflict_-_a_literature_review.

Bathke D., Haigh T., Bernadt T., Wall N., Hill H., & Carson A. (2019). Using Serious Games to Facilitate Collaborative Water Management Planning Under Climate Extremes. J. Contemporary Water Research & Education, 167, 50-67.

Bercovitch, J. (2019). Social Conflicts And Third Parties: Strategies Of Conflict Resolution. Routledge.

BMUV (2023). Nationale Wasserstrategie, Kabinettsbeschluss vom 15. März 2023: https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Binnengewaesser/nationale_wasserstrategie_2023_bf.pdf (last accessed 18.05.2023).

Bonacker, T. (2005). Sozialwissenschaftliche Konflikttheorien. Springer-Verlag. Accessed through https://link.springer.com/book/10.1007/978-3-322-95688-0

Brauner, S., Brumme, A., Hölzlberger, F., & Moschner, J. (2023): More than chair circles? Serious Games related to water governance and their potential effects on policy design. ICPP6, Toronto 27.-29.06.2023; URL: https://www.ippapublicpolicy.org//file/paper/6476fc34ba65d.pdf (last accessed 13.06.2023).

Burton, J. (1990). Conflict: Human Needs Theory. Springer.

Coser, L. A. (1965). Theorie sozialer Konflikte / Lewis A. Coser. [Übers.: Sebastian u. Hanne Herkommer]. Neuwied a. Rh.: Luchterhand.

Dahrendorf, R. (1965). Gesellschaft und Demokratie in Deutschland. München: Piper.

Diemel, T. (2022). Wassernutzungskonflikte in Deuschland. Eine Herausforderung für die Wasserwirtschaft. Bachelor's thesis, Ruhr Universität Bochum.

DVGW (2023). Klimafolgenstudie für das DVGW-Innovationsprogramm „Zukunftsstrategie Wasser. https://www.dvgw.de/medien/dvgw/forschung/berichte/w202122-dargebotsanalyse-abschlussbericht.pdf (last accessed 13.06.2023).

DVGW (2022). Auswirkungen des Klimawandels auf das Wasserdargebot Deutschlands. Überblick zu aktuellen Ergebnissen der deutschen Klimaforschung. URL: https://www.dvgw.de/medien/dvgw/wasser/zukunftsprogramm/auswirkung-klimawandel-wasserdargebot-zukunft-wasser-factsheet.pdf (last accessed 13.06.2023).

DWD (2023). https://www.dwd.de/DE/klimaumwelt/klimaatlas/klimaatlas_node.html (last accessed 18.05.2023).

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annu. Rev. Environ. Resour.*, *30*, 441-473. Annual Review of Environment and Resources 2005 30:1, 441-473.

ElSawah, S., Hamilton, S., Jakeman, A., Rothman, D., Schweizer, V., Trutnevyte, E., Carlsen, H., Drakes, C., Frame, B., Fu, B., Guivarch, C., Haasnoot, M., Kemp-Benedict, E., Kok, K., Kosow, H., Ryan, M., & van Delden, H. (2020): Scenario processes for socio-environmental analysis: A review of recent efforts and a salient research agenda to support decision making. In: Science of the Total Environment; https://doi.org/10.1016/j.scitotenv.2020.138393

Feindt, P. H., & Saretzki, T. (2010). Umwelt- und Technikkonflikte. Springer Fachmedien Wiesbaden. Accessed through https://link.springer.com/book/10.1007/978-3-531-92354-3

Feitelson, E. (2003). Packaging policies to address environmental concerns. In: *Handbook of Transport and the Environment*; Hensher, D.A., Button, K.J., Eds.; Elsevier: Amsterdam, The Netherlands, 757–769.

Galtung, J. (1999). Conflict transformation by peaceful means: The Transcend method. UN.

Givoni, M. (2014). Addressing transport policy challenges through Policy-Packaging. *Transp. Res. Part A: Policy Pr.* 2014, *60*, 1–8.

Grunwald, A. (2013). Modes of orientation provided by futures studies: making sense of diversity and divergence. *Eur J Futures Res* **2**, 30 (2014). https://doi.org/10.1007/s40309-013-0030-5

Head, B. W. (2022). The Rise of 'Wicked Problems'—Uncertainty, Complexity and Divergence. In Wicked Problems in Public Policy (pp. 21-36). Palgrave Macmillan, Cham.

Hockaday S., Jarvis T., Taha F. (2017). Serious Gaming in Water. URL: https://www.mediate.com/articles/HockadayS1.cfm.

Hölzlberger, F. (2023): The Turów Water Conflict – A Socio-Economic Analysis. Master's thesis, Technische Universität Bergakademie Freiberg.

Hoppe, R. (2011). The governance of problems: Puzzling, powering and participation. Policy Press.

Hoppe, R., & Turnbull, N. (2022). The politicality of problem structuring. IWPP3 workshop, Budapest, 28.-29.06.2022.

Hou, X., Li, R., & Song, Z. (2022). A Bibliometric Analysis of Wicked Problems: From Single Discipline to Transdisciplinarity. Fudan Journal of the Humanities and Social Sciences, 1-31.

Houdret, A. (2010). Wasserkonflikte sind Machtkonflikte. Springer. Accessed through https://link.springer.com/book/10.1007/978-3-531-92318-5

Howlett, M. (2014). From the 'old' to the 'new' policy design: Design thinking beyond markets and collaborative governance. *Policy Sci.* 2014, *47*, 187–207.

Howlett, M.; Rayner, J. (2013). Patching Vs Packaging: Complementary Effects, Goodness of Fit, Degrees of Freedom and Intentionality in Policy Portfolio Design. In Proceedings of the ESEE Meetings, Lille, France, 18–21 June 2013.

Kern, F.; Kivimaa, P.; & Martiskainen, M. (2017). Policy packaging or policy patching? The development of complex energy efficiency policy mixes. *Energy Res. Soc. Sci. 23*, 11–25.

Kern, F.; Rogge, K.S.; & Howlett, M. (2019). Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies. *Res. Policy 48*, 103832.

Kingdon, J. W. (1984): Agendas, Alternatives and Public Policies. Little, Brown and Company, Boston.

Kirschke, S., & Kosow, H. (2022). Designing policy mixes for emerging wicked problems. The case of pharmaceutical residues in freshwaters. Journal of Environmental Policy & Planning, 24(5), 486-497. https://dx.doi.org/10.1080/1523908X.2021.1960808

Kirschke, S., Avellán, T., Benavides, L., Caucci, S., Hahn, A., Müller, A., & Rubio Giraldo, C. B. (2022). Results-based management of wicked problems? Indicators and comparative evidence from Latin America. Environmental Policy and Governance; https://doi.org/10.1002/eet.1991

Kirschke, S., Franke, C., Newig, J., & Borchardt, D. (2019). Clusters of water governance problems and their effects on policy delivery. Policy and Society, 38(2), 255–277. https://doi.org/10.1080/14494035.2019.1586081

Kivimaa, P.; Kern, F. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Res. Policy* 2016, *45*, 205–217.

Kosow, H., Wassermann, S., Bartke, S., Goede, P., Imbert, I., Grimski, D., Jenssen, T., Laukel, O., Protzer, J., Proske, M., Schumacher, K., Siedentop, S., Wagner-Endres, S., Wittekind, J., & Zimmermann, S. (2022c): Addressing goal conflicts: New policy mixes for commercial land use management. In: LAND 11, 795. https://doi.org/10.3390/land11060795

Kosow, H., Weimer-Jehle, W., Leon, C., & Minn, F. (2022b). Designing synergetic and sustainable policy mixes - a methodology to address conflictive environmental issues. In: Environmental Science & Policy 130, 36-46. https://dx.doi.org/10.1016/j.envsci.2022.01.007

Kosow, H., Kirschke, S., Borchard, D., Cullmann, J., Guillaume, J. H. A., Hannah, D. M., Schaub, S., & Tosun, J. (2022a): Scenarios of water extremes - framing ways forward for wicked problems. In: Hydrological Processes, https://doi.org/10.1002/hyp.14492

LAWA (2017). Auswirkungen des Klimawandels auf die Wasserwirtschaft – Bestandsaufnahme, Handlungsoptionen und strategische Handlungsfelder 2017 (Kurztitel: LAWA Klimawandel-Bericht 2017). Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA).

LAWA (2022). Positionspapier zum Umgang mit Zielkonflikten bei der Anpassung der Wasserwirtschaft an den Klimawandel. Fokus: Konflikte im Nexus Wasserwirtschaft, Landwirtschaft und Forstwirtschaft. Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA).

Lazurko A., Schweizer V., & Armitage D. (2023): Exploring "big picture" scenarios for resilience in social–ecological systems - transdisciplinary cross-impact balances modeling in the Red River Basin. Sustainability Science. DOI: 10.1007/s11625-023-01308-1

Lederach, J. P. (1996). Preparing For Peace: Conflict Transformation Across Cultures. Syracuse University Press.

León C. D., Brauer F., Hügler M., Keller S., Kosow H., Krauss M., Wasielewski S., & Wienhöfer J. (Eds.) (2021): Integrated Water Management Solutions in the Lurín Catchment, Lima, Peru – Supporting United Nations' Sustainable Development Goal 6. Final report of the joint project TRUST. University of Stuttgart, ISBN 978-3-00-068498-2; DOI: 10.18419/opus-11390

Medema W., Chew C., Adamowski J.F., Mayer I., Wals A. (2019). Understanding Game-based Approaches for Improving Sustainable Water Governance. Water, special issue reprint, ISBN 978-3-03928-763-5.

Motschmann, A., Teutsch C., Huggel C., Seidel J., León C.D., Muñoz R., Sienel J., & Drenkhan F. (2022): Current and future water balance for coupled human-natural systems – Insights from a glacierized catchment in Peru. Journal of Hydrology: Regional Studies 41, 101063. DOI:10.1016/j.ejrh.2022.101063

Pahl-Wostl, C., Knieper, C., Lukat, E., Meergans, F., Schoderer, M., Schütze, N., …& Vidaurre, R. (2020). Enhancing the capacity of water governance to deal with complex management challenges: A framework of analysis. Environmental Science & Policy, 107, 23–35. https://doi.org/10.1016/j.envsci.2020.02.011

Perillieux, T. (2023). Lösungsstrategien für Nutzungskonflikte in der bewässerten Landwirtschaft. Master's thesis, Technische Hochschule Köln.

Reichardt, K.; Negro, S.O.; Rogge, K.S.; & Hekkert, M.P. (2016). Analyzing interdependencies between policy mixes and technological innovation systems: The case of offshore wind in Germany. *Technol. Forecast. Soc. Chang. 106*, 11–21.

Renn, O., Klinke, A., & van Asselt, M. (2011). Coping with complexity, uncertainty and ambiguity in risk governance: a synthesis. Ambio, 40(2):231-46. doi: 10.1007/s13280-010-0134-0

Renn, O., Jager, A.; Deuschle, J., & Weimer-Jehle, W. (2009). A normative-functional concept of sustainability and its indicators. Int. J. Glob. Environ. Issues, 9, 291-317.

Rogge, K., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Res. Policy 45*, 1620–1635.

Ruth, M., Özgüna, O., Wachsmuth, J., & Gößling-Reisemann, S. (2015). Dynamics of energy transitions under changing socioeconomic, technological and climate conditions in Northwest Germany. Ecological Economics 111, 29–47. http://dx.doi.org/10.1016/j.ecolecon.2014.12.025

Scheer, D.; Schmidt, M.; Dreyer, M.; Schmieder, L.; & Arnold (2022). A. Integrated Policy Package Assessment (IPPA): A Problem Oriented Research Approach for Sustainability Transformations. *Sustainability* 2022, *14*, 1218. https://doi.org/10.3390/su14031218

Schütze, M., Seidel, J., Chamorro, A., & León C. (2019). Integrated modelling of a megacity water system – The application of a transdisciplinary approach to the Lima metropolitan area. Journal of Hydrology 573, 983-993. DOI: 10.1016/j.jhydrol.2018.03.045

Schweizer, V.J., & Kriegler, E. (2012). Improving environmental change research with systematic techniques for qualitative scenarios. Environ. Res. Lett. 7. 044011; DOI 10.1088/1748-9326/7/4/044011

Schweizer V. J., & O'Neill B. C. (2014). Systematic construction of global socioeconomic pathways using internally consistent element combinations. Climatic Change 122, 431–445.

Simon, H. A. (1973). The structure of ill structured problems. Artificial intelligence, 4(3-4), 181-201.

Taylor, P., & Sonnenfeld, D. (2017). Water Crises and Governance: Reinventing Collaborative Institutions in an Era of Uncertainty.

Tori, S., te Boveldt, G., & Keseru, I. (2023): Building scenarios for urban mobility in 2030. The combination of cross-impact balance analysis with participatory stakeholder workshops. Futures, 150, 103160. DOI: 10.1016/j.futures.2023.103160.

Tröltzsch, J., Stein, U., Vidaurre, R., Bueb, B., Schritt, H., Flörke, M., Wriege-Bechtold, A., & Herrmann, F. (2021). Auswirkung des Klimawandels auf die Wasserverfügbarkeit- Anpassung an Trockenheit und Dürre in Deutschland. Praxis Wasserwirtschaft, 44-48.

Voinov, A., & Bousquet, F. (2010). Modelling with stakeholders. Environmental modelling & software, 25(11), 1268-1281.

Niedersächsisches Ministerium für Umwelt, Energie, Bauen und Klimaschutz (2022): Wasserversorgungskonzept Niedersachsen URL: https://www.umwelt.niedersachsen.de/startseite/themen/wasser/wasserversorgungskonzept-niedersachsen-210626.html (last accessed 13.06.2023)

Weimer-Jehle, W., Vögele, S., Hauser, W., Kosow, H., Poganietz, W.-P., & Prehofer, S. (2020). Socio-technical energy scenarios: State of the art and CIB-based approaches; In: Climatic Change, special issue: Integrated scenario building in energy transition research; https://doi.org/10.1007/s10584-020-02680-y

Weimer-Jehle W., Buchgeister J., Hauser W., Kosow H., Naegler T., Poganietz W., Pregger T., Prehofer S., von Recklinghausen A., Schippl J., & Voegele S. (2016). Context scenarios and their usage for the construction of socio-technical energy scenarios. Energy 111, 956–970. DOI: 10.1016/j.energy.2016.05.073

Weimer-Jehle, W.; Deuschle, J.; & Rehaag, R. (2012). Familial and societal causes of juvenile obesity—a qualitative model on obesity development and prevention in socially disadvantaged children and adolescents. J. Public Health 20, 111–124

Weimer-Jehle, W. Cross-Impact Balances (2006). A System-Theoretical Approach to Cross-Impact Analysis, *Technol. Forecast. Soc. Chang. 73*, 334–361. https://doi.org/10.1016/j.techfore.2005.06.005.

Wunsch, A., Liesch, T. & Broda, S. (2022). Deep learning shows declining groundwater levels in Germany until 2100 due to climate change. Nat Commun 13, 1221; https://doi.org/10.1038/s41467-022-28770-2

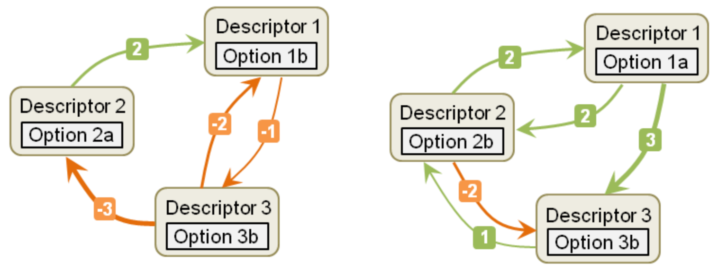
Supplements

Supplement A: CIB in a nutshell

Figure S1: CIB in a nutshell (Source: Kosow et al. 2022b[5], supplement S1)

"CIB analyzes a discrete configuration space defined by a set of system variables ('descriptors', typically 10–20) and a discrete set of alternative futures for each descriptor (typically 2–4). The alternative futures can be defined qualitatively, quantitatively, or a mix of both. This 'morphological box' opens a space of typically thousands to billions of configurations or more, depending of the number of descriptors and assigned alternative futures. As a database for judging the internal consistency of configurations, a 'cross-impact matrix' is built, answering the question of how a certain future of one descriptor would promote or restrict the development of a certain future of another descriptor. The impact usually is rated on a seven-point integer scale running from -3 (strongly restricting) to +3 (strongly promoting). Sources for the ratings can be literature review or expert/stakeholder judgments. The configuration space is searched, and only few configurations satisfying a self-consistency criterion are accepted to be 'consistent scenarios'." (Weimer-Jehle et al. 2020)[6].

Target →	D1		D2		D3	
↓ Source	1a	1b	2a	2b	3a	3b
Descriptor 1						
Option 1a			-1	2	-3	3
Option 1b			0	0	2	-1
Descriptor 2						
Option 2a	-2	2			0	0
Option 2b	2	-2			3	-2
Descriptor 3						
Option 3a	-1	1	0	0		
Option 3b	0	-2	-3	1		



Information about interdependencies between the system descriptors are coded on an ordinal scale and collected in a cross-impact matrix.

The interrelations between the options for each specific option configuration can be retrieved from the matrix. Some configurations are dominated by hindering impacts and rejected, therefore.

Only few configurations are dominated by promoting impacts and form a Nash equilibrium with respect to the impact sums of the descriptors. They are accepted to be 'consistent' system states.

As a measure for the overall coherence of a configuration and as a second criterion besides consistency (Nash stability) for the plausibility of a configuration, CIB uses the "Total-Impact-Score" (TIS). The TIS of a configuration is defined as the sum of the impact strength values of all active impact relations (TIS=-4 in the left configuration, TIS=+6 in the configuration on the right side). Nash-stable configurations tend to have high TIS values. However, high TIS values do not guarantee Nash stability. A comparison of CIB to other methods of qualitative systems analysis can be found in Kosow (2016)[7].

[5] Kosow, H. Kosow H, Weimer-Jehle W, Leon C, Minn F. Designing synergetic and sustainable policy mixes - a methodology to address conflictive environmental issues. In: Environmental Science & Policy 130, 2022, 36-46. https://dx.doi.org/10.1016/j.envsci.2022.01.007

[6] Weimer-Jehle, W.; Vögele, S.; Hauser, W.; Kosow, H.; Poganietz, W.-P.; Prehofer, S. Socio-technical energy scenarios: State of the art and CIB-based approaches. *Climatic Change* 2020, 162, 1723–1741, DOI: 10.1007/s10584-020-02680-y.

[7] Kosow, H. The best of both worlds? An exploratory study on forms and effects of new qualitative-quantitative scenario methodologies. Dissertation, University of Stuttgart, Stuttgart, 2016. http://dx.doi.org/10.18419/opus-9015

Supplement B: Internal consistency and synergy in CIB

"Internal consistency of policies is measured by the CIB balance algorithm, which evaluates the direct and indirect influences of the policies on each other. With the help of the CIB algorithm, all thinkable policy combinations are analyzed, and the consistent mixes are identified. Consistency of a policy mix explains whether all sub-goals of a policy mix are present in an optimal state, i.e., whether, in a policy mix for each sub-goal, the optimal policy alternative (the one with the highest sum of impact arguments) is selected. Consistent policy mixes represent the Nash optima of the policy-impact network. They avoid major conflicting impacts, i.e., trade-offs, among all policies and maximize all related sub-goals, individually but at the same time. Consistency informs about the inner stability of a policy mix. *Synergy* of a policy mix is measured by the sum of positive and negative impacts within each mix, i.e., the sum of interactions or total impact score (TIS). Synergy explains how well a policy mix combines fostering relations and avoids hindering relations between policies. It must be understood as a relative statement, i.e., policy mix X is more synergetic than policy mix Y. Maximizing synergies in policy mixes allows to benefit from supportive policy interactions and gives information on the overall effectiveness of a policy mix. The mix with the highest synergy (measured by TIS) can be considered the most (overall) effective one." (Kosow et al. 2022c, own emphasis)

Regarding the *relation between consistency and synergy*: "CIB solutions imply that each objective is 'choosing' its policy in an attempt to optimize its own synergy gains and the TIS represents the sum of all individual synergy gains". Synergy helps policy makers to decide which mix would be the overall most effective combination (global information). Consistency describes the individual contradictions showed by a mix and helps in indicating the unequal distributions of gains and losses among the goals that also appear in synergetic mixes and can jeopardize the stability of the mix." (Kosow et al. 2022c, own emphasis).