A Framework for Analyzing Climate Change Adaptations as Actions

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Developing generalized theories about adaptation to climate change requires common concepts to map different adaptation situations. The paper aims to contribute to this endeavor by presenting a novel framework that conceptualizes adaptations to climate change as actions. The framework is intended to systematically analyze the actor relations involved in adaptations and the barriers to their implementation. By combining established scientific action theories with terminology from the Intergovernmental Panel on Climate Change (IPCC) in an innovative way, it can be used to clarify the notion of adaptation used in adaptation assessments. The framework's potential is illustrated by a case study on cooling water management in the river Rhine catchment and by the elucidation of some prominent concepts in adaptation research. We show that by framing adaptations as actions, the purpose of adaptations and how they tend to connect up in means-ends-chains becomes crucial. Actors can take different functional roles as exposure unit, operator and receptor of adaptation. A mismatch of these roles can lead to barriers to adaptation, of which we deduce four types: complex actor relations, missing operators, missing means and unemployed means. The case study yields a complex bundle of adaptations, and shows that the potential barriers involved are quite diverse. There is thus no blueprint solution. Although we identify entry points for adaptation, the analysis leads to a skeptical conclusion for adapting cooling water management in the whole Rhine catchment.

Keywords: stimulus, exposure unit, operator, barriers to adaptation, adaptive capacity, cooling water, Rhine catchment

1. Introduction

As the prospects for an effective global environmental agreement on climate change are currently not the best, at least in the short-term, more emphasis is currently being placed on the need for adaptation to the inevitable consequences of global warming. Although adaptation research is assuming greater prominence on the scientific agenda, this interdisciplinary field is still characterized by an evolving epistemological base. For example, a discourse on barriers to adaptation is currently emerging (e.g. Arnell and Delaney 2006; Adger et al. 2009; Moser and Ekstrom 2010; Measham et al. 2011), but a comprehensive set of theories to explain these is still not in sight. It remains difficult to come up with a common language to conceptualize the broad diversity of adaptations. In addition to the empirical problems, this might be one explanation for the current limits of generalized theories on adaptation.

To contribute to this endeavor, we introduce a novel framework in this paper that carefully conceptualizes adaptations as actions. Its purpose is twofold. First, it provides a structure to analyze actual or proposed adaptations, with a specific focus on the actors and institutions involved. This helps to map or deduce barriers to adaptation in a systematic way. The second goal is to contribute to the clarification of the concept of adaptation in a way that is applicable for the design of adaptation assessments. This opens a new view on adaptation that also sheds light on some other concepts often used in adaptation research.

This paper builds on and contributes to established theoretical literature on adaptation (e.g. Smithers and Smit 1997; Smit et al. 2000; Adger et al. 2005). These contributions provide a sound basis for understanding adaptation and propose some crucial variables to characterize adaptations. The current mainstream is, however, less comprehensive in drawing conclusions about barriers to adaptation. This requires consideration of the actors and decisions involved in adaptation.

While the seminal papers mainly analyze crucial components of (single) adaptations to climate change, the research field gains complexity by considering adaptive capacity. For example, Brooks (2003) is careful to distinguish between actual adaptation and adaptive capacity, being the potential for adaptation that does not necessarily become real. Adaptive capacity links adaptation to the discourses on vulnerability and resilience (Engle 2011). There is a broad body of theoretical literature that reflects on the relation of these concepts (e.g. Kelly and Adger 2000; Turner et al. 2003; Smit and Wandel 2006; Gallopín 2006, O'Brien et al. 2007; Füssel 2007b; Nelson et al. 2007). Unfortunately, adaptive capacity does not automatically lead to actual adaptive action (Adger and Barnett 2009).

While most of the vulnerability and resilience approaches take a system-oriented view, one can also take an action-oriented perspective. While the former investigates *system properties* that might enable action, the latter focuses on the *purposeful activities* ("adaptations") that moderate harm from climate change. Smit & Wandel (2006) distinguish different types of adaptation scholarship. A more system-oriented view is taken by those studies that aim to estimate modeled impacts of climate change or that compare the vulnerability of countries, regions or communities. On the other hand, those that aim at practical adaptation initiatives or assess specific adaptation measures for specific exposure units can be seen as action-oriented. The bibliometric analysis of Arnell (2010) indicates that there are, in comparison to system-oriented studies, very few papers that explicitly deal with adaptation assessments, adaptation management and the institutions that shape adaptations.

The primary objective of our paper is to contribute to the latter type of exercises. Here, "adaptation is concerned with actors, actions and agency" (Nelson et al. 2007, p. 398). Although several papers informally characterize adaptations as "actions", there is little work that explicitly exploits this framing. An exception is Bohle (2001) with a reference to Giddens' relationship between structure and agency, and Jetzkowitz (2007), for the norms and conditions that shape adaptation in a particular application to tourism. The analysis of barriers to adaptation by Arnell and Delaney (2006) is an interesting step into this direction as it rests on a process model of adaptation. The same holds for Moser and Ekstrom (2010) that complement the process model with a "structural" decomposition of the action situation (Ostrom 2005) into the actors involved, the system of concern, and the (institutional, human and bio-physical) context. Moser and Ekstrom (2010) discuss the case of multiple actors (embedded in a system of institutions) having diverging objectives, but yet not present a framework to explicitly map these relations.

Our paper takes up this thread by framing adaptations as actions. By referring to established theories of action from philosophy and sociology we want to clarify the meaning of adaptation and different types of adaptation in an applicable way, and systematize barriers to adaptation. We thus restrict ourselves to adaptations that are made by human actors, in contrast to, e.g., adaptations by eco-systems. We show that a crucial starting point of analysis is the purpose of single actions, such that adaptations need to be unpacked into means-end chains. Actors appear in different functional roles. Barriers can evolve from the complexity of actor networks, missing operators of adaptations, unavailable means or, finally, means that are not employed sufficiently although they are available. This is illustrated by applying the framework to a small case study on adapting cooling water management in the river Rhine catchment. Systematically mapping adaptations by using the core concepts of the framework reveals a broad spectrum of actors and adaptations. They connect up in complex means-ends chains and are associated with different barriers to adaptation.

The next section introduces the basic ingredients of the framework and relates it to other theories. The third section utilizes the framework to analyze some established concepts in adaptation research. Section four derives some generic types of barriers to adaptation, while the fifth section illustrates the applicability of the framework with the case study. We conclude with a critical reflection, potential extensions and further applications.

2. Framework for analyzing adaptations as actions

2.1 Core Concepts

In the IPCC definitions and the analysis of Smit et al. (2000), adaptation is a response to (potential) environmental stimuli that affect given entities, subjects or systems. Adaptations are processes within entities and systems, or adjustments made by human systems. In our approach, we specifically refer only to human systems, individuals and collective actors. This leads to the following outline of the framework that can partially be built around established concepts (see figure 1). Action requires actors and an intention. The intention is directed towards an impact of climate change. Furthermore, adaptations require the use of resources as means to achieve the intended ends. This outline will be detailed and qualified in the following discussion. It is crucial to note here that the framework as presented in this section serves as a basic unit of analysis. It describes a core configuration that is meant to be as simple as possible. When complex real-world adaptations are to be analyzed, the following conceptual building blocks need to be re-combined in different ways to consider multiple interrelated actors.

In the framework, a *stimulus* is defined as a change in biophysical (in particular meteorological) variables associated with climate change. In a very precise meaning, this has to be distinguished from weather events. Stimuli can refer to changed values of statistical parameters such as average intensity, frequency, or higher statistical momenta (e.g. variance). They can also refer to abrupt large-scale events in the earth system. In many practical cases it is not relevant to insist on this distinction. There is also a difference between strictly meteorological effects, such as temperature and precipitation patterns on the one hand, and more or less indirect effects such as rising sea level or greater frequency of river floods (we further discuss this issue below).

A stimulus is only relevant for adaptation when it influences an *exposure unit*. The latter term broadly refers to all those actors, social, technical or non-human systems that depend on climatic conditions, and are therefore exposed to stimuli (cf. IPCC 2001). The abstract term is necessary to encompass the broad diversity of affected entities or systems that may be considered in an adaptation assessment. Although we are concerned with an action theory here, we explicitly do not restrict exposure units to human systems.

By an *impact* of climate change we understand a combination of a stimulus and an exposure unit. More broadly, it can be a set of stimuli with an associated set of exposure units. For example, reduced energy production of a thermal power plant (exposure unit) due to more frequent scarcity of cooling water (stimulus) is an impact. This is not a quantitative definition, e.g. in terms of a damage measure. Such a measure is not needed in the following, but might be a relevant extension of the concept.

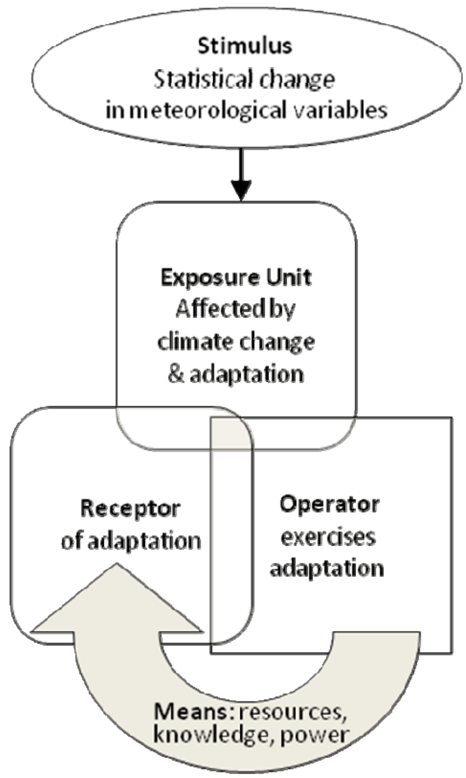

Figure 1: Schematic representation of some core concepts of the framework. Boxes with rounded corners can be both actors or biophysical units, while operators are always actors. Operator, receptor and exposure unit are not necessarily identical (indicated by overlapping boxes). The straight arrow indicates a causal relation, and the large arrow a teleological relation.

The following example of an adaptation illustrates the different concepts introduced so far. Consider a public early warning system that informs about upcoming extreme weather conditions (say, heavy rain) that increase the risk of using specific modes of transport (e.g. travelling by car, bicycle or by foot). This adaptation may be motivated by the impact of more frequent precipitation extremes (the stimulus) on transport safety. The exposure units are users of the above-mentioned modes of transportation.

In our framework, the individual or collective actor that exercises the response is called the *operator*. We need this distinct term, since actors will also play other roles in this framework (see below). An operator can be, for example, a private household, a firm or a governmental actor. But in all cases it is a social entity, so that machines, artifacts and natural systems are ruled out as operators.

Not all activities of an operator are actions. Only those activities with a *purpose* qualify for this term. The operator tries to achieve intended ends that are associated with (other) actors, social or non-human systems. The ends are ultimately targeted at impacts (see below for a further discussion of this statement).

The actor or system that is the target of an adaptation (the purpose) is called the *receptor*. Receptors can be both biophysical entities (e.g. the crops of a famer) and social systems (e.g. the farmer household), depending on the objective of analysis. It is further not required that the receptor of an adaptation is an exposure unit at the same time. This is a crucial point that will become clear in what follows.

We illustrate this with the early warning system example introduced above. The operator is a public body that runs the system. It receives weather forecasts and transmits them to the public in an accessible way. The purpose of that adaptation is to reduce harm to individual transport users (that can decide to use other modes of transportation or avoid travelling in the case of a warning). The intention is to change behavior of transport users, making them the receptors. The public body is not the exposure unit (it is not affected by heavy rain); the receptors of the early warning system are the exposure units.

The emphasis on the purpose of an action requires further comment. There are, of course, many social phenomena that are not purposeful. In this case, we do not call them actions, but mere processes. *Processes* are sequences of events in time that may occur in a biophysical, technical or social entity or system. They can be framed as being linked through causality, that is, in a mechanistic way. Actions are a special class of social processes that additionally have a teleological component (cf. Weber 1922, and the discussion in the next section).

To implement the adaptation, the operator needs resources, here called *means*. These could be access to financial or other material resources, legal power, social networks, knowledge, or availability of information. Action is further shaped by constraints and resources that cannot be controlled by the operator. These are called the *conditions* (cf. Parsons 1937, see next section).

In the example, the primary means employed by the operator of the early warning system is the information that is provided to the receptors. Further means involved are the public funding and the education of the people running the system, but these are not channeled directly to the transport users. As an example of a condition, we can cite the attitudes of the receptors toward the early warning system: Do they actually listen to the forecasts? Do they trust the forecasts? Does the information they are given lead to behavioral change? Another is the institutional and legal context: Is there stable funding for the early warning system? Are operators liable if forecasts are incorrect?

It is helpful to further differentiate three notions of means: *available means*, *employed means* and *necessary means*. Available means are those that are disposable by the operator, while the employed means is that part that is actually used for a specific adaptation. That does not imply that the adaptation is effective, since success requires the use of the necessary means – which might be available or not. It is important to note that these three types of means are not necessarily identical.

In the early warning system, there is probably (unused) capacity to provide more detailed information (available means are greater than employed means). However, the conditions, for example reluctance by the transport users to take heed of the warnings, may additionally require the temporary closure of certain roads to achieve the desired effect – other means than just information are necessary.

2.2 Types of adaptation

Based on the above concepts, further key characterizations can be made. The most straightforward adaptations are those where the receptor is also an exposure unit. The purpose of the action is then to improve the situation of a system that is affected by a climate stimulus. We may call this *direct* adaptation. In contrast, in the case of actions where receptor and exposure unit are not identical, adaptations can be described as *indirect*, in the sense that the action is intended to enable the receptor to take certain measures, and only these are finally targeted at an exposure unit. For example, it might be necessary to provide an actor with resources such that she has sufficient available means. The early warning system is a direct adaptation, since the receptors of the information are the transport users that are exposed to the weather. An indirect adaptation would be, for example, an internal reform of the system to improve its quality. This action is only indirectly targeted at the exposure units. The distinction between direct and indirect adaptation has some similarity to the difference between material and institutional intervention as they are described by Pelling and High (2005).

Similarly, operators and receptors may or may not be identical. When operators act with the purpose to change something for other actors or biophysical systems, this is called a *facilitating* adaptation (cf. Hinkel 2007). If the operator's purpose is to change something for herself, we can call this a *reflexive* adaptation. For an adaptation that is both direct and reflexive, the operator, receptor and exposure unit would all be identical. The early warning system is a facilitating adaptation, since it is distinct from the transport users (the receptors of the adaptation).

Investigating the case of the early warning system more closely shows that the public body for information provision was set up by a political administration. This is a further adaptation that can be distinguished from the early warning system itself. The operator is now the political administration, employing legal means and financial resources to set up the public body that now has the role of a receptor. The stimulus and the exposure units that motivate the adaptation are the same as before, but now distinct from both operator and receptor. The action of the political administration is thus an indirect and facilitating adaptation. One can intuitively see that the roles of operators, receptors and exposure units may be combined in various different ways.

One might object that by admitting indirect and facilitating adaptations nearly every action can be classified as an adaptation, since it is not required that adaptations directly improve the situation of an exposure unit towards a stimulus from climate change. Depending on the objective of research we might narrowly consider only direct adaptations, since only those will actually affect exposure units. However, the relevance of indirect and of facilitating adaptations is that they illustrate a basic property of social actions: means and ends tend to come in chains where the effect of one action is the precondition for another one. It might thus be practicable to consider (again depending on the research objective) only those adaptations where at least one means-end chain ends up in an exposure unit. This is, by the way, structurally similar to cause-effect-chains that link direct and indirect impacts. Here also it will depend on the boundaries of analysis whether only first and second order stimuli are considered (e.g. increased precipitation and rising sea level), or also higher order stimuli (e.g. coastal flooding, closed harbor due to flooding, economic losses due to close harbors etc.).

A further distinction relates to the purpose of adaptation and the case where the ultimate exposure unit is not an explicit target of the action. Smithers and Smit (1997) already distinguish purposeful and incidental adaptation. This is intuitive as there might be many actions that are not explicitly taken with having adaptation in mind, but that nevertheless have strong (harmful or beneficial) side effects with respect to consequences of climate change. The purpose of such actions is not linked to any exposure units, neither directly nor indirectly. However, in the light of an action theory the term "incidental" is not as precise as needed. Also processes that may contribute to adaptation although they have another intention are nevertheless actions, and thus not incidental. This is different from mere processes without any intention that may or may not contribute to adaptation. When considering actions that come in means-ends chains, things become more complicated. Some actions may only have the intent to facilitate other actions (e.g. reducing poverty in developing countries), and only those might be adaptations by purpose. We thus propose to call direct adaptations with a purpose targeted at an impact of climate change *explicit* adaptations. An indirect adaptation is also called explicit, if the ultimate purpose refers to an impact of climate change. Otherwise, the action is labeled as an *implicit* adaptation. Thus, adaptations where means-end chains do not end up in an exposure unit, but have an unintended co-benefit, can be considered in the analysis as well. Both types are different from *incidental* adaptations that have no intentions and are thus not actions in the strict sense. Should actions that are only implicitly linked to exposure units be regarded as adaptations at all? The decision again will depend on the research objectives.

2.3 Theoretical background

Since our framework was not developed in a vacuum, we shortly want to illuminate its intellectual roots in this section. First, a theory of adaptation requires considering more than social processes alone, as might be appropriate for a purely socio-economic issue. As the focus is on climate change, we need to widen the scope of our inquiry beyond social processes and actions, since the relation to the natural environment are crucial. We have to deal with an interdisciplinary problem of interlinked biophysical and socioeconomic systems. One of the most straightforward options for doing so is to employ the IPCC terminology, where the exposure unit is defined as “an activity, group, region, or resource that is subjected to climatic stimuli” (IPCC 2001, p. 987), and adaptation is an adjustment of “natural or human systems in response to actual or expected climatic stimuli or their effects“. These definitions remain compatible with conceptions of contextual vulnerability used by O’Brien et al. (2007, see introduction), since it is possible to focus on the means and conditions for operators independently from the actual occurrence of a stimulus.

The definition of action as being the subset of social processes (‘acts’) that are associated with intention is established in analytical philosophy (e.g. Wilson 2008). The other terminology we employ is rooted in the “action frame of reference” from Parsons (1937) that analyses actions in terms of the actor, the ends, the situation, and the mode of relationship between these elements. The situation is decomposed into the conditions, referring to those elements the actor cannot control, and the means, which can be controlled. Action is further shaped by norms and values. The ends of actions can be made more specific for our purpose, since they are directly or indirectly targeted at actors or systems that are influenced by changing climatic conditions (exposure units). Parsons is criticized for not explaining if and how norms and values are different from each other or not considering how they might change. This critique is valid but not so relevant for our purposes. We recognize that norms and values strongly influence the behavior of an actor. However, the aim here is not to explain how norms and values evolve, but to compare the outcomes of different actions. Moreover, the action frame of reference is an established starting point for discussing alternative action theories.

Many terms of the framework as outlined here can be mapped to the clarifying questions of Smit et al. (2000). “Adaptation to what?” inquires about the purpose of an adaptation in terms of an impact, i.e. a stimulus that affects a considered exposure unit. “Who or what adapts?” asks for the operator, the receptor, and their relation to the exposure unit. Smit et al. (2000) already acknowledge in a short note “… that ‘who’ and ‘what’ are not necessarily synonymous. For example, actions by forest managers (who) may result in bio-physical adaptations in a forest (what)” (p. 236), but that relation is not further investigated. Finally, “how does adaptation occur?” is answered by providing description of how means and purpose are interlinked, and whether just processes, or even actions are considered.

3. Analyzing IPCC concepts

In this section we want to demonstrate how the framework can be used to elucidate some other established concepts of adaptation and vulnerability research. The authors of the IPCC (e.g. 2007) distinguish between autonomous and planned adaptation. The precise meaning of this distinction is not as clear as it first seems. Füssel (2007a) claims that planned adaptation makes use of information about expected future conditions, while autonomous adaptation does not. For example, ecological changes in natural systems are typically considered as autonomous, while government programs are planned. However, at least three further interpretations are possible.

The difference could be interpreted as being between adaptations as actions (as discussed in this paper) and mere processes, or it could be between explicit and implicit adaptation. Third, the term “planned adaptation” could refer to the type of operator, i.e. to the actor category involved. However this seems problematical, since there is a broad spectrum of relevant entities to consider between biophysical entities and governments, e.g. technical infrastructure, companies, markets, local authorities, educational institutions or NGOs. Where is the appropriate place to draw the line between actors that adapt in a “planned” and “autonomous” way? This would need to be defined with reference to the specific research context.

A similar distinction can be made between anticipatory and reactive adaptation (e.g. IPCC 2007), which is often defined in terms of the temporal dimensions of adaptations (e.g. Smit et al. 2000; Füssel 2007b). The core of the distinction appears to be the question of whether or not action is taken in advance. How can this be rooted in the framework? One interpretation relates to the purpose of the action (cf. Füssel 2007a). For some adaptations there is a substantial time lag between employing the means for the adaptation and its effect. Thus, an adaptation is reactive when it is intended to have effects in the present, and is anticipatory when it is planned to come into effect only in the future (anticipatory adaptation in the “purpose sense”). Alternatively, a distinction can be made between the means available to the operator, in particular knowledge. A reactive adaptation is based on knowledge about the present and the past while an anticipatory one also responds to assumptions about the future, e.g. to climate change projections or scenarios (anticipatory adaptation in the “available means sense”). Finally, adaptation can also be anticipatory in the sense of expectations about means that will become available in the future (anticipatory adaptation in the “conditions sense”). These interpretations are not equivalent. Adaptations that are reactive in the available means sense are likely also to be reactive in the purpose sense as well, since in most cases actions that are planned to take effect in the future will take assumptions about the future into account. In contrast, it is not unlikely that actions which are reactive in the purpose sense are based on anticipatory assumptions about the future. Of course, adaptations can also be anticipatory in both senses. This discussion supports the claim that the distinction often made between anticipatory and reactive adaptation is anything but clear.

A classic IPCC typology of adaptations is provided by Carter et al. (1994). They differentiate infrastructural, legal and legislative, institutional, administrative, organizational, regulatory, financial, research and development, market mechanism and technological adaptations. This are basically means categories that may also be associated with typical operator types.

We finally want to try our best to contribute to the conceptualization of adaptive capacity and vulnerability. The literature that tries to disentangle different interpretations of vulnerability is quite complex (e.g. Smit and Wandel 2006; Gallopín 2006; Füssel 2007b). Some authors define adaptation as decision-making processes and actions that enhance adaptive capacity. Conversely, it is also stated that adaptive capacity encompasses the enabling conditions for adaptation. The conceptual complexity, in our opinion, arises from the difficulties involved in maintaining the distinction between potential and actual action. When adaptive capacity refers to potential adaptation, it might be, in the simplest case, a measure of the available means. However, since the available means are unlikely to completely explain the implementation of adaptations, adaptive capacity refers to conditions as well. In any case we are able to avoid confusion between the statement that adaptive capacity enables adaptation on the one hand, and the statement that adaptations are reducing vulnerability on the other hand. In the first statement, adaptive capacity considers the means and conditions for action. The second one talks about more complex means-ends-chains, where a facilitating adaptation has the purpose to change the means and conditions for another action.

4. Barriers to adaptation

There are different generic barriers to adaptation proposed in the literature (e.g. Füssel 2007a). Lecocq and Shalizi (2007) build their argument on an economic analysis. Another way is to derive barriers from process models of adaptation that are based on planning exercises in other fields of activity (Arnell and Delaney 2006; Moser and Ekstrom 2010). In a similar manner, we proceed by systematically combining the concepts introduced in the previous sections. By barriers to adaptation we understand sets of conditions that might hinder the implementation of specific adaptations. They are not necessarily absolute limits to adaptation (cf. Adger et al. 2009), as conditions and available means might be changed by other (facilitating) adaptations. Mapping adaptation situations with the framework then helps to identify barriers that might be addressed by successful rules and institutions. The barriers to adaptation presented below outline possible examples for such an analysis. The extent, to which one or more of the following barrier types apply in a specific case, is, of course, an empirical matter. In the following, the barriers are grouped along the dimension of the operator and the means.

Missing operator: When there is no operator, there is no adaptation. The simplest example for a generic barrier in this group is the ignorance of impacts by all involved actors. This might be due to the conditions as, e.g., limited problem recognition of potential operators, missing frames of reference, rigid social habits and normative standards that prohibit understanding of the underlying stimulus. This hinders adaptation, even though action is not constrained by limited available means.

Missing means: Although there is an operator (e.g. an exposure unit) who perceives a need to act, the necessary means are not available. Barriers in the group can be distinguished by the type of means that are missing, e.g. limited institutional capacity or budget constraints. This is crucial, in particular, in developing countries that are disproportionally exposed to climate change and already have limited capacities to cope with other severe stresses. In the worst case, failure to adapt due to unavailable means might result in poverty traps. Another variant is when the legislative framework limits adaptation; that is, when motivated operators do not have the legal power to act.

Unemployed means: Means are not sufficiently employed although there is an operator to whom the necessary means are available. Barriers of this type mostly lie in misaligned economic incentives. When an adaptation has positive externalities for other actors, the operator may choose to under-adapt if she considers that other exposure units that benefit from the adaptation are not contributing their share to the means. Conversely, it might happen that an operator over-adapts when the action has negative external effects on other exposure units. There are also moral hazard situations where perverse incentives encourage actions that increase the impacts of climate change. For example, settlements may be (re)built in areas where there is a high risk of flooding by investors (exposure units) who expect to receive compensation from a public agency (as operator) in the case of a disaster.

Complex actor relations: It might also be that the network of exposure units, operators and receptors is too complex to come to decisions. Since climate change has very diverse effects which are relevant for many exposure units in different ways, there are likely to be many decisional conflicts. These might be amplified by institutional arrangements that are not tailored to respond to the new challenges posed by climate change. Moreover, when new problems arise, it is not always *ex ante* clear who the relevant actors are. Economically speaking, all these problems raise the transaction costs of information collection, monitoring and enforcement. This increases the necessary means, and can result in a shortfall of available means.

These proposed barriers and their description give a flavor of how the framework can be used to be very precise about further barriers to adaptation, e.g. resulting from different interests of operators and receptors, or specific combinations of indirect and facilitating adaptations.

5. Case study: adapting cooling water management of the river Rhine

In this section we want to illustrate the functionality of the framework by applying it to an adaptation case study. For the sake of exposition and due to space limitations, the analysis presented here is only a small part of a more extensive research project. The water of the river Rhine is used for multiple purposes, inter alia to cool down power plants. Cooling releases heat to the water body, imposing interference with the river ecosystem. On the other hand, shutting down power plants when water becomes too hot can be a threat to energy security. It is likely that this conflict intensifies under climate change. The question, in general, is how to manage cooling water, taking into account the ecological consequences and conflicting water uses. We break down some already existing institutions, potential adaptations, and barriers to adaptation by using core concepts of the framework.

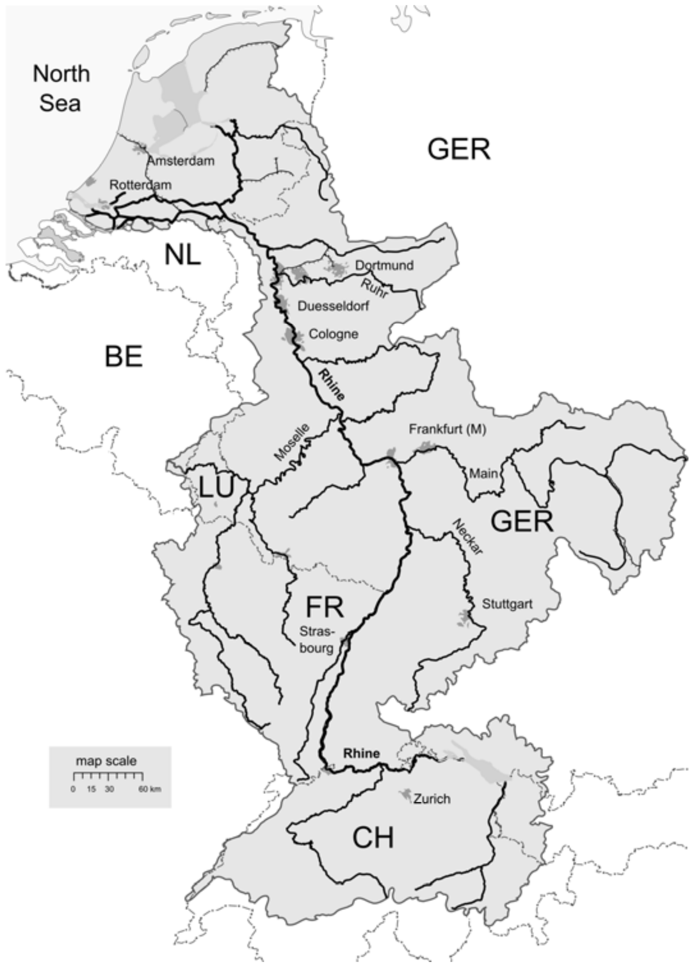

Figure 2: The river Rhine catchment (published with permission of the IKSR, www.iksr.org/index.php?id=240, own modifications).

5.1 Overview

The Rhine connects the Alps to the North Sea. With its length of 1,320 km, it is one of the most important rivers in Europe. The river catchment covers about 200,000 km^2 with 58 million inhabitants, with Cologne, Rotterdam and Düsseldorf being the largest cities. Riparian states are Italy, Austria, France, Germany, Luxemburg, Belgium, the Netherlands, Liechtenstein and Switzerland (see figure 2). The Rhine catchment lies in an area with moderate climate and generally exhibits average water temperatures from 0 °C to 25 °C (BUND 2009). Its average discharge to the North Sea is about 2200 m^3/s. The Rhine is one of the busiest waterways of the world (about 800 km are navigable). Rhine water is heavily used for important industrial and agricultural purposes, hydropower generation, wastewater disposal, recreational activities, potable water, and, crucial for the present case, to cool thermal power plants. The Rhine is a natural habitat for a diverse flora as well as many birds, fish and other species that depend on water quality, availability and temperature (Frijters and Leentvaar 2003).

Due to the laws of thermodynamics, thermal power generation (e.g. nuclear, coal, gas or biomass) is associated with substantial waste energy that needs to be discharged. Depending on the technology, power plants are cooled down by increasing river water temperature or by evaporating water (Koch and Vögele 2009). This leads to consequences for further usage downstream. In Germany, 13 thermal power plants are located at the Rhine. There is an average total heat discharge from power generation of 17.309 MW, while 4921 MW are discharged by other industries (BUND, 2009). There are different cooling technologies used in the power plants: water cooling, once-trough cooling, cooling towers and hybrid models of these. They differ in terms of efficiency, heat load to the river and costs (Koch and Vögele 2009). All cooling technologies affect the river flora, fauna and the quality of potable water. Especially fish reacts sensitive to changes in temperatures and the resulting lower oxygen content. This cooling water problem is well-known and has been subject to environmental and water regulation in the past. Regulation basically sets upper limits for the temperature directly downstream of power plants. We describe below how this currently accomplished.

Under climate change it is likely that the cooling water problem will intensify. It is expected that water and air become hotter, and that river water will be less available during droughts (IKRS 2009a). The unusually hot summers in 2003 and 2006 caused critical conditions for fish in the Rhine. In 2003, numerous power plant units were forced to shut down or reduce their power production in order to avoid violations of water regulation (Förster and Lilliestam 2010). When multiple power plants are affected at the same time, these energy disruptions cause a threat to energy security in this economically important region. There have thus been extra-ordinary exemptions from water regulation in some cases (BUND 2009). However, as other users of cooling water downstream face the problem of already heated or consumed water, another resource use conflict may be come more severe.

There is a set of explicit or implicit actions to address this challenge. Some are already in place, while others are proposed by different actors. In the following, we map some of them with the framework. The analysis is based on official documents (in particular development approval documents for power plants), public information of the International Commission for the Protection of the Rhine (IKRS), interviews with representatives from energy utilities, and a study of an environmental NGO (BUND 2009). There is a regional focus to the laws and administrative restrictions in the German federal state (Bundesland) of Baden-Württemberg. Table 1 presents very short overview of some adaptations, of which one is discussed more extensively below. This is just a small set of adaptations, and further actions are currently analyzed with the framework. More fundamentally, transforming the energy system towards less use of thermal energy (e.g. hydropower, wind and solar energy) may relax the cooling water problem.

Adaptation	Operator	Receptor	Exposure Unit	Means	Type
Hydraulic measures	structures like weirs or oxygen enrichment at the outlet of sewage works, and the rules that determine their operation				
(a) Infrastructure use	sewage works or weir operator	river	river, power plants	operational decisions	direct, facilitating
(b) Infrastructure extension	sewage works or weir operator and local public administration	sewage works or weir operator	river, power plants	investments, development approval	indirect, reflexive or facilitating
(c) Control rules	environmental administration, sewage works, and weir operators	sewage works and weir operator	river, power plants	contracts or administrative acts	indirect, facilitating
Alternative cooling technologies	availability, use and regulation of different cooling technologies, which differ in their costs and water use				
(a) Short-term technology switching	power plant	power plant, river	power plant, river	operational decisions	direct, reflexive
(b) Implement hybrid cooling technology	electric utility	power plant	power plant, river	investments	direct, reflexive
(c) Implement alternative cooling technology	electric utility	power plant	power plant, river	investments	direct, reflexive
(d) Obligatory cooling standards	department of environment in the regional council (Regierungspräsidium)	electric utility	river	development approval	indirect, facilitating
Exemptions of water law restrictions	see text for a detailed discussion				
(a) Regular exemption rules	department of environment in the regional council (Regierungspräsidium)	electric utility, power plant	electric utility, power plant	administrative act	direct, facilitating
(b) Short term extraordinary exemptions	federal state government	department of environment in the regional council (Regierungspräsidium)	electric utility, power plant	administrative act	indirect, facilitating
(c) Rules for extraordinary exemptions	federal state legislative	federal state government	electric utility, power plant, river	laws	indirect, facilitating
(d) Coordination of exemptions	federal state and national governments	federal state government	electric utility, power plant, river	laws or public contracts	indirect, facilitating or reflexive

Table 1: Mapping of selected adaptations to address the cooling water problem by using the concepts of the framework (further explanations in the text).

5.2 Exemptions of water law restrictions

The restrictions for heat discharge and water use by power plants are defined in the development approval process of each single power plant (Anlagengenehmigung), primarily with the objective to safeguard environmental conditions, and partially to protect other users (e.g. fishery). Although referring to European and national law, the approval leaves discretion to the regional council (Regierungspräsidium, being part of the federal state government), that releases the approval. This sets upper limits for the discharged energy and water use for each particular power plant (Greis et al. 2011). Typically, the mixed temperature of the water body at the discharge point is not allowed to exceed 21.5 °C or 28 °C, depending on the respective fish fauna living in the river. These limits are currently defined and fixed at the time of approval of power plants, although they have economic life times of 20 to 50 years and more (Stecker et al. 2010). In the context of this regulation we identified, inter alia, the following adaptations.

(a) Regular exemption rules. Some development approval documents already contain rules for „regular exemptions“, that allow to exceed temperature limits for some hours. As these rules are currently defined for single power plants, there is no explicit coordination for the catchment. The regional council that is responsible for the development approval is the operator. The means come in terms of the binding approval documents. These affect the power plant scheduling of the electric utility and the power plant as receptor. The main purpose of exemptions is to keep energy production stable and to avoid an economically very ineffective throttling if the water and weather conditions are only restrictive for a short time. Thus, the power plant is the primary exposure unit. These rules are facilitating and direct adaptations.

(b) Short term extraordinary exemptions. As reported above, there were already cases of „extraordinary exemptions“, where the federal state government allowed exceeding temperature limits for longer times. This is an ad hoc reaction to specific weather conditions. Operator is the federal state government. As means they enact a temporary relaxation of the heat discharge restrictions in the approval documents. Receptor is the department of environment in the regional council that controls the emission restrictions. Exposure units are the power plants that are affected by the weather conditions and the water regulation. Extraordinary exemptions are facilitating and indirect adaptations. A critical question lasts: How many exceptions of the rule are reasonable against the background of water quality on the one hand and energy supply on the other hand? This balancing is certainly difficult.

The ad-hoc extraordinary exemptions can be extended to develop more sophisticated institutional adaptations, for example:

(c) Rules for extraordinary exemptions. If extraordinary exemptions should not follow an ad-hoc pattern and are to be tailored to climate change, more general rules need to be designed. This is, in particular, to guarantee a long-term and legitimate tradeoff between environmental and economic objectives, and consequently requires operators at the federal state or even the federal level. Means are thus laws or modifications of existing water laws. As the rules determine when the federal state government declares an extraordinary exemption, it is the receptor. In addition to the electric utilities, the river is an exposure unit due to the environmental objectives. Rules for extraordinary exemptions are facilitating and indirect adaptations.

(d) Coordination of exemptions. Alternatively or additionally, rules can be crafted that determine the place and timing of extraordinary exemptions within the river catchment. This could help to allocate scarce cooling water to different uses, in particular between different federal states or countries. Spatial differences of the river ecosystems can be considered. As upstream cooling water use affects downstream use, efficiency gains are possible. This can be accomplished by public contracts between governments, or by modified water laws (as means). Operators are those governments that negotiate the contract or the legislative that enacts appropriate laws. The federal state governments are the receptors as they are responsible for declaring extraordinary exemptions. Exposure units are the same as for (c). The adaptation is indirect and facilitating if the rules are enacted by laws, it is reflexive if it takes the form of a negotiated contract between governments.

5.3 Potential barriers to the adaptation measures

(a) Regular exemption rules already exist and are used in practice. The necessary means (e.g. legislative framework, development admission documents, knowledge) are available to the operator, and they are indeed employed.

(b) Although short-term extraordinary exemptions are already observable, barriers to adaptation are nevertheless conceivable, in particular missing means: frequent extraordinary exemptions may violate more general norms. It is also difficult to judge for the operator which exemptions are sustainable. Complex actor relations can also be a barrier, as extraordinary exemptions affect many different actors in different ways.

(c) Currently, there are no rules for extraordinary exemptions. This adaptation potentially faces different barriers than the first two. First, there may be no operator. Although it is clear that only the federal state legislative can pass a law, it is not clear that it takes the initiative. If this would be the case, missing means can be a second barrier if frequent extraordinary exemptions violate more general norms (as for b). However, even if this problem can be resolved, unemployed means remain as a third potential barrier when the adaptation does not gain the necessary political support. This is can be problematical as environmentalists could subject since they have no political interest in admitting exemptions regularly.

(d) There is currently no coordinated effort between the different governments in the catchment to manage water law exemptions. This faces, first, the problem of complex actor relations. This makes it difficult to come to decisions, in particular when a contract needs to be negotiated.

Second, there might be missing means as this adaptation has the same legitimacy problems as other frequent extra-ordinary exemptions. Finally, the means might remain unemployed as it is difficult to align conflicting interest between upstream and downstream users of the river water in a contract. In this case there would be no coordination, although the necessary means are at hand.

By analyzing the case study with our framework we can summarize some interesting conclusions. Usage of the core concepts guides the analysis to be precise about the actor relations and institutions involved. This reveals a complex and broad set of adaptations and illustrates that we have to deal with whole bundles of adaptations and not just single ones. By dismantling these bundles along means-ends-chains, we can analyze potential barriers for each part of these chains. In our case, some of the proposed adaptations differ in the potential barrier types (e.g. unemployed means due to upstream-downstream conflicts), but some barrier types also re-appear (e.g. missing means due to legitimacy problems). All types appear somewhere, but for each adaptation the necessary means and the configuration of barriers are quite different. There is thus no simple solution (or facilitating adaptation) that resolves all barriers at the same time. Thus, if cooling water scarcity becomes indeed more severe in the future, the complexity of actor relations in the Rhine catchment with multiple jurisdictions will make it difficult to come up with a coordinated effort. We thus draw a pessimistic conclusion for managing cooling water in the Rhine catchment under climate change.

6. Conclusions

Our framework proposes a new way to analyze adaptations from an action-oriented perspective. It emphasizes the interconnectedness of complex activities that address societal consequences of climate change along means-ends-chains. It is crucial for analysis to spell out the purpose of adaptations, and to consider that operators and receptors of adaptation may be different from the exposure units. The rigorous definitions provided in our contribution help elucidating prominent types of adaptation in a crisp way. By combining the core concepts proposed in the framework in different ways, crucial barriers to adaptation can be deduced and precisely formulated.

Based on the framework one can define adaptations as individual or collective actions that are explicitly or implicitly intended to affect exposure units of climate change, or that indirectly achieve this end. However, this is still just one possible definition using the terms introduced by the framework. It leaves partially open what is to be considered as an adaptation. Depending on the research design or on practical considerations, it may be useful to consider only, e.g., direct or reflexive adaptations. We argue, however, that the framework is in particular fruitful to make precise statements about what adaptations are considered in a concrete context. This is not only crucial for terminological reasons, but also to operationalize adaptation assessments: The framework makes explicit statements about key variables for understanding the governance of adaptation.

Our case study example illustrates that mapping adaptations by using the core concepts of the framework reveals a broad spectrum of options where some actors appear in multiple functional roles as operator, receptor or exposure unit. Most adaptations connect up in complex means-ends chains. All types of barriers are identified, but at different positions along these chains. This makes it difficult to address the cooling water problem with simple “one size fits all” solutions. The analysis shows that there are already some implicit adaptations that may be entry points for more explicit adaptation to climate change. However, the analysis leads to the impression that it might be very difficult to achieve an adapted cooling water management on the level of the whole Rhine catchment.

Coming to the conceptual level there is the difficulty that the framework is very analytic in the following sense. Already Parson’s action frame of reference (1937) is intended to analyze a unit act. This incorporates the notion of an “atomistic” action unit into which all more complex actions can be decomposed. “Simple” adaptations may be part of more “comprehensive” adaptations. Indeed, carefully investigation of prima facie single adaptations from this perspective is likely to reveal a broad bundle of “atomistic” adaptations that are linked together in a kind of “molecule”. Similar problems are known from the literature on policy classification (cf. Steinberger 1980): policies are difficult to demarcate (when does a policy begin and end in time?, where does it enter the domain of another policy?, etc.), and classification schemes are known to depend on the frame of reference.

On the other hand, there are further interesting applications of the framework. The terminology of the operator, receptor and exposure unit can be exploited to map complex actor networks. This could provide the basis for understanding adaptation conflicts between different actors, or used to measure transaction costs associated with the coordination of multiple actors in developing and implementing adaptation policies. The framework has also been used to classify and systematize adaptations (e.g., in Eisenack et al. 2011). There is also room for promising extensions. Parson’s action theory gives a prominent role to the norms and values that shape social action. This is currently not addressed by the framework, but could – together with investigation of available means and conditions – improve the analysis of the institutional dimensions of adaptation. Finally, the important role of uncertainty and time in adaptation suggest promising lines of research that give more explicit consideration to how stimuli and means unfold in time, along with the perceptions and beliefs of actors. These remarks illustrate the interdisciplinary potential of the framework, and are a major motivation for its design. Although it is rooted in action theory, the components referring to climate change and to the causal effects of stimuli and actions provide a link between the natural and the social sciences.

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