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From risk to vulnerability: the role of perceived adaptive capacity for the acceptance of contested infrastructure

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Infrastructure projects such as repositories for nuclear waste or hazardous waste sites impose risks (in the form of potential burdens or losses) over extensive timescales. These risks change dynamically over time and so, potentially, does their management. Societies and key actors go through learning processes and subsequently may be better able to deal with related challenges. However, social scientific research on the acceptance of such projects is mainly concerned with (static) risk perception issues and does not include dynamic aspects. Adaptive capacity, which is part of the concept of vulnerability, therefore represents a promising complementing facet for this line of research. The aim of this paper is to examine the role of perceived adaptive capacity (PAC) for the acceptance of contested long-term infrastructure for the two issues of nuclear and hazardous waste. In an online experimental survey ($N = 300$) examining either the acceptance of a nuclear waste repository or of a hazardous waste site, we demonstrate that (i) PAC can be separated empirically as a psychological construct from risk and benefit perception, and (ii) PAC explains a significant additional share of variance in the acceptance of both waste types beyond risk and benefit perception. Furthermore, we report what adaptation mechanisms of PAC participants expect to occur in the future. We conclude that such a dynamic perspective yields important insights in understanding individual decision-making regarding long-term infrastructure projects.

Keywords: perceived adaptive capacity; risk perception; vulnerability; acceptance of contested infrastructure; nuclear waste; hazardous waste

Introduction

In the siting of large infrastructure projects such as nuclear power plants, nuclear waste repositories, dams, wind power plants, deep geothermal, or carbon capture and storage (CCS) implementers often face enormous difficulties. Such projects, also referred to as contested infrastructure (Boholm 2004), share some common characteristics: they are often large-scale projects in which burdens and benefits are unequally distributed over time and space, and they include a broad range of actors with differing interests and values. Moreover, these infrastructures often pose risks over very long timescales due to uncertainties in physical processes and knowledge (ignorance). In a nutshell, they 'combine technical factors and social factors in

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complex multi-attribute trade-offs' (Reiner and Nuttall 2011, 312). Considering the difficulties in siting such contested infrastructure projects, understanding individual and societal decision-making is crucial.

One example of such contested infrastructure projects is the issue of nuclear waste disposal. Repositories for nuclear waste entail all the above-mentioned characteristics and, in particular, long timescales are highly salient (Svenson and Karlsson 1989; Drottz-Sjöberg 2010; Moser et al. 2012). Technical experts are considering timescales of up to one million years for the disposal of high-level nuclear waste and spent fuel (Nagra 2002). The risks of such a repository change dynamically within this timescale. For example, while the radiotoxicity of the waste decreases over time due to radioactive decay, the canisters containing the spent fuel or vitrified high-level wastes will become ever more likely to leak due to corrosion (Nagra 2002). Furthermore, the societies responsible for managing these risks also change. New technologies or learning processes in general may provide future societies with better knowledge on how to deal with the risks. On the other hand, relevant knowledge could also be lost over time, thus impairing future societies' successful risk management. This example demonstrates that a dynamic perspective on technical and societal systems is crucial for understanding decisions about nuclear waste disposal and probably other contested infrastructure projects as well. This also appraises the capability of the system exposed to negative outcomes to cope with these.

However, current social scientific research examining the acceptance of contested infrastructure does not take such a dynamic view but predominantly focuses on the perception of risks (e.g. Bord and O'Connor 1992; Chung and Kim 2009; Drottz-Sjöberg 2010, Seidl et al. 2013). This static view can be found both with pure risk and speculative risk (Fishburn 1982; Scholz and Siegrist 2010), the former referring to only potential negative outcomes, the latter to potential positive as well as potential negative outcomes. We use in the following for the valuation on the negative aspects the term 'risk perception' (RP) as it is given by pure risk, and for positive aspects the term 'benefit perception' (BP) (see e.g. Fischhoff et al. 1978; Finucane et al. 2000; Slovic et al. 2004; Siegrist, Gutscher, and Earle 2005). The mentioned static view is also reflected on the level of item construction in RP questionnaires. In some studies, participants are asked to judge the overall risks emerging from an issue, others ask participants to judge probabilities and outcomes of negative events, or participants are asked to judge risks for humans and for the environment separately (nuclear waste: Stauffacher, Krütli, and Scholz, 2008; Sjöberg and Drottz-Sjöberg 2009; nuclear power: Whitfield et al. 2009; waste incineration: Lima 2004; environmental risks: Böhm and Pfister 2005). Hence, the RP items used in currently published studies relate to risks as a static construct and do not take into consideration the aforementioned dynamic aspects of long-term risks.

Scholz, Blumer, and Brand (2012) demonstrate that vulnerability judgments may be understood as including a dynamic management potential. Vulnerability is usually conceived as a function of exposure, sensitivity, and adaptive capacity (McCarthy et al. 2001; Adger 2006; Smit and Wandel 2006). According to Scholz, Blumer, and Brand (2012), adaptive capacity is the supplementary aspect involved in vulnerability, which is not inherent in common notions of risk. Adaptation may occur as a response to or in anticipation of a negative event related to a perceived risk or threat. These events or threats may take the form of a discrete extreme event, (temporal) variability of state variables, or long-term changes (Smit et al. 1999).

The scientific use of adaptation has been first established in evolutionary biology and 'refers to the development of genetic or behavioral characteristics which enable organisms or systems to cope with environmental changes in order to survive and reproduce' (Smit and Wandel 2006, 283). At the societal level, adaptation can be conceived as 'a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity' (Smit and Wandel 2006, 282). In other words, adaptive capacity refers to a system's ability to maintain its function in case of disturbance (i.e. negative events related to threats) but also to its capacity to reorganize in order to deal with challenges (Folke 2006).

Key aspects of adaptive capacity on a societal level thus comprise learning, innovation, and technological development. In other words, adaptive capacity can be considered a highly relevant component in the process of realizing resilient human-environment systems (Scholz 2011). Such systems are – amongst other things – better able to deal with negative future impacts caused by infrastructure projects. One can distinguish between (supposedly) objective adaptive capacity (e.g. time, money, staying power, knowledge, entitlements, social and institutional support, see Grothmann and Patt 2005) and (more subjective) perceived adaptive capacity (PAC), i.e. judgments on how well individuals or societies are expected to be able to cope with negative events and developments. Particularly when extensive timescales are considered, it is important to distinguish between these two types: actual technological development (objective adaptive capacity) might, for example, not keep up with what a technologically optimistic person expects for the future (PAC). PAC therefore yields important insights into people's expectations of coping with future developments and could take on the function of a self-fulfilling prophecy in triggering or re-enforcing those expectations over time and converting them into action.

A considerable body of empirical or conceptual studies regarding adaptive capacity is focused on climate change (e.g. Smit et al. 1999; McCarthy et al. 2001; Grothmann and Patt 2005; Alberini, Chiabai, and Muehlenbachs 2006; Smit and Wandel 2006; Kuruppu and Liverman 2011). With respect to other long-term risks, such as nuclear or hazardous waste disposal, perceived risks have received a great deal of attention in social scientific studies. However, none of these studies accounts for PAC.

Smit et al. (1999) suggest that studies on adaptation should clarify the following questions: (1) Adaptation to what? (2) who adapts? and (3) what kind of adaptations are considered? The focus of this study lies on adaptation toward *potential threats represented by contested infrastructures*. Individuals today are asked about the *expected adaptation of future societies* to these threats by *learning processes and technological progress*. In other words, we look at how individuals currently perceive the adaptive capacity of future societies, how this perception affects their acceptance of contested infrastructure projects today, and what mechanisms of adaptive capacity they expect to occur in the future. While PAC refers to a general judgment about the ability of future societies to adapt to challenges, the related mechanisms describe specific processes that may be involved in coping with the negative outcomes/events that are related to a specific risk. They provide more details into what adaptive capacity might mean more concretely, why people believe that future societies are able adapting, i.e. they describe processes that hinder or promote adaptive capacity of future societies (effective crisis management system, technological progress, change of individual behavior, political and economical crises, loss of relevant knowledge).

We take nuclear waste and hazardous waste as examples. As outlined above, nuclear waste disposal can be considered a prototype of contested and stigmatized infrastructure projects, with a large body of research examining decision and site selection processes (e.g. NRC 2003; Strandberg and Andrén 2009; Krütli et al. 2010a, 2012). As a second issue, we examine hazardous waste to better understand whether nuclear waste is a special case or if our insights potentially also apply to other contested infrastructure projects. Switzerland does not have a deep geological repository for nuclear waste yet; wastes are currently stored in the nuclear power plants or in a central interim storage. After plans for a nuclear waste repository in central Switzerland failed due to local resistance and two negative votes in local referenda (Flüeler 2006; Krütli et al. 2010a), the Swiss Federal Office of Energy (SFOE) initiated a sectoral plan to guide a participatory stepwise decision process to select sites for a repository in Switzerland (SFOE 2008). In contrast, hazardous waste sites do exist in Switzerland. One well-known example is Kölliken, a hazardous waste landfill that opened in 1978. Due to leakage, this site has to be cleaned up at very high costs (Flüeler 2010). Both waste types impose a risk for humans and the environment over extensive timescales. Important differences between both waste types refer to the volumes. In Switzerland, 100,000–200,000 *t* of hazardous waste are produced per year compared to 100,000 *t* of nuclear waste for a time period of 60 years (about 3000 *t* of that are high-level waste). Furthermore, nuclear waste in Switzerland contains only few and well-characterized pollutants whose impacts are known in detail (apart from very low doses whose impacts are currently investigated scientifically). In contrast, hazardous waste can be characterized by a multitude of interacting pollutants, whose impacts are only partly known (Flüeler 2010).

The main aim of this paper is to examine the role of perceived adaptive capacity (PAC) for the acceptance of contested infrastructure for the two issues of nuclear waste and hazardous waste. More specifically, we aim at testing whether PAC can explain an additional share of variance in acceptance of the infrastructure projects that cannot be explained by RP and BP alone. Furthermore, we aim at describing the construct of adaptive capacity in more detail with respect to its adaptation mechanisms for the issues of nuclear waste and hazardous waste. The following research questions form the core of our investigation:

- Do RP, BP, and PAC of the issues of nuclear waste and hazardous waste represent different psychological constructs?
- What is the role of PAC in the acceptance of contested infrastructure such as nuclear waste and hazardous waste?
- What mechanisms of adaptive capacity do people today expect to develop in the future with respect to negative consequences of nuclear waste or hazardous waste?

Our research thereby aims to a contribution to the further development of RP research by including a future-oriented perspective, or to express it in other terms, to extend or transfer the static risk concept towards the notion of vulnerability.

Method

Design of the experimental survey

Manipulated variable

Waste type. We examined the role of PAC in acceptance for either a nuclear waste repository or for a hazardous waste site. Participants were randomly assigned to one of these two conditions and received a short description of the respective issue before responding to the variables of interest. Descriptions for both waste types are taken from Moser et al. (2013, see Appendix 1).

Measured variables

RP (scale). The scale measuring RP of a nuclear waste repository (adapted from Stauffacher, Krütli, and Scholz 2008) consisted of seven items referring to risks associated with a nuclear waste repository (e.g. transport accidents, health risks, environmental risks, release of radioactivity into groundwater, and economic risks). This scale was slightly adapted for the issue of hazardous waste (see Table 3, items RP for the full list of items). Participants judged how strongly they associated a nuclear waste repository (or a hazardous waste site) with these risks on a seven-point scale, while one indicated 'not at all' and seven 'very strongly'. The calculated scale had very good reliability: Cronbach's $\alpha = 0.90$.

BP (scale). The scale measuring BP (adapted from Stauffacher, Krütli, and Scholz 2008) consisted of five items with benefits associated with a nuclear waste repository or a hazardous waste site (e.g. additional jobs, tax reduction, and improvement of regional infrastructure). The identical scale was used for both waste groups (see Table 3, items BP for the full list of items). Participants judged how strongly they associated a nuclear waste repository (or a hazardous waste site) with these potential benefits on a seven-point scale, while one indicated 'not at all' and seven 'very strongly'. The calculated scale had good reliability: Cronbach's $\alpha = 0.81$.

PAC (scale). To our knowledge, an established scale measuring PAC for threats posed by contested infrastructure does not yet exist. We informed participants that the safety of a nuclear waste repository or hazardous waste site has top priority in Switzerland, but that at the same time no one can guarantee 100% safety. Afterwards, participants judged how well the society would be able to manage several potential negative consequences of a nuclear waste repository or hazardous waste site. Referring to the used RP items, we chose the following four potentially negative consequences of a nuclear waste repository (in parentheses for hazardous waste site: (i) release of radioactivity (toxic material) into groundwater; (ii) unintentional recovery of the repository (hazardous waste site) by future generations; (iii) economic losses caused by the repository (hazardous waste site); and (iv) release of nuclear waste (hazardous waste) due to a transport accident (see Table 3, items PAC for the full list of items). Participants judged how well society would be able to manage these situations on a seven-point scale, where one indicated 'very badly' and seven 'very well'. The calculated scale had good reliability: Cronbach's $\alpha = 0.84$.

Mechanism of adaptive capacity (single processes/items). We developed a list of items covering different mechanisms of adaptive capacity. It includes three mechanisms of a successful management (technological progress, individual behavior, and well-organized crisis management) and three mechanisms of an unsuccessful management (loss of relevant knowledge, economic crisis, and political crisis, see Table 5 for the list of items). Participants rated these mechanisms on seven-point scales while one indicated ‘I do not agree at all’ and seven ‘I agree very strongly.’

Acceptance (scale). We measured acceptance of a nuclear waste repository or a hazardous waste disposal site with three items related to different places where the disposal would be built: (i) in Switzerland, (ii) in the region where one lives, and (iii) one’s own community on a seven-point scale, one indicating ‘I’m strongly opposed’ and seven ‘I’m strongly in favor’. The calculated scale had very good reliability: Cronbach’s $\alpha = .97$.

Manipulation check (open-ended question). To check whether the manipulation of waste type had been successful, participants were asked to write down in a textbox some examples of wastes they had considered, while answering the questionnaire.

Procedure and participants

Data collection took place in mid-November 2011 (15–17 November 2011). Participants were all recruited from an online panel. An equal number of males and females (in total 1000 people) were contacted and invited to participate by email. After entering the survey by clicking on a link, they were welcomed to the study and randomly assigned to either the nuclear waste condition or to the hazardous waste condition. First, participants read a brief description of either nuclear waste or hazardous waste. The subsequent procedure was similar for both groups: the first group always responded to questions concerning nuclear waste and the second group always responded to questions concerning hazardous waste. First, they responded to the RP and BP scales. On the next screen, they answered the PAC items as well as the items on mechanisms of adaptive capacity. After responding to the acceptance items on the subsequent page and the manipulation check items, they provided demographic information. Completion of the whole questionnaire took on average about 10 min; participants received a small incentive for participation (approximately 0.60 €). Of the 1000 contacted people, 355 people started the survey within three days (until quota was full). While 55 participants dropped out, 300 participants, of them 155 women (51.7%) and 145 men (48.3%) completed the questionnaire and were included in the subsequent statistical analyses. The completion rate among those 355 people who started the survey is quite high (85%). Participants live in the German-speaking part of Switzerland; their age ranges between 18 and 69 years (M = 41.6 years, SD = 13.15 years). Seven (2.3%) had completed compulsory school, 131 (43.7%) vocational education, 44 (14.7%) senior high school, 36 (12.0%) higher vocational training, 79 (26.4%) went to university, and 3 (1.0%) people did not specify their educational level. With respect to living conditions, 87 (29.0%) participants live alone, 12 (4.0%) live in a shared flat, 103 (34.3%) live with their partner, 95 (31.7%) live in a family with kids, and 3 (1.0%) people did not specify their living condition. Our sample is approximately representative for Switzerland’s population with respect to age (Swiss average in 2012: 41.6 years; BFS 2014a) and gender (49% male and 51% female in 2012; BFS 2014a) as well as living conditions (BFS 2014b). Our sample included more people with a university degree and less people who only finished compulsory school compared to Switzerland's population (educations levels in Switzerland in 2012: 13.7% compulsory school, 41.7% vocational training, 8% senior high school, 12.9% higher vocational training, and 23.7% universities; BFS 2013). These differences are similar as in postal surveys.

Results

Manipulation check

Participants' open-ended responses with regard to the waste types they had been thinking of were coded according to the following scheme: (i) only nuclear, (ii) only hazardous, (iii) both waste types, or (iv) no response (missing). Table 1 reports the observed frequencies as well as the corrected standardized residuals of each code under the two experimental conditions (waste types). There was a significant association between experimental conditions and assigned manipulation check code: $\chi^2(3) = 73.62$, $p < .001$. Participants in the nuclear waste condition were more likely to mention nuclear waste only and participants in the hazardous waste condition were more likely to mention hazardous waste only, thus indicating that our manipulation had been successful. However, for the interpretation of the subsequent results, it is important to note that participants in the hazardous waste condition mentioned a broader spectrum of waste types. They were also more likely to mention both waste types.

PAC as a separate psychological construct

As a first step in analysis, we explored whether RP, BP, and PAC each represent different psychological constructs. We performed a principal component analysis (PCA) including all items of RP, BP, and PAC. According to the Kaiser criterion and to the visual inspection of the Scree-Plot, a three-factor solution is recommended, explaining 63.3% of the total variance. The result of the PCA indicates that RP, BP, and PAC can be considered as three separate psychological constructs (see Table 2). The factor RP explains 27.5% of variance, BP explains 18.2% of variance, and PAC explains 17.6% of variance.

Table 3 displays the mean values of RP, BP, PAC, and acceptance for both nuclear waste and hazardous waste for the total sample. Examining the total sample indicates that the mean RP of both waste types is not significantly different from each other, $t(283.07) = 0.29$, $p = .77$, $r = .02$. (two-tailed). Acceptance of a nuclear waste repository is lower than acceptance of a hazardous waste site, but this

Table 1. Observed frequencies and corrected standardized residuals (in parentheses) of assigned manipulation check codes by experimental condition $N = 300$; $n_{\text{nuclear}} = 147$; $n_{\text{hazardous}} = 153$.

		Assigned manipulation check code				
		(i) Nuclear	(ii) Hazardous	(iii) Both	(iv) No response	Total
Conditions	Nuclear waste	87 (7.4)	12 (–3.4)	21 (–6.3)	33 (1.3)	153
	Hazardous waste	23 (–7.4)	32 (3.4)	69 (6.3)	23 (–1.3)	147
	Total	110	44	90	56	300

Table 2. Items assumed to measure RP, BP and PAC. Parentheses indicate changes made for the hazardous waste condition. Factor loadings (after Varimax Rotation) and communality (h^2); bold factor loadings indicate the items corresponding to the respective factor $N = 300$.

Items	Factor loadings: Factor 1 risk perception	Factor 2 benefit perception	Factor 3 perceived adaptive capacity	h^2
(RP) Release of nuclear waste (hazardous waste) in transport accidents	**0.72**	−0.14	−0.14	0.56
(RP) Health risks for yourself	**0.79**	−0.14	−0.19	0.68
(RP) Health risks for future generations	**0.83**	−0.17	−0.17	0.75
(RP) Damage of the environment because of the repository (hazardous waste site)	**0.82**	−0.22	−0.15	0.75
(RP) Release of nuclear materials (toxic materials) into groundwater due to leakage of a container	**0.80**	−0.17	−0.02	0.67
(RP) Unintentional recovery of the repository (hazardous waste site) by future generations	**0.73**	−0.09	−0.18	0.58
(RP) Economic losses because of image loss in the region	**0.66**	−0.04	−0.24	0.49
(BP) Establishment of additional workplaces	−0.25	**0.70**	0.13	0.57
(BP) Advancement of regional infrastructure	−0.18	**0.74**	0.16	0.61
(BP) Lower taxes for residents	−0.04	**0.74**	−0.05	0.55
(BP) Economic impulses for local businesses	−0.17	**0.80**	0.09	0.68
(BP) Promotion of sustainability projects in the region	−0.08	**0.66**	0.10	0.46
(PAC) In transport accidents, nuclear waste (hazardous waste) is released	−0.17	0.18	**0.81**	0.72
(PAC) Due to leakage of a container, nuclear materials (toxic materials) are released into groundwater	−0.15	0.17	**0.86**	0.79
(PAC) The repository (waste site) has been recovered unintentionally by future generations	−0.23	0.13	**0.82**	0.74
(PAC) The region suffers from economic losses because of image loss	−0.18	−0.05	**0.70**	0.53

Notes: Question for RP and BP items reads: ‘How strongly do you associate a nuclear waste repository (or a hazardous waste site) with these issues?’ Responses were given on a seven-point scale while one indicated ‘not at all’ and seven ‘very strongly’. Question for PAC items reads: ‘Safety of a nuclear waste repository (or hazardous waste site) has top priority in Switzerland, but that at the same time no one can guarantee 100% safety. Please indicate how well society will be able to manage the consequences of the following situations’. Responses were given on a seven-point scale while one indicated ‘very badly’ and seven ‘very well’.

difference in means is not statistically significant, $t(298) = 1.92$, $p = .06$, $r = .11$. (two-tailed). Furthermore, participants perceive significantly fewer benefits, $t(298) = 2.63$, $p < .01$, $r = .15$ (two-tailed) and less adaptive capacity $t(298) = 2.73$, $p < .01$, $r = .16$ (two-tailed) in the nuclear waste condition compared to those of the hazardous waste condition. Due to the relatively large sample size, it is important to consider the effect sizes r (according to Rosnow and Rosenthal 2003), which are all rather small.

Table 3. RP, BP, PAC, and acceptance (Acc) for nuclear waste or hazardous waste, mean values and standard deviations (in parentheses). Scale ranges from one to seven; seven indicates perception of high risks, high benefits, high adaptive capacity, and high acceptance $N = 300$; $n_{\text{nuclear}} = 147$; $n_{\text{hazardous}} = 153$.

	RP *M* (SD)	BP *M* (SD)	PAC *M* (SD)	Acc *M* (SD)
Nuclear waste (*n* = 147)	4.99 (1.52)	3.20 (1.32)	2.38 (1.21)	2.61 (1.87)
Hazardous waste (*n* = 153)	5.04 (1.16)	3.59 (1.23)	2.76 (1.15)	3.01 (1.74)

Exploration of the role of PAC in the acceptance of contested infrastructure

To explore whether PAC can explain a share of variance in acceptance that cannot be explained by perceived risk and benefit alone, we calculated hierarchical linear regression models for nuclear waste and hazardous waste separately. In a first step, we included RP and BP as predictors in the regression analysis. In a second step, we entered PAC to examine whether this predictor could explain an additional share of variance in acceptance. Table 4 displays the results of the two analyses for nuclear waste and hazardous waste.

Including only RP and BP in the regression models to predict acceptance of a nuclear waste repository or hazardous waste site reveals that both perceived risks and benefits significantly predict acceptance. Together they explain 35% of variance in acceptance for the issue of nuclear waste and 26% of variance for the issue of hazardous waste. As one can expect, RP is a stronger (negative) predictor for acceptance of both issues, in particular for the issue of nuclear waste.

PAC has a similar positive effect on acceptance of a nuclear waste repository and a hazardous waste site. For both waste types, the inclusion of PAC explains a significant additional share of variance in acceptance resulting in higher explained

Table 4. Hierarchical linear regression models for acceptance of a nuclear waste repository or a hazardous waste site, respectively $N = 300$; $n_{\text{nuclear}} = 147$; $n_{\text{hazardous}} = 153$.

	Nuclear waste			Hazardous waste		
	B	SE *B*	*β*	*B*	SE *B*	*β*
Step 1						
Constant	5.06	0.69		5.14	0.76	
Risk perception	−0.63	0.09	−0.51***	−0.64	0.11	−0.42***
Benefit perception	0.21	0.11	0.15*	0.30	0.10	0.21**
Step 2						
Nuclear waste: ΔR^2 = .06***						
Hazardous waste: ΔR^2 = .05***						
Constant	3.70	0.75		3.38	0.92	
Risk perception	−0.50	0.09	−0.41***	−0.49	0.12	−0.33***
Benefit perception	0.12	0.10	0.09	0.30	0.10	0.21**
Perceived adaptive capacity	0.44	0.11	0.28***	0.37	0.11	0.24**

Notes: For nuclear waste: Corrected $R^2 = .35$ for Step 1 ($p < .001$); $\Delta R^2 = .06$ for Step 2 ($p < .001$). For hazardous waste: Corrected $R^2 = .26$ for Step 1 ($p < .001$); $\Delta R^2 = .05$ for Step 2 ($p < .01$).
*$p < .05$.
**$p < .01$.
*** $p < .001$.

variances (nuclear waste: 41%, hazardous waste: 31%). This indicates that PAC is an important additional factor in decisions regarding acceptance of a nuclear waste repository or a hazardous waste site. Compared to hazardous waste, perceived benefits seems to be a rather weak predictor for acceptance of a nuclear waste repository, and its influence even decreases if PAC is included in the regression.

Mechanisms of adaptive capacity

Visual inspection of Table 5 indicates that participants seem more confident that future societies will be able to manage negative consequences of hazardous waste than those of nuclear waste. Mechanisms enhancing management participants most strongly agreed upon were individual behavior of inhabitants for the issue of nuclear waste and technological progress for the issue of hazardous waste. Mechanisms hindering management that participants most strongly agreed upon were economic crises for the issue of hazardous waste and political crises for both issues. Compared to participants in the hazardous waste condition, participants in the nuclear waste conditions agreed less that well-organized crisis management by public authorities, $t(298) = 2.89,\ p < .01,\ r = .17$ (two-tailed) or technological progress $t(294.98) = 5.05,\ p < .001,\ r = .28$ (two-tailed), will provide future societies with abilities to overcome the challenges. Compared to the participants in the hazardous waste condition, participants in the nuclear waste condition also rather think that political crises would hinder future societies to overcome the challenges $t(298) = 3.23,\ p < .01,\ r = .18$. All the other group differences are not statistically significant.

Table 5. Mechanisms of adaptive capacity, mean values, and standard deviations (in brackets) for the total sample. Scale ranges from one to seven, one indicating 'I do not agree at all' and seven 'I agree strongly' $N = 300$; $n_{\text{nuclear}} = 147$; $n_{\text{hazardous}} = 153$.

Items	Nuclear waste *M* (SD)	Hazardous waste *M* (SD)	*t*-value
Society will probably be able to manage such a challenge because of the well-organized crisis management of public authorities	3.22 (1.64)	3.76 (1.55)	2.89**
The crisis will probably be managed because affected inhabitants will change their habits or move away	4.14 (1.75)	3.95 (1.53)	1.01
Because of technological progress, society will probably be able to manage such a challenge	3.63 (1.76)	4.59 (1.52)	5.05***
Because of a political crisis, the nation states of today do not exist anymore, this is why society probably won't be able to manage such a challenge	4.36 (1.81)	3.71 (1.64)	3.23**
The knowledge about nuclear waste (hazardous waste) was lost, this is why society probably won't be able to manage such a challenge	3.24 (1.89)	3.03 (1.76)	0.99
Because of an economic crisis, the society lost all its money and probably won't be able to manage such a challenge	3.80 (1.78)	3.69 (1.61)	0.60

**$p < .01$ (two-tailed).
***$p < .001$ (two-tailed).

Discussion

The goal of this study was to examine the role of PAC in the context of individual decisions regarding contested infrastructure. Research on such decisions predominantly focuses on the perception of risks and benefits as important aspects for acceptance or rejection (e.g. Bord and O'Connor 1992; Drottz-Sjöberg 2010). We aim at contributing to this line of research by including a future-oriented perspective. In our view, adaptive capacity, a construct up to now mainly applied in climate research and ecology, has the potential to contribute to this area. In our study, we applied the concept of PAC to the issues of nuclear and hazardous wastes. This concept extends the notion of risk and transfers it to the notion of vulnerability.

Our analyses demonstrate that PAC can be considered as a separate psychological construct. PAC explains a significant additional share of variance in the acceptance of a nuclear waste repository or hazardous waste site in addition to RP and BP. This indicates that individual decision processes about contested infrastructure projects such as hazardous wastes sites or nuclear waste repositories are not only characterized by trade-offs between perceived risks and benefits, but that people also consider how societies today and in the future may be able to manage the potential negative consequences of such infrastructures.

Of course, we are aware that especially in the case of nuclear waste, a decision process is not only characterized by risk and benefit considerations; procedural fairness (Krütli et al. 2012), the site selection process in general (Stern and Fineberg 1996; Krütli et al. 2010b), trust (Siegrist, Gutscher, and Earle 2005), and attitudes toward nuclear power (Sjöberg 2004) play additional important roles. The focus of this study, however, lies on a contribution to RP research, as this approach still represents a very dominant line of investigation in social scientific studies about contested infrastructure.

Our data also indicates what mechanisms participants consider to be drivers of PAC. The most popular strategy to handle negative consequences of nuclear waste is individual behavior, e.g. leave a contaminated region (as e.g. in Tschernobyl or Fukushima). In contrast, for negative consequences of hazardous waste, participants expect that technological progress will help future societies to manage negative consequences. Most participants do not seem concerned that relevant knowledge about nuclear waste or hazardous waste could be lost over such timescales. This seems interesting as studies about permanent markers of deep geological repositories often pick this problem out as a central theme (e.g. Buser 2010).

Our study yields insights about the role of PAC in decisions about nuclear or hazardous waste disposal. However, what can we learn for other contested infrastructure projects? The patterns observed in the regression analyses reveal similar patterns for both waste types. This indicates that PAC might be a construct that is relevant for decisions about contested infrastructure on a more general level. However, we still need to keep in mind that the manipulation check shows that many participants in the hazardous waste group also considered nuclear waste while responding to the questions. Furthermore, participants' responses to the scales measuring RP and BP, PAC, and acceptance are comparable in both waste groups and even though most of the differences reached statistical significance, these effects are only small (all effect sizes $r < .17$). Our investigation on mechanisms of adaptive capacity also indicates that participants distinguish between different infrastructure projects. To know more about a potential generalization of the concept of PAC to other issues, it is therefore necessary to include further contested infrastructure projects such as deep geothermal, nuclear power plants, gas-fired power plants, dams, wind power, or CCS.

A critical issue concerns the measurement of PAC. In our study, PAC was measured as the expected managing abilities of future societies regarding four specific threats (transport accident, groundwater contamination, unintentional recovery, and economic losses), where a negative consequence already occurred. One could argue that adaptive capacity would also entail the ability to prevent such negative events from occurring at all. This aspect has not been included in our study. We rather focused on coping capacity, i.e. the capacity to react to a negative event directly (Peltonen 2006). For future studies, it would be interesting to examine PAC in a broader form by examining the expected capacity of societies to prevent negative events from occurring. In order to capture the dynamic aspect of PAC more precisely, future studies could also use panel designs where participants are surveyed more than once. Furthermore, future studies should also investigate if and how individuals today expect future societies to go through learning processes after a negative event to prevent further negative events from occurring.

Conclusions

Conceptualizing risks in a decision-theoretic framework (Scholz, Blumer, and Brand 2012) means that we are not just looking at the exposure to losses which emerge from a risk situation, but that we are at least partly incorporating the capability of an exposed human system to actively manage them. Therefore, societal learning processes as well as organizational and technological development over time are crucial, in particular with respect to long-term risks like the disposal of nuclear or hazardous waste. In our view, this dynamic perspective should be given more consideration in RP research. From the results of this study, we conclude that PAC plays an important role in individual decision-making regarding such infrastructures.

In order to better understand decision processes about contested infrastructure, future research should consider and examine PAC as an important, dynamic factor to complement the predominant focus on (static) RP. This in particular is important as decision-making processes about contested infrastructures are ongoing in Switzerland (e.g. finding a site for a nuclear waste repository). Furthermore, not only Switzerland but also other countries face a major energy transition after having decided to phase out nuclear energy production as a result of the accident at the Japanese Fukushima Daiichi nuclear power plant in March 2011. Moreover, debates about constructing potentially contested energy infrastructures such as combined cycle power plants, including CCS, deep geothermal, and hydropower are becoming ever more widespread.

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References

Adger, W. N. 2006. "Vulnerability." *Global Environmental Change-Human and Policy Dimensions* 16: 268–281.

Alberini, A., A. Chiabai, and L. Muehlenbachs. 2006. "Using Expert Judgment to Assess Adaptive Capacity to Climate Change: Evidence from a Conjoint Choice Survey." *Global Environmental Change-Human and Policy Dimensions* 16: 123–144.

BFS. 2013. *Gleichstellung von Frau und Mann – Daten, Indikatoren: Bildungsstand* [Gender Equality – Data, Indicators: Education Levels]. Accessed February 7, 2014. http://www.bfs.admin.ch/bfs/portal/de/index/themen/20/05/blank/key/gleichstellung_und/bildungsstand.html

BFS. 2014a. *Bevölkerung: Die wichtigsten Zahlen* [Population: The Most Important Figures]. Accessed February 7, 2014. http://www.bfs.admin.ch/bfs/portal/de/index/themen/01/01/key.html

BFS. 2014b. *Familien, Haushalte – Daten, Indikatoren: Privathaushalte nach Haushaltstyp*, 2011 [Families, Households – Data, Indicators: Private Households according to Household Type, 2011]. Accessed February 7, 2014. http://www.bfs.admin.ch/bfs/portal/de/index/themen/01/04/blank/key/haushaltstypen.html

Böhm, G., and H.-R. Pfister. 2005. "Consequences, Morality, and Time in Environmental Risk Evaluation." *Journal of Risk Research* 8: 461–479.

Boholm, Å. 2004. "Editorial: What Are the New Perspectives on Siting Controversy?" *Journal of Risk Research* 7: 99–100.

Bord, R. J., and R. E. O'Connor. 1992. "Determinants of Risk Perceptions of a Hazardous Waste Site." *Risk Analysis* 12: 411–416.

Buser, M. 2010. *Literaturstudie zum Stand der Markierung von geologischen Tiefenlagern* [State of the Art Literature Review Regarding the Implementation of Markers of Geological Repositories]. Ittigen: Bundesamt für Energie.

Chung, J. B., and H.-K. Kim. 2009. "Competition, Economic Benefits, Trust, and Risk Perception in Siting a Potentially Hazardous Facility." *Landscape and Urban Planning* 91: 8–16.

Drottz-Sjöberg, B.-M. 2010. "Perceptions of Nuclear Wastes across Extreme Time Perspectives." *Risk, Hazards & Crisis in Public Policy* 1: 231–253.

Finucane, M. L., A. Alhakami, P. Slovic, and S. M. Johnson. 2000. "The Affect Heuristic in Judgments of Risks and Benefits." *Journal of Behavioral Decision Making* 13: 1–17.

Fischhoff, B., P. Slovic, S. Lichtenstein, S. Read, and B. Combs. 1978. "How Safe is Safe Enough? A Psychometric Study of Attitudes towards Technological Risks and Benefits." *Policy Sciences* 9: 127–152.

Fishburn, L. 1982. *The Foundations of Expected Utility*. Dordrecht: Reidel.

Flüeler, T. 2006. *Decision Making for Complex Socio-technical Systems: Robustness from Lessons Learned in Long-term Radioactive Waste Governance*. Dordrecht: Springer.

Flüeler, T. 2010. *Modul 3: Nuklearabfall im Vergleich mit Sonderabfall: Umgang und Wahrnehmung. Systemstudie, Teil 1* [Module 3: Nuclear Waste Compared to Hazardous Waste: Handling and Perception. System Study, Part 1]. Zürich: ETH Zürich.

Folke, C. 2006. "Resilience: The Emergence of a Perspective for Social–ecological Systems Analyses." *Global Environmental Change-Human and Policy Dimensions* 16: 253–267.

Grothmann, T., and A. Patt. 2005. "Adaptive Capacity and Human Cognition: The Process of Individual Adaptation to Climate Change." *Global Environmental Change-Human and Policy Dimensions* 15: 199–213.

Krütli, P., T. Flüeler, M. Stauffacher, A. Wiek, and R. W. Scholz. 2010a. "Technical Safety vs. Public Involvement? A Case Study on the Unrealized Project for the Disposal of Nuclear Waste at Wellenberg (Switzerland)." *Journal of Integrative Environmental Sciences* 7: 229–244.

Krütli, P., M. Stauffacher, T. Flüeler, and R. W. Scholz. 2010b. "Functional-dynamic Public Participation in Technological Decision Making: Site Selection Processes of Nuclear Waste Repositories." *Journal of Risk Research* 13: 861–875.

Krütli, P., M. Stauffacher, D. Pedolin, C. Moser, and R. W. Scholz. 2012. "The Process Matters: Fairness in Repository Siting for Nuclear Waste." *Social Justice Research* 25: 79–101.

Kuruppu, N., and D. Liverman. 2011. "Mental Preparation for Climate Adaptation: The Role of Cognition and Culture in Enhancing Adaptive Capacity of Water Management in Kiribati." *Global Environmental Change-Human and Policy Dimensions* 21: 657–669.

Lima, M. L. 2004. "On the Influence of Risk Perception on Mental Health: Living near an Incinerator." *Journal of Environmental Psychology* 24: 71–84.

McCarthy, J., O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White. 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the IPPC*. Cambridge, MA: Intergovernmental Panel on Climate Change.

Moser, C., M. Stauffacher, P. Krütli, and R. W. Scholz. 2012. "The Crucial Role of Nomothetic and Idiographic Conceptions of Time: Interdisciplinary Collaboration in Nuclear Waste Management." *Risk Analysis* 32: 138–154.

Moser, C., M. Stauffacher, T. Smieszek, R. Seidl, P. Krütli, and R. W. Scholz. 2013. "Psychological Factors in Discounting Negative Impacts of Nuclear Waste." *Journal of Environmental Psychology* 35: 121–131.

Nagra. 2002. *Project Opalinus Clay. Safety Report: Demonstration of Disposal Feasibility of Spent Fuel, Vitrified High-level Waste and Long-lived Intermediate-level Waste. NTB 02-05*. Wettingen: Nagra.

NRC. 2003. *One Step at a Time: The Staged Development of Geologic Repositories for High-level Radioactive Waste*. Washington, DC: National Academies Press.

Peltonen, L. 2006. *Coping Capacity and Adaptive Capacity. Centre for Urban and Regional Studies*. Helsinki: Helsinki University of Technology.

Reiner, D. M., and W. J. Nuttall. 2011. "Public Acceptance of Geological Disposal of Carbon Dioxide and Radioactive Waste: Similarities and Differences." In *Geological Disposal of Carbon Dioxide and Radioactive Waste: A Comparative Assessment*, edited by F. L. Toth, 295–315. Dordrecht: Springer.

Rosnow, R. L., and R. Rosenthal. 2003. "Effect Sizes for Experimenting Psychologists." *Canadian Journal of Experimental Psychology* 57: 221–237.

Scholz, R. W. 2011. *Environmental Literacy in Science and Society: From Knowledge to Decisions*. Cambridge: Cambridge University Press.

Scholz, R. W., Y. B. Blumer, and F. Brand. 2012. "Risk, Vulnerability, Robustness, and Resilience from a Decision-theoretic Perspective." *Journal of Risk Research* 15: 313–330.

Scholz, R. W., and M. Siegrist. 2010. "Low Risks, High Public Concern? The Cases of Persistent Organic Pollutants (POPs), Heavy Metals, and Nanotech Particles." *Human and Ecological Risk Assessment* 16: 185–198.

Seidl, R., C. Moser, M. Stauffacher, and P. Krütli. 2013. "Perceived Risk and Benefit of Nuclear Waste Repositories: Four Opinion Clusters." *Risk Analysis* 33: 1038–1048.

SFOE (Swiss Federal Office of Energy). 2008. *Sectoral Plan for Deep Geological Repositories: Conceptual Part*. Bern: Department of the Environment, Transport, Energy and Communications (DETEC).

Siegrist, M., H. Gutscher, and T. C. Earle. 2005. "Perception of Risk: The Influence of General Trust, and General Confidence." *Journal of Risk Research* 8: 145–156.

Sjöberg, L. 2004. "Local Acceptance of a High-level Nuclear Waste Repository." *Risk Analysis* 24: 737–749.

Sjöberg, L., and B.-M. Drottz-Sjöberg. 2009. "Public Risk Perception of Nuclear Waste." *International Journal of Risk Assessment & Management* 11: 248–280.

Slovic, P., M. L. Finucane, E. Peters, and D. G. MacGregor. 2004. "Risk as Analysis and Risk as Feelings: Some Thoughts about Affect, Reason, Risk, and Rationality." *Risk Analysis* 24: 311–322.

Smit, B., I. Burton, R. J. T. Klein, and R. Street. 1999. "The Science of Adaptation: A Framework for Assessment." *Mitigation and Adaptation Strategies for Global Change* 4: 199–213.

Smit, B., and J. Wandel. 2006. "Adaptation, Adaptive Capacity and Vulnerability." *Global Environmental Change-Human and Policy Dimensions* 16: 282–292.

Stauffacher, M., P. Krütli, and R. W. Scholz, eds. 2008. *Gesellschaft und radioaktive Abfälle. Ergebnisse einer schweizweiten Befragung* [Society and Radioactive Waste: Results of a Survey in Switzerland]. Zürich: Rüegger.

Stern, P. C., and H. F. Fineberg, eds. 1996. *Understanding Risk: Informing Decisions in a Democratic Society*. Washington, DC: National Academies Press.
Strandberg, U., and M. Andrén. 2009. "Editorial: Nuclear Waste Management in a Globalised World." *Journal of Risk Research* 7–8: 879–895.
Svenson, O., and G. Karlsson. 1989. "Decision-Making, Time Horizons, and Risk in the Very Long-term Perspective." *Risk Analysis* 9: 385–399.
Whitfield, S. C., E. A. Rosa, A. Dan, and T. Dietz. 2009. "The Future of Nuclear Power: Value Orientations and Risk Perception." *Risk Analysis* 29: 425–437.

Appendix 1. Descriptions of waste types (taken from Moser et al. 2013)

Nuclear waste is a material whose radiation is higher than background radiation (e.g. cosmic background radiation). Nuclear waste is produced in nuclear power plants, in medicine, research, and industry. In Switzerland, there is a differentiation between low-level and high-level waste based on the half-life of radioactive decay. A deep geological repository is a concept for the long-term storage of nuclear waste, including limited monitoring and retrievability. Such repositories are planned to be built 500–1000 meters below the surface. The disposal of nuclear waste is a technical challenge and it is possible that containers will start to leak over time.

Hazardous waste is a material that has to be collected separately and that has to be disposed off in a controlled manner. These are highly toxic or environmentally harmful substances that require special technical and organizational measures in their disposal. Households, business, and industry produce hazardous waste. Some examples are: batteries, neon tubes, heavy metals, mixes of mineral oils, sludges-containing metal, filter ash from waste incineration, and so on. Hazardous waste is stored in disposal sites at the surface of old mines. The disposal of hazardous waste is a technical challenge and it is possible that a disposal site will start to leak over time.