ON THE UNDERSTANDING AND PROCESSING OF EXTENSIVE TIMESCALES:
THE LONG-TERM DIMENSION OF NUCLEAR WASTE

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Summary

Many countries in the world, among them Switzerland, produce nuclear waste in nuclear power plants and in medical, industrial or research processes. Disposing of these wastes is challenging on a technical level but also on a societal level. One reason for this are the extensive timescales required to dispose of nuclear waste due to the hazardous potential of these wastes over time. Technical experts consider timescales of up to one million years for high-level wastes to be kept isolated from humans and the environment. This not only poses a challenge on a technical level, but also on the societal level, as such timescales lie clearly beyond mankind’s horizon of experience. On a technical level, experts deal with such timescales by the means of the safety case, a set of arguments and analyses as to why the safe storage of nuclear waste in the long run appears plausible. However, on the societal side there is as yet a lack of research on how people understand and deal with such timescales. The guiding questions of this thesis are i) how are extensive timescales understood in the context of nuclear waste disposal? and ii) how is temporal information integrated in judgments about nuclear waste?

Time is a multifaceted concept. This thesis approaches the issue of time and nuclear waste from different perspectives and by the use of different social scientific research methods. Four research contributions aim to answer the aforementioned guiding questions. The basis of all these contributions is an investigation of the conception of time within the technical safety assessment (safety case) in order to better understand the issue at hand as well as how technical and geological experts of nuclear waste disposal understand and manage the timescales involved.

The first paper uses qualitative interviews to examine how experts for long-term phenomena from different disciplines understand extensive timescales in general and also with respect to nuclear waste. With regard to extensive timescales, experts from the social sciences and humanities referred to the complex development of societies and to rapid technological developments. Hence, they tended to understand time as undetermined in the sense that at least societal developments are not predictable in the long run. On the other hand, natural scientists more strongly referred to cycles and natural laws and, hence, tended to understand time as determined in the sense that some processes can be predicted in the long run. Based on these different understandings, we discuss the potential safety-relevance of non-technical contributions to the safety assessment of nuclear waste disposal.

The second paper refers to the two classical linear and cyclical temporal representations and tests how such representations affect risk perception of nuclear waste in a classical experimental setting. Linear and cyclical representations as activated by a priming procedure both had a lessening effect on risk perception of nuclear waste, in particular if participants were still ambivalent about their opinion regarding nuclear waste. It is possible that temporal representations reduce complexities, increase perceived predictability of processes, and hence, reduce perceived risks of a nuclear waste repository.

The third paper takes a closer look at the influence of temporal distance on the perceived seriousness of a negative consequence (leak) of a nuclear waste repository. An online experiment, based on the discounting approach, tests how temporal scales used (up to 4000 years, up to 1 million years) and response scales affect participants’ seriousness judgments over time and at the same time assesses psychological factors motivating discounting. Surprisingly, participants’ seriousness judgments reflect sensitivity toward different future timescales. Furthermore, mainly
two psychological factors have been found to drive discounting: perceived adaptive capacity and emotional involvement with future generations.

The fourth paper focuses on the role of the perceived adaptive capacity of future societies in decisions regarding a nuclear waste repository or a hazardous waste site. In this online experiment, time is not operationalized directly as in the previous experiments but, rather, indirectly in the sense of expected societal dynamics (e.g., learning processes, technological development) over time. Perceived adaptive capacity (i.e., the expectation that societies will undergo learning processes and will be better able to deal with future challenges) has been shown to be an important component in individual decision-making regarding a nuclear waste repository or a hazardous waste site.

Conclusions inter alia include i) the integration of potentially safety-relevant contributions from non-technical communities into the safety assessment of nuclear waste, ii) the importance of graphic representations of time for risk communication on nuclear waste, iii) the need for further research on applying the discounting paradigm to long-term issues such as nuclear waste, iv) the need for further examination of the concept of perceived adaptive capacity, i.e. examining how people expect societies to develop over time. On a more general level, this thesis concludes that the recognition of temporal dimensions of environmental decisions is a major component of sustainability learning. With respect to nuclear waste this means recognizing other temporal scales involved, e.g., the time taken by a societal decision making process (about a decade in Switzerland), the time needed until a repository is built (at least three decades for a high-level waste repository), and the time needed until the repository is finally sealed and closed. These timescales are very short compared to the million year timescale, yet they are very long from a societal perspective, bearing the potential for unexpected events or transformations while the nuclear wastes are not yet disposed of in a deep geological repository but held in interim storage on the surface.
Zusammenfassung


Der zweite Beitrag testet in einem psychologischen Experiment, wie zwei klassische zeitliche Repräsentationen (linear und zyklisch) die Risikowahrnehmung von radioaktiven Abfällen beeinflussen. Wenn eine lineare oder zyklische zeitliche Repräsentation aktiviert wurde (durch ein Primingverfahren) nahmen die Teilnehmenden weniger Risiken wahr, insbesondere wenn sie eine ambivalente Haltung gegenüber radioaktiven Abfällen hatten. Es ist daher denkbar, dass graphische Repräsentationen von Zeit Komplexität reduzieren, die wahrgenommene Vorhersagbarkeit von Prozessen erhöhen, und dadurch weniger Risiken von radioaktiven Abfällen wahrgenommen werden.
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Der dritte Beitrag untersucht den Einfluss von zeitlicher Distanz auf die Beurteilung einer negativen Konsequenz von radioaktiven Abfällen (Leckstelle im Lager). Ausgehend vom Diskontierungsansatz erforschen wir in einem Online Experiment, wie die verwendeten Zeitskalen (bis zu 4000 Jahren vs. bis zu 1 Million Jahren) und die Antwortenkalen (diskret vs. kontinuierlich) die Beurteilungen der Leckstelle über die Zeit hinweg beeinflussen. Zusätzlich erfassten wir psychologische Faktoren, die hinter der Diskontierung stehen. Erstaunlicherweise reagierten die Teilnehmenden sensitiv gegenüber den verwendeten Zeitskalen. Insbesondere zwei psychologische Faktoren scheinen hinter der Diskontierung zu stehen, nämlich wahrgenommene (gesellschaftliche) Anpassungsfähigkeit von zukünftigen Gesellschaften und der emotionale Bezug zu zukünftigen Generationen.


Schlussfolgerungen beinhalten (unter anderem) i) die Integration von potentiell sicherheitsrelevanten Beiträgen von nicht-technischer Seite in die Sicherheitsanalysen radioaktiver Abfälle, ii) die Wichtigkeit graphischer Repräsentation von Zeit in der Risikokommunikation über radioaktive Abfälle, iii) die Wichtigkeit von zukünftiger Forschung zur Anwendbarkeit des Diskontierungsparadigmas bei langfristigen Themen wie radioaktiven Abfällen und iv) die Wichtigkeit zukünftiger Forschung zum Konzept der wahrgenommenen Anpassungsfähigkeit. Auf allgemeiner Ebene wird geschlussfolgert, dass das Erkennen der zeitlichen Dimensionen von Umweltentscheidungen eine wichtige Komponente von Nachhaltigkeitslernen ist. Im Bezug auf radioaktive Abfälle bedeutet das, dass auch andere Zeitskalen erkannt werden, beispielsweise die Zeit des gesellschaftlichen Entscheidungsprozesses (ungefähr ein Jahrzehnt in der Schweiz), die Zeit bis ein geologisches Tiefenlager gebaut ist (mindestens drei Jahrzehnte für ein Lager für hochaktive Abfälle), und die Zeit bis das Lager versiegelt und verschlossen wird. Diese Zeitskalen sind sehr kurz im Vergleich zur Million Jahre, aber aus einer gesellschaftlichen Perspektive sind sie trotzdem enorm. In diesen Zeiträumen können unerwartete Ereignisse und Prozesse geschehen, während die Abfälle noch nicht in einem geologischen Tiefenlager entsorgt sind, sondern auf der Erdoberfläche zwischengelagert sind.
Some remarks

This thesis is a cumulative thesis consisting of four research papers already published or to be published in peer-reviewed journals connected by a common introduction and conclusions. The four papers were all written by several authors and, for the sake of consistency, the personal pronoun ‘we’ is used throughout this thesis, even in the introduction and conclusion, which were written by myself.

For the same reason, slight changes have been made to the four papers (e.g., numbering of the titles). However, the content, numbering of Figures and Tables as well as the citation style are the same as in the published version, except for the last two papers that have not been published yet and will most likely be adapted during the peer review process.

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“An abstract, intellectual understanding of deep time comes easily enough – I know how many zeroes to place after the 10 when I mean billions. Getting it into the gut is quite another matter” (Gould, 1987, p. 3).

1 Introduction

1.1 Time and nuclear waste: What is the problem?

For decades, many countries have been accumulating nuclear wastes resulting from electricity production, medical apparatus, industries and research. Up to now, no country worldwide has yet constructed a deep geological repository, which however is the preferred disposal option for high-level wastes among international experts (IAEA, 1995, 2003). Nuclear waste imposes a challenge for societies both from a technical perspective but also from a societal perspective. From a technical point of view, questions like finding an adequate host rock for a repository and choosing the most appropriate technical barriers (e.g., copper or steel canisters) are challenging. Finding a societally acceptable solution for the waste problem represents a societal challenge. Nuclear waste can therefore be considered a so-called socio-technical problem (Flüeler, 2006).

One particular characteristic of nuclear waste causing difficulties from societal as well as from technical perspectives is the extreme timescales inherent in the issue. Experts are considering timescales of up to one million years for the disposal of high-level wastes and spent fuel (Nagra, 2002b, 2002a). This refers to potential hazards posed by a release of radionuclides for a very long period of time as indicated by the radioactive half-lives (e.g., $^{239}$Pu = 24'110 years). This, in turn, has serious implications for the technical and geological disposal concept. On the societal side, these timescales create challenges as well: In a survey in Switzerland (Nagra, 2002b), participants on average indicated that they are more concerned about future generations when they think about nuclear waste than they are about themselves, their families, or their living space (Stauffacher, Krütli, & Scholz, 2008). Some participants in the survey also added comments in which they mentioned the timescales involved, for example (Stauffacher et al., 2008, p. 51):

"Ich hoffe, dass wir wirklich eine Lösung finden, die auch spätere Generationen mittragen können." [I hope that we really find a solution that subsequent generations can also go along with].

Furthermore, in interviews on values and opinions regarding nuclear waste in a project conducted for the Swiss Federal Office of Energy (Seidl, Moser, Krütli, & Stauffacher, 2011), some participants mentioned the extensive timescales. To illustrate their thoughts, some statements are printed below (English translation in brackets):

"Die Sicherheit ist sehr wichtig. Ich bin einfach ein bisschen kritisch, weil es sich um Zeiträume handelt, die wir nicht abschätzen können. Es ist ein wenig eine Scheinsicherheit." [Safety is very important. I am just a bit skeptical because the issue concerns timescales we cannot estimate. It is a kind of pseudo safety]. (IH17)

"Wenn wir schauen, was nur schon in den letzten 10 Jahren passiert ist, seien es Erdbeben, Wetter oder so. Wir können doch einfach nicht sagen, was in dieser riesigen Zeitspanne von

---

1 The most advanced project is located in Olkiluoto, Finland, where a deep geological repository is currently under construction.
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100,000 Jahren alles passieren kann.” [If we only look at what has happened during the last ten years, be it earthquakes, the weather or so on. We cannot tell what might occur in this huge timeframe of a hundred thousand years]. (IaM7)

“Die Halbwertszeiten sind immens! In 2000 Jahren ist die Sprache eine andere, ich frage mich, ob die unsere Unterlagen verstehen werden.” [The half-lives are immense! In 2000 years, the language will be different, I wonder if they will understand our documents]. (IB14)

The extensive timescales also shape public discourse about nuclear waste and they are used by Swiss NGOs (for example Schweizerische Energiestiftung, SES) as an argument against a nuclear waste repository. Figure 1 displays some screenshots of an animated internet campaign where SES picks out possible negative consequences of a nuclear waste repository over time as a central theme (e.g., starting after construction and filling the repository (here: year 2050), they display negative consequences of a borehole penetration, a repository leak, and glaciation).

Figure 1. Screenshots of an animated internet campaign by SES: Possible negative consequences of a nuclear waste repository over time (SES, 2012).

Finally, the extensive timescales pose challenges for establishing a concept of permanent markers of the repository to communicate information about the site to future generations (Buser, 2010; United States Department of Energy, 2004).

1.2 Guiding questions

On a technical level, experts deal with these challenges using the so-called safety case, a set of sound technical and geological arguments and analyses demonstrating the plausibility of the long-term safe storage of nuclear waste (for Switzerland, see Nagra, 2002b, 2002a, 2002c; Junker, Flüeler, Stauffacher, & Scholz, 2008). However, on the societal level a comprehensive research project on the public’s understanding and management of such timescales does not yet exist. The goal of this PhD thesis is to take a closer look at the long-term dimension of nuclear waste from a social scientific perspective. The corresponding guiding questions are:

- How are extensive timescales understood in the context of nuclear waste disposal?
- How is temporal information integrated in judgments about nuclear waste?

The temporal dimension of nuclear waste disposal represents a complex problem in a coupled socio-technical system comprising not only a complicated technical issue but also various actors, ranging from technical experts to affected communities to societies. Experts in geology, for example, are used to thinking about extensive timescales, which is usually not the case for the general public. But geologists usually examine how geological structures have emerged and developed; hence, they study extensive timescales in the past. However, the issue of nuclear waste disposal requires geologists to project their geological knowledge into the distant future. Managing the uncertainties involved, as well as ignorance, is already a challenge within the

2 The focus of the thesis is on Switzerland and its cultural, political, geological, legal, and organizational setting.
technical and geological community, but even more of a challenge to inform the public about the disposal concept and the extensive timescales involved. To appropriately address the complexity of the issue, and to recognize crucial aspects and perspectives, we therefore utilized a structuring tool for i) analyzing the socio-technical system, ii) identifying relevant research questions, and iii) structuring the thesis in a meaningful way. As a first step, we provide an overview of the human-environment systems (HES) Framework which was utilized for that purpose (Scholz, 2011).

1.3 Research strategy: Starting from a thorough understanding of the issue at hand

The HES Framework represents a structure-process framework for investigating human-environment systems which has its conceptual roots in systems theory and game and decision theory (Scholz, 2011). It is based on seven postulates which assume complementarity between human-environment systems, integrate different societal hierarchical levels (represented by the different layers in Figure 2), including their awareness of the environment, interferences between them and their respective decision rationales and actions and also consider different types of feedback loops. The HES Framework can thus be seen as a comprehensive “methodological guide or template to investigate human-environmental systems” (Scholz, 2011, p. 453). Figure 2 gives an overview of the postulates and the framework.

<table>
<thead>
<tr>
<th>No.</th>
<th>Content of HES Postulate</th>
<th>The HES Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Human and environmental systems are complementary</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>Human and environmental systems both have hierarchical structures</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>There are disruptive interactions among and within different levels of human and environmental systems, in particular between the micro and macro levels</td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>There are different types of feedback loops within and between human and environmental systems</td>
<td></td>
</tr>
<tr>
<td>P5</td>
<td>Human systems can be conceived as decision-makers who have drivers and who act to satisfy goals</td>
<td></td>
</tr>
<tr>
<td>P6</td>
<td>Human systems have different types of environmental awareness</td>
<td></td>
</tr>
<tr>
<td>P7</td>
<td>The effective analysis of inextricably coupled human and environmental systems [...] requires a thorough analysis of the material and social environment that builds the matrix of HES</td>
<td></td>
</tr>
</tbody>
</table>

To understand a complex, socio-technical issue such as the temporal dimension of nuclear waste disposal, a thorough understanding of the issue is prerequisite to being able to identify specific relevant research questions (see HES Postulate 7 in Scholz, 2011; see also Scholz & Tietje, 2002; Brunswik, 1955; Scholz & Stauffacher, 2009). The knowledge of geologists is essential in designing a safe disposal concept for nuclear waste in geological formations over extensive timescales. Their knowledge includes information about how certain geological formations have emerged and developed over extensive timescales. How geologists understand extensive timescales and how they handle them is therefore crucial for their problem understanding of
nuclear waste. As a first step, we therefore conduct a historical analysis of how geologists became aware of extensive timescales and how they understood them in the past. Hence, we do not start from the issue or from the environment directly but rather from how geologists cognitively constructed it and how this cognitive construct developed over time. This means that we take a look at the history of geology, where, after the enlightenment, the age of the Earth increased in geologists’ minds from a few thousand years to millions and billions of years and the “abyss of time” (Albritton, 1980) opened up. As a second step we take a more detailed look at the present concept of nuclear waste disposal in Switzerland with a specific focus on the temporal dimension within the safety case (Nagra, 2002b). This document reveals how the geological and technical community intends to dispose of nuclear waste safely over extensive timescales in the future.

1.3.1 The discovery of geological time

Gould (1987) starts his book “Time’s arrow, time’s cycle: Myth and metaphor in the discovery of geological time” with a short overview of how different sciences have “shattered yet another facet of an original hope for our own transcendent importance in the universe” (Gould, 1987, p. 1). Astronomy has demonstrated that the Earth is not the center of the universe. Biology has demonstrated that humans were not created specially, but descended from animals. Psychology has demonstrated that humans are not (entirely) rational beings and geology has demonstrated that the age of humankind is virtually nothing in contrast to the age of the world. In the following paragraphs, we illustrate some important cornerstones in the discovery of extensive timescales in geology.

The 17th century: The discovery of strata

During the 17th century, European theories about the Earth were strongly framed by religion. Christianity defined fundamental assumptions and also served as a scheme for interpretation (Toulmin, 1975 [1962-1963]). Around 1650, Bishop Ussher calculated that the Earth has been created in 4004 BC based on lineage accounts in the Old Testament (Halliday, 1997). These interpretations were based on scripture, but early geologists also started to investigate geological formations and matters such as fossils. One of them was Niklaus Steno (1638-1687), a Danish doctor living in Tuscany. He recognized that fossils are not ‘lusus naturae’ (freaks of nature) but remains of living things. He also observed that fossils can be found in sediments and critically asked how it had happened that remains of living things became embedded in hard matter. Based on these observations he invented a first theory of stratigraphy and recognized a temporal sequence in geological layers (the principles of superposition of strata, i.e., “in a sequence of sedimentary strata, as originally deposited, any stratum is younger than the stratum upon which it rests and older than the stratum that rests upon it”, Albritton, 1980, p. 34). Unfortunately, Steno’s work was ignored by most researchers at his time (Albritton, 1980; Weissert & Stössel, 2009).

The 18th century: The beginning of modern geology

In the 18th century, Comte de Buffon assumed that the Earth had emerged from a collision between the sun and a comet. In the beginning, the Earth consisted of fluid, i.e., hot matter that slowly began to become solid. It should therefore be possible to estimate the Earth’s age based on its temperature. Comte de Buffon did experiments with fluid metal balls and extrapolated his findings to the size of the Earth. According to his calculations, the Earth was about 100’000 years old (Albritton, 1980). Another theory, put forward by James Hutton, is regarded by many to be the beginning of modern geology. His idea was that the Earth is shaped by large geological cycles of erosion and sedimentation, he thus, “believed that geologic time is virtually infinite in duration” (Albritton, 1980, p. 89).
The 19th century: Catastrophism vs. uniformitarianism

The geological history of the 19th century is characterized by a conflict between catastrophists and uniformitarianists. Catastrophists, for example Georges Cuvier, thought that the surface of the Earth had been shaped by abrupt changes, e.g., flooding. In contrast, uniformitarianists, for example Charles Lyell, thought that the surface of the Earth emerged from continuous, long-term processes like erosion and sedimentation. His basic idea was that geological processes observable today suffice to explain the development of the Earth’s crust if very extensive timescales are given (Albritton, 1980). Hence, enormous developments can be explained by very slow, continuous processes if extensive timescales are considered. This idea also had a tremendous influence on the young Charles Darwin, who read the “Principles of Geology” (Lyell, 1830-1833) on his Beagle expedition and applied it to the development of species. Lord Kelvin pursued an idea similar to that of Buffon by assuming that the Earth is in a continuous cooling process and calculated the age of the Earth to be between 20 and 40 million years. The discovery of radioactivity at the turn of the century allowed for new methods of assessing the age of the Earth. Current radiometric dating methods indicate that the Earth is about 4.6 billion (4'600'000'000) years old (Weissert & Stössel, 2009).

Theories and timescales

This short outline of geological history from the 17th century to the present shows how European geologists’ temporal frame came to stretch from a few thousand to billions of years. This was not a linear process but strongly depended on the available “knowledge concerning the nature of matter in general and of that particular matter available for inspection in the outermost parts of solid earth” (Albritton, 1980, p. 17). It becomes obvious that the theories about the origin of the Earth and its further development strongly influenced the timescales considered. Uniformitarianists assume almost infinite timescales within which continuous, predictable processes occur, while catastrophists conceive shorter timescales with abrupt changes in the system. Those who believe in God’s creation of the Earth assume very short timescales, which indicates that they consider the Earth to be created especially for humans. The extremely important role of radioactivity also becomes obvious: its discovery had groundbreaking consequences for the exploration of the Earth’s age (and of course also that of other materials). Furthermore, the use of radioactive materials in energy production, medicine, research and industry creates nuclear wastes that have to be kept isolated from humans and the environment for very long periods in the future. Thus, one could say that radioactivity, or more precisely humans’ use of radioactivity, opened up enormous timescales both in the past and in the future.

1.3.2 Time and nuclear waste management in Switzerland

Switzerland runs five nuclear power plants at four different sites (Beznau 1, since 1969, 380 megawatt (MW); Beznau 2, since 1971, 380 MW; Mühleberg, since 1972, 380 MW; Gösgen, since 1979, 1035 MW, and Leibstadt, since 1984, 1220 MW) yielding about 40% of total electricity production in Switzerland. These facilities as well as medical apparatus, industry and research produce different types of nuclear wastes: high-level wastes (HLW, spent fuel, vitrified high-level wastes from reprocessing of spent fuel), alpha-toxic waste and low and intermediate level waste (IAEA, 1994). As the subject of this PhD thesis is about extreme timescales, we will in the following focus on high-level wastes only. Assuming an operation time of 50 years, the Swiss nuclear power plants will have produced in total a predicted volume of 7325 m³ of high-level wastes (packaged) (Nagra, 2012, see Table 1). This volume is rather small compared to the volumes of low- and intermediate level wastes. However, high-level wastes are much more active in terms of radioactive decays per second (Bq). In terms of activity, high-level wastes account for 98.3% of the total activity of all radioactive wastes in Switzerland.
Table 1. Predicted nuclear waste inventory for Switzerland after 50 years operation of each nuclear power plant (Nagra, 2012).

<table>
<thead>
<tr>
<th>Low- and intermediate-level waste L/ILW</th>
<th>Alpha-toxic waste ATW</th>
<th>High-level waste HLW including spent fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total volumes (rounded), packaged</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>89,410 m³ (90.3%)</td>
<td>2,280 m³ (2.3%)</td>
</tr>
<tr>
<td>Activity</td>
<td>4.7 \times 10^{17} Bq (1.6%)</td>
<td>3.4 \times 10^{16} Bq (0.1%)</td>
</tr>
</tbody>
</table>

Note: Activity refers to the year 2050.

At the moment, these wastes are stored at the nuclear power plants (as they have to be cooled for several decades) or in interim storage in Würenlingen. Switzerland does not yet have a nuclear waste repository for these wastes. Initial plans to build a nuclear waste repository in central Switzerland (Wellenberg) have failed due to strong local resistance and two negative votes in cantonal referenda in the years 1995 and 2002 (Krütli, Flüeler, Stauffacher, Wiek, & Scholz, 2010; Flüeler, 2006). In 2008, the Swiss Federal Office of Energy (SFOE) established a stepwise participatory process to find a site in Switzerland for two repositories, one for high-level wastes and one for low and intermediate level wastes (SFOE, 2008). While the SFOE organizes the societal decision process, the Swiss Nuclear Energy Act states that producers are responsible for the safe disposal of nuclear wastes, including all preparatory work such as research and geological investigation as well as the provision of a deep geological repository (KEG, 2003, article 31). For this purpose, all Swiss producers of nuclear energy as well as the Swiss Confederation (which is responsible for the disposal of nuclear wastes from research, medicine and industry) constituted Nagra (national cooperative for the disposal of radioactive waste) which can, thus, be considered the implementer.

A safety report by Nagra claiming to demonstrate that the disposal of high-level waste is in principle feasible in Switzerland (Nagra, 2002b, 2002a) was approved by the Swiss Federal Council in 2006. Besides other evidence, this report is based on studies of the sediment layer ‘Opalinus Clay’ in the Zürcher Weinland. This safety report constitutes a key document for Switzerland’s plans for future high-level waste management. It consists of a so-called safety case, which basically is a set of technical as well as geological analyses and arguments as to why the safe storage of nuclear waste over extensive timescales appears plausible. To get a more precise idea of the relevant timescales as well as of how technical experts in nuclear waste management handle them, we take a look at two documents, namely the technical report itself (Nagra, 2002b) as well as a summary of this report (Junker et al., 2008). Due to space limitations, it is not possible to give a comprehensive overview of the whole safety report here. Instead, we focus on its most relevant aspects with respect to time.

**Relevant timescales for the disposal of high-level wastes**

In the report the radiotoxicity indices (RTI)\(^3\) of different nuclear waste types over time are compared with the RTI of natural occurrences of radionuclides in 1 km\(^3\) of Opalinus Clay (OPA) and

\[^{3}\text{The RTI is a measure used to estimate potential health effects following from the ingestion of radioactive materials. It considers the activity of the radionuclides } A_j \text{ at time } t \text{ and their dose coefficient for ingestion } F_j. \\
\text{The RTI is “the hypothetical dose resulting from ingestion of the activity } A_j \text{ at time } t, \text{ divided by } 10^{-4} \text{ Sv (derived from the Swiss regulatory annual dose limit)”}.
\]

\[
RTI(t) = \sum A_j(t) F_j / (10^{-4} \text{ Sv}) \quad (\text{Nagra, 2002b, Appendix 3, C-1}).
\]

The Swiss regulatory annual dose limit is defined by the guideline HSK-R-21 (HSK & KSA, 1993, as of April 2009 ENSI, 2009).
with three uranium ores of different concentrations (3%, 8%, and 55%), each assumed to have the volume of the emplacement tunnels of the planned repository. Figure 3 indicates that after about one million years, the radiotoxicity of spent fuel (SF) has dropped below the level of the radiotoxicity of a natural 3% uranium ore of sufficient volume to fill the tunnels of the repository (Nagra, 2002b). Hence, for this timescale, spent fuel represents a hazard and has to be kept isolated from the biosphere.

**Figure 3.** Radiotoxicity index (RTI) of spent fuel (SF), vitrified high-level waste (HLW) and long-lived intermediate-level waste (ILW) as a function of time (Nagra, 2002b, p. 30). The values can be interpreted as numbers of hypothetical ‘portions’ for ingestion complying with the annual dose limit of $10^{-4}$ Sv in Switzerland resulting from the total volume of SF, HLW, or ILW (see Table 1) (Flüeler, Scholz, Krütli, & Stauffacher, 2007).

The extensive timescales involved are one reason why deep geological repositories are the preferred disposal option among international technical experts (IAEA, 1995, 2003). When considering one million years in the future, technical experts strongly differentiate between the development of the host rock and repository system and the biosphere (NEA, 1999). The development of a well-understood host rock like Opalinus Clay is supposed to be predictable over such timescales, whereas the biosphere clearly is not. With respect to the future development of humans, the report states:

"It is acknowledged that human technology and society will change over the timescales of relevance for repository safety assessment. These changes are unpredictable. To limit speculation, it is assumed that human technological capabilities and societal patterns observed today, and in the past, provide a reasonable model to assess the safety of the repository in the future. Thus, only future human actions that could be undertaken with present-day technology are considered" (Nagra, 2002b, p. 33).

Figure 4 displays the perceived predictability of different environmental systems by the technical community. It becomes obvious that radiological exposure modes (e.g., eating habits or other human behavior patterns) are perceived as being very unpredictable, whereas the host rock and the engineered barrier system (EBS) are perceived as being highly predictable over very long timescales. However, noticing that human activities can be considered to be geological forces (Crutzen, 2002a, 2002b), for example because of land use change, deforestation or the burning of fossil fuels, this assumption might harbor some serious pitfalls.
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Figure 4. Schematic illustration of the limits of predictability of the different elements of a geological disposal system (Nagra, 2002b, p. 32).

The disposal concept of high-level nuclear waste in Switzerland

Due to the extensive timescales, the maintenance and monitoring of surface interim storages of nuclear waste cannot be guaranteed, because these processes require political and economic stability (EKRA, 2000). In accordance with international experts (IAEA, 1995, 2003) disposal of nuclear waste in deep geological repositories (including a monitoring phase during which retrieval of the waste is relatively easy, EKRA, 2000) is the preferred disposal option in Switzerland. Such deep geological repositories should be built in a suitable host rock (crystalline, clay, or salt) several hundred meters deep. In Switzerland, the current focus lies on clay sediments. The disposal concept consists of multiple passive barriers to i) isolate waste from the biosphere, ii) ensure long-term confinement and radioactive decay within the disposal system, and iii) attenuate release of radionuclides to the environment (Nagra, 2002b). This multi-barrier-system consists of steel canisters for spent fuel and vitrified high-level waste, bentonite backfill, and geological barriers provided by the host rock. Key “pillars of safety” (Nagra, 2002b, p. 185) are summarized in Box 1.

Pillars of Safety

The pillars of safety are features of the disposal system that are key to providing the safety functions:

- **The deep underground location of the repository**, in a setting that is unlikely to attract human intrusion and is not prone to disruptive geological events and to processes unfavourable to long-term stability;
- **the host rock** which has a low hydraulic conductivity, a fine, homogeneous pore structure and a self-sealing capacity, thus providing a strong barrier to radionuclide transport and a suitable environment for the engineered barrier system;
- **a chemical environment** that provides a range of geochemical immobilisation and retardation processes, favours the long-term stability of the engineered barriers, and is itself stable due to a range of chemical buffering reactions;
- **the bentonite buffer (for SF and HLW)** as a well-defined interface between the canisters and the host rock, with similar properties as the host rock, that ensures that the effects of the presence of the emplacement tunnels and the heat-producing waste on the host rock are minimal, and that provides a strong barrier to radionuclide transport and a suitable environment for the canisters and the waste forms;
- **SF and HLW waste forms** that are stable in the expected environment;
- **SF and HLW canisters** that are mechanically strong and corrosion resistant in the expected environment and provide absolute containment for a considerable period of time.

Furthermore, the safety report provides an extensive body of evidence and arguments about how the different components of the disposal concept will evolve over time. It also uses sensitivity analysis, utilizing different scenarios to demonstrate the robustness of the repository system. The authors conclude by stating that all the calculated dose maxima in the scenarios considered are below the Swiss regulatory guideline (HSK & KSA, 1993; as of April 2009 ENSI, 2009).

**Different timescales in nuclear waste management**

Looking at the timescales relevant in nuclear waste management thus reveals that different timescales are at work. The most striking one is probably the one million years, the time period for which high-level wastes have to be isolated from the biosphere. In contrast, the several decades that spent fuel has to be cooled before it can be disposed of, or the time the societal decision process takes to find a site for the repository seem rather short. However, from a societal perspective, a decade or several decades are very long timescales in particular considering the fact that nuclear wastes are stored on the surface and, of course, there is the potential for occurrences no one can anticipate today.

1.4 Structuring the issue and identifying relevant research questions: Embedding the contributions of the thesis

Looking at the development of the geological time perspective and at the temporal conceptions in the safety assessment of a nuclear waste repository served to deepen system understanding. To identify relevant research questions, we again utilize the HES Framework to structure the complex socio-technical issue of nuclear waste. Using this structuring tool reminds the researcher to consider different perspectives of the issue at hand; it thus prevents one-dimensional approaches and encourages a multidisciplinary view. Therefore, it also provides a good start for the development of relevant specific research questions about the topic. The strategy of this PhD thesis is to take the HES Framework as a starting point and critically reflect upon the role of time in its different system components and assumptions. With respect to time, six distinct interesting aspects can be elaborated within the framework and the papers of this thesis can be structured accordingly. Figure 5 highlights these aspects, they refer to i) a coupled systems perspective on the temporal dimension of nuclear waste, ii) system understanding of time and nuclear waste, iii) differences in understandings of time between scientific disciplines, iv) time and risk perception of nuclear waste, v) intertemporal judgments and decisions, vi) feedback loops in long-term decisions regarding nuclear waste.

The following paragraphs describe these temporal aspects in more detail, thereby elaborating on the respective research questions and providing an embedding of the four studies conducted within this thesis. Conclusions for research on human-environment systems research will be drawn in the last chapter. However, before embedding the contributions of the thesis we provide a brief state of the art literature review about studies empirically examining the perception of the temporal dimension of nuclear waste.
1.4.1 State of the art literature review: The perception of the temporal dimension of nuclear waste disposal

Research about time and about the perception of time has been an important topic in psychology since its beginnings (e.g., James, 1890; Van der Meer, 2006; McGrath & Tschan, 2004). Research foci inter alia are differences between objective duration and perceived duration (e.g., Wittmann, 2009), the cognitive construction and representation of events in time (e.g., Trope & Liberman, 2003; Liberman, Sagristano, & Trope, 2002; Henderson, Trope, & Carnevale, 2006; Atance & O’Neill, 2001), cultural differences in the perception of time (e.g., Yamada & Kato, 2006; Ji, Guo, Zhang, & Messervey, 2009), and how language affects temporal representation (e.g., Fuhrman & Boroditsky, 2010; Boroditsky, Fuhrman, & McCormick, 2011).

However, even though time is such a fundamental research topic in psychology, only a few studies have focused on extensive timescales as relevant for nuclear waste disposal. A literature review based on work by Miesler (2007) revealed that three studies had examined perception of the long-term dimension of nuclear waste (Drottz-Sjöberg, 2010; Svenson & Karlsson, 1989; Kunreuther & Easterling, 1990).

Drottz-Sjöberg’s (2010) results are based on a survey conducted in two communities that were at the time of the survey both under consideration as candidates for a deep geological repository in Sweden (Oskarshamn and Östhammar). She looks at time in quite a broad manner (e.g., questions how long spent fuel represents a hazard for humans, poses time-related questions about specific events in the past and estimates how long it will take for some future events like a...
war or a leak in the repository to occur). One of her main results involves measuring participants’ seriousness judgments on the consequences of a repository leak occurring at different times in the future (up to one million years). She demonstrated that participants on average judge a leak at a later time as less serious than a leak occurring sooner. This is an indicator that participants on average discount the negative consequences of a nuclear waste repository over time, i.e. they assign less value to a negative consequence occurring later compared to a negative consequence occurring sooner.

Further, Svenson and Karlsson (1989) conducted relatively broad surveys to study temporal perception and nuclear waste, starting from assessing the ability of students in different study programs to estimate when past events happened and when future events will occur. He also included discounting by asking participants to judge the seriousness of a future repository leak for different timescales (up to two million years in the future). In contrast to Drottz-Sjöberg (2010), he calculated individual-based analyses and concluded that about 30% of the subjects did not discount, i.e. they gave the same seriousness judgment regarding a repository leak for different future timescales up to one million years.

Kunreuther and Easterling (1990) examined perceptions of risks and benefits, attitudes, and acceptance of a nuclear waste repository via survey. The temporal dimension enters their model of analysis as a variable measuring imposed risks on future generations. Even though its meaning in terms of how many generations was not specified, this variable had a substantial influence on participants voting for or against a repository. The higher perceived risks for future generations the stronger was participants’ rejection of a nuclear waste repository. The authors therefore conclude that participants not only take their own welfare into account but also the welfare of future generations in a decision regarding a nuclear waste repository.

Looking at the state of the art research linking the perception of extensive timescales and the issue of nuclear waste (which will be further elaborated in the subsequent papers) already indicates potential research gaps. We can conclude that a comprehensive research project aiming to study the perception of the temporal dimension inherent in nuclear waste disposal from different perspectives has not yet been done. The existing approaches are mainly based on data collected in large-scale surveys with a dominant focus on discounting. Of course, these surveys give a first impression of how people react when they are confronted with extensive timescales in the context of nuclear waste disposal. However, there is a paucity of more qualitative approaches allowing for a more in-depth comprehension of how people understand such extensive timescales. Also, studies shedding more light on the causality of the relationship between time and judgments about nuclear waste are lacking.

In the following paragraphs, the four research contributions of this thesis are briefly described and embedded in the HES Framework. It is also shown how the contributions are related to each other and how later contributions elaborate on specific insights gained in earlier research steps.

**1.4.2 Paper 1: The crucial role of nomothetic and idiographic conceptions of time: Interdisciplinary collaboration in nuclear waste management**

The socio-technical problem of nuclear waste is coupled with a specific perspective on time. Or, to put it differently, how the problem of nuclear waste is framed and perceived is directly related to a specific cognitive temporal representation. One important distinction between the disposal of nuclear waste and other environmental problems (e.g., the disposal of hazardous wastes like heavy metals) is that the timescales involved in nuclear waste disposal are very salient because of the radioactive half-lives. Obviously, geological timescales are involved in the problem.
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and the know-how of geologists represents a major cornerstone of the disposal concept (Junker et al., 2008; Stauffacher & Moser, 2010). Of course, geologists cognitively represent the disposal of nuclear waste on a geological timescale. However, adopting such a perspective carries with it the potential of overlooking shorter timescales (e.g., decades) that are nevertheless societally highly relevant, such as the time required for the decision making process. On the other hand, a strong focus on societal processes and in general, shorter timescales, might ‘blind out’ geological processes (Gibson, Ostrom, & Ahn, 2000; Wood, 2008; Toomela, 2010; McGrath & Tschan, 2004). Thus, one might say that a coupled systems perspective on the long-term dimension of nuclear waste reveals a problem of scale (Gibson et al., 2000) that is interesting to investigate from both research and practice perspectives.

A second perspective on this problem of scale starts from the human system. According to Scholz (2011), human systems are hierarchically structured from individuals up to societies and supranational organizations. Within and between these hierarchical levels, different decision rationales can be found. One important component of human systems is the science system, which also has its subsystems, namely the scientific disciplines. Scientific disciplines have different rationales and they differ with respect to their interests, language, and epistemics (Petts, Owens, & Bulkeley, 2008; Althaus, 2005; Newell et al., 2005). They have different thought styles (Fleck, 1980 [1935]) and, hence, might differ in their understanding of time, and, accordingly, in their problem framing of nuclear waste disposal. As nuclear waste management is an interdisciplinary field, different understandings of time could pose challenges (e.g., in communication among experts and between experts and the public) but also opportunities, because if the differences are made explicit, this could help in detecting blind spots as illustrated by the problem of scale mentioned above. The research questions of the first paper, therefore, read: i) how can extensive timescales be understood both in general and with respect to nuclear waste? and ii) how do different scientific disciplines differ in their understanding of extensive timescales?

The goal of the first paper (Moser, Stauffacher, Krütli, & Scholz, 2012) which is published in Risk Analysis was to examine how different disciplines understand extensive timescales in general and, in particular, with regard to nuclear waste. Method: Eighteen qualitative explorative interviews were conducted with experts from different disciplines (ranging from humanities to social sciences and natural sciences). Important results: Time understandings are closely related to processes experts focus on in their daily work (e.g., a climate scientist conceptualized time in cycles). Thereby, one can distinguish between two distinct understandings of time corresponding to idiographic and nomothetic research approaches: Scientists from the humanities and social sciences tend to have a more open, undetermined representation of time; this means they stress the role of rapid societal development including uncertainties and ignorance and therefore seriously question the possibility of future predictions. Natural scientists tend to focus on a more determined representation that includes some undetermined aspects. This means they focus more strongly on cycles or natural laws enabling them to make predictions for the future, at least to a certain extent. These differences pose challenges for communication among experts but also between experts and the public. However, they also provide opportunities, as the perspective of experts from the social sciences and humanities could contribute important aspects to safety assessment, a domain that is still predominantly handled by natural and technical scientists.

1.4.3 Paper 2: The influence of linear and cyclical temporal representations on risk perception of nuclear waste: An experimental study

In the first paper, experts were consulted on their understanding of extensive timescales. The study revealed that temporal representations have an influence on the problem understanding of nuclear waste. Furthermore, in structuring these understandings, the linear or cyclical temporal
representation was often mentioned. After studying temporal understandings in a broad and explorative manner we aimed at systematically examining the influence of temporal representations on risk perception of nuclear waste. Hence, we shifted from experts to the public and from explorative qualitative research to a classic psychological experiment.

We were interested in the perception of the environment (here: a socio-technical risk), i.e. in environmental awareness, which basically represents the interface between human and environmental systems (Scholz, 2011). The HES Framework distinguishes between different types and levels of environmental awareness: a cognitive-epistemic type ranging from non-awareness of the environment via awareness of human impacts on the environment to awareness of feedback loops resulting from humans’ actions on the environment, and a motivational awareness including how people’s values, motives, knowledge, behavior and other psychological variables are related (Scholz, 2011). Our study focuses on cognitive-epistemic awareness by examining how participants perceive the risks of nuclear waste. There are numerous studies that examine risk perception of nuclear waste (e.g., Sjöberg & Drottz-Sjöberg, 2009; Slovic, Flynn, & Layman, 1991; Flynn, Slovic, & Mertz, 1993; Van der Pligt, Eiser, & Spears, 1987; Stauffacher et al., 2008; Siegrist, Gutscher, & Earle, 2005) as well as people’s perceptions of the extensive timescales involved in nuclear waste disposal (Drottz-Sjöberg, 2010; Kunreuther & Easterling, 1990; Stauffacher et al., 2008; Svensson & Karlsson, 1989). In the second study of this PhD thesis, both time and risk perception were interlinked in an innovative experimental setting. The research question of the second paper reads: how do different cognitive temporal representations affect risk perception of nuclear waste?

The goal of the second paper (Moser, Stauffacher, Krüttli, & Scholz, 2012) which has been accepted for publication in the Journal of Risk Research was to examine the influence of a linear or cyclical temporal representation on risk perception of nuclear waste. Method: In a psychological experiment, we randomly primed participants \(N=83\) with a linear or cyclical temporal representation, or assigned them to the control group where no specific representation was activated. Important results: Compared to the control condition, participants in the linear and cyclical condition perceived fewer risks of nuclear waste. Furthermore, data revealed that this effect was especially pronounced for participants who did not hold stable beliefs about nuclear waste. We can only speculate about the reasons, but one possibility is that temporal representations like an arrow or a spiral give participants some indication as to how to interpret a very extensive timescale (e.g., a spiral implies repetition of major events and developments). Thus, temporal representations might reduce complexity, increase perceived predictability of the future and therefore decrease risk perception of a nuclear waste repository.

1.4.4 Paper 3: Psychological factors for discounting negative impacts of nuclear waste

After examining the influence of different temporal representations on risk perception of nuclear waste, the third contribution explores judgments about the potential negative consequences of nuclear waste over time. While the second contribution looked at time as a ‘Gestalt’ in the sense of a line or a spiral without specifying time points in the future, the third contribution explicitly examines how serious individuals judge the negative consequences of a nuclear waste repository to be if they occur at specific time points in the future. Hence, the third study addresses judgments over time.

Time is an important factor in human judgment and decision-making. Individuals decide differently if the consequences of decisions occur subsequently or if they are delayed. The temporal dimension often forces people to make trade-off decisions between a sooner but smaller or a later but larger reward (Frederick, Loewenstein, & O’Donoghue, 2002). Examples are
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investment decisions or the delay of gratification paradigm (Mischel, Shoda, & Rodriguez, 1989). In economics, such decisions are approached by the means of the discounting paradigm which is a tool for comparing investments made today or in the future. It assumes that the utility of a consequence decreases with increasing temporal distance (Frederick et al., 2002). However, the discounting approach is also applied to non-monetary decisions in the environmental domain (Gattig & Hendrickx, 2007). One very prominent example is the Stern report (“The economics of climate change”, Stern, 2007), which has been criticized because of its low discount rate (see Nordhaus, 2007). As the state of the art literature about studies examining the temporal dimension of nuclear waste demonstrates, discounting is also a dominant approach here (Drottz-Sjöberg, 2010; Svenson & Karlsson, 1989). This is also one of the reasons why this thesis takes a closer look at the paradigm. In the world of financial economics, much smaller timescales are relevant compared with the timescales that need to be considered in nuclear waste disposal. Therefore the assessment of discounting judgments for such extensive timescales represents a challenge from both a content-related and methodological perspective. From a content-related perspective, discounting judgments are difficult to interpret (Frederick et al., 2002), as the rationales behind such judgments are often unclear. From a methodological perspective, the study by Drottz-Sjöberg (2010) as well as our own unpublished data collected in the course of the first experiment raise the question of whether the choice of timescales as well as of response formats may frame participant’s responses. The main concern was that participants are not sensitive toward very extensive timescales in the future (as suggested by e.g., Baron, 2000; Boniecki, 1980; Baird, 1986; Björkman, 1984) and therefore, use the Likert scale as a cue to respond (e.g., take one step on the scale for each additional future time point). The research questions of the third paper therefore read: i) what psychological factors underlie discounting of negative consequences of nuclear waste? and ii) what are methodological and content-related challenges in assessing discounting judgments for nuclear waste over extensive timescales?

The goal of the third paper (Moser et al., submitted) which has been submitted to the Journal of Environmental Psychology was to assess the perceived seriousness of long-term negative consequences of nuclear waste, utilizing the discounting paradigm, and to investigate the influence of methodological and content-related parameters on such judgments. Method: In an online experimental setting (N=314), we varied the timescale (up to 4000 years vs. up to one million years), the response scale (7-point Likert Scale vs. visual analogue scale) as well as the waste type (nuclear waste vs. hazardous waste) and assigned participants randomly to these conditions. Furthermore, we compiled a list of psychological factors potentially driving discounting judgments. All participants judged the seriousness of a leak of the repository for five subsequent future time points. Important results: The most surprising result was that participants seem to be sensitive toward different timescales. Participants considering a shorter timescale (up to 4000 years) judged negative consequences as more serious compared to participants considering a longer timescale (up to one million years). Furthermore, we found that mainly two psychological factors drive discounting: Expectations about societal learning, i.e. a higher perceived adaptive capacity of future societies, leads to lower seriousness judgments. Furthermore, greater emotional involvement with future generations leads to higher seriousness judgments.

1.4.5 Paper 4: Beyond risk perception: The role of perceived adaptive capacity for the acceptance of contested infrastructure

The third paper revealed the important role of perceived adaptive capacity for judging the seriousness of a negative consequence of a nuclear waste repository over time. This indicates that participants adopt a dynamic perspective: If they expect that future societies will be able to adapt
to future challenges (e.g., because of societal learning and/or technological progress) a repository leak is judged as less severe because future societies will be able to manage it. If they perceive only a low level of adaptive capacity of future societies, the reverse applies.

The fourth paper investigates perceived adaptive capacity and its role in decision-making in more detail. With regard to societies, adaptive capacity 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 & Wandel, 2006, p. 282). Perceived adaptive capacity thereby takes on the function of a feedback loop. The HES Framework (Scholz, 2011) distinguishes among different types of feedback loop between humans’ decisions and actions, and immediate as well as delayed environmental responses. Discussing feedback loops always includes a temporal perspective because feedback loops are time-bound. They include immediate but also delayed, unanticipated, and possibly unwanted consequences. According to Scholz (2011), identifying and managing feedback loops is a key component of sustainability learning. High perceived adaptive capacity, for example the expectation that technologies will develop further, however, can be considered a two-edged sword. On one hand, it could, in the sense of a self-fulfilling prophecy (Merton, 1948) trigger corresponding societal investments to enhance the adaptive capacity of future societies. On the other, it could also imply that today’s societies do not take over responsibilities for their actions because they expect future societies to be able to manage them (maybe in an even more effective way than we are today). Perceived adaptive capacity therefore represents an important concept in environmental decisions, for example in infrastructure projects like a nuclear waste repository. However, apart from climate change (Grothmann & Patt, 2005), recent psychological research about individual decision-making regarding contested infrastructure hardly takes this concept into account but predominantly focuses on risk and benefit perception as the main explanatory variables. The research question of the fourth paper reads: what is the role of perceived societal adaptive capacity in individual decision-making regarding contested infrastructure projects such as a nuclear waste repository or a hazardous waste site?

The goal of the fourth paper (Moser, Stauffacher, Blumer, & Scholz, to be submitted) which will be submitted to the Journal of Risk Research was to examine the role of perceived societal adaptive capacity in the acceptance of contested long-term infrastructure, for the two examples of nuclear and hazardous waste. Method: In an online experimental setting (N = 300) participants filled out a questionnaire about risk perception, benefit perception, and perceived adaptive capacity either with regard to a nuclear waste repository or a hazardous waste site. Important results: Factor analysis revealed that perceived adaptive capacity can be considered a separate psychological construct (in addition to risk and benefit perception). Furthermore, perceived adaptive capacity explains a significant additional share of variance in acceptance of a nuclear waste repository or hazardous waste site. Adopting a dynamic perspective by including perceived adaptive capacity therefore yields important insights into individual decision-making with respect to contested infrastructure projects.

1.5 References


On the understanding and processing of extensive timescales: The long-term dimension of nuclear waste


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2 The crucial role of nomothetic and idiographic conceptions of time: Interdisciplinary collaboration in nuclear waste management


Abstract

The disposal of nuclear waste involves extensive time scales. Technical experts consider up to one million years for the disposal of spent fuel and high-level waste in their safety assessment. Yet nuclear waste is not only a technical but also a so-called socio-technical problem and, therefore, requires interdisciplinary collaboration between technical, natural, social sciences and the humanities, in its management. Given that these disciplines differ in their language, epistemics, and interests, such collaboration might be problematic. Based on evidence from cognitive psychology, we suggest that, in particular, a concept like time is presumably critical and can be understood differently.

This study explores how different scientific disciplines understand extensive time scales in general and then focuses on nuclear waste. Eighteen qualitative exploratory interviews were conducted with experts for time-related phenomena of different disciplines, among them experts working in nuclear waste management. Analyses revealed two distinct conceptions of time corresponding to idiographic and nomothetic research approaches: Scientists from the humanities and social sciences tend to have a more open, undetermined conception of time, whereas natural scientists tend to focus on a more determined conception that includes some undetermined aspects. Our analyses lead to reflections on potential difficulties for interdisciplinary teams in nuclear waste management. We focus on the understanding of the safety assessment, on potential implications for communication between experts from different disciplines (e.g. between experts from the humanities and engineering for risk assessment and risk communication), and we reflect on the roles of different disciplines in nuclear waste management.

Keywords: Representation of extensive time scales, nuclear waste management, interdisciplinary collaboration

2.1 Introduction

Many environmental and technical problems involve time scales that are extensive with respect to the lifespan of human beings. In nuclear waste, for example, technical experts consider a period of up to one million years for the disposal of spent fuel and for high-level nuclear waste.\(^1\) This long-term dimension refers to hazards posed by a release of radionuclides to humans and the environment, as indicated by the extensive half-lives (e.g. \(^{239}\text{Pu} = 24,110\) years). One million years is about one hundred times longer than the period since the end of the last glaciation, about 11,000 years ago. Also in view of recorded human history, this long-term dimension is beyond humankind’s horizon of experience. Therefore, it strongly challenges humans’ time concepts and encounter epistemological boundaries. The time frame of one million years poses a challenge for nuclear waste management in providing evidence guiding technical decisions. The way technical experts deal with this challenge is the so-called “safety case”, in essence, a set of sound techno-
geological arguments and analyses as to why the safe storage of nuclear waste in the long run appears plausible.[(1)]

However, nuclear waste presents not only a technical but a so-called socio-technical problem.[13] In the past, many initiatives to find sites for a nuclear waste repository, specifically for high-level waste,[14] failed due to a lack of public acceptance within the chosen host community.[5] Therefore, it became apparent that nuclear waste not only poses challenges in technical and geological dimensions but also in social dimensions. Issues like public perceptions of risk,[6] and differences between experts and the public,[7] became part of the problem as well. Considering these differences in risk perception between experts and the public, risk communication,[8] and trust,[9-10] have become important issues. Furthermore, public participation,[11, 12] and, more generally, societal decision processes in siting a nuclear waste repository,[13] (for the United States see e.g.[14], for Switzerland see e.g.[5, 15, 16]), and the integrated approach of risk governance,[7, 18] have started to become the focus of interest. This broad focus in nuclear waste management requires interdisciplinary collaboration and needs to meet societal expectations as well as technical constraints. Yet it is to be expected that different disciplines will differ in their perspectives on the problem.

We recognize that technical risk assessment in nuclear waste management already involves an interdisciplinary perspective, by including, for example, geologists, physicists, engineers and hydrologists. However, by interdisciplinarity, we refer here to a broader base of disciplines. More precisely, we mean that the technical and natural sciences collaborate together with the social sciences and humanities. Successfully integrating these different disciplinary perspectives, however, is difficult for structural and epistemological reasons. Structurally speaking, social, technical, and natural sciences traditionally do not collaborate very closely. This, of course, depends as well on the field of study. In the health domain, for example, multidisciplinary teams often work closely together.[9, 10] This is not necessarily the case in other fields, like nuclear waste management, as the dominant “epistemic community”[20, 21] from engineering and natural sciences still draws clear boundaries. In fact, the different disciplines are occupied with different aspects of nuclear waste management: Social scientists deal with risk perception and risk communication, while natural and technical scientists work in the domains of risk analysis and risk assessment. Similar phenomena are known from many other fields.[22-24] Of course, these aspects depend on each other, since, for example, experts in risk communication need to know the outputs of the risk assessment.[25] However, successfully integrating natural, technical, and social science perspectives is a challenge. As early as 1993, Jasanoff made the criticism that the “two cultures of risk assessment” (she refers to them as “hard” and “soft” sciences) are hardly integrated effectively in risk analysis.[25] And looking back at the first 25 years of the Society for Risk Analysis, Thompson, Deisler, and Schwing[26] comment on difficulties for their readers in understanding discipline-crossing articles. They cite a letter by Robert B. Cumming, one of the founders of the Society for Risk Analysis, from 1980, stating that “The purpose of the Society (...) is to promote communication among different disciplines involved in dealing with risk” (p. 1342). Still today, one of the visions of the society is to foster understanding and collaboration as well as bringing together different disciplines in risk analysis.[27] Horlick-Jones and Sime[28] even go a step further by pointing out that the situation is more complicated because social sciences are not epistemologically homogeneous: Some social science perspectives regard risks as “objective attributes of the world” while others “recognize that risks are, at least in part, socially constituted” (p. 446).[28] Epistemologically, difficulties in understanding among or even within different disciplines also emerge because disciplines differ in their language, epistemics, and interests.[23, 29] Althaus[29], for example, analyzed conceptions and definitions of the term “risk” in different disciplines. She identified remarkable differences between disciplines regarding their perspectives
and understandings of risk, reflecting respective epistemics within these disciplines. Even though
time, as a central dimension in many disciplines, has been referred to as having the potential to
“facilitate communication across those [disciplinary] divides” (p. 210), (30) we would like to challenge
this assumption by arguing that time – as an essential concept in nuclear waste management –
could be as prone to different understandings as is the concept of risk.

Time is a highly complex construct and an essential concept in many scientific disciplines
(e.g. philosophy, geology, economy, psychology). However, disciplines differ in how they
conceptualize and use time. (30) From a philosophical point of view, many questions regarding time,
for example, whether time is continuous or discrete or whether it flows linearly or cyclically, have
been issues of discussion for a long time. (32) In astronomy, for example, a cyclic concept of time has
been emphasized. In physics, time has been conceptualized as linear by Newton and as relative by
Einstein. These ideas of time have subsequently influenced how time was conceptualized in other
disciplines, for example, in psychology, (33) where differences between objectively measured time
durations and subjectively perceived time estimations are a focus of study. (34) In economics, time is
conceptualized within the discounting paradigm (for a critical review see (35)), which is also the
predominant paradigm in current studies on time and environmental risk perception. 
(36, 37) Time
sociologist Barbara Adam (38) criticizes the simple and singular notion of time (clocks and
calendars) in the “thought traditions of the industrialized West” (p. 9) and argues for a more
integrative, contextualized view on time. She introduced the concept of “timescapes”, meaning
the adoption of a perspective on the environment that enables one, for example, to detect
rhythmicity, time-scales of change, context dependence, and a broad variety of other aspects of
time. (39) Already, these fragmentary considerations suggest that time can be understood in a
variety of ways and that scientific disciplines differ with respect to how they understand the
concept.

Empirical indications for differing understandings of time can, as well, be taken from
cognitive psychology. Based on Lewin’s (39) concept of “psychological distance”, construal-level
theory (40) (for a review see (41)) suggests that time, or more precisely, events in the future, can be
represented differently with respect to the level of abstraction at which they are construed. So-called
“low-level construals” consist of concrete, contextual, and incidental details, whereas so-called
“high-level construals” are characterized by general, abstract, and decontextualized features. This differentiation refers to two hierarchical structures within our knowledge base,
namely to directly accessible knowledge and higher ordered knowledge. (42) According to construal-
level theory, the greater the temporal distance, the more abstract are the events cognitively
represented. These construals can translate into different cognitive processes guiding judgment
and decisions. (43) In experimental studies, Liberman and Trope (40) were able, for example, to
demonstrate that thinking about events in the near future (e.g. next week) tended to activate
concrete feasibility considerations, whereas thinking about distant future events (e.g. next year)
rather activated more abstract desirability considerations. Other experimental studies suggest
that temporal distance affects behavior in forthcoming negotiations: increased temporal distance
increased preference for integrative, multi-issue offers and decreased preference for piecemeal,
fragmented offers. (43) In a subsequent experiment, Henderson and Trope (44) demonstrated that
merely the instruction to think about future negotiations in concrete or abstract terms had a
similar effect on mitigation behavior. This means that future events can be cognitively construed
in a more concrete or more abstract manner, irrespectively of the actual temporal distance. Even
when the future time frames in these studies were much shorter than the relevant time frames
for nuclear waste disposal, the reported findings still indicate that i) time can in fact be
understood in different ways and that ii) these differences can have far-reaching consequences
with respect to the activation of goals, preferences, and behaviors.
Based on theoretical considerations on the disciplinary differences mentioned above, as well as on the diverging cognitive representations of time, we expect scientific disciplines to differ in their understanding of the term “time”. This could point to a potential challenge for interdisciplinary collaboration in nuclear waste management. These questions, however, have not been studied empirically so far. Some empirical studies investigating correlations between time and risk perception for the case of nuclear waste do exist\textsuperscript{[45, 46]} However, these studies conceptualized time unidimensionally (as a certain duration) and, hence, did not focus on different understandings of time. Taking one of the Society for Risk Analysis’ aims as a starting point, namely enhancing communication between different disciplines in risk research\textsuperscript{[16, 17]} we argue that communication requires, above all, a thorough understanding of existing differences.

Thus, the goals of the following study are: i) to explore how time and extensive time scales are understood, both in general and with respect to nuclear waste and ii) to demonstrate differences in the understanding of time in different scientific disciplines. In a second step, we apply our findings to nuclear waste management and discuss potential challenges for the understanding of the safety case and for communication in interdisciplinary teams, also reflecting on the role of different scientific disciplines in nuclear waste management.

2.2 Methods

A qualitative, explorative, and iterative approach (as recommended e.g. in \textsuperscript{[47, 48]}) was chosen throughout the study, especially due to two considerations. First, we were interested in capturing a very broad range of conceptualizations of time. Second, a thorough literature review revealed a lack of comparable empirical studies that would have allowed for deriving and testing hypotheses directly. Therefore, we conducted in-depth semi-structured qualitative interviews with experts on time-related phenomena from different scientific disciplines. This qualitative and explorative approach was applied for all research steps (i.e., sampling, interview procedure, and data analysis).

Such an exploratory approach is especially suitable for this study, since it allows for capturing different and unexpected understandings of time. This is due to the strategy of using an open, non-predefined coding scheme that emerges from the interview material itself. In contrast to the “mental models approach”,\textsuperscript{[49]} an approach commonly used in risk communication research that also includes qualitative expert interviews, our aim was not to compare an elicited expert model and laypeople’s conceptions of time but to focus on the diversity of conceptions of time existing among experts from different scientific disciplines.

2.2.1 Sampling procedure and sample description

We included scientists from natural sciences as well as from social sciences and humanities. Overall, two goals were followed in our sampling strategy. On one hand, disciplines that are directly involved in nuclear waste management had to be represented (e.g. geology, physics, environmental psychology, physical geography). On the other, the focus was to be broadened to include disciplines dealing with long time scales that are not directly involved in nuclear waste management (e.g. theology, astronomy). Data collection and analysis took place in an iterative manner.\textsuperscript{[47, 48]} We followed the strategy of looking for potentially contrasting experts after the first interviews had been conducted and analyzed. All interviewed scientists study processes that include rather long time scales and, therefore, are considered to be experts on time-related phenomena. Of course, “long” has a completely different meaning in different disciplines: For example, a long process in astronomy surpasses a long process in history with respect to its factual duration. This means, on the one hand, that we covered a large range of time spans but, more importantly, that we were also able to grasp different conceptualizations of time.
Contacts to experts in nuclear waste management were facilitated by recommendations of the transdisciplinary steering board (consisting of people from, e.g., the implementer of nuclear waste repositories and from nuclear power plants) of a broader project on nuclear waste, wherein this study is embedded. As we were not only interested in present problems of communication in nuclear waste management but rather in future perspectives of potentially more experts in the social sciences and humanities being involved, we went beyond this field. The other sample of experts consisted, on one hand, of a small convenience sample, i.e., researchers already known by the authors. This sample was complemented by other researchers, almost all working in Swiss universities, who had been contacted on the basis of recommendations of those already interviewed or due to the research areas indicated on their websites. Overall, we aimed at a broad spectrum of different disciplines. The experts were contacted to participate in the interview by email. Eight experts did not react or refused to participate for several reasons (e.g., time restrictions). In most cases, these experts recommended colleagues who were contacted instead. This sampling procedure resulted in 18 interviews (see Table I). The majority (n = 14) of the experts are Swiss, three are German, and one is from the United States. All experts have an academic background, and a large number of them are currently employed in an academic institution (six of them are professors, and seven are PhD students or post-doctoral fellows). The others work in non-academic institutions. Four of the interviewed experts have been involved with the issue of nuclear waste and three of them are currently working in nuclear waste management (in either technical risk assessment or spatial planning). Men are overrepresented in the sample. Table I gives an overview of the experts, their scientific disciplines, whether they work in an academic or non-academic institution, their genders, and years of work experience.

Table I. Experts’ disciplinary backgrounds, institutions, genders, and years of work experience (N = 18).

<table>
<thead>
<tr>
<th>Disciplinary background (N = 18)</th>
<th>Institution</th>
<th>Gender</th>
<th>Years of work experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astronomy</td>
<td>Academia</td>
<td>Male</td>
<td>More than 20 years</td>
</tr>
<tr>
<td>Biology</td>
<td>Non-academia</td>
<td>Male</td>
<td>Less than 5 years</td>
</tr>
<tr>
<td>Climate geography</td>
<td>Academia</td>
<td>Female</td>
<td>Less than 5 years</td>
</tr>
<tr>
<td>Climate physics</td>
<td>Academia</td>
<td>Male</td>
<td>Less than 5 years</td>
</tr>
<tr>
<td>Climate physics</td>
<td>Academia</td>
<td>Male</td>
<td>Less than 5 years</td>
</tr>
<tr>
<td>Economics</td>
<td>Academia</td>
<td>Male</td>
<td>More than 20 years</td>
</tr>
<tr>
<td>Environmental history</td>
<td>Academia</td>
<td>Male</td>
<td>More than 20 years</td>
</tr>
<tr>
<td>Environmental philosophy</td>
<td>Academia</td>
<td>Female</td>
<td>More than 20 years</td>
</tr>
<tr>
<td>Environmental physics</td>
<td>Academia</td>
<td>Male</td>
<td>Less than 5 years</td>
</tr>
<tr>
<td>Environmental psychology</td>
<td>Academia</td>
<td>Female</td>
<td>Less than 5 years</td>
</tr>
<tr>
<td>Geology</td>
<td>Academia</td>
<td>Male</td>
<td>More than 20 years</td>
</tr>
<tr>
<td>Geology</td>
<td>Non-academia</td>
<td>Male</td>
<td>More than 20 years</td>
</tr>
<tr>
<td>History of sciences</td>
<td>Academia</td>
<td>Male</td>
<td>More than 20 years</td>
</tr>
<tr>
<td>Modern history</td>
<td>Academia</td>
<td>Female</td>
<td>Between 10 and 15 years</td>
</tr>
<tr>
<td>Physical geography</td>
<td>Non-academia</td>
<td>Female</td>
<td>Between 5 and 10 years</td>
</tr>
<tr>
<td>Physics</td>
<td>Non-academia</td>
<td>Male</td>
<td>More than 20 years</td>
</tr>
<tr>
<td>Religious studies</td>
<td>Academia</td>
<td>Male</td>
<td>More than 20 years</td>
</tr>
<tr>
<td>Theology</td>
<td>Non-academia</td>
<td>Male</td>
<td>More than 20 years</td>
</tr>
</tbody>
</table>

2.2.2 Interview procedure

Some questions were formulated to structure the interviews and make sure that all aspects of interest were covered. These questions included: i) The role of time within the experts’ scientific
discipline and current field of research, ii) Spontaneous associations with the time duration of one million years and 100,000 years, iii) Ideas of what could happen in a nuclear waste repository within one million years and 100,000 years, iv) Ideas about which scientific disciplines should deal with nuclear waste, and v) Personal planning behavior and background (see Appendix for detailed wording of the interview protocol).

Experts where explicitly assigned the expert role for time related questions during the conversation. By this means we aimed first to bring them into a mode of scientific discourse and only later allowed for a broader, more colloquial discourse. This seemed to us essential to gain insight into the broader area of discourse modes that these experts generally use with different audiences. They were encouraged to elaborate on these questions, and, if necessary, more detailed follow-up questions were asked. Most of the interviews were conducted in the offices of the experts or in another room at their workplace, thus enabling a contextual frame for scientific discourse. On average, the interviews took 40 minutes, the shortest being 22 minutes, and the longest 64 minutes. Interviews with natural scientists took longer (mean of 48 minutes) than interviews with social scientists or scientists from the humanities (mean of 35 minutes). All interviews were conducted by the first author; one was conducted in English, and all the others in German. They were digitally recorded and transcribed verbatim.

2.2.3 Data coding

We used an exploratory approach, meaning that we did not predefine codes but systematically assigned codes to themes emerging from the interview data. Thus, we coded the whole interview at one time and did not analyze the different questions separately. Key codes were discussed within our research group. More issues than time were touched upon during the interview, but within this article, we will focus solely on time-related aspects. Table II displays an overview of the most relevant time-related codes, their descriptions, and examples from the interview data. All analyses were conducted using ATLAS.ti (version 6.5.1 \( ^{[50]} \)), a software program for analyzing qualitative data. This tool allows assignment of codes to interview data, displaying associationist networks between these codes, and writing extensive memos to document the development of the research process.

Table II. Most relevant time-related codes, descriptions, and respective examples from interview data. The numbers in brackets indicate how many times this code was assigned to the interview material (whole sample).

<table>
<thead>
<tr>
<th>Code name</th>
<th>Description</th>
<th>Examples (translated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;determined&quot;</td>
<td>Superordinate code, was assigned when processes were described as closed, cyclical, or determined.</td>
<td>&quot;The classic example is apocalypticism, which means expecting that there is a first and a second time, and then there is a cut and everything will be completely different ... and the idea of the world’s end, of a beginning of the world, of a better world, this is an important issue in religious studies.&quot; (Expert from religious studies)</td>
</tr>
<tr>
<td>(115)</td>
<td></td>
<td>&quot;In celestial mechanics, in astronomy this is under certain conditions completely different; there are all these disturbing effects, all the disturbing influences, are practically zero ... I would say you can calculate all the planetary motion and everything for millions of years.&quot; (Astronomer)</td>
</tr>
<tr>
<td>&quot;undetermined&quot;</td>
<td>Superordinate code, was assigned when processes were described as open, undetermined.</td>
<td>&quot;Maybe there are things where one does not necessarily consider or think about possible influences.&quot; (Climate researcher)</td>
</tr>
<tr>
<td>(100)</td>
<td></td>
<td>&quot;In my view, social sciences anyway cannot make future predictions, even those who claim this. Well, they don’t like to hear it, if I say so.&quot; (Historian)</td>
</tr>
<tr>
<td>Code name</td>
<td>Description</td>
<td>Examples (translated)</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<tr>
<td>Future of (at least) societal processes cannot be predicted</td>
<td>Boundaries of predictability for social processes</td>
<td>“Somehow one has the feeling, it is a characteristic of modern times, the acceleration of time, the acceleration of the perception of time. And the more it accelerates, the more difficult it is to only imagine 100 years.” (Historian)</td>
</tr>
<tr>
<td>Future can (to some extent) be predicted from the past</td>
<td>Experiences and data from past times enable us to learn about a system and,</td>
<td>“Now, as geologists we are used to looking back many 100 million years, if we see this history. And knowing what has happened during the last millions of years we dare to predict what is going to happen in the next million years.” (Geologist)</td>
</tr>
<tr>
<td></td>
<td>hence, allow for future predictions.</td>
<td></td>
</tr>
<tr>
<td>Cycles</td>
<td>Cycles carry information, and they reduce complexity. From cycles, information</td>
<td>“Because, as I mentioned before, we think in rhythms, and if we gain an additional 200,000 years, then we do not gain much more than two, three additional rhythms. But the eight rhythms we already have, eight glaciation periods, already provide us with a lot of information and I doubt, okay, there can always be surprises, that only 200,000 years will provide a lot of new information.” (Climate researcher)</td>
</tr>
<tr>
<td>Rapid societal development</td>
<td>Social systems develop very quickly. Especially rapid technological</td>
<td>“Within the last several generations we developed the ability to completely destroy the human race; clearly our social and political institutions are not keeping pace with our technological development and capabilities.” (Economist)</td>
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<td></td>
<td>development was often mentioned.</td>
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<tr>
<td>Level of abstraction: unique cases vs. “laws”</td>
<td>“Abstract” more strongly refers to general laws and processes, whereas</td>
<td>“Extreme events show us how the system reacts, what feedback loops are at play … so we can learn a lot about the system Earth … We cannot learn about details, we don’t know how it will be in the “Engadin” 30 years from now … So we have basic knowledge that we gain, that is important for predicting future developments, but we cannot, in detail, we cannot predict it.” (Geologist)</td>
</tr>
<tr>
<td></td>
<td>“concrete” refers more strongly to unique cases and processes. The more</td>
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<tr>
<td></td>
<td>abstract the processes, the more grainy and rough are they cognitively</td>
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<tr>
<td></td>
<td>represented. The more concrete, the more detailed is the cognitive</td>
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<tr>
<td></td>
<td>representation. Represents a problem of resolution: If the focus is</td>
<td></td>
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<tr>
<td></td>
<td>broad and abstract, details disappear from the perspective.</td>
<td></td>
</tr>
<tr>
<td>Society as a complex system</td>
<td>Human systems are described as a highly complex, vulnerable systems.</td>
<td>“If I look now, what has changed in the last century during one lifetime, if you imagine the circumstances in which [my father] grew up and how we see ourselves today, and our governmental organizations, if I imagine what happens … I think these possible future transformations have not yet been considered enough.” (Philosopher)</td>
</tr>
<tr>
<td>“timeless” processes, “laws”</td>
<td>Processes that are assumed to work irrespectively of certain timeframes;</td>
<td>“There are anyway general laws that are more or less well studied, we have models that have turned out to be very valid, we know certain relationships … and we basically know what is happening.” (Environmental physicist)</td>
</tr>
<tr>
<td></td>
<td>for example, certain chemical or physical laws.</td>
<td></td>
</tr>
<tr>
<td>Basic societal dynamics</td>
<td>Very basic properties of a society or of human beings are stable and</td>
<td>“Until now, human beings have most of the time been reasonable, and have found ways.” (Theologian)</td>
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<tr>
<td></td>
<td>predictable.</td>
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</tbody>
</table>

2.2.4 Data analysis strategy: Iterations between interview data and literature

As suggested in Miles and Huberman\(^{49}\) and Patton,\(^{47}\) we applied a stepwise procedure in analyzing our data. In the first step, we realized that none of the experts was talking about time per se, but we could sample many different forms of how time was related to processes. As expected, the experts mentioned a broad range of processes when they were talking about long time scales. A geologist, for example, instanced the development of the Alps, an environmental historian referred to strategies of how people memorize and transfer knowledge about rare and
extraordinary events (e.g. floods) to the next generations, while a climate physicist mentioned oscillations between glacial and interglacial periods (climate cycles).

In the second step, we aimed at finding a common structure within this broad range of processes. Reviewing literature on time as a process, we found the classical representation of time as a cycle or time as an arrow \(^5\) and contrasted it in a third step with our interview data. In principle, these linear and cyclic elements could be found in our interview data. A critical point, however, was that both these representations indicate to a certain extent the predictability of the future. Cycles are indicative of repetition and, hence, allow for predictions of future processes. Linear processes are directional and imply a certain sequence of steps, therefore allowing for future predictions as well. Since some experts fundamentally questioned the predictability of the future during the interview, we developed an alternative and more integrative representation of time, namely a continuum in which time is represented as an “undetermined process” at one endpoint and as a “determined process” (in the sense of following a general law) at the other. In contrast to the linear vs. cyclic representation, this model includes the factor of predictability represented as a continuum. Linear and circular representations are both placed on the more “determined” side of the continuum.

To compare disciplines we took these two representations as a starting point. We looked at how many times each expert referred to determined or undetermined processes. By comparing the ratios of determined and undetermined representations, we aimed at finding clusters of similar and different disciplines. We then compared the groups thus found with respect to the other codes.

2.3 Results

In this section, we first demonstrate how determined vs. undetermined representations of time are related to different types of processes and how these are linked to the predictability of future events. Second, we illustrate differences in time representation among different scientific disciplines.

2.3.1 Processes and representation of time

In the first step, the processes were assigned codes; for example, when a climate physicist mentioned the cycle of CO\(_2\) in the ocean, the code “cycles” was assigned, and when a historian mentioned that lifestyles and societal organizations have changed dramatically during the last century, the code “rapid societal development” was assigned (see Table II for an overview). In the second step, these codes were assigned to the superordinate codes “determined” and “undetermined” representation of time. This means that multiple codes were assigned to the same passage. To illustrate the links between processes and time representation, we structured the codes along three different levels: processes, representation, and predictability of future events (see Fig. 1).
A more undetermined representation of time is characterized by complex and rapid processes. A process mentioned here was, for example, the rapid technological development in recent centuries. Asked to imagine one million years, an environmental philosopher, for example, mentioned that this was not imaginable for her from a social point of view. She illustrated this by pointing out that her father grew up in a world without cars or computers, but for her the use of a computer is commonplace. She stated:

My father, born shortly after the turn of the century ... experienced the world without cars for example, and only with mechanical devices ... if I now look at what has changed in the last century during one lifetime, if I imagine the circumstances when he grew up in contrast to how we understand ourselves today...

Similarly, a researcher in religious studies referred to quickly changing knowledge and technological development when he was asked what could happen to a nuclear waste repository within a period of one million years: “At all times one deals with a problem by taking into consideration given knowledge and technical possibilities and those seem to be out-of-date quite quickly.” Very closely related to these technological changes is the notion of society as a complex system. Linked with this, for example, are statements that political constellations change rapidly.

When asked if there is a future time of which she has an overview, a psychologist said:

I hope that for my own lifetime things will more or less stay as they are ... but honestly, I can imagine very well, I mean, I don’t believe in the end of the world in the next 100 years, but I think that societal and political constellations can change. I am not sure if Switzerland with its current institutions will exist in 100 years.

Another statement (by an economist) asserts that there are complex interactions among social conflicts, poverty, and global warming. Being asked about spontaneous associations in imagining one million years, he replied, “Of course a big issue is poverty, which kind of contributes to global warming and contributes to prospects for conflict, so they’re all kind of tied together to some extent.”

From such processes, it has often been concluded that the future, at least of societal processes, cannot be predicted. A theologian, asked to imagine one million years into the future, said, “I think predicting the future even for the next 100 years is very difficult. All our imaginations of the future are projections from the present and, most of the time, they are not correct, because everything is so complex.” A historian mentioned the relationship between the past and the future by stating that we can only learn from experience that many processes do not develop in a predictable manner. When she was asked what could happen to a nuclear waste repository within a period of one million years, she said:
And even if we assume that we will have a stable political system in Switzerland for the next 20, 30 years, which I consider wishful thinking, can we assume that for the next 100, or 150 years? And this is something we can learn from history, why a development is not contingent and therefore cannot be predicted.

Similarly, while referring to societal processes, a physicist stated, “Maybe the most we can learn from the past is that we cannot learn that much”, upon being asked if the past can be utilized to learn for the future.

In contrast, a more determined representation of time is characterized by cycles and laws. Processes that have been mentioned here are, for example, oscillations between glacial and interglacial periods. When asked about the role of time in his current research, a climate physicist stated:

For me, a long-term timescale, hence a rhythm, mostly we talk about rhythms, because time, the climate oscillates in rhythms. And a long-term rhythm for me is 100,000 years, this is approximately the time from one global glaciation to the next. Glacial-interglacial cycles as we call them.

Other processes mentioned are natural laws, like chemical processes or physical laws. Upon being asked if the past could be used to learn for the future, an environmental physicist said, “There are anyway general [physical] laws that are more or less well studied; we have models that have turned out to be very valid.”

Other processes that were mentioned were basic societal dynamics, in the sense that societies rise and fall or that humans have continuously managed to overcome obstacles. When asked if he was optimistic about the future, an astronomer said, “I still believe in rationality and also in humanity, that these problems can be overcome.” One can infer from this that the future, at least to some extent, can be predicted. When asked to imagine one million years, the same astronomer replied, “In celestial mechanics, you can calculate astronomical phenomena quite accurately for the next million years. The laws of celestial mechanics are given.”

Similarly, after being asked about the role of time in his current work, a geologist argued:

If you investigate certain [geological] formations, how long have they been stable, how long have they been unaffected by surface processes ... for example the Opalinus Clay that has been down there for 180 million years and still contains saltwater, we use that as an argument ... We look at the whole history, if it has been stable for so long then it will most probably be stable for the next million years ... All our insights from the past, if we understand them, allow us to make this prediction.

In comparing these types of processes, it becomes obvious that they differ with respect to their level of abstraction. This refers to the degree to which processes describe generally valid processes or unique, specific processes. Processes characterizing an undetermined representation of time, for example, the introduction of a new technology into society, are more concrete and, hence, more specific and unique than processes that characterize a determined representation of time, for example, geological processes or physical laws. Processes that characterize a determined representation of time, in contrast, are more abstract in the sense that the attempt is made to generalize from these processes and to find generally valid laws. The more determined the representation of time, the more abstract are the processes described.

As already mentioned, the representation of time has implications for the predictability of future events. In this context, the function of the past seems to be crucial: for some people, the past serves to help them understand a current situation, whereas for others, the past serves not only to help them understand the present but also to learn about the future. Unsurprisingly, experts with a rather undetermined representation of time held that the future (at least) of societal processes cannot be predicted. For them, the past can be used mainly to understand how current situations have developed over time.
Some experts stated that the past could also be used to learn about a system or even to predict the future, but only on a certain level of abstraction. For such statements, we assigned the code “level of abstraction: unique cases vs. laws”. The basic idea of these statements was the establishment of a link between concrete and abstract processes. Unique cases are represented more concretely but are less generalizable than laws. Laws or cycles, on the other hand, allow for predictions, but only on a certain level of abstraction. For example, knowledge about climate cycles allows us to predict another glacial period, but we cannot predict in detail how a very specific landscape will be shaped by the glaciers or how societies will then be organized. Basically, there is a problem of resolution: The more abstract the process, the grainier the picture of the future prediction. Very concrete processes, on the other hand, are more detailed but also more specific and, therefore, tend not to allow for future predictions. When asked if he makes predictions about the future, a geologist illustrated this by responding:

> Extreme events show us how the system reacts, what feedback loops are at play ... so we can learn a lot about the system Earth ... We cannot learn about details, we don’t know how it will be in the “Engadin” [a valley in the Swiss Alps] 30 years from now ... but we learn generally how life reacts as a whole. So we have basic knowledge that we gain that is important for predicting future developments, but we cannot, in detail, we cannot predict it.

An astronomer argued similarly, after being asked to imagine one million years in the future: “Even continental drift is difficult to predict. Maybe on a rough level, but what will happen locally I would not dare to predict. Maybe for the next 10 or 100 years, but for one million years I would not dare.”

2.3.2 Illustration of differences among scientific disciplines

To illustrate the differences among disciplines, we added up determined and undetermined representations of time and calculated the percentage of undetermined representations per discipline. As displayed in Figure 2, we did not find disciplines with purely determined or purely undetermined representations of time. At least to some extent, all those interviewed included determined as well as undetermined temporal representations in their statements. Sorting the disciplines according to their share of undetermined and determined representations (as in Figure 2) reveals two groups of disciplines: disciplines from natural sciences tend to have more determined representations of time, whereas disciplines from social sciences and humanities tend to have more undetermined representations of time.
Fig. 2. Percentage of undetermined (in dark gray) and determined (in light gray) understandings of time by discipline (N = 18).

To explore how these two groups of disciplines differ with respect to mentioned processes, representations, and predictability of future events, we accordingly constructed two groups, namely “natural sciences” (n = 10; astronomy, biology, physical geography, climate geography, geology (2), climate physics (2), environmental physics, and physics), and “social sciences and humanities” (n = 8; economics, environmental history, modern history, history of sciences, environmental philosophy, environmental psychology, religious studies, and theology). The dark gray and light gray parts of the boxes in Figure 3 indicate the relative proportions of “natural sciences” and “social sciences and humanities” in the allocated codes. They are normalized (100% is represented by the total length of each box) and corrected for the unequal sample sizes. Natural scientists in general made more statements that could be assigned to time-related codes. This is probably because interviews with natural scientists took, on average, longer than interviews with experts from social sciences and humanities.
Fig. 3. Interrelations among different codes structured by time representations, processes, and predictability of future developments for different sciences. The dark gray and light gray parts of the boxes indicate the relative proportions of “natural sciences” (n = 10) and “social sciences and humanities” (n = 8) in the allocated codes. Numbers in brackets indicate the frequency of the code within the overall sample; thicker lines represent stronger association (N = 18).

As Figure 3 indicates, experts from social sciences and humanities are, in general, more clustered around the undetermined representation. If they mentioned determined representations of time, they mainly focused on very basic dynamic societal processes (e.g., societies rise and fall again) but rarely on cycles or general laws. On the other hand, experts from natural sciences are more clustered around the determined representation. However, they also include undetermined representations and, hence, seem to have a broader view. They seem to represent time as both determined and undetermined. A physicist, for example, mentioned that many processes (e.g., certain physical processes) within the natural system can be predicted over the long term. On the other hand, he perceives the societal system to be very unstable and unpredictable. In this statement, both an undetermined and a determined representation of time can be found, depending on the focus of processes. If the interviewee focuses on his disciplinary field, where general laws are investigated, a more determined representation of time is activated. However, if he focuses on his everyday experiences of a rapidly changing society, a more undetermined representation is activated. Since the interviewed experts from social sciences and humanities focus more on unique and specific cases in their research, the aforementioned switch between undetermined and determined representations of time could not be observed as clearly as in the natural scientists. They generally tended toward a more undetermined representation of time. This can as well be illustrated by looking at disciplinary differences in the code “level of abstraction: unique cases vs. laws”, a code representing statements that integrate determined and undetermined perspectives on time. From the natural science group, almost all experts made statements related to this code, while in social sciences and humanities, only half of the experts made such statements. When referring to the abstract level, the disciplinary groups differed with respect the issue or system they used: experts from social sciences and humanities referred more frequently to social or cultural phenomena that include predictions, for example, cycles in religions (e.g. Buddhism). Meanwhile, natural scientists referred more frequently to phenomena like climate cycles, geological processes, or natural laws. Moreover, they made more explicit reference to the integration of determined and undetermined representations than those from social sciences and humanities by, for example, explaining the phenomenon as a problem of resolution. However, even though discussed phenomena differed, the underlying argument itself
was very similar, namely that the level of abstraction corresponds to the possibility of valid predictions.

2.4 Discussion

Extensive time scales are an essential factor in technical decisions regarding radioactive waste disposal. However, research from cognitive psychology indicates that time can be understood differently (construal-level theory) \(^{(41)}\), which can have dramatic consequences for the activation of goals, preferences, and concrete behaviors \(^{(43, 44)}\). The main purpose of this study, therefore, was i) to explore how time and extensive time scales are understood in general, and with respect to nuclear waste in particular, and ii) to study differences in the understanding of time between different disciplines.

We analyzed the understanding of time in qualitative interviews with experts on time-related phenomena of different scientific disciplines. These experts never talked about time per se but linked time to certain processes. These processes could be clustered around either an undetermined or a determined representation of time. We found that scientific disciplines differed in their understanding of time: Those from the social sciences and humanities tended to have a more open, undetermined representation of time, whereas natural scientists tended toward a closed, determined representation. However, they are generally likely to have a broader view, inasmuch as they also included undetermined representations of time. The role of the past seems to be crucial, having the function either of understanding a present situation or of learning for future developments.

One reason for these findings could be that the disciplines differ with respect to their epistemology, which has an influence on their understanding of time, just as it was shown to have an influence on their conception and definition of risk.\(^{(29)}\) The reason for these differences might be differences in the respective research traditions of disciplines: Some disciplines focus strongly on establishing and developing general laws in their research, whereas others focus more on specific, unique cases. This differentiation corresponds to the terms “nomothetic” and “idiographic” that Windelband \(^{(54)}\) introduced to describe the different methodological approaches of the natural sciences and humanities. According to Windelband, empirical sciences strive for insights either in searching for general principles (for example, natural laws) or in searching for the unique in a historically defined issue. Nomothetic approaches, which strive for generally applicable laws and rules, tend to be found in the natural sciences. Idiographic approaches, on the other hand, which focus more strongly on unique and specific issues, tend to be found in the humanities. The identical phenomenon, of course, can be studied by both approaches, but interestingly, the perspectives on the phenomenon differ depending on whether one uses an idiographic or a nomothetic approach. Nomothetic approaches, for example, strive for generalizations and future predictions. This is clearly not the aim of idiographic approaches. Even if the nomothetic approach appears to be more systematic, a closer look reveals that both approaches include analytic as well as intuitive aspects. Both approaches include, for example, logical reasoning and the separation of details of information. These are aspects characterizing analytic thought. But both approaches also include holistic aspects, which characterize intuitive thought.\(^{(42)}\)

However, besides their research activities on temporal phenomena, experts also experience temporal processes in their everyday lives, which might also be reflected in their understanding of time. Our interviewed experts from the natural sciences tend to focus on general processes and abstract laws in their research (e.g. climate cycles, physical laws), but they also experience rapid societal and technological changes in their daily lives. Our interviewed experts from the social sciences and humanities, on the other hand, focus mainly on specific, concrete societal processes,
and, therefore, more determined views of time are probably not as accessible to them as they are to natural scientists. As outlined in the introduction, this concept of abstraction level is represented within construal-level theory, which does not explicitly link the level of abstraction to the level of determinism of future events. However, Trope and Liberman do mention confidence in future predictions:

Normatively, predictions about the more distant future should be made with less confidence because it is harder to make accurate predictions about the distant future than the near future. However, if people base their predictions for the more distant future on higher level construals and if high-level construals promote greater confidence, then people may feel no less and even more confident in predicting the distant future than the near future (p. 412).

According to Nussbaum, Liberman, and Trope a very abstract representation of a future event can be problematic, as it potentially leads to so-called overconfident predictions, because it is based on an oversimplified representation of how others ideally behave and because it neglects complexity.

Overall, our empirical findings suggest various potential challenges for interdisciplinary collaboration in nuclear waste management. Therefore, we will briefly discuss how different representations of time could affect the understanding of the safety assessment of a repository for high-level nuclear waste and spent fuel. Afterwards, we will discuss possible implications for communication within interdisciplinary expert teams in nuclear waste management and elaborate on the role of experts from the social sciences, humanities, and natural sciences in the safety assessment of nuclear waste management.

2.4.1 Implications for interdisciplinary collaboration in nuclear waste management

The safety case for the disposal of high-level nuclear waste and spent fuel is, in essence, a set of techno-geological arguments and analyses to justify why a specific repository system will be safe. The models to calculate this safety assessment are obviously based on a determined representation of time. Our results on different representations of time bear potentially fundamental implications for understanding this safety assessment. People with a more determined representation of time share the time-related assumptions of the safety case approach. Nevertheless, they also mentioned critical points concerning the modeling procedures involved in determining long-term developments. More specifically, they questioned whether all relevant parameters are represented in the models and how uncertainty and ignorance are managed in the technical risk assessment. As a geologist concisely replied on being asked what could happen to a nuclear waste repository within a period of one million years: "Scientifically, the experiment will only have terminated after a million years. Only then can we conclude whether the forecasts were correct or not."

In contrast, people with a more undetermined representation of time will have serious difficulties in understanding the safety case approach because they have a different representation of time than that assumed in the safety case. They could fundamentally question the capability to predict future developments based on insights gained from past development and, hence, call the legitimacy of the safety case approach into question. This can be exemplified by a quote from an economist, in answer to the same question: “And even if you put this into a geologically fairly inert area, there is no guarantee that a million years from now conditions wouldn’t have changed, so that what you thought was a really safe site, for some reason has water going through it or is more active in terms of movements and so on.”

A historian, for example, questioned the ability of geologists and physicists to make long-term predictions after being asked about the stability of predictions from different disciplines:
what they [physics and geology] cannot take into account are external developments, outside of the area of physics or geology ... There are many things about the future that are simply unimaginable, which does not allow for long-term predictions.” She used the example of the history of a specific tunnel to illustrate this. In this case, many calculations and predictions proved to be wrong during the actual construction phase. This rationale represents a classical case of an undetermined time representation that makes long-term predictions impossible and even unthinkable. Thus, unlike what one might expect, our findings indicate that the underlying assumptions, not primarily the complicated calculations or modeling procedures of the safety case, might be problematic and lead to misunderstandings.

Our findings suggest that time cannot (or only under specific circumstances) serve as a bridge of communication between disciplines, even when time is a central construct in many disciplines, because the concept seems to be prone to different understandings. Furthermore, because temporal aspects are often not explicitly discussed, our findings suggest fundamental challenges for communication within interdisciplinary teams in nuclear waste management, and consequently serious potential obstacles to risk communication between experts and the public. As has been shown in many risk issues, natural and technical sciences are often occupied with risk assessment, whereas social scientists are occupied with designing risk communication strategies. It is obvious that risk communication strategies must be based on the results of risk assessment. But how can we expect social scientists to design appropriate risk communication strategies if one of the key elements in the respective risk assessment, namely time, might be comprehended differently? For risk communication, therefore, it is important that experts for different disciplinary domains work together more closely and discuss their understanding of basic concepts, like time.

However, to enhance mutual understanding among experts from different disciplines, they must be able (at least to a certain extent) to shift in their time representation (determined vs. undetermined). The underlying question is whether the representation of time is a fixed construct or whether we can find intra-individual variance (as it is the case for many other psychological constructs, see e.g. depending on the context communication takes place in or on processes people talk about. This question cannot be answered on the basis of our interview data alone, but in the data we find some indications that such shifting of perspectives might in fact take place. An important concept is the level of abstraction. As shown above, some of the experts interviewed mentioned processes at differing levels of abstraction, each referring to different levels of future predictability. This indicates that experts are not fixed on a specific point on the continuum, but shift with respect to the types of processes they are talking about.

However, closer collaboration carries with it the potential not only for designing effective risk communication strategies but possibly also for improving risk assessment itself. Our results suggest that people from social sciences and humanities could contribute to this domain by bringing in their perspective (similarly as the role of the public, see not by questioning the models and calculations used, but more by reflecting on basic assumptions about time – and probably other concepts – which the safety assessment models are based on.

Experts from the social sciences and humanities could adopt the role of a “stretcher”. The stretching function, mainly discussed in the context of public participation, means challenging natural scientists and technical experts by posing critical questions, and especially questioning the underlying assumptions of their models. According to Fischhoff, every disciplinary domain has accustomed itself to its limitations and assumptions and has learned “to live with the reality of critical unresolved problems” (p. 138). Scientists from social sciences and humanities could contribute by reflecting on these limitations and assumptions, which could potentially be safety-relevant. Through a closer collaboration, potential blind spots, such as the aforementioned ones,
but also group phenomena such as group think\textsuperscript{(63)} could be detected and possibly resolved. In that sense, experts from social sciences and humanities could bring a different perspective to safety analyses. However, a coupled systems perspective is probably most promising when discussing about the collaboration between natural, technical, social sciences and humanities. Nuclear waste management faces different steps probably requiring different understandings of time. Before a repository is built, filled with nuclear waste, sealed and monitored, societal and political processes are highly relevant for managing the waste. Even when this timeframe is relatively short compared to one million years, it is from a societal perspective still very long (in Switzerland, about one century is considered for this phase)\textsuperscript{(64)}. This timeframe bares the potential for substantial societal transformations. Therefore, we regard contributions from social sciences and humanities as utmost important especially during this phase.

2.4.2 Limitations of the study

First, we have to keep in mind that sampling, coding, analyzing, and interpreting data in an iterative manner, as well as the strategy to generate codes directly from the interview material, can be problematic. The crucial point is that the results might be shaped by the way the interview data was generated and interpreted by the authors. Dealing with this problem of potential circularity in the analysis is challenging and there are no simple solutions\textsuperscript{(65)}. We used the same structured protocol for all interviews and aimed at documenting data sampling, coding, and analysis strategy as transparently as possible. Furthermore, we discussed and reflected intensely within our research group about sampling, coding, and analyzing data. Similar discussions also took place within the interdisciplinary and transdisciplinary steering board (consisting of people from the implementer of nuclear waste repositories and nuclear power plants, among others) of a transdisciplinary research project on radioactive waste governance, in which the current study is embedded. Despite these efforts, the influence of prior assumptions on the results cannot be fully excluded.

Of course, the context of the social interaction has to be considered as well. What people say and what language they use to say it depends strongly on the context of the interaction. Gilbert and Mulkay\textsuperscript{(66)}, for example, report that scientists use different linguistic repertoires when arguing about their own or their peer’s scientific views. The situation in which a scientist tries to persuade a peer about his or her viewpoint on a certain problem therefore probably strongly differs from the context of this study, where scientists were clearly assigned the expert role in the interview. We have to be aware that our results also reflect the situation in which the data was generated. Data gathered in other situations (e.g. recording and analyzing speeches at scientific conferences) could have yielded different results. It would have been interesting to study examples of communication between social scientists, researchers in the humanities, natural scientists, and engineers in nuclear waste management. However, as pointed out above, such a close collaboration between different social sciences, humanities, and natural sciences does not yet exist in nuclear waste management, making this situation still a hypothetical one. Thus, we decided to interview a broad range of potential contributors. By firstly inducing scientific discourse and later more colloquial, private conversation, we still tried to gain insights into different varieties of language and thus different perspectives used by the same person.

A further critical point considers the sample of experts. On one hand, the size of the sample is quite small, so any generalizations should be made with great caution, not only because of sample size but also with respect to the issues raised above. Furthermore, not all scientific disciplines are reflected in the sample. In particular, the natural science sample seems rather restricted, and some interesting time-related phenomena, for example, genetics, were not been touched upon. However, since we were specifically interested in the understanding of time in the context of
nuclear waste management, especially in the natural sciences, we were focusing on disciplines that are relevant within this issue. Despite these restrictions, we experienced a certain saturation (i.e., a point when further collection of data or codings no longer provide additional contributions) at the end of the interview phase, at least with respect to our research question about the representation of time. This was probably the result of our sampling procedure to look for potentially contrasting experts after each interview.

Even though we formed two contrasting groups of experts, it does not mean that the groups were homogeneous. Figure 2 already provides indications of substantial differences between disciplines with respect to their temporal understanding. It is for example important to note here that some social sciences seek to find general laws while others are following idiographic approaches. Also in natural sciences by far not all researched phenomena are considered determined (e.g. quantum physics). As Horlick-Jones and Sime [28] point out, there might even be differences within one discipline. This interesting question cannot be answered by our data, since our focus was on interviewing a broad range of disciplines, and not on studying different epistemics within one discipline.

2.5 Conclusions

Numerous publications both from research and from practice illuminate the importance of tackling the issue of nuclear waste management not only from a geological technical perspective, but also from psychological and societal perspectives. Nuclear waste management, therefore, is or will presumably become an increasingly interdisciplinary field. How these different disciplines understand such a basic and essential construct as time has, to the best of our knowledge, not been investigated so far. Our study clearly demonstrates that, in fact, different disciplines understand the term “time” fundamentally differently. Researchers from the humanities and social sciences tend to have a more open, undetermined understanding of time, whereas natural scientists tend to include both representations with a focus on a cyclic, determined understanding of time.

Applied to the case of nuclear waste, our findings suggest potentially serious implications. On the one hand, this can present a serious challenge for effective communication between different disciplines, especially for bridging the disciplinary gap between the domains of safety assessment and risk communication. In fact, this might hinder the development of promising risk communication messages. On the other hand, it could also represent a potential since different perspectives and understandings can broaden the focus of investigation if they are integrated successfully. Discussing different understandings or assumptions concerning time can raise mutual understanding between disciplines, which is a prerequisite for interdisciplinarity. It might also increase awareness of assumptions regarding time or other basic concepts that underlie different safety assessment approaches, which could lead to more robust solutions [67] both technically and socially. Thus, our study reveals vital and novel insights for the field of nuclear waste management and similar risk issues from both research and practice perspectives.

Notes

1 We are aware that this is not common practice in analyzing qualitative interviews but believe that this helps to illustrate the substantive and striking difference found.
Appendix: Interview protocol (translated)

Block 1: Time perception in the expert’s field
First, I would like to ask you how you deal with time in your scientific research field; in what way is time a relevant issue? What are the relevant time scales in your research field? Do you make predictions about the future? If yes, how do you do it?

Block 2: Time perception in general
If I tell you to imagine one million years, what comes to your mind spontaneously when you think about this time perspective? How about one hundred thousand years? Is there a difference between 1 million years and 100,000 years?

Block 3a: Time perception in the context of nuclear waste
Now we have talked about very large scales; similarly, large time scales are relevant in the context of nuclear waste. If you imagine a deep geological disposition facility for nuclear waste, what do you think could happen with this waste within one million years? Or in 100,000 years?

Block 3b: Stability of different systems
Which scientific disciplines do you think should deal with nuclear waste? For how many years can these disciplines predict the stability of the systems they are studying, and how reliable are these forecasts?

Block 4: Personal time horizon
How do you plan your personal future? For how much time do you plan ahead? Are there differences for different domains in your life? Do you consider future generations when you are making your decisions?

Block 5: Biographical background
Before we stop, I would like to ask you some questions about your educational and professional background. Could you tell me something about that? Do you have a special interest in time issues, for example a hobby, historical interest, etc.?

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References


On the understanding and processing of extensive timescales: The long-term dimension of nuclear waste


3 The influence of linear and cyclical temporal representations on risk perception of nuclear waste: An experimental study


Abstract

Time is an important aspect of the issue of nuclear waste, both from a technical and from a perceptual perspective. Previous studies have investigated the relationship between time and risk perception of nuclear waste, applying the discounting paradigm and therefore limiting time to one very narrow aspect: Its duration. However, time is a multifaceted concept and encompasses more than a linear property. The aim of our study is to test the influence of a different aspect of time, namely temporal representations (linear or cyclical) on risk perception of nuclear waste. In an experimental study we demonstrate that both linear and cyclical representations have a reducing effect on risk perception compared to the control condition, where no specific time representation was activated. Examining group differences, we also demonstrate that temporal representations have a differing influence depending on whether participants have a stable belief about nuclear waste or whether they belong to an ambivalent group that does not yet hold a stable belief. Furthermore, we replicate the well documented gender gap in risk perception. Our results bear potentially interesting implications for risk communication by demonstrating a causal relationship between the graphic representation of time and risk perception of nuclear waste.

Keywords: temporal representation; linear and cyclical time; nuclear waste; risk perception

3.1 Introduction

Siting nuclear waste is still a major concern worldwide (e.g., Strandberg and André 2009). In many countries, siting projects are vehemently disputed and even aborted. Beside procedural and participatory aspects of the site selection procedure (Krütli et al. 2010b; Krütli et al. 2010a; Stern and Fineberg 1996; Sjöberg and Drottz-Sjöberg 2001), different qualities of nuclear waste or radioactivity and, more generally, fear of radiation (Sjöberg and Drottz-Sjöberg 2009), lack of trust (Siegrist et al. 2005), or negative attitudes towards nuclear power (Sjöberg 2004) are often thought to be at the core of this resistance. However, the extensive timescales involved in the disposal of nuclear waste give rise to concern as well. In a survey conducted in a Swiss region previously proposed to host a nuclear waste repository, participants (N = 524) reported strong concern for future generations (Krütli 2007). On a technical level, experts consider a period of up to one million years for the disposal of spent fuel and for high-level nuclear waste (Nagra 2002a; b). In the geological and technical risk assessment of nuclear waste, time and risk are very closely interrelated. On the one hand, the hazard potential of the waste decreases over time due to radioactive decay; on the other, uncertainties increase over time, thereby challenging assumptions regarding different components of the disposal system in geological formations (e.g., containers, host rock). Taking a perceptual perspective, imagining one million years might be easy for a geologist who is used to dealing with much more extensive timescales (Moser et al. forthcoming; Stauffacher and Moser 2010), but how does the public perceive the extensive timescales related to nuclear waste?
Only few studies have examined the relationship between time and risk perception of nuclear waste. These studies predominantly applied the discounting paradigm, testing the hypothesis that the negative utility of a consequence decreases exponentially as temporal distance increases. Thereby, it is possible to distinguish between the discounting of time (i.e., in the sense of the Weber-Fechner law that one year today is perceived as longer compared to one year in 100 years) and the discounting of value. Most studies focus on the latter: Drottz-Sjöberg (2010), for example, found that people perceive the consequences of a leakage in a repository for nuclear waste differently depending on the respective temporal distance. The longer the temporal distance is (from 'during the working period' to 1 million years), the less severe are the perceived consequences. The overall discounting function she discovered was rather low: The average judgment of the seriousness of a leakage during the working period was 4.64; it was still 2.49 on a scale from one (insignificant) to five (very serious) after 1 million years. She further reports a significant difference in mean values between men and women for every given time period: Women considered negative consequences as being more serious than men. Similar discounting functions were found in a study by Svensson and Karlsson (1989). Furthermore, Svensson and Karlsson performed individual-based analyses and discovered that 30% of their participants refused to discount future consequences of a repository leakage, even if they were to occur 2 million years in the future. These results are in line with those of other studies on more general environmental risks covering much shorter timescales. Discount rates for negative environmental consequences (e.g., climate change: Nicolaij and Hendrickx 2003) are found to be rather low, and individual-based analyses reveal that a substantial amount of respondents do not discount negative future consequences at all. Similar results were also found in an experimental study where the delay of negative environmental consequences (coastal degradation and oil pollution) was manipulated. Böhm and Pfister (2005) did not find any effect of this manipulation on risk judgment and therefore concluded that environmental risks seem to be partly immune to discounting.

Although the cited studies demonstrate a relationship between time and risk perception of nuclear waste, the causality of this relationship remains unclear because of the correlational nature of the studies. Therefore, it cannot be concluded that the perception of time influences the perception of risk or vice versa. The main objective of this study is to experimentally examine the influence of time on risk perception of nuclear waste and thereby to shed light on the relationship between time and risk perception. We will focus in particular on different temporal representations (linear and cyclical) and consider individual differential measures in our study.

3.1.1 Time is a multifaceted concept

All the studies cited above examining time and risk perception applied the discounting paradigm. This paradigm has been criticized for various reasons (e.g., on an ethical level that future rights and intergenerational justice are disregarded; Shrader-Frechette 2000). However, we would like to point out a conceptual issue about this paradigm, namely, its very narrow notion of time. In the discounting paradigm, time is only understood as a given time duration, which neglects other probably important facets of the construct. Time is a multifaceted construct that entails far more dimensions than simply the actual duration between two points in time. We can, for example, distinguish between a continuous and an episodic understanding of time (e.g., Atance and O’Neill 2001; Scholz 1988), and time as a discrete or continuous variable (in physics). Cognitively, time can be represented on different levels of abstraction, from very concrete to very abstract (temporal construal theory, see, e.g., Liberman et al. 2002; Trope and Liberman 2003). Furthermore, time can be represented differently on a cognitive or graphic level: A linear representation refers to the irreversibility of time, whereas a cyclical representation suggests...
repetition (Overton 1992; Müller and Giesbrecht 2006). A cyclical representation implies that events repeat themselves, leading to a significant similarity between past, present, and future, while a linear representation implies that time flows unidirectionally and never returns to a previous state (Ji et al. 2009; Yamada and Kato 2006). There are different forms of cyclical temporal representations. A cycle which is conceptualized as a closed circle indicates a completely determined view (e.g., events are expected to repeat themselves in precisely the same way). A cyclical representation can be conceptualized as a spiral as well. This form also indicates that certain types of events (e.g., earthquakes) are expected to repeat themselves, yet not always necessarily in precisely the same way (Overton 1992). The spiral-like representation therefore allows for some variation in the events themselves as well as in the context. One might, for example, expect that earthquakes repeatedly occur in a seismic area. However, they might differ with respect to their intensity, and the situation in the region (e.g., the share of earthquake-proof buildings) might change over time. In the case of siting nuclear waste, one cannot imagine a completely pre-determined view, and we thus more specifically refer to a spiral-like representation when using the term ‘cyclical’. The difference to the linear representation is nonetheless clear.

We can therefore distinguish between the development of a certain attribute over time (e.g., radioactive decay) and the shape of this time dimension. The same development can be represented by different shapes of time: A person with a linear temporal representation perceives the process of, e.g., radioactive decay as increasingly temporally distant, while a person with a cyclical temporal representation perceives the same development as coming closer again. This example shows that both linear and cyclical temporal representations include aspects of duration, because depending on the temporal representation, events are perceived as being closer or more distant. However, the cyclical representation, in particular, also includes the aspect of expected repetition of events and processes, which qualitatively differs from mere duration.4

3.1.2 Linear and cyclical temporal representations and risk perception

Extensive timescales with regards to nuclear waste are widely discussed in the public discourse on siting projects (Scholz et al. 2007). Thus, temporal representations can be conceived as important aspects of respective mental models (Morgan et al. 2002). Temporal representations are therefore expected to influence the mental models individuals construct of a deep geological repository. This in turn means that different temporal representations might translate into different risk perceptions. For instance, in the cyclical representation, due to its repetitive character, future events might be perceived as being closer to the present than in the linear representation, and one might expect major catastrophes from the past to be repeated. We argue that people feel more affected psychologically by an event that is perceived as being closer, and therefore perceive a higher level of risk in contrast to events that are considered to be more distant. However, both representations include a certain degree of predictability of the future (because cycles imply repetition while an arrow suggests a certain order of events), therefore, we expect both representations to reduce perceived risk in contrast to a situation where temporal representation is not salient. Especially in the field of nuclear waste, where the timescales involved are extremely long, the cognitive representation of time is probably essential for expectations about long-term developments. Qualitative interviews even indicate that time representation might be more important than time duration in determining people’s belief in the possibility of long-term predictions, for example, about the geological host rock chosen to host the repository (Moser et al. forthcoming). Although linear and cyclical representations of time seem to be essential aspects of the construct of time in general, both cognitively and in graphic

4 This point was raised by an anonymous reviewer.
representations, no study has, to our knowledge, explored the influence of different temporal representations on risk perception. Our aim is to examine the influence of linear and cyclical representations on risk perception of nuclear waste in an experimental setting. In qualitative interviews participants shifted their temporal representations according to the issues under discussion (Moser et al. forthcoming). Temporal representation therefore is not only a stable trait, but is intra-individually changeable, depending on the issue one is thinking about at the moment (Nesselroade 2001). We predict the following outcomes:

Hypothesis 1a): Participants primed with a linear or cyclical temporal representation will perceive fewer risks of nuclear waste than participants primed with no specific temporal representation (control group).

Hypothesis 1b): Participants primed with a linear temporal representation will perceive fewer risks of nuclear waste than participants primed with cyclical temporal representation.

3.1.3 Group differences in risk perception

Time representations are, of course, not the only determinant of risk perception linked to nuclear waste. On an individual level, perceived risk of nuclear waste has been shown to be associated with negative affect, low level of trust, and negative attitudes toward nuclear power (Stauffacher et al. 2008). Yet studies also show that different groups of people react differently toward nuclear waste: With respect to concerns, risk and benefit perception, emotions, trust, and fairness, stable pro and con groups can be distinguished from a more ambivalent group (Stauffacher et al. 2008): According to a representative survey conducted in Switzerland (N = 2428), a large share of participants (36.7%, n = 890) belong to this ambivalent group. This study also demonstrated that group membership corresponds with political opinion: Individuals with more extreme political views were also more likely to have stable beliefs for or against a nuclear waste repository. Referring to the core definition of attitudes as including values and beliefs (Fishbein 1967), the ambivalent group tends to have ambiguous beliefs toward nuclear waste, or is simply not as concerned about it. For this group, it is expected that the process of forming a belief is a rather constructive process which can be influenced by situational factors. This group, for example, is more sensitive toward procedural fairness in the site selection procedure compared to groups with more stable beliefs (Stauffacher et al. 2008). On the other hand, stable groups are expected to have a strong belief about nuclear waste, that is, a political opinion that is stable and resists or remains insensitive toward external information, (e.g., counterarguments in a political debate): “In particular, a strong attitude toward the opinion object provides its own means of heuristic guidance, and the individual with a strong attitude need not construct the opinion from scratch” (Huckfeldt et al. 1999, 891). Since these groups of individuals differ in terms of their perception of nuclear waste, a further objective of our study is to examine whether their perception of nuclear waste can be influenced by different temporal representations. We predict the following outcomes:

Hypothesis 2: Participants from the ambivalent group will show a higher sensitivity to the manipulation of temporal representations in contrast to stable groups.

Furthermore, many studies have found that men and women differ strongly in their risk perception of nuclear waste, with women showing higher levels of risk perception than men (e.g., Davidson and Freudenburg 1996; Freudenburg and Davidson 2007; Scholz et al. 2007; Stauffacher et al. 2008; Drottz-Sjöberg 2010). To replicate this so-called gender gap in risk perception, we predict the following outcomes:

Supplementary Hypothesis: Male participants will perceive fewer risks of nuclear waste than female participants.
3.2 Methods

3.2.1 Participants

Eighty-three students from the ETH Zurich, the University of Zurich, and the University of Berne participated in the study. They were enrolled in various scientific disciplines in the natural sciences, social sciences, and humanities on the Bachelor’s as well as on the Master’s level. Respondents were recruited individually on the three campuses. They were presented with a movie theater voucher for their participation. Their ages ranged from 19 to 54 years (M = 24.00 years, SD = 5.61). Forty-one participants (49.4%) were male and 42 (50.6%) were female.

3.2.2 Experimental design

As a first independent variable, we manipulated temporal representation on three levels. As a second independent variable we formed two groups, namely one with stable and one with ambivalent beliefs based on participants’ responses (see below). Gender was the third independent variable. We investigated the influence of these independent variables on risk perception of nuclear waste.

Independent variables

Temporal representation: Due to the lack of similar studies, the manipulation of temporal representation could not be based on existing experiences from literature and is therefore of an explorative nature. A priming procedure (i.e., the introduction of a stimulus which exerts influence on the subsequent performance of the processing system; Baddeley 2001) was used to implement the experimental manipulation. All participants were asked to determine when eight past events or processes had occurred during the last 20,000 years (the cave paintings of Lascaux, the end of the Second World War, the formation of the Rhine Falls, the construction of the Pyramids of Gizeh, the end of the last glacial period in Europe, the disappearance of mammoths in Europe, the construction of Stonehenge, and the invention of the wheel). To prevent primacy and recency effects, the order of the events was varied across questionnaires. As experimental conditions, participants were given two distinct representations of time on paper and were asked to indicate the events on these representations: Participants in the linear condition were handed a two meter long arrow drawn on a folded piece of paper (see Figure 1a). A mark every 10 cm, which was labeled accordingly, indicated 1,000 years of time, and participants had the possibility of extending the folded arrow to its full length. Participants in the cyclical condition were handed a spiral of time (see Figure 1b). As in the linear condition, 2 meters represented 20,000 years, but the time period was displayed as a spiral that was fixed on a piece of paper in the middle that participants could turn around the spiral. As in the linear condition, a mark every 10 cm indicated 1,000 years of time. Both the linear and the cyclical representation were constructed in such a way as to not explicitly introduce temporal discounting. Hence, we did not choose a logarithmic scale and instead assigned 10 cm to the temporal intercepts of 1,000 years, independently of their temporal distance from today. Participants in the condition without specific representation (control group) were asked to write down the time points on a line next to the description of each event; they did not receive any graphic support.

Figure 1a: Time as an arrow (reduced image, only the last 3,000 years are displayed, reduced size of labeling). The actual length of the arrow is 2 meters (corresponding to 20,000 years).
Stable/ambivalent beliefs: In terms of defining the two groups with stable and ambivalent beliefs, we faced a difficult situation. Due to potential framing effects, we did not want to ask participants about their beliefs on nuclear waste before the experiment. Asking participants after the experiment, however, was problematic as well, since we could not be sure that these measurements were not also influenced by the priming. Thus, we looked for a close proxy, where we did not expect to find any effects of the experimental manipulation. As mentioned in the introduction, a representative survey in Switzerland indicated that political opinion corresponds well with this group membership (Stauffacher et al. 2008): Participants who sympathize with a left-wing or right-wing party were more likely to have stable beliefs, i.e., show consistent answer patterns across all respective scales with respect to risk, benefits, emotions, and concerns. In contrast, participants from the center of the political spectrum often show answer patterns that are ambivalent or ambiguous, for instance, a simultaneous perception of high risks and high benefits. We measured political opinion on a ten-point scale where ‘one’ indicated ‘entirely left’ and ‘ten’ indicated ‘entirely right’. Participants who scored among the first or last three points were defined as having stable beliefs. We used the mean value of all responses for one participant who did not indicate a political opinion. As we used a student sample, the distribution was positively skewed: Almost no one was positioned on the right tail ($M=3.99$, $SD=1.69$). We therefore only formed one group with stable beliefs (on the left wing of the political spectrum) and one group with ambivalent beliefs. Again, we must stress that this political spectrum can only serve as proxy here (see above).

Gender: Participants were asked to indicate their gender at the end of the questionnaire.

Dependent variable

We measured risk perception on a scale developed by Stauffacher et al. (2008). The scale was slightly adapted and consisted of six items with several risks associated with nuclear waste. One new item (risk of recovery of the repository after the next ice age) was added to the existing list of items. This additional item was chosen because it represents a concern that has frequently been mentioned in previous qualitative interviews on the perception of extensive timescales (Moser et al. forthcoming) (see Appendix for the full list of items). Participants judged these risks on seven-point scales (‘one’ indicated ‘no risk at all’, ‘seven’ indicated ‘very high risk’). The resulting scale of seven items ($M=3.81$, $SD=1.10$) demonstrated good reliability (Cronbach’s $\alpha=.84$). We used the following items for the manipulation check: i) one item to measure the perceived predictability of the future (6-point scale), and ii) three items to measure the perceived possibility to make valid
predictions for 100,000 years from a geological, technical, and social perspective (7-point scales each; see Table 1 for the wording of the items).

3.2.3 Procedure

Participants were invited to take part in a study about long timescales. They were randomly assigned to one of the two experimental groups or to the control group. All materials were presented in a questionnaire booklet; the graphic time representations for the experimental groups were handed to the participants together with the booklet. The control group received the questionnaire booklet only. First, participants concluded the priming task, that is, they determined when several events or processes had occurred over the last 20,000 years. The two experimental groups noted their estimations either on the arrow (linear condition) or on the spiral (cyclical condition). Participants in the control group noted their estimations in a list. After concluding the priming task, participants answered two blocks of questions. First, they answered a number of questions about the stability of certain systems and the regularity of certain processes (e.g., the development of the political system in Switzerland or the geological development of the Swiss Alps). This article does not deal with these questions. The second block of questions concerned nuclear waste as one example where extensive timescales are relevant. Participants were given a brief description of the Swiss concept of a deep geological repository for high-level waste. Subsequently, participants answered the risk perception items. After providing demographic information, the participants were thanked and debriefed. Completion of the entire task required between 30 and 40 minutes.

3.3 Results

3.3.1 Manipulation check

As the manipulation was explorative in nature, we used explorative manipulation check scales as well. The means indicate the following patterns (see Table 1): Individuals in the control condition tended to perceive the future as being more open compared to the experimental groups. They also tended to perceive that it was less possible to make valid future predictions from a geological, technical, and social perspective in comparison to the experimental groups. One-way ANOVAs, however, only revealed a significant difference for item 4 between the cyclical and the control group, $F(2,80)=3.11, p = .05$, indicating that people in the cyclical condition perceived that it was more possible to make valid future predictions for the next 100,000 years from a social perspective compared to the control group. Although the other means show the expected pattern (at least between the experimental groups and the control group), these differences did not reach statistical significance (item 1, perceived predictability: $F(2,80)=1.56, p = .22$; item 2, valid predictions from a geological perspective: $F(2,80)=0.54, p = .58$; item 3, valid predictions from a technical perspective: $F(2,80)=1.33, p = .27$).
Table 1: Means and standard deviations for the items of the manipulation check by condition (N = 83).

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Items for manipulation check</th>
<th>condition</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Is the future rather predictable based on the past or is it open and undetermined?</td>
<td>control</td>
<td>3.26</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>linear</td>
<td>3.71</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cyclical</td>
<td>3.71</td>
<td>1.05</td>
</tr>
<tr>
<td>2.</td>
<td>How do you judge the possibility of making valid predictions for the next 100,000 years from a geological perspective?</td>
<td>control</td>
<td>3.41</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>linear</td>
<td>3.61</td>
<td>1.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cyclical</td>
<td>3.89</td>
<td>1.71</td>
</tr>
<tr>
<td>3.</td>
<td>How do you judge the possibility of making valid predictions for the next 100,000 years from a technical perspective?</td>
<td>control</td>
<td>2.81</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>linear</td>
<td>3.07</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cyclical</td>
<td>3.50</td>
<td>1.80</td>
</tr>
<tr>
<td>4.</td>
<td>How do you judge the possibility of making valid predictions for the next 100,000 years from a social perspective?</td>
<td>control</td>
<td>1.48</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>linear</td>
<td>1.54</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cyclical</td>
<td>2.04</td>
<td>1.04</td>
</tr>
</tbody>
</table>

Note: Item 1 was measured on a 6-point scale (1 = future is open, 6 = future is predictable), items 2-4 were measured on 7-point scales (1 = no possibility at all, 7 = very good possibility).

3.3.2 Test of hypotheses

To test the hypotheses we applied a 3 x 2 x 2 (temporal representation x stable/ambivalent beliefs x gender) multifactorial analysis of variance (ANOVA) with risk perception as a dependent variable. All analyses were calculated using the program PASW Statistics 18.0. We adjusted the ANOVA model to test for the formulated hypotheses, i.e., we included all main effects and the two interactions between stable/ambivalent beliefs and temporal representation, as well as between gender and temporal representation. Table 2 presents the results of the overall analysis. In the following paragraphs, the results are described in detail based on the hypotheses.

Table 2: ANOVA with temporal representation, stable/ambivalent beliefs and gender as independent variables and risk perception as dependent variable (N = 83).

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>df</th>
<th>F</th>
<th>η</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal representation</td>
<td>2</td>
<td>3.23*</td>
<td>.28</td>
</tr>
<tr>
<td>Stable/ambivalent beliefs</td>
<td>1</td>
<td>.04</td>
<td>.00</td>
</tr>
<tr>
<td>Gender</td>
<td>1</td>
<td>5.72*</td>
<td>.27</td>
</tr>
<tr>
<td>Temporal representation x stable/ambivalent beliefs</td>
<td>2</td>
<td>3.87*</td>
<td>.31</td>
</tr>
<tr>
<td>Temporal representation x gender</td>
<td>2</td>
<td>.89</td>
<td>.15</td>
</tr>
<tr>
<td>Error</td>
<td>74</td>
<td>(1.08)</td>
<td></td>
</tr>
</tbody>
</table>

Note: The value enclosed in parentheses represents the mean square error. *p < .05.

Hypotheses 1a) and 1b): Main effect of temporal representation

We hypothesized 1a) that participants primed with a linear or cyclical temporal representation would perceive fewer risks of nuclear waste than participants primed with no specific temporal representation (control group), and 1b) that participants primed with a linear temporal representation would perceive less risks of nuclear waste than participants primed with a cyclical temporal representation. The analysis revealed a main effect of temporal representation, \( F(2,74) = 3.23, p < .05 \). Planned contrasts showed the expected picture for Hypothesis 1a): Participants in the control group perceived more risks than participants in either experimental condition, \( t(80) = 2.10, p < .05 \) (one-tailed). However, Hypothesis 1b) was not supported: The two experimental conditions did not differ significantly, \( t(80) = .45, p = .33 \) (one-tailed). Figure 2 illustrates the differences in mean risk perception between the three conditions. Our results suggest a risk-reducing effect induced by both experimental conditions and no further reduction.
by the linear temporal representation as had originally been hypothesized. The linear temporal representation reduced perceived risk slightly more strongly than the cyclical representation, but this difference was not statistically significant.

![Figure 2: Mean risk perception of nuclear waste by experimental condition. Error bars represent standard errors. Risk perception was measured on a 7-point scale; the cut-out between 2.5 and 5.5 is displayed (N = 83).](image)

**Hypothesis 2: Interaction effect between temporal representation and stable/ambivalent beliefs**

We predicted an interaction effect between temporal representation and stable/ambivalent beliefs. We expected participants from the ambivalent group to be especially sensitive toward temporal representations compared to the stable group. The main effect of temporal representation reported above was qualified by the expected interaction effect between temporal representation and stable/ambivalent beliefs, $F(2,74) = 3.87$, $p < .05$. Figure 3 displays the expected pattern: The responses of the stable group seem to be rather unaffected by the different experimental conditions, while the responses of the ambivalent group seem to differ across conditions. Post-hoc comparisons using Tukey’s HSD (honest significant difference) test indicated the following pattern: In the stable group, we could not detect significant differences between the control group and either experimental condition. However, in the ambivalent group, the control group differed significantly ($p < .05$) from the cyclical condition and marginally significantly ($p = .11$) from the linear condition. The experimental manipulation seems to have had a stronger effect on the ambivalent group than on the stable one: In the ambivalent group, both experimental manipulations had a risk-reducing effect (compared to the group without specific representation), whereas this was not the case in the stable group, in which risk perception was rather stable across the three experimental conditions.
Supplementary Hypothesis: Main effect of gender

We hypothesized that men would perceive less risk of nuclear waste than women. As expected, the main analysis revealed a significant main effect for gender, \( F(1, 74) = 5.72, p < .05 \). As hypothesized, men perceived less risk (\( M = 3.53, SD = 1.01 \)) compared to women (\( M = 4.09, SD = 1.14 \)), \( t(81) = 2.37, p < .01 \) (one-tailed). Our analysis therefore replicates the often-reported gender gap in risk perception of nuclear issues. Looking at the means and standard deviations, it becomes obvious that both men and women tend to be distributed around the midpoint of the scale. However, female participants’ mean risk perception was slightly above the midpoint of the scale, whereas male participants tended toward the lower bound of the scale. The interaction between gender and temporal representation was not statistically significant, \( F(2, 74) = .96, p = .42 \), indicating that temporal representation did not have a differing effect on men and women’s risk perception.

3.4 Discussion

The aim of the present study was twofold. On the one hand, we wanted to study the influence of different temporal representations on risk perception of nuclear waste. To our knowledge, this is the first study in the field to conceptualize time not exclusively as duration, but looks instead at different cognitive representations of time. On the other hand, we wanted to explore whether different groups of people (individuals with different beliefs about nuclear waste; men and women) varied in risk perception depending on temporal representations. In an experimental study we primed our participants with a linear temporal representation, a cyclical temporal representation or no specific representation (control group), and measured their risk perception of nuclear waste. The results revealed that our experimental manipulation had an effect: Participants primed with either a linear or a cyclical representation perceived less risk compared with the control group. Unexpectedly, however, the two experimental groups did not differ in risk perception: Both the linear and the cyclical representation practically had the same influence on risk perception. Unfortunately, we have no clear empirical evidence by what processes the experimental manipulations affected risk perception. Therefore, we can only speculate about possible explanations. One explanation may be that it is very difficult for...
individuals who are confronted with a particularly extensive timescale to actually grasp it, and the timescale may therefore only be perceived as a number with many zeros or as a blank space. Depicting time as an arrow or spiral may give people some indication about how to interpret this extensive duration of time. This may even have been fostered by our experimental material, whose use required physical activity. Participants had to use their hands to unfold the arrow or turn the spiral around. The concept of embodied cognition assumes a relationship between cognition and physical activity: “cognitive processes are deeply rooted in the body’s interactions with the world” (Wilson 2002, 625). It is therefore possible that the physical activity (unfolding or turning), combined with the cognitive activity in the priming task gave shape to imagining future times. Both experimental groups performed a physical activity that fosters the idea of predictability, which could explain why we did not find any difference in risk perception between the two experimental groups.

In our case, both representations had a certain direction: The arrow moved forward and the spiral followed a circular path, but also had a direction. This may suggest the idea of the predictability of the future to a certain extent, e.g., how given geological layers will develop, and consequently fill the extensive time duration with at least some content. Thus, the representation of time might have helped to decrease some uncertainty, and may therefore have decreased risk perception. Both representations produced the same effect, implying that the representation itself might not be particularly important. Looking at the items of the manipulation check, the means tend to show this pattern of less perceived predictability in the control group. However, this must be interpreted carefully due to the lack of significance in the differences of means.

Similarly, one could also argue that the two priming tasks affected the level of abstraction regarding how time is cognitively construed (Liberman et al. 2002; Trope and Liberman 2003). We provided the experimental groups with a visual structure or tool to organize the eight past events on a specific temporal structure. These eight past events were listed in randomized temporal order and the participants in the experimental groups positioned them with the support of either an arrow or spiral of time. Our goal for the experimental groups, hence, was not to activate thoughts about specific past events, but rather to activate a certain structure of how events are ordered with respect to time. The control group, however, did not receive such a temporal structure. We can expect that they thought about past events, though not necessarily in a specific order or in a specific structure. Thinking about a general structure or about a ‘Gestalt’ indicates more abstract representations compared with thinking about specific events (Liberman et al. 2002; Trope and Liberman 2003). Therefore, the representation of time as a spiral or arrow may have triggered a more abstract temporal representation compared with that of the control group. Abstract temporal representations can lead to so-called overconfident predictions (Nussbaum et al. 2006): Because complexity is being reduced, events are expected to happen as planned and context-specific or unexpected events are neglected. This could be one reason why participants in the two experimental conditions perceived fewer risks from a nuclear waste repository compared to the control group.

It would be interesting to investigate whether different modes of thought were triggered by the different temporal representations and how risk perception was shaped by these cognitive processes. In psychology, authors distinguish between a more analytical and a more intuitive mode of thought (e.g., Chaiken and Trope 1999; Slovic et al. 2004; Scholz 1987; Hammond et al. 1987; Hogarth 2001). These have a differing effect on risk perception (e.g., Visschers 2007; Grasmück and Scholz 2005), because different aspects of nuclear waste, such as radioactive decay over time, probabilities of negative consequences, the valence of negative consequences, emotions, and values tied to the issue at hand are, depending on the mode of thought, more or less salient when judging the risks of nuclear waste. The observation that our experimental
groups differed from our control group with respect to risk perception therefore raises the question whether temporal representations triggered more analytical or more intuitive cognitive processes in our experimental groups. This question seems particularly interesting when considering that graphical tools are important tools for risk communication (Smerecnik et al. 2010). Actors involved in risk communication about nuclear waste use similar tools as we used in our experiment to represent the extensive timescales involved (e.g. an arrow indicating the geological development of the past 300 million years in Switzerland or a spiral of time, see Nagra 2007). Our data indicates that graphical representations potentially alter the way people process risk information, however, more research is required to better understand how people process time and risk information in the case of nuclear waste and probably also of other long-term risks.

The main effect of temporal representation was qualified by an interaction effect between temporal representation and stable/ambivalent beliefs. The risk perception of the stable group remained rather unaffected by the experimental manipulation, whereas the experimental manipulation had a stronger effect on the participants of the ambivalent group: Both temporal representations decreased risk perception compared to the control condition. This result indicates that the stable group already had strong beliefs on nuclear waste, which were retrieved from memory to answer the risk perception item. Research on the concept of attitudes shows that strong attitudes are more predictive of judgments and less prone to influence from context or additional information in contrast to weaker attitudes (e.g., Petty et al. 1997). Therefore, the manipulation of time representations probably did not influence their preexisting strong beliefs on nuclear waste. In contrast, the ambivalent group was not expected to have a strong belief. For them, risk perception of nuclear waste was probably more a constructive process, where different temporal representations could exert a certain influence. Our study provides an additional indication that members of the ambivalent group are probably more sensitive to external factors than those from the stable group who already have a strong belief about the issue at hand.

Note that although the ambivalent group even shows higher levels of risk perception compared to the stable group, the overall effect is not significant. This is surprising and we would have expected participants with stable beliefs to perceive more risks, because this group was comprised of participants who are on the left of the political spectrum. In Switzerland, people on the left of the political spectrum in general take a more critical view and tend to perceive more risks compared to those on the center or right of the political spectrum (Stauffacher et al. 2008). However, our sample is not representative of Switzerland, but only included university students, half of who are studying natural or engineering science. One reason for the generally low risk perception could be that many of our participants have some technical affinity and therefore judge the risks to be rather low. Since we are interested in relative changes within these groups, this does not, however, disprove our results and conclusions.

Unsurprisingly, we were also able to replicate the gender gap in risk perception of nuclear technologies (e.g., Davidson and Freudenburg 1996; Freudenburg and Davidson 2007; Scholz et al. 2007; Stauffacher et al. 2008): Women perceived more risk than men. The interaction between gender and temporal representation was not statistically significant. This implies that men and women’s risk perception of nuclear waste differs. This difference, however, was neither significantly accentuated nor attenuated by different temporal representations. Moreover, a thorough literature review revealed that the empirical basis for gender differences in temporal representations is rather weak. One explorative study indicated that women more often than men tend to perceive time as being circular (Brown and Herring 1998). Even if such differences in temporal representation exist, our experiment indicates that both representations are available in both genders and can be activated in a priming procedure. The reason why men and women differ
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with respect to perceived risks deserves an article of its own and will therefore not be discussed here in detail. Suffice it to say that the two main lines of argumentation refer, on the one hand, to biological factors and to factors of socialization, on the other (e.g., Venables and Pidgeon 2009; Davidson and Freudenburg 1996).

3.4.1 Limitations of the study

Time can be represented in a variety of ways, for example, as a line, a spiral, a closed circle, a tree, or a sinusoidal curve, determined or undetermined, and so on (Overton 1992; Müller and Giesbrecht 2006; Yamada and Kato 2006; Moser et al. forthcoming). Studying only linear and cyclical representations imposes a certain restriction. However, since this is the first study in the field to examine temporal representations and risk perception of nuclear waste, we aimed at demonstrating at a very basic level that temporal representations can influence risk perception. We therefore decided to study two classic representations of time, namely the linear and the cyclical representation. These two representations also form some a sort of foundation within which most of the other representations are rooted. It might be interesting to include further temporal representations in a study and to examine the differences between them.

Since this is the first study to experimentally manipulate temporal representation, the manipulation used is of an explorative nature. Our manipulation checks did not yield clear results and it therefore remains unclear what processes were triggered by the different experimental manipulations and why exactly people in the experimental conditions perceived fewer risks compared to the control group. We can only speculate about the reasons based on the literature or previous studies. It would have been interesting to include other potentially mediating variables as manipulation checks (e.g., perceived closeness of the consequences of a nuclear waste repository, indicators for analytical or intuitive processing, how concrete or abstract the consequences of a nuclear waste repository are cognitively construed), or to perform qualitative interviews with participants after the experiment to find out more about their cognitive representations of time and the cognitive processes involved in risk judgments.5

A potential weakness of the study concerns our sample, which was by no means representative of the general public, even though we included students from different study programs and disciplines to survey a broad and diverse sample. However, our primary aim was not to make generalizing statements, but to study the causal relationship between temporal representations and risk perception of nuclear waste, and the results still yield important insights into the role of time in such risk perception.

3.4.2 Recommendations for further research

Our study highlights that temporal representations potentially influence risk perception of nuclear waste, primarily among those with ambivalent beliefs. However, the cognitive processes involved remain unclear. Knowing more about the underlying cognitive processes could be crucial for risk communication in nuclear waste management. The extensive time periods involved are often visualized utilizing different temporal representations (e.g., Nagra 2007). As our experiment demonstrates, participants utilizing a temporal representation judged risks as being lower compared to the control group. This indicates that temporal representations might change the cognitive processes of participants. Therefore, future research should investigate these underlying cognitive processes, e.g., by measuring reaction times (Schunk and Betsch 2006) by eliciting thinking-aloud protocols to identify concepts and cognitive representations (Scholz 1987). Such

5 This point was raised by an anonymous reviewer.
studies could clarify the role of temporal representations in risk perception both in general and for different groups of people, in particular. Having recognized temporal discounting as a central research paradigm in the field, it would also be interesting to investigate the relationship between temporal representations and discounting, and to test whether different temporal representations are able to affect discounting rates.

3.5 Conclusions

Time is a multifaceted concept. Especially with an issue like nuclear waste, which involves extreme timescales, time duration might be very difficult for most individuals to grasp; yet time is essential for technical risk assessment as well as for risk perception. Therefore, aspects of time other than its pure duration might be more useful, for example, its cognitive or graphic representation. Our study is the first to show that linear and cyclical temporal representations actually matter in risk perception of nuclear waste, especially for individuals who do not have strong beliefs about nuclear waste. Our results bear important consequences for risk communication, as graphic representations of time or of future projections are potentially relevant for the public's perception of risk. Unlike geologists, individuals in general are not used to thinking in the extensive temporal dimensions relevant in nuclear waste disposal. Graphic representations of time could give the public (especially those from the ambivalent group) an idea of how these extensive timescales are understood by technical experts, e.g., which processes they expect to be predictable for the future. As such, temporal representations may potentially be able to induce a thought process and reflections about knowledge gaps, which can be taken as a starting point for the provision of information.

Appendix: Risk perception items

Risk perception items (translated, items 1 to 6 from Stauffacher et al. 2008)

Please imagine a deep geological repository for nuclear waste. How do you judge the risk that one of the following will happen? Response scale from 1 to 7, 1 = very low, 7 = very high.

1. Release of radioactivity in transport accidents.
2. Health risks for yourself because of the deep geological repository.
3. Health risks for other people because of the deep geological repository.
4. Health risks for later generations because of the deep geological repository.
5. Release of radioactivity to groundwater due to damaged canisters.
6. Economic losses because of image loss in the region.
7. Recovery of the repository after the next glacial period (additional item).

Acknowledgements

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References

On the understanding and processing of extensive timescales: The long-term dimension of nuclear waste


Paper 2: The influence of linear and cyclical temporal representations on risk perception of nuclear waste
An experimental study


On the understanding and processing of extensive timescales: The long-term dimension of nuclear waste


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4 Psychological factors for discounting negative impacts of nuclear waste


Abstract

The aim of this paper is to examine discounting of negative consequences of nuclear waste and to take a critical perspective at discounting from both content-related and methodological perspectives by means of a psychological experiment. From a content-related cognitive and motivational perspective, discounting judgments for nuclear waste are difficult to interpret because they may not only reflect a devaluation of the future but account for radioactive decay over time. We thus compare discounting for nuclear with that for hazardous waste. Further we investigate the psychological factors underlying discounting. From a more methodological perspective we investigate how sensitive participants are toward very extensive timescales and if they differentiate properly between effects in the distant future. Data from a mixed between-within-subjects-design experiment (N = 314) indicate that mainly two factors drive discounting: Expectations about societal learning, i.e. a higher perceived adaptive capacity of future societies leads to steeper discounting curves, and a greater emotional involvement with future generations leads to flatter discounting curves. Discounting curves are steeper for the issue of nuclear than for hazardous waste. Data indicate that participants are sensitive toward different extensive timescales: confronted with a logarithmic timescale of up to 1 million years, participants produced steeper discounting curves than for a linear timescale of up to 4000 years. We discuss implications of our work for future research on the discounting of negative environmental impacts of technologies on extreme timescales.

Keywords: Discounting, psychological discounting factors, extreme timescales, nuclear waste, hazardous waste, long-term environmental problems

Research highlights

- Perceived seriousness of a repository leak (hazardous / nuclear waste) was measured.
- Waste type, time scale, and response scale were experimentally manipulated.
- Participants discounted a future leak only weakly; 38.5% did not discount.
- Participants’ seriousness judgments differ regarding timescales and waste types.
- Perceived adaptive capacity and emotional involvement drive seriousness judgments.

4.1 Introduction

Extensive timescales are one essential characteristic of many environmental problems such as climate change and the disposal of high-level nuclear waste. The long-term dimension poses a challenge for assessing possible impacts of these environmental problems in natural scientific research but also calls for social scientific research (Scholz, 2011). If we want to understand the impact of such long-term environmental problems on social systems and vice-versa, it is imperative to gain a thorough understanding of how people comprehend and deal with the long-term dimension. The temporal dimension may, for example, influence people’s willingness to make sacrifices for future generations. Research on time in the social sciences, however, rarely includes timescales that surpass the expected lifespan of a human being (see e.g., Table 1 in
Frederick, Loewenstein, & O’Donoghue, 2002; Liberman, Sagristano, & Trope, 2002; Tsukayama & Duckworth, 2010; Chao, Szrek, Pereira, & Pauly, 2009). One exception is a study by Chapman (2001) investigating inter- and intragenerational discounting rates and taking into account timescales of up to 900 years.

The discounting paradigm was originally conceptualized as a tool for comparing the value of investments that can be made today or in the future. Because of its simplicity and its resemblance to the compound interest formula it soon became a popular approach in “decisions involving tradeoffs between costs and benefits at different times” (Frederick et al., 2002, p. 351). It assumes that the utility of a consequence decreases with increasing temporal distance. Discounting a certain utility, e.g., $100, means that $100 is of less utility later in time than sooner in time. If A and B both receive $100 but A receives $100 now and B receives the same amount of money in one year, A could make a financial investment with the money and be better off financially in one year compared to B who would then have just received $100. Thus, receiving $100 in one year is of less value than receiving it today. The same logic is applied to negative consequences. Losing $100 today has a higher negative value than losing it than in the future, as it may be invested for some time until it is lost. Having its origins in economics (Frederick et al., 2002) and in investment decisions (Ott, 2003), the discounting paradigm soon became common as well for other social sciences like psychology and also for studying non-monetary decisions involving different time points such as health risks and environmental risks.

In the domain of environmental risks discounting has been applied for the issues of nuclear waste storage, soil pollution, greenhouse effect, water pollution, and coastal degradation (for an overview, see Gattig & Hendrickx, 2007). This implies that everything (e.g. the loss of a species) can be monetized, a position which initiated critical reflection (e.g., Ott, 2003; Hellweg, Hofstetter, & Hungerbühler, 2003). One can distinguish between different discounting approaches (Baum, 2009): a prescriptive one, where discounting rates are based on ethical considerations (e.g., Stern, 2007), and a descriptive one where discount rates are based on observations of the financial market (e.g., Nordhaus, 2007). One example of the descriptive approach considers public judgments. Hence, some studies do not necessarily apply the discounting paradigm as an economic tool, but more so to examine the public’s perception of long-term decisions.

An often-reported finding of such studies is that a substantial portion of participants refuses to discount; they are so-called “non-discounters”. Studying discounting in the context of greenhouse effect, Nicolaj and Hendrickx (2003) report that about 50% of participants did not discount. Typically, in discounting studies, researchers use a within-subjects design with temporal delay as the repeated factor. This makes the manipulation of temporal delay quite conspicuous (Hendrickx & Nicolaij, 2004) and could, therefore, promote non-discounting. However, also in between-subjects designs, where different participants make judgments on different temporal delays, a common result is that no effect of delay manipulation is found (Böhm & Pfister, 2005; Hendrickx & Nicolaij, 2004). This indicates that overall, participants tend toward non-discounting. However, also in between-subjects designs, where different participants make judgments on different temporal delays, a common result is that no effect of delay manipulation is found (Böhm & Pfister, 2005; Hendrickx & Nicolaij, 2004). This indicates that overall, participants tend toward non-discounting, even when they are not aware of the manipulation of temporal delay. This high share of non-discounters seems to be “typical for the environmental domain” (Gattig & Hendrickx, 2007, p. 30). This could be because ethical considerations (e.g., social justice and the equitableness of outcomes) are particularly relevant in this domain (Böhm & Pfister, 2005). Another explanation for this effect considers that discounting studies in the environmental domain are about negative outcomes and that low discounting rates in this domain can be explained by the fact that losses are discounted less than gains (Hardisty & Weber, 2009).

Also for the issue of nuclear waste, Svenson and Karlsson (1989) report that about 30% did not discount negative consequences over a time period of 2 million years. Social science studies about the public’s understanding of the long-term dimension of nuclear waste are rare and the
discounting approach is predominantly applied. In survey studies, for example, participants were asked to judge the seriousness of a nuclear waste repository for different points in time up to one million years (Drottz-Sjöberg, 2010) or two million years (Svenson & Karlsson, 1989). Research on the psychological factors underlying discounting negative consequences of nuclear waste, however, is so far lacking.

The aim of this paper is to examine discounting of negative consequences of nuclear waste. We thereby take a critical look from both content-related and methodological perspectives by means of a psychological experiment. More specifically, we aim i) to explore the cognitive and motivational factors underlying discounting as well as ii) to identify methodological challenges in assessing discounting judgments.

It is important to note that the timescales involved in nuclear waste disposal, are much larger compared to timeframes in financial economics including (where the discounting paradigm was developed). Due to involved uncertainties and ignorance, we therefore did not apply a measure of discounting in the classical sense (e.g., monetary values) but rather asked participants about the perceived seriousness of a leak of a nuclear waste repository occurring at different future times. These seriousness judgments serve in the following as an indicator for discounting judgments.

4.1.1 Development of hypotheses: challenges in research on discounting

Challenges from a content-related cognitive and motivational perspective

Discounting negative consequences over time is sometimes interpreted as a devaluation of the future. This, however, may not necessarily be true for nuclear waste. An alternative explanation could be that participants take into account radioactive decay and therefore, judge a negative consequence at a later point in time as being less severe than a negative consequence occurring sooner. This could be considered rational reasoning, because radiotoxicity decreases over time, and thus a leak in the distant future might, indeed, be less serious than one in the near future. Discounting judgments for the issue of nuclear waste therefore contain several types of information (discounting because less value is assigned to a negative consequence in the future, discounting because of radioactive decay, and so on) and, hence cannot be interpreted in a straightforward manner.

This problem of interpretation is of paramount importance in discounting research. Frederick et al. (2002) conclude their critical review on time discounting by claiming that we need more information about the factors behind discounting or not discounting: “To better understand the pattern of correlations in implied discount rates across different types of intertemporal behaviors, we may need to unpack time preference itself into more fundamental motives […]” (Frederick et al., 2002, p. 392). The authors provide a list of factors potentially driving discounting, namely that “future consequences may confer less utility”, or “uncertainty”, “inflation”, “opportunity costs”, “changing tastes”, “increasing wealth” and so on. Nicolaij and Hendrickx (2003) empirically explored psychological factors underlying discounting. One of their conclusions is that such discounting factors are highly domain specific (Nicolaij & Hendrickx, 2003). We also argue that the temporal dimension itself is important for identifying psychological discounting factors. The issue of nuclear waste includes timescales of up to one million years (e.g., Nagra, 2002; Junker, Flüeler, Stauffacher, & Scholz, 2008). As the history of mankind demonstrates, tremendous societal transitions are possible within much shorter timescales (see e.g., Scholz, 2011; Grin, Rotmans, & Schot, 2010). Therefore the expected ability of future societies to adapt to challenges could be an important driver for discounting negative future consequences. This so-called “adaptive capacity” (Smit & Wandel, 2006) represents an important aspect of the concept of resilience and
“vulnerability”. In contrast to the term “risk”, vulnerability includes a dynamic component (Scholz, Blumer, & Brand, 2012) and, thus, seems especially suitable for the study of long-term phenomena.

Previous studies which used the discounting paradigm for investigating the temporal dimension of nuclear waste (Svenson & Karlsson, 1989; Drottz-Sjöberg, 2010) have not specifically explored the psychological factors underlying discounting the negative consequences of nuclear waste. Studying these is one aim of this study. We approach this aim via two different strategies within an experimental design.

On the one hand, we compare discounting of the negative consequences of nuclear waste and of hazardous waste. We decided to compare nuclear waste and hazardous waste on the basis of a previous study characterizing and comparing both waste types (Flüeler, 2010). Both waste types possess current practical relevance and are subject to public discourse. Currently, Switzerland runs four nuclear power plants (five reactors) that produce about 40% of total electricity. Switzerland does not yet have a deep geological repository either for low-level wastes or for high-level wastes, and the wastes are currently stored in the nuclear power plants or in a central interim storage. After plans to construct a geological repository in central Switzerland failed due to intense public protest and a subsequent negative vote (see e.g., Flüeler, 2006; Krütli, Flüeler, Stauffacher, Wiek, & Scholz, 2010), the Swiss Federal Office of Energy (SFOE) has initiated a sectoral plan to guide a participatory stepwise decision process to select sites for both repositories in Switzerland (SFOE, 2008). With respect to hazardous wastes, Swiss sites already exist. One especially well-known example is Kölliken, a hazardous waste site that opened in 1978. Due to leak, this hazardous waste site has to be cleaned up at very high cost. Nuclear wastes and hazardous wastes both have to be collected separately and require special technical and organizational measures for their disposal. Both waste types also represent a risk for humans and the environment over extensive timescales. However, nuclear waste includes radionuclides that decay, whereas some hazardous wastes (e.g., heavy metals) do not. Examining reactions to these two waste types therefore potentially yields important insights into the influence of radioactive decay on discounting judgments.

On the other hand, we include a list of various psychological factors involved in discounting based on the previous research presented above. As stated above, discounting factors are domain-specific. We started from the propositions of Frederick and colleagues and Nicolaij and Hendrickx (2003) and continued by consistently including more cognitive, motivational and content-specific factors specifically tailored to the long-term dimension of the issues studied.

With respect to the seriousness judgments over time regarding a leak in a repository or waste site, we hypothesize: Participants in the nuclear waste group display steeper curves of seriousness judgments over time than participants in the hazardous waste group because they take radioactive decay into account while making their seriousness judgments (Hypothesis 1). We furthermore explore how different psychological factors are related to participants’ seriousness judgments (explorative research question).

Challenges from a methodological perspective

In the disposal of nuclear waste, especially of high-level nuclear waste and spent fuel (IAEA, 1994), geological timescales are involved (Nagra, 2002; Junker et al., 2008). It may be possible for experts such as geologists to conceptualize such extensive timescales (Moser, Stauffacher, Krütli, & Scholz, 2012; Stauffacher & Moser, 2010), but it is very difficult if not impossible for the average member of the public to imagine timescales of up to one million years and to judge the severity of a leak of a hypothetical repository over this time span. Because such timescales are so difficult to think about, one can imagine that participants in discounting studies use all available cues to answer the questionnaire.
One possible cue enabling respondents to cope with such extensive timescales is the response scale itself. If, for example, seven-point-scales are used to measure seriousness judgments at different time points, participants could use the strategy of setting one anchor (how severe is a leak in the repository today) and then going down step by step on the response scale for the subsequent time points. Discounting judgments would thereby represent methodological artifacts. Such methodological questions are already subject to debates in psychometrics. They are investigated in studies in different research areas assessing psychological variables in questionnaires (e.g., pain research, see Ohnhaus & Adler, 1975; Duncan, Bushnell, & Lavigne, 1989; e.g., assessment of coping patterns, see Flynn, van Schaik, & van Wersch, 2004). Based on a study comparing pain judgments on either (discrete) verbal rating scales or (continuous) visual analog scales, Ohnhaus and Adler (1975) conclude that judgments on continuous visual analog scales reflect more precisely the actual pain experience of participants. They explain this finding by the fact that discrete rating scales introduce artificial steps on which a continuous feeling has to be judged.

A closely related issue concerns the question of whether people are actually sensitive toward extensive timescales. This indicates that besides the choice of response scales discussed above, the choice of timescale is also methodologically challenging. The question is, if it matters for participants’ discounting judgments whether, say, five future time points lie between, today and 4000 years from now or between today and 1,000,000 years from now. Previous research suggests that people seem rather indifferent toward very long timescales, or, put differently, that people seem to have rather restricted time horizons. Boniecki (1980), for example, concludes from an interview study that most participants are unable to imagine how their lives will be in 20 years and that 10-15 years seem to be the most distal time horizon for planning the future. From a study where participants had to judge life saving or species saving programs for a timeframe of up to 50 years, Baron concluded that “They [participants] distinguish between present and future, but they are insufficiently sensitive to the amount of future delay” (2000, p. 866). Baird (1986) concluded from a study exploring estimations of the future development of different environmental risks that participants’ view of the next 20 years was almost the same as for the next 5000 years. Similarly Björkman (1984) argues that involvement with respect to distal times (in the past or in the future) decreases exponentially with temporal distance, indicating that people do not respond sensitively toward different time points in the very far past or future. Literature review⁶ thus suggests that people do not respond sensitively toward two different time points far in the future.

For studies measuring discounting with a long-term perspective, this could indicate that participants do not distinguish between different temporal delays that all lie in the future.

From our perspective, these two aspects, the effect of discounting-relevant response format and temporal scale, represent major methodological concerns that also jeopardize the results of present studies utilizing the discounting paradigm for issues involving extensive timescales. To our knowledge, no study exists that examines these concerns in a systematic way. A second aim of our research therefore is to test these methodological concerns systematically within the experimental design also utilized for testing the content-related concerns. By providing different experimental groups with different response formats (discrete seven-point-scales and continuous graphic analog scales), we aim to explore their influence on discounting judgments. Similarly, by providing participants with different timescales (shorter, linear scale and longer, logarithmic scale) we aim to test if participants respond sensitively toward them.

⁶ However, we should note that the reviewed literature focused on participants in Europe or USA and that these results cannot be generalized to other cultures that, for example, have a more circular perception of time (e.g., Yamada & Kato, 2006).
With respect to the seriousness judgments over time regarding a leak in a repository or waste site, we hypothesize: Participants are not sensitive with respect to temporal scales and we consequently do not expect any differences in seriousness judgments between the shorter (linear) and the longer (logarithmic) temporal scale (Hypothesis 2). Furthermore, we expect differences in the seriousness judgments between the group using discrete seven-point scales and the group using continuous visual analog scales (Hypothesis 3).

4.2 Methods

4.2.1 Participants

We examined our explorative research question and hypotheses by the means of an online psychological experiment. Participants were sampled from a large pool of individuals registered for participation in online studies according to the following criteria: they had to be residents of the German-speaking part of Switzerland and between 18 and 70 years of age. An equal number of males and females were contacted (in total 1300 people) and invited to participate by email. In all, 314 participants, 152 of them women (48.4%) and 162 men (51.6%) completed the questionnaire up to the end and were included in the data analysis. Participants have a broad range of educational backgrounds: 8 (2.5%) had completed compulsory school, 110 (35%) vocational education, 51 (16.2%) senior high school, 51 (16.2%) higher vocational training; 93 (29.6%) went to university, and one person did not specify his educational level. The age of participants ranged between 19 and 70 years ($M = 42.8$ years, $SD = 14.24$ years).

4.2.2 Experimental design

We manipulated three independent variables (IV), namely waste type (WT), time scale (TS), and response scale (RS). Furthermore, we counterbalanced the polarity of captions of the response scales\textsuperscript{7}. Each independent variable was manipulated on two levels and participants were assigned to the different conditions randomly (see Table 1 for an overview of the different experimental conditions and sample sizes per cell). We measured seriousness judgments of negative consequences for five different time points. These seriousness judgments served as an indicator for discounting. This resulted in a mixed between- and within-subjects design: the manipulated variables are between-subjects factors, seriousness judgments for different time points were measured within subjects. Furthermore, psychological factors for discounting were assessed for all participants.

Table 1: Overview of experimental conditions, $n$ per cell is displayed. $N = 314.$

<table>
<thead>
<tr>
<th></th>
<th>$WT_1$, Nuclear waste</th>
<th>$WT_2$, Hazardous waste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$TS_1$, Linear</td>
<td>$TS_1$, Linear</td>
</tr>
<tr>
<td>$RS$, Discrete</td>
<td>37, 38</td>
<td>36, 42</td>
</tr>
<tr>
<td>$RS$, Continuous</td>
<td>34, 40</td>
<td>44, 43</td>
</tr>
</tbody>
</table>

4.2.3 Independent variables (IV)

Waste type ($WT$): Participants judged the severity of a leak of a repository either for nuclear waste ($WT_1$) or for hazardous waste ($WT_2$). For both conditions, participants received specific definitions for the respective waste type (see Appendix A for both definitions).

\textsuperscript{7} Polarity of the captions had no effect on the results and is therefore not elaborated in more detail.
**Time scale (TS):** Participants judged the severity of a leak in a repository for five different time points either on a linear timescale (\(TS_1\)) or on a logarithmic timescale (\(TS_2\)). The important difference between the two timescales is their temporal spread. The linear scale comprises a temporal spread of about 4000 years, while the logarithmic scale comprises a temporal spread of about one million years. More specifically, the linear timescale comprised the following time points: \(t_1\) “shortly after building and filling the repository / waste site” (representing about 100 years), \(t_2\) “after 1000 years”, \(t_3\) “after 2000 years”, \(t_4\) “after 3000 years”, and \(t_5\) “after 4000 years”. The logarithmic timescale started at \(t_1\) “shortly after building and filling the repository / waste site” (representing about \(10^2\) years) and then exponentially increased over the subsequent time points: \(t_2\) “after 1000 years” (\(10^3\) years), \(t_3\) “after 10,000 years” (\(10^4\) years), \(t_4\) “after 100,000 years” (\(10^5\) years), and \(t_5\) “after 1,000,000 years” (\(10^6\) years). The terms in quotation marks were used as labels for participants. Note that the first two time points \(t_1\) and \(t_2\) are identical for both groups.

**Response scale (RS):** Participants judged the severity of a leak either on discrete (\(RS_2\)) or on continuous scales (\(RS_1\)). The discrete scale was a seven-point-scale and the continuous scale was represented by a line without intersections of the same length as the seven-point scale. Participants could move a slider on the line to make their judgment. The extreme points of both scales were labeled “not at all severe” and “very severe”.

### 4.2.4 Measures

**Seriousness judgments:** After reading the definitions of “nuclear waste” or “hazardous waste”, participants were instructed to judge the severity of a repository leak for five subsequent time points (\(t_1\) until \(t_5\), according to the independent variable time scale). These seriousness judgments over time served as an indicator for discounting. We used a scale similar to that used by Drottz-Sjöberg (2010) and Svenson and Karlsson (1989). Responses have been recoded and transformed to a scale from one to 100, one indicating “not at all severe” and 100 indicating “very severe”. To increase readability, mean values were rounded to full numbers.

**Psychological discounting factors:** Frederick et al. (2002) point out that multiple factors potentially underlie discounting. As we described earlier, our study covers a larger timescale (even in the linear time scale condition) than most social science discounting studies. Therefore, we could not utilize an already tested list of items to assess discounting factors but had to compile a list of items specifically tailored to our studied issues. Starting from the suggestions by Frederick and colleagues (2002) as well as Nicolaij and Hendrickx (2003), we adjusted this list and added more factors specifically tailored to the long-term dimension of the issues studied in our experiment. The final list of 20 items covered the following seven issues, which can be grouped into three aspects: i) cognitive aspects: uncertainty, ignorance, adaptive capacity, level of abstraction, ii) motivational aspects: concernedness, emotional involvement, and iii) content-specific aspects: further development of waste (see Table 2 for items). Participants rated how important each of these factors was in making the five seriousness judgments on a seven-point-scale. The endpoints of the scale were labeled one “not at all important” and seven “very important”. Exploratory factor analysis (principal component analysis with Varimax rotation) yielded four factors explaining 57.6% of the total variance (see Table 2). Based on this factorial structure, we built four scales: *unconcernedness* (6 items, Cronbach’s \(\alpha = .87, M = 3.20, SD = 1.45\)), *ignorance* (5 items, Cronbach’s \(\alpha = .77, M = 4.50, SD = 1.31\)), *perceived adaptive capacity* (5 items, Cronbach’s \(\alpha = .73, M = 3.99, SD = 1.31\)), and *emotional involvement* (4 items, Cronbach’s \(\alpha = .65, M = 4.31, SD = 1.26\)).
Table 2: Items, factor loadings (after Varimax rotation) and communality ($h^2$); bold factor loadings indicate the items corresponding to the respective factor. $N = 314$.

<table>
<thead>
<tr>
<th>Items</th>
<th>Factor loadings</th>
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<tbody>
<tr>
<td></td>
<td>Factor 1 unconcernedness</td>
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<td></td>
<td>Factor 2 ignorance</td>
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<td></td>
<td>Factor 3 perceived adaptive capacity</td>
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<td></td>
<td>Factor 4 emotional involvement</td>
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<tr>
<td>I don’t care about what happens in such a long time.</td>
<td>0.78</td>
<td>0.70</td>
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<td></td>
<td>0.10</td>
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<td>0.06</td>
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<tr>
<td>Events that lie so far in the future leave me cold.</td>
<td>0.75</td>
<td>0.68</td>
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<td></td>
<td>0.11</td>
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<td></td>
<td>0.33</td>
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<td>-0.05</td>
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<td>I have troubles in imagining such long timescales.</td>
<td>0.54</td>
<td>0.43</td>
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<td></td>
<td>0.37</td>
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<td>0.05</td>
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<tr>
<td>I will be dead when something happens.</td>
<td>0.75</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What lies farther in the future is less severe compared to something happening now.</td>
<td>0.68</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The farther something lies in the future, the less I care about it.</td>
<td>0.77</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>We cannot know how humankind will develop within such timescales.</td>
<td>0.14</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is not sure how life will develop on the Earth’s surface within such timescales.</td>
<td>0.16</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is not known how the waste will develop over a long time.</td>
<td>0.06</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.07</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I only have unclear images about the future.</td>
<td>0.41</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>We cannot know what will happen in the future.</td>
<td>0.11</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Future generations will be able to deal with the burdens we leave behind.</td>
<td>0.33</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Because of technological progress, future generations will be able to deal with the leak.</td>
<td>0.29</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The waste will become less dangerous over time.</td>
<td>0.30</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>-0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The consequences of other environmental problems will be more severe for future generations.</td>
<td>0.07</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humankind has repeatedly managed to cope with major challenges, this will also be the case in the future.</td>
<td>0.28</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I care about the protection of future generations.</td>
<td>-0.29</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Even if the leak occurs far in the future, I am emotional about it.</td>
<td>-0.16</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I can imagine what the distant future could look like.</td>
<td>0.27</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>-0.08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If I think about such extensive timescales I feel scared.</td>
<td>0.30</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.06</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Risk perception:** The scale measuring risk perception (adapted from Stauffacher, Krütli, & Scholz, 2008) consisted of seven items with several risks associated with nuclear waste. Similar items were used to assess risk perception of hazardous waste (see Appendix B 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 seven-point-scales, with one indicating “not at all” and seven “very strongly”. The resulting scale had very good reliability: Cronbach’s $\alpha = .91$.

### 4.2.5 Procedure

Data collection took place in the beginning of May 2011. The study was designed as an online experiment and participants were all invited to participate by an email containing a link to the experiment. After entering the experiment they were welcomed to the study and randomly assigned to the different experimental conditions. On the next screen, they read a brief definition of nuclear waste or of hazardous waste (depending on the assigned experimental condition, see Appendix A for the definitions). The participants then judged the seriousness of a leak for five time points $t_1$ until $t_5$. Depending on the assigned experimental condition, they did so either considering a linear ($TS_1$) or a logarithmic timescale ($TS_2$), and either on a discrete seven-point scale ($RS_1$) or on a continuous slider scale ($RS_2$). On the next screen, participants were asked to write down their thoughts while responding to the previous questions in a textbox. On the subsequent screen they responded to the cognitive, motivational and content-specific discounting items (see Table 2). On the subsequent screens, they responded to the risk perception scales and other scales that are not the subject of the present article, and therefore are not explained in detail. Afterwards, they provided demographic information. Completion of the whole survey took on average about 13 minutes; participants received a small incentive for participation (0.75 €).

### 4.3 Results

First, we report descriptive and inferential statistics characterizing the risk perception items and seriousness judgments. In the second section we report results from a MANOVA testing our hypotheses and research question.

#### 4.3.1 Risk perception of nuclear waste and hazardous waste

As a first analytical step we examined our risk perception items of both nuclear waste and hazardous waste. For nuclear waste mean risk perception is $M = 5.02$, $SD = 1.55$, and for hazardous waste it is $M = 5.07$, $SD = 1.30$. This difference is not statistically significant indicating that both waste types are perceived similarly with respect to their imposed risks, $t(312) = 0.29$, $p = .77$ (two-tailed).

#### 4.3.2 Description of seriousness judgments

Looking at the whole sample including all experimental conditions, the seriousness judgments of participants decreased with increasing temporal distance of the negative consequence from $M = 78$ (SD = 27) for $t_1$ to $M = 50$ (SD = 37) for $t_5$ (see Figure 1). The data indicate a linear trend with a significant decrease in means between every time step from $t_1$ to $t_5$ (all $p$-values < .001). Also the standard deviations increased from $t_1$ to $t_5$ probably indicating that uncertainties as well as ignorance increase with increasing timescales. Comparing the variance ratios ($F$-Test) reveals that the standard deviations of $t_1$ and $t_5$ are similar ($F = 1.04$, $p = .76$) but there is a significant increase in the standard deviation of $t_5$ compared to $t_1$ ($F = 1.25$, $p < .05$). Further increases in standard deviations between $t_1$ and $t_4$ ($F = 1.18$, $p = .15$) as well as between $t_4$ and $t_5$ ($F = 1.22$, $p = .08$) are not statistically significant.
4.3.3 Analyses according to the hypotheses and research question

To analyze our data in terms of our hypotheses and the research question derived in the introduction, we used Multivariate Analysis of Variance (MANOVA) and included the psychological discounting factors as covariates in the model. In a first step, we entered the three independent variables as well as the four covariates to calculate a full model. Two discounting factors (ignorance and unconcernedness) did not significantly affect the five seriousness judgments. Similarly we did not find any group differences between the group using the discrete and
continuous scale\(^8\). Therefore, we calculated a more parsimonious MANOVA model, including only the two independent variables \textit{waste type} and \textit{timescale} as well as the two covariates \textit{perceived adaptive capacity} and \textit{emotional involvement}. We also included significant interactions between our independent variables and covariates in the model to test whether the discounting factors have a similar effect on seriousness judgments across the different levels of the independent variables. The significant MANOVA effects are interpreted by means of Univariate Analyses of Variance (ANOVAs). The results of this more parsimonious model are reported in Table 3 (MANOVA) and Table 4 (ANOVAs). Table 5 displays the corresponding descriptive statistics.

Table 3: Results of MANOVA of five seriousness judgments by time scale, waste type and controlled for discounting factors (multivariate tests). \(N = 314\).

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Pillai’s Trace</th>
<th>(F)</th>
<th>(\eta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived adaptive capacity</td>
<td>.21</td>
<td>15.76***</td>
<td>.45</td>
</tr>
<tr>
<td>Emotional involvement</td>
<td>.19</td>
<td>14.56***</td>
<td>.44</td>
</tr>
<tr>
<td>Time scale</td>
<td>.07</td>
<td>4.42**</td>
<td>.26</td>
</tr>
<tr>
<td>Waste type</td>
<td>.05</td>
<td>3.09*</td>
<td>.22</td>
</tr>
<tr>
<td>Time scale x waste type</td>
<td>.02</td>
<td>1.33</td>
<td>.15</td>
</tr>
<tr>
<td>Perceived adaptive capacity x time scale</td>
<td>.05</td>
<td>3.27**</td>
<td>.23</td>
</tr>
<tr>
<td>Emotional involvement x time scale</td>
<td>.03</td>
<td>2.02</td>
<td>.18</td>
</tr>
</tbody>
</table>

Note. Hypothesis \(df = 5\); error \(df = 302\). *\(p < .05\), **\(p < .01\), ***\(p < .001\).

Table 4: Univariate Analyses of Variance (ANOVAs) for \(t_1\) to \(t_5\); only significant MANOVA results are examined in detail. \(N = 314\).

<table>
<thead>
<tr>
<th>IV</th>
<th>Judgment (t_1)</th>
<th>Judgment (t_2)</th>
<th>Judgment (t_3)</th>
<th>Judgment (t_4)</th>
<th>Judgment (t_5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(df)</td>
<td>(F)</td>
<td>(\eta)</td>
<td>(df)</td>
<td>(F)</td>
</tr>
<tr>
<td>PAC</td>
<td>1</td>
<td>13.93***</td>
<td>.21</td>
<td>1</td>
<td>60.81***</td>
</tr>
<tr>
<td>EI</td>
<td>1</td>
<td>5.76*</td>
<td>.13</td>
<td>1</td>
<td>36.61***</td>
</tr>
<tr>
<td>TS</td>
<td>1</td>
<td>.04</td>
<td>.00</td>
<td>1</td>
<td>2.08</td>
</tr>
<tr>
<td>WT</td>
<td>1</td>
<td>11.37**</td>
<td>.06</td>
<td>1</td>
<td>8.73**</td>
</tr>
<tr>
<td>PAC x TS</td>
<td>1</td>
<td>5.72*</td>
<td>.13</td>
<td>1</td>
<td>.05</td>
</tr>
<tr>
<td>Error</td>
<td>306</td>
<td>(669.02)</td>
<td>306</td>
<td>(592.40)</td>
<td>306</td>
</tr>
</tbody>
</table>

Note. IV = independent variables, PAC = perceived adaptive capacity, EI = emotional involvement, TS = timescale, WT = waste type. The values in parentheses represent the mean square errors; *\(p < .05\), **\(p < .01\), ***\(p < .001\).

\(8\) Excluding this variable slightly changed the values of parameters; however, the pattern reported below seems rather robust across different models.
On the understanding and processing of extensive timescales: The long-term dimension of nuclear waste

Table 5: Descriptive statistics (M, SD) of the five judgments t₁ to t₅, N = 314.

<table>
<thead>
<tr>
<th>Timescale</th>
<th>Waste type</th>
<th>Judgment t₁ M (SD)</th>
<th>Judgment t₂ M (SD)</th>
<th>Judgment t₃ M (SD)</th>
<th>Judgment t₄ M (SD)</th>
<th>Judgment t₅ M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logarithmic</td>
<td>Hazardous (n = 85)</td>
<td>73 (29)</td>
<td>64 (28)</td>
<td>56 (32)</td>
<td>49 (34)</td>
<td>41 (36)</td>
</tr>
<tr>
<td></td>
<td>Nuclear (n = 78)</td>
<td>81 (29)</td>
<td>72 (29)</td>
<td>63 (31)</td>
<td>53 (32)</td>
<td>40 (35)</td>
</tr>
<tr>
<td></td>
<td>Total (n = 163)</td>
<td>77 (29)</td>
<td>68 (28)</td>
<td>59 (32)</td>
<td>51 (33)</td>
<td>41 (35)</td>
</tr>
<tr>
<td>Linear</td>
<td>Hazardous (n = 80)</td>
<td>72 (26)</td>
<td>66 (27)</td>
<td>64 (30)</td>
<td>60 (34)</td>
<td>57 (38)</td>
</tr>
<tr>
<td></td>
<td>Nuclear (n = 71)</td>
<td>85 (22)</td>
<td>74 (27)</td>
<td>70 (30)</td>
<td>65 (34)</td>
<td>62 (36)</td>
</tr>
<tr>
<td></td>
<td>Total (n = 151)</td>
<td>78 (25)</td>
<td>70 (27)</td>
<td>67 (30)</td>
<td>62 (34)</td>
<td>59 (37)</td>
</tr>
<tr>
<td>Total</td>
<td>Hazardous (n = 165)</td>
<td>73 (28)</td>
<td>65 (28)</td>
<td>60 (31)</td>
<td>54 (34)</td>
<td>49 (37)</td>
</tr>
<tr>
<td></td>
<td>Nuclear (n = 149)</td>
<td>83 (26)</td>
<td>73 (28)</td>
<td>66 (31)</td>
<td>58 (34)</td>
<td>50 (37)</td>
</tr>
<tr>
<td></td>
<td>Total (N = 314)</td>
<td>78 (27)</td>
<td>69 (28)</td>
<td>63 (31)</td>
<td>56 (34)</td>
<td>50 (37)</td>
</tr>
</tbody>
</table>

The effect of waste type (Hypothesis 1)

We hypothesized that participants in the nuclear waste group would display curves of seriousness judgments than participants in the hazardous waste group. This hypothesis is confirmed by our data. The significant main effect of waste type in the MANOVA and the subsequent ANOVAs reveals that participants judging negative consequences of a nuclear waste repository made higher seriousness judgments than participants judging negative consequences of a hazardous waste site (see Tables 3 and 4). This effect, however, was only statistically significant for the first three time points. For the later time points, there was no significant difference between the groups, which indicates that the negative consequences of a nuclear waste repository are judged as being more severe in the beginning compared to the consequences of a hazardous waste site. However, the curve of seriousness judgments regarding a leak in a nuclear waste repository is steeper compared to the curve regarding a leak in a hazardous waste site, so that there remains no difference between the two waste types when negative consequences in the very distant future (t₄ and t₅; see Figure 2) are judged.

Figure 2: Mean (+/- 2 SE) seriousness judgments for t₁ to t₅ for the two groups judging negative consequences of nuclear waste or hazardous waste. All scales were transformed to a scale from 1 = “not at all severe” to 100 = “very severe”. (N = 314).
Why do people discount? (Explorative research question)

Of the four psychological discounting factors, only “perceived adaptive capacity”, and “emotional involvement” were significantly related to the seriousness judgments (see Tables 3, 4). The more emotional participants felt about the future, or the more emotionally they were involved with future generations, the more severe they judged the future damage of a nuclear waste repository or hazardous waste site (see Table 6). Comparing the correlation coefficients of the different time points indicates that the correlations \( t_1 \) to \( t_5 \) are all (marginally) significantly higher than the correlation \( t_1 \) \( (p = .05 \) for \( t_5 \) and lower for \( t_1 \) to \( t_5 \)). On the other hand, the more participants expressed a belief that societies will be able to adapt to future challenges, e.g., by technological innovation, the less severe they judged the future damage of a nuclear waste repository or hazardous waste site. Comparing the correlation coefficients of the different time points indicates that the correlations \( t_1 \) to \( t_5 \) are all significantly higher than the correlation \( t_1 \) \( (p < .05 \). The correlation \( t_1 \) is marginally significantly higher compared to the correlation \( t_5 \) \( (p = .06 \). With respect to the two factors, we observe a significant increase in correlations between \( t_1 \) and \( t_5 \); further changes are not statistically significant.

Table 6: Pearson’s correlation coefficients \( r \) between “emotional involvement”, “perceived adaptive capacity”, and seriousness judgments for \( t_1 \) to \( t_5 \), \( N = 314 \).

<table>
<thead>
<tr>
<th></th>
<th>Judgment ( t_1 )</th>
<th>Judgment ( t_2 )</th>
<th>Judgment ( t_3 )</th>
<th>Judgment ( t_4 )</th>
<th>Judgment ( t_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emotional involvement</td>
<td>( .11^{*} )</td>
<td>( .26^{***} )</td>
<td>( .32^{***} )</td>
<td>( .34^{***} )</td>
<td>( .34^{***} )</td>
</tr>
<tr>
<td>Perceived adaptive capacity</td>
<td>( -.19^{**} )</td>
<td>( -.36^{***} )</td>
<td>( -.38^{***} )</td>
<td>( -.36^{***} )</td>
<td>( -.33^{***} )</td>
</tr>
</tbody>
</table>

Note. \( ^* p<.05 \), \( ^{**} p<.01 \), \( ^{***} p<.001 \) (two-tailed).

This however depended on the timescales participants considered as the significant interaction between “perceived adaptive capacity” and timescale revealed (see Tables 3 and 4). Looking at the correlations between “perceived adaptive capacity” and the seriousness judgments separately for the two different timescales reveals the following pattern (see Table 7): for participants considering a linear timescale, the (negative) correlations between perceived adaptive capacity and the seriousness judgments increase over time and stagnate for the last three seriousness judgments. For participants considering a logarithmic timescale, the (negative) correlations between perceived adaptive capacity and the seriousness judgments over time form a kind of U-shaped curve: first, the negative correlations increase over time but when very distant time points are considered the correlations become weaker again.

Table 7: Pearson’s correlation coefficients \( r \) between “perceived adaptive capacity” and five seriousness judgments for two timescale formats. \( N = 314 \), \( n_{\text{linear}} = 151 \), \( n_{\text{logarithmic}} = 163 \).

<table>
<thead>
<tr>
<th>Perceived adaptive capacity by timescale</th>
<th>Judgment ( t_1 )</th>
<th>Judgment ( t_2 )</th>
<th>Judgment ( t_3 )</th>
<th>Judgment ( t_4 )</th>
<th>Judgment ( t_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear timescale</td>
<td>-0.07</td>
<td>-0.38***</td>
<td>-0.41***</td>
<td>-0.44***</td>
<td>-0.44***</td>
</tr>
<tr>
<td>Logarithmic timescale</td>
<td>-0.29***</td>
<td>-0.35***</td>
<td>-0.34***</td>
<td>-0.27***</td>
<td>-0.22**</td>
</tr>
</tbody>
</table>

Note. \( ^{*} p<.01 \), \( ^{**} p<.001 \) (two-tailed).

The effect of temporal scale (Hypothesis 2)

We hypothesized that participants are not sensitive toward different temporal scales and therefore, we did not expect any differences in seriousness judgments between the group using a logarithmic temporal scale and the group using a linear temporal scale. Based on the results of the MANOVA and subsequent ANOVAs, this hypothesis has to be rejected, as the seriousness judgments differ significantly between the two groups for the last three time points (see Tables 3.
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The group judging the severity of a negative consequence on a linear scale judged these consequences for the last three time points (indicating: \( t_3 \) after 2000 years, \( t_4 \) after 3000 years, \( t_5 \) after 4000 years) as significantly more severe compared to the other group (time points indicate: \( t_3 \) after 10,000 years, \( t_4 \) after 100,000 years, \( t_5 \) after 1,000,000 years). The first two time points (indicating: \( t_1 \) shortly after building and filling the repository and \( t_2 \) after 1000 years) were the same for both groups and as one would expect, the analyses revealed no significant differences for these two time points between the two groups. The results indicate that participants are sensitive to different extents of timescales: for the linear timescale (up to 4000 years), participants made judgments indicating less discounting compared to the participants judging the severity of consequences on a logarithmic timescale (up to 1,000,000 years, see Figure 3).

![Figure 3: Mean (+/- 2 SE) seriousness judgments for \( t_1 \) to \( t_5 \) for the two groups judging consequences on a linear or logarithmic scale. Time points indicate for the linear group: \( t_1 \) shortly after building and filling the repository, \( t_2 \) after 1000 years, \( t_3 \) after 2000 years, \( t_4 \) after 3000 years, and \( t_5 \) after 4000 years; and for the logarithmic group: \( t_1 \) shortly after building and filling the repository, \( t_2 \) after 1000 years, \( t_3 \) after 10,000 years, \( t_4 \) after 100,000 years, and \( t_5 \) after 1,000,000 years. Note that \( t_1 \) and \( t_2 \) are identical for both groups. All scales were transformed to a scale from 1 = “not at all severe” to 100 = “very severe”. \( N = 314 \).](image)

The effect of response format (Hypothesis 3)

We expected differences in seriousness judgments between the group using discrete seven-point scales and the group using continuous scales. In the full model we did not find significant differences between these two groups, therefore, this hypothesis has to be rejected. Different response formats did not produce significantly different seriousness judgments. Consequently, we did not include this variable in the more parsimonious model described above.

4.4 Discussion

The aim of this study was to examine discounting of negative consequences of nuclear waste and to take a critical perspective at discounting from both content-related and methodological perspectives. Utilizing a mixed between- and within-subjects design, we analyzed how seriousness judgments of a negative consequence (serving as an indicator for discounting) are influenced by waste type, temporal scale and response formats. Furthermore, we explored the role of different psychological factors for seriousness judgments.
4.4.1 Content-related cognitive and motivational concerns

With respect to our content-related concerns, the experiment demonstrates that participants’ curves of seriousness judgments over time are steeper for the issue of nuclear waste than for the issue of hazardous waste (see Figure 2). For the first three time points, participants in the nuclear waste group judged a negative consequence as being more serious than the hazardous waste group. For the last two time points, the judgments of both groups are similar. As outlined in the introduction, discounting judgments include a variety of information, and therefore, cannot be interpreted in a straightforward manner. By comparing nuclear waste and hazardous waste, we aimed at finding out more about the role of radioactive decay in discounting judgments. Our results could indicate that discounting negative future consequences of a nuclear waste repository does not necessarily mean that the future is devalued but that participants are also taking into account radioactive decay. However, the differentiation between the two curves of seriousness judgments over time could also have other causes, because nuclear waste and hazardous waste differ in more than the characteristic of radioactive decay. We should, for example note that the experiment took place after the tsunami and subsequent accident in the Fukushima-Daiichi nuclear power plant in Japan in March 2011. The accident had a substantial effect on public discourse about production of nuclear power in Switzerland. After the accident in Fukushima concerns about nuclear power increased and acceptance decreased (Visschers & Siegrist, submitted). The Swiss Federal Council as well as the parliament decided to phase-out nuclear electricity production. This could also have affected the perception of nuclear waste storage, thereby resulting in higher seriousness judgment of nuclear waste for the nearer future compared to hazardous waste.

This problem of interpretation is common in discounting studies because the psychological factors behind discounting judgments are not often included (Frederick et al., 2002). Our research demonstrated that two major factors underlie seriousness judgments which serve as an indicator for discounting. These factors are perceived adaptive capacity and emotional involvement. The belief that future societies will be able to adapt to challenges is negatively correlated with seriousness judgments over time. The idea that technological and societal development will continue in the future thus made participants assume that future societies will be able to recognize a leak and that they will be able to take the measures needed to protect humans and the environment from harm. Due to technological development, they might even be better able to react than societies are today. Therefore, a negative consequence in the future is judged as being less severe, because future society may be able to cope with it better. Adaptive capacity is a key term in the resilience (Folke, 2006; Carpenter, Walker, Anderies, & Abel, 2001) and vulnerability literature (Adger, 2006; Smit & Wandel, 2006; Scholz et al., 2012). It includes a dynamic component in the sense that societies change over time by adapting to challenges. This is exemplified in the significant interaction effect between perceived adaptive capacity and timescale. The negative correlation between perceived adaptive capacity and seriousness judgments first increases for a time span in the future of about 4000 years. When larger timescales are considered (up to one million years), the negative correlation decreases again (see Table 7). To estimate whether a future society will be able to adapt to challenges, one must be able to imagine how such a future society might be characterized, organized, and how developed it will be with respect to technologies. For very extensive timescales of up to one million years, this is practically impossible, and some participants might even have doubted that human beings will still exist then. This might explain the U-shaped relationship between perceived adaptive capacity and seriousness judgments over time.

Perceived adaptive capacity can be considered as a cognitive construct (Grothmann & Patt, 2005), but also emotions play a role in discounting. The more emotionally involved people feel
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with respect to the future and future generations the flatter is the curve of seriousness judgments over time. Emotions such as fear or concerns about the future in general or the need to protect future generations motivate participants to judge a negative consequence in the future as serious; they even motivate them not to discount a future damage but to judge it as having the same seriousness as if it were to happen today.

4.4.2 Methodological concerns

With respect to our methodological concerns, the experiment demonstrates that participants seem to be sensitive toward different timescales far in the future. Based on previous studies, we expected no differences between the group making seriousness judgments on a shorter timescale and the group making the same judgments on a longer scale. Our between-subjects design demonstrates the opposite. Keeping in mind that experiments utilizing a between-subjects design to manipulate temporal delay usually failed to find an effect of temporal delay (Böhm & Pfister, 2005; Hendrickx & Nicolaij, 2004), this finding is particularly surprising. As one might expect, participants are not perfectly sensitive toward these different timescales but they nevertheless distinguished between the two differently extensive timescales. This is on the one hand indicated by the different seriousness judgments; on the other, participants using the linear timescales were also more likely to decide not to discount negative future consequences compared to the group utilizing the logarithmic timescale. One reason for this differentiation could be that, even though both timescales are extensive with respect to the time horizon of humans (e.g., 20 years in Boniecki, 1980), 4000 years are easier to imagine, because 4000 years ago, humans already existed and recorded history helps us to trace how societies have developed since then. This knowledge might help in constructing possible future scenarios or speculating about the development of human beings in the next 4000 years. This is not the case for a timescale of 1,000,000 years.

In the introduction, we also hypothesized that participants produce different seriousness judgments depending on the response format, because a coarse seven-point-scale may tend to frame the responses whereas the continuous scale does not. However, we found no differences in seriousness judgments between these two groups, indicating that in the current study, seven-point scales produce the same quality of data as do continuous scales. Our hypothesis regarding response formats therefore has to be rejected.

4.4.3 Limitations

We have to take into account that the conclusion that nuclear waste is more steeply discounted than hazardous waste is not completely coherent because nuclear waste differs in many aspects from organic and inorganic hazardous waste. A logically coherent test of our hypothesis would have entailed comparing nuclear waste that decays and nuclear waste that does not decay. This, however, would represent a completely artificial experimental condition without any real world basis, as radioactive decay is an essential of radioactive materials. We therefore decided to take hazardous waste as a contrast, a material that has to be collected and disposed of separately through the use of special technical and organizational measures, because it represents a risk to both humans and the environment over an extensive time period. These characteristics are very similar for nuclear waste disposal. As the risk perception measures demonstrate, participants judged both waste types as being equally risky, which also supports our choice of comparison. Another possible approach would be to compare high-level nuclear waste and low-level nuclear waste (IAEA, 1994) and manipulate respective half-life values between subjects.
Another shortcoming, which applies to much discounting literature, is that we only considered judgments but not actual decisions or behavioral measures. In our study, the curves of seriousness judgments over time were rather flat and 38.5% of participants did not discount. However, it remains unclear whether participants would, for example, be willing to pay more money today for a nuclear waste repository or hazardous waste site to be constructed so that it is safer for future generations.

**4.5 Conclusions**

Measuring discounting with respect to issues including extensive timescales is a challenge. Based on our analyses, we were able to demonstrate that seriousness judgments on negative impacts of waste types over extensive timescales are difficult to interpret. These judgments, serving as an indicator for discounting, include a broad variety of information, for example participants’ expectations of what the future will be like, temporal representations (Moser, Stauffacher, Krüttli, & Scholz, accepted), issue-related knowledge (e.g. decay rate in the issue of nuclear waste), concerns about the future, expressed uncertainty, general value orientation and so on. This makes interpretation of long-term discounting judgments extremely difficult. Discounting judgments alone can therefore be considered non-transparent indicators including high levels of uncertainty and ignorance. Again taking up the call by Frederick and colleagues (2002) for a more thorough study of the psychological factors behind discounting, we would like to suggest that further research should basically turn the approach upside down and put a focus on these factors to start with. One could start with the question as to what factors might determine the judgment of a negative consequence over a long time span. Such a factor might for example be perceived adaptive capacity of future societies. Looking at the whole range of perceived adaptive capacity also implies a broad range of very different consequences of a leak in a repository or a waste site depending on the understanding of societal development over time. For a perfectly adaptable society, one could expect that people are able to detect the leak and protect humans and the environment from harm. One might expect the opposite for a society that is not at all able to adapt to challenges. It could be interesting to construct different future scenarios based on the factors motivating discounting and hand the scenarios to participants to rate the consequences. In this procedure, participants would not rate the consequence of leak from a nuclear waste repository after 1000 years “blindly”, but based on a specific description of a hypothesized future situation. In our view, such a procedure would be more transparent and more straightforward in its interpretation and could serve as a meaningful extension of the current approach used to elicit discounting judgments from the public.

**Appendices**

*Appendix A: Definitions of waste types*

_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 material that has to be collected separately and that has to be disposed of 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: batteries, neon tubes, heavy metals, mixes of mineral
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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.

Appendix B: Risk perception items (adapted from Stauffacher et al., 2008)

How strongly do you associate a deep geological repository (hazardous waste site) with the following possible outcomes? Response scale from 1 to 7, 1 = not at all low, 7 = very high. The brackets indicate changes made for the hazardous waste group, if there are no brackets, the same item was used for both waste types.

1. Release of nuclear waste (hazardous waste) in transport accidents.
2. Health risks for yourself.
3. Health risks for future generations.
4. Damage to the environment because of the repository (hazardous waste site).
5. Release of nuclear waste (hazardous waste) into groundwater.
6. Unintentional recovery of the repository (hazardous waste site) by future generations.
7. Economic losses because of image loss in the region.

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5 Beyond risk perception: The role of perceived adaptive capacity for the acceptance of contested infrastructure


Abstract

Infrastructure projects such as repositories for nuclear waste or hazardous waste sites impose risks over extensive timescales. These risks, however, change dynamically over time and so, potentially, does their management, because societies 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. The dynamic concept of adaptive capacity therefore represents a promising complementing facet for this line of research. The aim of this paper is to examine the role of perceived societal adaptive capacity for the acceptance of contested long-term infrastructure for the two issues of nuclear and hazardous waste. In an online experimental setting ($N=300$) examining the acceptance of a nuclear waste repository or a hazardous waste site we demonstrate that i) perceived adaptive capacity can be separated empirically as a psychological construct from risk and benefit perception, and ii) perceived adaptive capacity explains a significant additional share of variance in the acceptance of both waste types beyond risk and benefit perception. Thus, including a dynamic perspective yields important insights in understanding individual decision-making regarding long-term infrastructure projects.

Keywords: Perceived adaptive capacity, risk perception, acceptance of contested infrastructure, nuclear waste, hazardous waste

5.1 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. Furthermore, implementers often face strong local resistance and a so-called NIMBY (not in my backyard) attitude in affected regions or communities (Kraft and Clary 1991; Portney 1991). Moreover, these infrastructures often pose risks over very long timescales, implying uncertainties and ignorance. In a nutshell, they “combine technical factors and social factors in complex multi-attribute trade-offs” (Reiner and Nuttall 2011, p. 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 entailing all the above-mentioned characteristics and where, in particular, long timescales are highly salient (Drottz-Sjöberg 2010; Svenson and Karlsson 1989) is the issue of nuclear waste disposal. 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 imposed change dynamically within this timescale. For example,
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The radiotoxicity of the waste decreases over time due to radioactive decay, but the canisters containing the spent fuel or vitrified high-level wastes will be more likely to leak over time due to corrosion (Nagra 2002; Junker et al. 2008). Furthermore, the societies responsible for managing these risks also change over time. New technologies or learning processes in general may provide a future society with better knowledge on how to deal with the imposed 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 entails an active perspective, as we generally not only perceive risks or are passively subjected to them, but also try to manage them.

However, current social scientific research examining the acceptance of contested infrastructure does not take such a dynamic and active view but predominantly focuses on the perception of risks (e.g., Bord and O’Connor 1992; Drottz-Sjöberg 2010) and sometimes the perception of benefits (such as additional jobs in the region or tax reduction for local residents, see e.g., Chung and Kim 2009; Seidl et al. submitted.; Stauffacher et al. 2008) as major explanatory variables. Risk conceptualized as a decision situation with different alternatives that are linked to different outcomes by probability vectors is a static concept that does not take into account such dynamics as those mentioned above (Scholz et al. 2012). This is also reflected on the level of item construction in risk perception questionnaires. In most studies, participants are asked to judge several risks (e.g., health risks, economic risks, risks to the environment) associated with a certain issue. In some studies, participants are asked to judge the overall risks emerging from the 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 (for the issue of nuclear waste see e.g., Sjöberg and Drottz-Sjöberg 2009; Stauffacher et al. 2008; Moser et al. accepted; for the issue of nuclear power see e.g., Whitfield et al. 2009; for the issue of waste incineration see e.g., Lima 2004; for environmental risks see e.g., Böhm and Pfister 2005). Hence, the risk perception items used in currently published studies assess a static construct and do not take into consideration the aforementioned dynamic aspects of long-term risks.

Scholz et al. (2012) propose the vulnerability concept as a dynamic perspective on risk. Vulnerability is usually conceived as a function of exposure, sensitivity, and adaptive capacity (Adger 2006; McCarthy et al. 2001; Smit and Wandel 2006). According to Scholz et al. (2012), the aspect of adaptive capacity is the reason why vulnerability differs from the static risk concept, as an adaptation can only occur as a response to or in anticipation of a stimulus, which may take the form of a discrete extreme event, (temporal) variability or long-term changes (Smit et al. 1999). The term adaptation has its origins in biology and “refers to the development of genetic or behavioural characteristics which enable organisms or systems to cope with environmental changes in order to survive and reproduce” (Smit and Wandel 2006, p. 283). Adaptation is an important concept in other disciplines as well, for example in psychology. With respect to the development of cognitive functions, Piaget (1936) distinguishes between two processes of adaptation which occur when individuals are confronted with a new problem. These processes are assimilation (i.e., modification of existing cognitive schemata) and accommodation (i.e., development of new cognitive schemata). 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, p. 282). In other words, adaptive capacity refers to a system’s ability to maintain its function in case of disturbance but also to its capacity to re-organize in order to deal with challenges (Folke 2006). Maintenance of function thereby refers to Piaget’s concept of assimilation, while re-organization refers to accommodation.
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 – judgement 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 (perceived adaptive capacity). Perceived adaptive capacity therefore yields important insights into people’s expectations of 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., McCarthy et al. 2001; Smit et al. 1999; Smit and Wandel 2006; Grothmann and Patt 2005; Alberini et al. 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 perceived adaptive capacity.

The focus of this study lies on the role of perceived societal adaptive capacity for the individual decisions of people today regarding contested infrastructure. In other words, we look at how individuals currently perceive the adaptive capacity of future societies and how this perception affects their decisions today. We take nuclear waste and hazardous waste as examples. As outlined above, nuclear waste disposal can be considered a prototype of contested infrastructure projects, with a large body of research examining decision processes. 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. Both waste types possess current practical relevance and are subjects of public discourse in Switzerland and elsewhere. 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 (Krüti et al. 2010a; Flüeler 2006), 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).

The main aim of this paper is to examine the role of perceived societal adaptive capacity for the acceptance of contested infrastructure for the two issues of nuclear waste and hazardous waste. More specifically, we aim at testing whether perceived adaptive capacity can explain an additional share of variance in acceptance of the infrastructure projects that cannot be explained by risk and benefit perception alone. Our research thereby aims to be a contribution to the further development of risk perception research by including a dynamic view, which is particularly suited to representing the perception of long-term risks in contested infrastructure projects.
5.2 Method

5.2.1 Experimental design

Manipulated variable

Waste type: We examined the role of perceived (societal) adaptive capacity 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 (see Appendix A for both descriptions).

Measured variables

Risk perception: The scale measuring risk perception of a nuclear waste repository (adapted from Stauffacher et al. 2008; Moser et al. accepted) consisted of seven items with several risks associated with a nuclear waste repository (e.g., transport accidents, health risks, environmental risks, release of radioactivity into groundwater, economic risks). This scale was slightly adapted to assess risk perception of a hazardous waste site (see Table 3, items RP for the full list). 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 $\alpha = .90$.

Benefit perception: The scale measuring benefit perception (adapted from Stauffacher et al. 2008; Moser et al. accepted) consisted of five items with several potential benefits associated with a nuclear waste repository or a hazardous waste site (e.g., additional jobs, tax reduction, improvement of regional infrastructure). The identical scale was used for both experimental groups (see Table 3, items BP for the full list). 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 $\alpha = .81$.

Perceived adaptive capacity: To our knowledge, an established scale measuring perceived adaptive capacity for long-term environmental problems does not yet exist. One central aspect of such a scale is that it includes a dynamic perspective. In our case we investigated whether participants expect societies to be able to manage risks posed by nuclear waste or hazardous waste by adapting to challenges. 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 society would be able to manage several potential negative consequences of a nuclear waste repository or hazardous waste site. With reference to the negative consequences of the risk perception 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). 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 $\alpha = .84$.

Acceptance: 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:** 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.

### 5.2.2 Procedure and participants

Data collection took place in mid-November 2011. Participants were all recruited from an online panel according to the following criteria: they had to be residents of the German-speaking part of Switzerland and between 18 and 69 years old. An equal number of males and females were contacted and invited to participate by email. After entering the experiment 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 risk and benefit perception scales. On the next screen, they answered the adaptive capacity items. After responding to the acceptance items on the subsequent page, they provided demographic information. Completion of the whole questionnaire took on average about 10 minutes; participants received a small incentive for participation (approximately 0.60 €). 300 participants, of them 155 women (51.7%) and 145 men (48.3%) completed the questionnaire and were included in the subsequent statistical analyses. Participants live in urban as well as rural regions of the German-speaking part of Switzerland; their age ranges between 18 and 69 years \((M = 41.6 \text{ years}, \ SD = 13.15 \text{ years})\).

### 5.3 Results

#### 5.3.1 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. 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 when asked what waste types they had been thinking about when answering the questionnaire. Of these 69 cases in the hazardous waste condition mentioning both waste types, 27 (39.1%) considered just one type of nuclear waste and one type of hazardous waste (e.g., “wastes from nuclear power plants, toxins”) while 42 (60.9%) considered several waste types, among them nuclear and hazardous wastes (for example: “pharmaceuticals, neon tubes, dissolvers, electronic waste, nuclear waste”).
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. 

<table>
<thead>
<tr>
<th>Assigned manipulation check code</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>i) nuclear</td>
<td></td>
</tr>
<tr>
<td>ii) hazardous</td>
<td></td>
</tr>
<tr>
<td>iii) both</td>
<td></td>
</tr>
<tr>
<td>iv) no response</td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td></td>
</tr>
<tr>
<td>Nuclear waste</td>
<td></td>
</tr>
<tr>
<td>87 (7.4)</td>
<td></td>
</tr>
<tr>
<td>12 (-3.4)</td>
<td></td>
</tr>
<tr>
<td>21 (-6.3)</td>
<td></td>
</tr>
<tr>
<td>33 (1.3)</td>
<td>153</td>
</tr>
<tr>
<td>Hazardous waste</td>
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</tr>
<tr>
<td>23 (-7.4)</td>
<td></td>
</tr>
<tr>
<td>32 (3.4)</td>
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<tr>
<td>69 (6.3)</td>
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<td>147</td>
</tr>
<tr>
<td>Total</td>
<td>300</td>
</tr>
</tbody>
</table>

5.3.2 Do risk perception, benefit perception, and perceived adaptive capacity represent different psychological constructs?

As a first step in analysis we explored whether risk perception, benefit perception, and perceived adaptive capacity each represent different psychological constructs. We therefore performed a principal component analysis (PCA) including all items of risk perception, benefit perception, and perceived adaptive capacity. 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 risk perception, benefit perception, and perceived adaptive capacity can be considered three separate psychological constructs (see Table 2). The factor risk perception explains 27.5% of variance, benefit perception explains 18.2% of variance and perceived adaptive capacity explains 17.6% of variance.

Table 2: Items assumed to measure risk perception (RP), benefit perception (BP) and perceived adaptive capacity (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. \( N = 300. \)

<table>
<thead>
<tr>
<th>Items</th>
<th>Factor loadings</th>
<th>( h^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Factor 1: RP</td>
<td>Factor 2: BP</td>
</tr>
<tr>
<td>(RP) Release of nuclear waste (hazardous waste) in transport accidents.</td>
<td>0.72</td>
<td>-0.14</td>
</tr>
<tr>
<td>(RP) Health risks for yourself.</td>
<td>0.79</td>
<td>-0.14</td>
</tr>
<tr>
<td>(RP) Health risks for future generations.</td>
<td>0.83</td>
<td>-0.17</td>
</tr>
<tr>
<td>(RP) Damage of the environment because of the repository (hazardous waste site).</td>
<td>0.82</td>
<td>-0.22</td>
</tr>
<tr>
<td>(RP) Release of nuclear materials (toxic materials) into groundwater due to leakage of a container.</td>
<td>0.80</td>
<td>-0.17</td>
</tr>
<tr>
<td>(RP) Unintentional recovery of the repository (hazardous waste site) by future generations.</td>
<td>0.73</td>
<td>-0.09</td>
</tr>
<tr>
<td>(RP) Economic losses because of image loss in the region.</td>
<td>0.66</td>
<td>-0.04</td>
</tr>
<tr>
<td>(BP) Establishment of additional workplaces.</td>
<td>-0.25</td>
<td>0.70</td>
</tr>
<tr>
<td>(BP) Advancement of regional infrastructure.</td>
<td>-0.18</td>
<td>0.74</td>
</tr>
<tr>
<td>(BP) Lower taxes for residents.</td>
<td>-0.04</td>
<td>0.74</td>
</tr>
<tr>
<td>(BP) Economic impulses for local businesses.</td>
<td>-0.17</td>
<td>0.80</td>
</tr>
<tr>
<td>(BP) Promotion of sustainability projects in the region.</td>
<td>-0.08</td>
<td>0.66</td>
</tr>
<tr>
<td>(PAC) In transport accidents, nuclear waste (hazardous waste) is released.</td>
<td>-0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>(PAC) Due to leakage of a container, nuclear materials (toxic materials) are released into groundwater.</td>
<td>-0.15</td>
<td>0.17</td>
</tr>
<tr>
<td>(PAC) The repository (waste site) has been recovered unintentionally by future generations.</td>
<td>-0.23</td>
<td>0.13</td>
</tr>
<tr>
<td>(PAC) The region suffers from economic losses because of image loss.</td>
<td>-0.18</td>
<td>-0.05</td>
</tr>
</tbody>
</table>
5.3.3 Descriptive results and group differences in risk perception, benefit perception, perceived adaptive capacity and acceptance

Table 3 displays the mean values of risk perception, benefit perception, perceived adaptive capacity, and acceptance for both nuclear waste and hazardous waste for the total sample. Examining the means of the total sample indicates that risks of both waste types are perceived very similarly, $t(283) = 0.29, p = .77, r = .02$ (two-tailed). Acceptance of a nuclear waste repository is lower than acceptance of a hazardous waste site, but this difference 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. However, due to the relatively large sample size we should also look at the effect sizes $r$ (according to Rosnow & Rosenthal 2003), which are all rather small.

Table 3: Risk perception (RP), benefit perception (BP), perceived adaptive capacity (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. $N = 300; n_{\text{nuclear}} = 147; n_{\text{hazardous}} = 153$.

<table>
<thead>
<tr>
<th></th>
<th>RP ($M$ ($SD$))</th>
<th>BP ($M$ ($SD$))</th>
<th>PAC ($M$ ($SD$))</th>
<th>Acc ($M$ ($SD$))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear waste</td>
<td>4.99 (1.52)</td>
<td>3.20 (1.32)</td>
<td>2.38 (1.21)</td>
<td>2.61 (1.87)</td>
</tr>
<tr>
<td>Hazardous waste</td>
<td>5.04 (1.16)</td>
<td>3.59 (1.23)</td>
<td>2.76 (1.15)</td>
<td>3.01 (1.74)</td>
</tr>
</tbody>
</table>

5.3.4 Correlations between risk perception, benefit perception, perceived adaptive capacity, and acceptance

As a next step we investigated correlation patterns between risk perception, benefit perception, perceived adaptive capacity, and acceptance. Table 4 displays these patterns for the overall sample. There are positive correlations ($p < .01$, two-tailed) between perceived adaptive capacity and acceptance, between perceived adaptive capacity and benefit perception as well as between acceptance and benefit perception. Risk perception correlates negatively ($p < .01$, two-tailed) with benefit perception, acceptance, and perceived adaptive capacity. Looking at both waste types separately revealed a similar pattern, except that the correlation between benefit perception and perceived adaptive capacity is significant for the issue of nuclear waste ($r = .39, p < .01$, two-tailed) but not for the issue of hazardous waste ($r = .10, p = .22$, two-tailed).

Table 4: Pearson’s correlation coefficients $r$ between risk perception (RP), benefit perception (BP), perceived adaptive capacity (PAC), and acceptance (Acc) for complete sample $N = 300$.

<table>
<thead>
<tr>
<th></th>
<th>RP</th>
<th>BP</th>
<th>PCA</th>
<th>Acc</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BP</td>
<td>-0.38**</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PCA</td>
<td>-0.42**</td>
<td>0.27**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Acc</td>
<td>-0.53**</td>
<td>0.37**</td>
<td>0.46**</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: ** $p < .01$ (two-tailed).
5.3.5 Exploration of the role of perceived adaptive capacity in the acceptance of contested infrastructure

To explore whether perceived adaptive capacity can explain a share of variance in acceptance that cannot be explained by perceived risk and benefit alone, we calculated stepwise linear regression models for nuclear waste and hazardous waste separately. In a first step, we included risk perception and benefit perception as predictors in the regression analysis. In a second step, we entered perceived adaptive capacity to examine whether this predictor could explain an additional share of variance in acceptance. Table 5 displays the results of the two analyses for nuclear waste and hazardous waste.

Table 5. Stepwise linear regression models for acceptance of a nuclear waste repository or a hazardous waste site, respectively. \( N = 300; n_{\text{nuclear}} = 147; n_{\text{hazardous}} = 153 \).

<table>
<thead>
<tr>
<th></th>
<th>Nuclear waste</th>
<th>Hazardous waste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( B )</td>
<td>( SE B )</td>
</tr>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>5.06</td>
<td>0.69</td>
</tr>
<tr>
<td>Risk perception</td>
<td>-0.63</td>
<td>0.09</td>
</tr>
<tr>
<td>Benefit perception</td>
<td>0.21</td>
<td>0.11</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>3.70</td>
<td>0.75</td>
</tr>
<tr>
<td>Risk perception</td>
<td>-0.50</td>
<td>0.09</td>
</tr>
<tr>
<td>Benefit perception</td>
<td>0.12</td>
<td>0.10</td>
</tr>
<tr>
<td>Perceived adaptive capacity</td>
<td>0.44</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Note: 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 (\( p < .01 \)). * \( p < .05 \), ** \( p < .01 \), *** \( p < .001 \).

Including only risk and benefit perception 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, risk perception is a stronger (negative) predictor for acceptance of both issues, in particular for the issue of nuclear waste.

Perceived adaptive capacity has a similar effect on acceptance of a nuclear waste repository and a hazardous waste site. The relation between perceived adaptive capacity and acceptance is positive for both waste types: the more adaptive capacity participants perceive, the stronger their acceptance. For both waste types, the inclusion of perceived adaptive capacity explains a significant additional share of variance in acceptance. Through the inclusion of perceived adaptive capacity, explained variance increased to 41% for the issue of nuclear waste and to 31% for the issue of hazardous waste. This indicates that perceived adaptive capacity is probably an important additional factor in decisions regarding acceptance of a nuclear waste repository or a hazardous waste site. For the issue of nuclear waste, perceived benefits seems to be a rather weak predictor and its influence even decreases if perceived adaptive capacity is included in the regression. For the acceptance of a hazardous waste site, perceived benefits still play a substantive role, even if perceived adaptive capacity is included in the analysis.

5.4 Discussion

The goal of this study was to examine the role of perceived adaptive capacity in the context of individual decisions regarding contested infrastructure. Research on such decisions
Paper 4: Beyond risk perception:
The role of perceived adaptive capacity for the acceptance of contested infrastructure

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 dynamic perspective. Until now, risk perception has been conceptualized as a rather static construct. However, especially long-term risks are characterized by dynamics in the sense that societies or individuals are able to actively manage risks. In our view, adaptive capacity, a construct up to now mainly applied in climate research, has the potential to contribute to this area. In our study, we applied the concept of perceived adaptive capacity to the issues of nuclear and hazardous wastes.

Our analyses demonstrate that perceived adaptive capacity can be considered a separate psychological construct which explains a substantial share of variance in the acceptance of a nuclear waste repository or hazardous waste site in addition to risk and benefit perception. 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. So far, such considerations have not been included in studies examining perceptions of nuclear waste or hazardous waste. 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 (Krüti et al. online first), the site selection process in general (Krüti et al. 2010b; Sjöberg and Drottz-Sjöberg 2001; Stern and Fineberg 1996), the extensive timescales involved (Moser et al. 2012; accepted; Drotz-Sjöberg 2010; Stauffacher et al. 2008), trust (Siegrist et al. 2005), and attitudes toward nuclear power (Sjöberg 2004) play additional important roles. The focus of this study, however, lies on a contribution to risk perception research, as this approach still represents a very dominant line of investigation in social scientific studies about contested infrastructure.

Even though risk perception, benefit perception, perceived adaptive capacity and acceptance are all correlated in our study, we can only speculate about causal relationships between these constructs. If perceived adaptive capacity refers to a more general construct concerning how future societies will develop over time, how they will be organized and what technologies they will have, it is possible that this more general construct may influence the more specific risk perception of a certain infrastructure and its acceptance. This would mean that the causal relationship between perceived adaptive capacity and acceptance is mediated or partially mediated by risk perception. The role of benefit perception in this model is less clear due to mixed correlational patterns for nuclear and hazardous wastes. However, our cross-sectional design does not allow testing for such a model. Longitudinal or experimental data could potentially yield interesting insights into the causal interrelations between the variables.

Our study yields insights about the role of perceived adaptive capacity in decisions towards 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 perceived adaptive capacity 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 risk and benefit perception, perceived adaptive capacity 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). For both waste types, mean perception of risks is above the midpoint of the scale, while mean perception of benefits as well as acceptance is below the midpoint of the scale. It is possible that perceived adaptive capacity takes on a different role in contested infrastructure projects where
perceived benefits are possibly judged higher (e.g., energy infrastructure like deep geothermal, Stephens and Jiusto 2010). To know more about a potential generalization of the concept of perceived adaptive capacity to other issues, it is therefore necessary to include further contested infrastructure projects like facilities for energy production (e.g., deep geothermal, nuclear power plants, photovoltaics, gas-fired power plants, dams, wind power), or carbon capture and storage in future research.

This study yields insights about a potential contribution of perceived adaptive capacity to the line of risk perception literature by including a dynamic perspective. However, it would obviously be interesting to know more about the ideas participants have regarding future societies, their organizational and technological development, and their capacities to manage challenging and unforeseen situations. Our quantitative study cannot provide details about these underlying conceptions. As a complementary approach to our study, it would therefore be interesting to use a more qualitative approach (e.g., qualitative interviews, focus groups) to examine in more detail what perceived adaptive capacity concretely means to participants and how they understand it.

5.5 Conclusions

Conceptualizing risks in a decision-theoretic framework (Scholz et al. 2012) means that we are not just exposed to such risks but that we are at least partly able 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 risk perception research. From the results of this study we conclude that perceived adaptive capacity 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 perceived adaptive capacity as an important, dynamic factor to complement the predominant focus on (static) risk perception. This is in particular important as decision-making processes about contested infrastructures are on-going 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, hydropower and photovoltaics are becoming more widespread.

Appendix: Descriptions of waste types

**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 material that has to be collected separately and that has to be disposed of 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.

Acknowledgements

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References


6 Concluding remarks

Although the background of the author of this thesis is social psychology, the thesis is not typical for that field. It links several disciplines in order to approach the issue of time and nuclear waste, which itself lies at the interface between society and technology. The most striking difference between a classical disciplinary psychological thesis and this one probably is that the latter did not start from a specific theory but from the issue itself (as suggested by e.g., Scholz & Stauffacher, 2009; Brunswik, 1955). A first step in this PhD project was a thorough attempt to understand i) the historical development of geological time, and ii) the concept of nuclear waste disposal in Switzerland with a specific emphasis on its temporal component. This included a review of existing technical and geological literature about the disposal concept (in particular Nagra, 2002b; Nagra, 2002a, 2002c; but also SFOE, 2008) as well as discussions with experts from the Swiss implementer Nagra (Junker, Flüeler, Stauffacher, & Scholz, 2008).

In this thesis, a sound technical understanding was combined with a social scientific research design utilizing different qualitative and experimental methods for the various research steps. Throughout the research, the technical understanding provided a basis for the subsequent steps, while the HES Framework (Scholz, 2011) provided the conceptual basis for embedding the research contributions. The expert interviews broadened out the space of different temporal understandings, but at the same time the technical basis served as a contrast for comparing the different understandings. The experiments follow the same logic, as they are based on the technical understanding but also on insights gained in the expert interviews. The later experiments are based on the results of previous experiments.

In this chapter, conclusions are drawn from the whole thesis, including the research contributions, but also experiences undergone while working on the project of the thesis. First, the two guiding questions from the introduction are answered. The corresponding research contributions are briefly summarized and conclusions are drawn for future research. Furthermore, overall conclusions are drawn for research on human-environment systems and for practice.

6.1 How are extensive timescales understood in the context of nuclear waste disposal?

6.1.1 The relationship between processes considered and temporal understanding

The question of how extensive timescales in the context of nuclear waste are perceived has been approached from two different perspectives in this thesis. One perspective comprised the analysis of technical documents in order to understand the temporal dimension of nuclear waste disposal and how technical experts handle this dimension in the disposal concept (see introduction to the thesis for a short overview and Junker et al., 2008 for more details). The other perspective comprised qualitative interviews with experts from different scientific disciplines working on long-term phenomena (see Paper 1, Moser, Stauffacher, Krütli, & Scholz, 2012). One important insight from both perspectives is that time is not referred to per se, but by the means of events or processes, or, to use the words of Gibson (1975): “Events are perceivable but time is not” (p. 295). Hence, temporal understanding and processes considered are coupled. In the technical safety assessment (Nagra, 2002b), experts refer to different processes, namely individual habits, human activities, ecological change, climatic change and geological change (see Figure 4 in the
introduction to this thesis). These processes are characterized by different predictabilities. For example, human behavior (e.g., nutrition habits) is characterized as very unstable and hence, as unpredictable, while certain geological formations are characterized as very stable and hence, as predictable in their development over extensive timescales. This again illustrates that how time is understood depends on the processes that are considered. Similar conclusions can be drawn from the expert interviews. A climate scientist, for example, referred to climate cycles and predominantly constructed time as a sequence of cycles. This understanding of time as a cycle implies a certain predictability of processes in the future. A philosopher referred to technological developments over the last 50 years and concluded that these developments are so complex that they cannot be predicted. Depending on the processes considered, Paper 1 suggests a continuum of different temporal understandings ranging from ‘determined’ (e.g., cycles, natural laws) to ‘undetermined’ (e.g., complex systems). From the expert interviews, we can also conclude that the respective background (social sciences, natural sciences, humanities) influences the types of processes that are considered. The experts “view time through the lenses of their training and experiences” (Greenberg & Lowrie, 2012, p. 1). There is not one specific temporal understanding but a multitude of different temporal understandings between but also within experts. A geologist, for example, mentioned the stability and predictability of certain rock formations. At the same time, he took a critical perspective by mentioning the potential of human use of the underground (for example: huge storage rooms underground, deep geothermal), or of human intrusion into the repository, hence he questioned the aforementioned predictability.

6.1.2 Further research on temporal understandings

The question as to how non-experts, i.e. members of the public, understand extensive timescales cannot be answered on the basis of data presented in this thesis. For most people, such timescales are not relevant as they clearly go beyond their own planning horizon (about 10-15 years according to a study by Boniecki, 1980). For people who are not occupied with extensive timescales on a daily basis, we would speculate that timescales such as those relevant in nuclear waste disposal are probably represented in a very abstract manner, maybe as a number with many zeroes or as a blank space. Also metaphors might be relevant in comprehending extensive timescales (Gould, 1987). Based on the literature we can also assume that the cultural background is important with respect to different understandings of extensive timescales (Yamada & Kato, 2006; Adam, 1998; Ji, Guo, Zhang, & Messervey, 2009; Wood, 2008; Munn, 1992).

For further research, qualitative interviews with members of the public about their understanding of extensive timescales could be conducted. First, it would be interesting to examine the processes or events they refer to in general when considering extensive timescales. Secondly, examining differences in temporal understanding regarding culture, gender, and age could potentially yield important insights about corresponding group differences. Thirdly, it would be interesting to examine if and how the understanding of extensive timescales is shaped by an increasing confrontation with extensive timescales. A research strategy here could be to interview participants in regions potentially suitable for a deep geological repository in Switzerland (SFOE, 2011). Compared to other regions in Switzerland, participants in such regions are potentially more exposed to the participatory process and communication strategies of Nagra, of the Swiss Federal Office of Energy, of the cantonal administration, or of different NGOs. As long-term safety is an important aspect of communication, interviews with local residents could yield insights into how their understanding of extensive timescales is shaped by their experiences during the site selection process of a nuclear waste repository.
6.2 How is temporal information integrated in judgments about nuclear waste?

The question of how temporal information is integrated into judgments about nuclear waste has been approached from three different perspectives in this thesis. The first perspective shed more light on the relationship between time and risk perception of nuclear waste (see Paper 2, Moser, Stauffacher, Krüttli, & Scholz, 2012). The second perspective examined how increasing temporal distance affects seriousness judgments about negative consequences of nuclear waste (see Paper 3, Moser et al., submitted). The third perspective took a closer look at how people judge societal dynamics over time (e.g., technological development, learning processes, loss of important knowledge) possibly inhibiting or enhancing the successful management of negative consequences of a nuclear waste repository by future societies (see Paper 4, Moser, Stauffacher, Blumer, & Scholz, to be submitted).

6.2.1 Temporal representations and risk perception of nuclear waste: Conclusions and further research

Experimental approaches studying the causality between time and risk perception have been lacking so far, as the rare studies covering the issue of time and nuclear waste are based on surveys (Drottz-Sjöberg, 2010; Svenson & Karlsson, 1989; Kunreuther & Easterling, 1990). From Paper 2 it can be concluded that linear as well as cyclical temporal representations lead to decreased risk perception of nuclear waste, in particular if participants are ambivalent about their beliefs about nuclear waste. The experiment shows an interesting effect, but unfortunately, the data does not reveal any information about the cognitive processes involved in this decrease in risk perception. We can conclude from the experiment that time and risk information are integrated but the process per se still represents a black box. Knowing more about the cognitive processes involved might yield important information about how temporal information is processed and how it exerts an influence on subsequent judgments, for example about risks of nuclear waste. In social psychology, two modes of thought are distinguished (e.g., Scholz, 1987; Chaiken & Trope, 1999; Slovic, Finucane, Peters, & MacGregor, 2004; Gawronski & Bodenhausen, 2007): a more analytic process characterized by logical, reason-oriented thinking independent of temporary moods and individual experience, by logical connections with high cognitive control, and by conscious information acquisition and processing (Scholz, 1987; Slovic et al., 2004) on the one hand, and a more intuitive process characterized by affect and spontaneous associations (Visschers, Meertens, Pashscher, & De Vries, 2007; LeDoux, 1994) on the other. It is possible that temporal representations induced a certain mode of thought, thereby moderating risk perception of nuclear waste. Another possible explanation is that temporal representations (of time as a spiral or as an arrow) activate the association of predictability, thereby reducing perceived complexity and perceived risks. Future research should therefore emphasize the cognitive processes triggered by temporal representations and the cognitive associations they might activate. This could be done for example by measuring reaction times (Schunk & Betsch, 2006), generating think-aloud protocols (Scholz, 1987; Ericsson & Simon, 1984), or by implementing dual-tasks to put participants in a situation of cognitive load and assess the respective effect on risk perception (e.g., Macrae, Milne, & Bodenhausen, 1994).

6.2.2 Discounting negative consequences of nuclear waste: Conclusions and further research

Previous research about time and nuclear waste predominantly focused on the discounting paradigm (Drottz-Sjöberg, 2010; Svenson & Karlsson, 1989). Similarly to these studies, Paper 3 also utilized discounting for assessing the perceived seriousness of a leak of a repository for different time points in the future. However, our study included an experimental approach where we systematically tested the influence of waste type, timescale as well as response format on
On the understanding and processing of extensive timescales: The long-term dimension of nuclear waste

seriousness judgments. We also assessed psychological discounting factors in order to better understand the rationales behind discounting judgments (as claimed by Frederick, Loewenstein, & O'Donoghue, 2002). From this experiment, we can conclude that participants judged a future leak of a repository as quite serious even if it were to occur far in the future. Even though these judgments might not directly reflect willingness to pay more for a safer repository, our results still indicate that long-term safety is a specific concern for participants and that they tend to be unwilling to discount a future negative consequence. This result is in line with the importance of perceived adaptive capacity for seriousness judgments: The more participants believed that future societies would have a high adaptive capacity (e.g., because of technological progress or societal learning processes), the less serious they perceive a leak, probably because they think that future societies will be able to manage this challenge successfully. The results also indicate that participants differentiate between timescales of different temporal spread in the future and do not seem to be influenced by the response format, which indicates that the method yields quite robust results.

However, discounting is an economic tool used to assess the utility of investments made today or later in time. This means that we need to critically reflect on whether it is an appropriate tool for measuring perceived seriousness of negative consequences over extensive timescales as are relevant in nuclear waste disposal. The applicability of discounting to non-monetary decisions and respective trade-offs between intra-generational and intergenerational justice are issues of discussion in the literature (Ott, 2003; Shrader-Frechette, 2000). Furthermore, if extensive timescales are considered, the future becomes worthless in the present, even if only a very small discount rate is applied (Adam, 1998; Chapman, 2001; Wood, 2008). Besides these rather ethical issues, we also have to conclude from our experiment that discounting judgments over such timescales are difficult to interpret and include a great deal of implicit information that would have to be made explicit in order to better understand participants’ judgments. For example, it would be important to understand how participants expect societies to develop and what kind of technological progress they expect. Future research should strive to make these implicit assumptions of participants more explicit, either by including qualitative interviews when assessing discounting judgments, or by constructing scenarios consisting of different assumptions in which a leak occurs (i.e., control and vary assumptions) and giving them to participants to rate.

6.2.3 Perceived adaptive capacity and acceptance: Conclusions and further research

While time was a direct parameter in the first two experiments, in the last experiment it was more indirect in character. In this experiment we considered the influence of expected societal changes over time on the acceptance of a nuclear waste repository or a hazardous waste site. The experiment shows that perceived adaptive capacity (a concept yet mainly applied in research about climate change, see e.g., McCarthy, Canziani, Leary, Dokken, & White, 2001; Smit & Wandel, 2006; Smit, Burton, Klein, & Street, 1999; Grothmann & Patt, 2005) is a potentially important component in decisions regarding a nuclear waste repository or a hazardous waste site. The more participants expect that future societies will undergo learning processes and/or develop new technologies to be better able to manage environmental challenges, the more they are willing to accept construction of a nuclear waste repository or a hazardous waste site today. Our experiment demonstrates that – even when not included as a dependent or independent variable in the experiment – time influences people’s decisions about nuclear waste or hazardous waste. It influences their judgments in the sense that they consider how future societies will change over time and how they will be able to manage challenges we burden them with. Our findings are in particular interesting for risk perception research, as risk is a static concept (Scholz, Blumer, &
Concluding remarks

Brand, 2012) and risk perception research has not yet taken up this dynamic perspective, which is especially crucial considering long-term risks that change over time. However, also here a more qualitative approach could yield important insights into people’s expectations about future societies and their development, and subsequent experiments would be needed to examine whether perceived adaptive capacity might also be important for decisions on contested infrastructure projects other than nuclear waste repositories or hazardous waste sites.

6.3 Contributions to research on human-environment systems

Nuclear waste management – in particular of high-level waste (IAEA, 1994) – is a long-term issue. In contrast to other long-term environmental problems (e.g., disposal of hazardous wastes, climate change, energy infrastructure projects such as dams) the temporal dimension in nuclear wastes is very salient and explicit. This is probably because radioactivity, which is usually indicated as radioactive half-life, is an essential characteristic of nuclear waste. The notion of extensive timescales is therefore closely coupled with this type of waste. This is not only the case for the technical and geological community but also for members of the public (see e.g., interviews conducted in the frame of a SFOE project: Seidl, Moser, Krütli, & Stauffacher, 2011). The timescales involved exert a vast influence on planning the disposal concept (IAEA, 1995, 2003; Nagra, 2002b) as well as on designing the societal decision process to find a site for a repository (NRC, 2003; SFOE, 2008) and for discussions about marking the repository to inform and warn future generations about the site (Buser, 2010; United States Department of Energy, 2004). Probably no other issue affecting future generations is handled with such effort to find a suitable solution with regard to the timescales involved. What can we, therefore, learn from nuclear waste management for the management of other long-term coupled human-environmental problems?

6.3.1 Explicit reference to the timescales involves raises awareness

As mentioned previously, the timescales involved in nuclear waste management are recognized instantly because of the radioactive half-lives. Even though members of the public may not know the exact times involved, it is widely known that these timescales are extensive. The explicit reference to the timescales involved seems to raise awareness that the problem is a long-term one (and hence, poses a serious threat) and requires a corresponding understanding in its management. However, this long-term dimension can also lead to a “temporal fallacy” (Wood, 2008, p. 275) in the sense that a focus on the geological timescale might be too grainy to allow for recognizing problems potentially arising within much shorter timescales, for example during the societal decision process or during the time until the repository is closed.

The time until the repository is closed encompasses most likely more than 100 years. The SFOE expects that the stepwise participatory decision process (which started in 2008) will last between 8 and 10 years. For granting the general license (by the Federal Council) and its approval (by the Parliament, possibly followed by a national referendum) another 2.5 years are projected. For further geological investigations, a construction license (for the rock laboratory and for the repository), construction of the repository and for the operation license, a further 23–29 years are foreseen. The earliest start for operation of a repository for high-level wastes is projected for the year 2040 (SFOE, 2008, p. 32). Before the repository is closed, it will be monitored. The monitoring period is not exactly specified. In EKRA (2000) the monitoring phase is described as lasting “for several decades” (p. 49). One further important aspect with respect to time is that spent fuel has to be cooled for several decades before it can be disposed of in the deep geological repository in clay formations, as foreseen in Switzerland (Nagra, 2003).

Even though these timescales are much shorter than the very salient million years that have to be considered for the disposal of high-level wastes, they still represent a very long timescale
from a societal perspective. The time until the wastes are contained in the repository is critical because the Swiss society and societies around Switzerland will change, and there is a potential for unexpected events or transformations.

6.3.2 Recognizing temporal dimensions of environmental decisions as a major component of sustainability learning

From this thesis we can learn for other coupled human-environment systems and for sustainability learning that a coupled system perspective on the temporal dimension of environmental decisions is needed. This means the ability to recognize different temporal dimensions and their implications linked with the different steps of a decision process. For research on human-environment systems, this thesis concludes that recognizing the temporal dimensions of environmental decisions, and thereby integrating potential societal and environmental consequences over time, represents a major component of sustainability learning. In nuclear waste management, the relevant timescales range from societally highly relevant timescales (e.g., during which the decision process takes place, or during which high-level nuclear wastes are stored on the surface of the Earth in order to cool down before they can be placed in the repository) to geologically relevant timescales (e.g., during which erosion processes or glaciation processes occur). Integrating these different dimensions can help to avoid problems of scale (Gibson, Ostrom, & Ahn, 2000) as described in the introduction of this thesis. Recognizing the temporal dimension of environmental decisions with a coupled systems perspective could, therefore, be considered an important “ability that is needed for establishing transitions towards sustainable human-environment systems” (see the concept of ‘sustain-abilities’, Scholz, 2011, pp. 533, slightly adapted).

The ability to recognize different temporal dimensions could be implemented as a tool for stakeholders and decision-makers where temporal dimensions of environmental decisions (e.g., building new energy infrastructure such as a nuclear power plant, a dam, or deep geothermal) are made explicit for different decision steps. Hence, awareness of the different timescales involved in a decision is raised. Through this, the different temporal dimensions of an environmental decision and its projected consequences can be discussed and hence they can serve as an additional basis for decision-making. Such a tool is currently the subject of another PhD thesis at NSSI-ETH (by E. Suter).

6.4 Contributions to practice

This thesis offers three contributions that could be relevant for nuclear waste management in practice. The first two refer to the safety assessment and potentially safety-relevant contributions from non-technical communities and to graphic representations of time in risk communication. These two contributions can be drawn straightforwardly from the research done in this thesis. The third contribution is a suggestion for practice, which resulted from the overall experience during working on the thesis project. It refers to “temporal fallacies” (Wood, 2008, p. 275) potentially occurring when focusing too strongly on the million years timescale. The suggestion to also focus on shorter timescales includes a list of still open research questions that might be of high relevance for practice as well.

6.4.1 Potentially safety-relevant contributions from non-technical communities

The qualitative interviews revealed that experts of different disciplines understand time differently and that they take differing perspectives on the predictability of processes in nuclear waste management. The safety case (Nagra, 2002b) assumes a stepwise increase in the
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predictability of changes from individual habits to the host rock (see Figure 4 in the introduction of this thesis). The assumption that the host rock is stable and predictable over extensive timescales has been challenged by experts from the social sciences and humanities. One reason for their skepticism is that experts from the social sciences and humanities have a stronger focus on societal development within their research. In reconstructing societal trajectories in the past, most of them argued that societal systems are complex, and technologies develop quickly, so that future societal developments are difficult to predict or cannot be predicted. This perspective is identical with the position of the safety case; however, experts from the social sciences and humanities tended to go a step further by also claiming that the actual development of a geological system is probably difficult to predict, considering the impossibility of predicting human activities (see also Crutzen’s claim that human activities have become a ‘geological factor’, Crutzen, 2002b, 2002a). Their claim is that it is impossible to predict how human activity will develop and, for example, if the use of the underground will become a more common practice in the future compared to today. What today is considered a stable, quiet and easily predictable geological formation could, after some time, have turned into an area occupied by new technologies or by other activities taking place underground. Experts from the social sciences and humanities could therefore adopt the role of ‘stretchers’ (Schneider, Schieber, & Lavelle, 2006) in the safety assessment in the sense of scrutinizing underlying assumptions and asking critical questions. Furthermore, they could contribute their knowledge in creating scenarios for testing the robustness of the models calculated. These contributions are potentially safety-relevant.

Besides that, a broader disciplinary basis of the safety assessment could also be an important factor in informing the public and trust building. Integrating these different perspectives could therefore lead to more robust solutions both technically and socially (Flüeler, 2001).

6.4.2 Communication of extensive timescales

The experiment studying the influence of different temporal representations on risk perception revealed that both linear and cyclical temporal representation had a decreasing effect on risk perception, in particular for ambivalent participants. For risk communication, this indicates that communicators should be aware that their messages about nuclear waste could be shaped by the way they represent long timescales. For receivers’ risk perception, it probably will make a difference whether communicators use a numeric representation of the timescales involved or if they use a graphic representation, in particular if they belong to an ambivalent opinion group regarding nuclear waste (see also Seidl, Moser, Stauffacher, & Krütli, submitted). However, the processes by which this decrease in risk perception took place in our experiment are as yet unclear and the experiment should be replicated to test whether the effect is stable. Therefore, we would be very careful in making direct recommendations for risk communication based on this study alone. In a broader sense, temporal representations can probably help to illustrate the projected predictability of different systems (e.g., societal system, climate system, host rock) and thereby help in communicating the rationale of a deep geological repository. Revealing these rationales can serve as a basis for discussion, for reflection about basic assumptions, and for providing further information.

6.4.3 Need for further research on societally-relevant extensive timescales

One million years is a very salient timescale and one therefore easily loses sight of other temporal scales relevant for nuclear waste management. The time taken until a site for a repository is selected, built, filled, monitored, sealed, and closed is very long from a societal perspective. During this time, the risks posed by nuclear waste are greatest due to radiotoxicity, but most importantly also because the waste is only enclosed by engineered barriers and there is
no geological barrier yet. Compared to storage in a deep geological repository, nuclear wastes stored on the surface represent a greater risk in terms of release of radionuclides but also in terms of access to and possibly misuse of the hazardous material.

How society will develop over time is highly uncertain, and up to a certain point also unknown. But expected trajectories can also become a problem. When the focus is on these shorter but societally-relevant timescales many questions arise that are still open; some examples are listed below. Some of these questions are specifically relevant for Switzerland because of its political context, but most of them are also relevant for other countries facing the challenge of disposing of nuclear waste:

- How can a participatory process over many years ensure that younger people enter into the ongoing process and actively shape it?
- How can it be ensured that highly qualified people can be recruited for the disposal of nuclear waste over time? Especially now that Switzerland – and also other countries – have decided to phase out nuclear energy production after the accident at the Japanese Fukushima Daiichi nuclear power plant in March 2011, this branch might be perceived as less attractive compared to other energy branches and at some point highly qualified and motivated people might be missing.
- How is nuclear waste management in Switzerland shaped by experiences gained in other European countries like Germany, Sweden, or Finland?
- How can sudden events (like for example an accident in a nuclear power plant or in a nuclear waste repository) influence nuclear waste management?
- How can economic and financial crises affect nuclear waste management?
- On a more abstract level, how do judicial, societal, economic, and political changes potentially affect nuclear waste management?
- How do we deal with the ‘unknown’?

Questions like these all are related to shorter timescales compared to the million years, but they are highly relevant for our society today and in the nearer future. These questions show how closely linked societal developments and nuclear waste management are and how both are embedded in a broader European and world-wide context. More research is needed to find out more about these societally-relevant extensive timescales.

### 6.5 Outlook

This thesis integrates a broad range of temporal aspects of nuclear waste management. These include different temporal understandings, the influence of time on risk perception, intertemporal judgments about the seriousness of negative consequences of a waste repository as well as the perceived adaptive capacity of future societies. One reason for this broad approach is that the field of time and nuclear waste has not been intensely researched so far and there are many open research gaps. This thesis closes some of them, but at the same time opens up many new ones. After opening up and integrating different approaches to the temporal dimension of nuclear waste, there remains an enormous potential for future research to go into more depth, as proposed in the papers and in this chapter.

Another potential outlook refers to examining the temporal dimension of other coupled human-environmental problems such as the construction of energy infrastructure, hazardous waste management, scarce resource management and so on. In these issues also, one will find different actors holding different understandings about the temporal processes involved, possibly
leading to conflicts between the actors in decision-making. This thesis provides some approaches as to how the temporal dimension of such problems could be tackled from a social scientific perspective. A better understanding of the temporal dimensions of coupled human-environmental problems might help in raising awareness about long-term negative consequences as well as in revealing the different rationales and temporal decision frames of different actors and thereby promote a better informed decision-making process.

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On the understanding and processing of extensive timescales: The long-term dimension of nuclear waste


Moser, C., Stauffacher, M., Blumer, Y. B., & Scholz, R. W. (to be submitted). Beyond risk perception: The role of perceived adaptive capacity for the acceptance of contested infrastructure.


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Additional publications and presentations

Peer reviewed papers


Publication for stakeholders


Conference presentations


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On the understanding and processing of extensive timescales: The long-term dimension of nuclear waste

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