Chapter 1

Introduction

1.1 Background

Two trends are currently reshaping the world's energy landscape: a shift from carbon-based to non-carbon-based sources of energy, and a diminishing role of nuclear power in global energy production. The first trend is observable in the fact that renewable energy sources (excluding hydropower) have experienced double-digit growth rates since 2005 and doubled their share in global power generation within the last 5 years to 6.7% in 2015 (PBL, 2016). Their share in global primary energy consumption has also doubled since 2010, reaching 2.8% in 2015. This is reflected in a decreasing global growth rate of CO_2 emissions over the last 15 years: While the 5-year average values for global annual emissions increased by 3.1% between 2001 and 2005, they grew by 2.5% and 1.4% in the years 2006 to 2010 and 2011 to 2015, respectively. In 2015 and 2016, global CO_2 emissions growth rates came to a standstill and emissions remained largely unchanged (IEA, 2017; PBL, 2016). This may signal a decoupling of CO_2 emissions and economic activity, as the world economy grew steadily in both years, with GDP growth rates of 3.2% and 3.1% for 2015 and 2016, respectively (IEA, 2017; IMF, 2017). Nevertheless, the regional differences in the CO_2 emission trends are considerable. In 2015, the United States and China reduced their CO_2 emissions by 2.6% and 0.7%, respectively, while the European Union and India increased their emissions by 1.3% and 5.1%, respectively.

The second global trend in energy supply is a shift away from nuclear power. The share of nuclear power in global electricity production peaked in the mid-1990s at around 20% and has been declining since, reaching 11% in 2015 (IAEA,

2015; PBL, 2016). Nevertheless, energy policies with regard to nuclear power diverge in different parts of the world: Germany, Switzerland, and Belgium have decided, with various degrees of legally binding decisions already taken, to phase-out nuclear power. At the same time, a number of countries are expanding nuclear electricity production substantially, most notably China, Russia, and South Korea.

In response to these trends, and coupled with a weakened public acceptance of nuclear power after the nuclear accident in 2011 in Fukushima, Japan, Switzerland revised its energy policy in a strategic long-term report – *Energy Strategy 2050* (Prognos, 2012; SFOE, 2013). The key components of the Swiss Energy Strategy 2050 include: the expansion of renewable sources of energy including hydropower; an increase in energy efficiency; and the phasing-out of nuclear power. This last aspect has important implications for the country's electricity supply, which has primarily been based on hydropower and nuclear power over the last decades. Hydropower and nuclear power produced, respectively, 59% and 33% of total electricity in 2016 (SFOE, 2017). Nuclear power is intended to be replaced with, among others, renewable energy sources. With respect to hydropower, the *Energy Strategy 2050* foresees an increase in electricity production of ca. 9% compared with the current hydropower production (SFOE, 2012).

However, the hydropower industry in Switzerland is in a difficult situation for a number of reasons. Most of the hydropower plants currently operate with losses, as a result of considerably lower prices and a reduced variation between peak and off-peak prices on electricity markets in the recent years. There are three main reasons for this: The increasing share of renewable electricity generation; low global coal prices; and the low CO_2 emission permit prices of the EU trading system (Barry et al., 2015). Although the environmental benefits of hydropower, such as low greenhouse gas emissions, are evident, the hydropower industry in Switzerland has a history of public dispute due to its environmental externalities. The negative effects of hydropower are mainly caused by a loss of connectivity between aquatic systems and altered flow regimes (hydropeaking). A loss of connectivity between water bodies affects the migration of animal species. Changes in flow regimes have an impact on wildlife, may endanger floodplains, and cause erosion. Another factor that hampers the industry is the

low public acceptance of the hydropower technology in Switzerland and elsewhere (Sternberg, 2008, 2010; Tabi and Wüstenhagen, 2017). This is likely to be associated with the above-mentioned negative environmental externalities of hydropower.

Switzerland has the highest proportion (88%) of already developed hydropower potential worldwide (IEA, 2010). In addition, considering the economic, environmental, and social obstacles that the hydropower industry in Switzerland currently faces, the envisaged expansion of hydropower production by 9% from its current level is challenging. The Swiss Federal Office of Energy hence concludes that such an expansion is only possible under a considerable improvement in economic conditions and public acceptance (SFOE, 2012).

1.2 Main objective, hypotheses, and research questions

This PhD thesis focuses on the public acceptance of hydropower expansion. It does so by investigating the values that the general public attaches to the various positive and negative externalities related to hydropower. These values are typically elicited using stated preference research methods, that is, research in which the public at large is asked to answer questions about the externalities involved, using different forms of survey methods. In the past two decades, discrete choice experiments (DCE) have become the most important stated preference (SP) elicitation approach (Johnston et al., 2017). The general objective of this PhD thesis is to quantify and explain variation in the non-market values attached to hydropower externalities. More specifically, it aims to test axioms and assumptions of microeconomic choice theory in the context of DCEs. A quantitative meta-analysis summarizes and synthesizes the results of the existing SP literature on hydropower externalities, and generates new insights that are used as inputs in the design of a DCE in this thesis. The choice survey that is subsequently designed and implemented consists of four versions which differ with respect to their methodological characteristics. Four independent samples of respondents answered the different versions of the DCE. This setup allows this dissertation to investigate the choice behavior of survey participants in a DCE and, in particular, it enables it to gain new insights into choice certainty, choice

consistency, and choice monotonicity, as well as the continuity of preferences and their dependence on reference points. All of these concepts are linked to the axioms and assumptions of choice theory. This dissertation is embedded in the context of Swiss energy policy, as the DCE elicits public preferences and willingness-to-pay (WTP) values for an expansion of electricity production by hydropower in Switzerland.

In the first part of this dissertation, a meta-analysis is conducted by estimating meta-regression models using the estimated non-market values for hydropower externalities. These values are elicited from existing SP studies implemented in different parts of the world. This is the first meta-analysis in the non-market valuation literature that explicitly focuses on hydropower and its external effects.

Next, a DCE is conducted as part of an online survey. The policy context described in the previous section serves as a case study for the implementation of the DCE. Research on the external effects of renewable energy typically investigates either direct externalities, e.g. the effects on wildlife, vegetation, and landscape, or indirect externalities, e.g. greenhouse gas emissions. Greenhouse gas emissions constitute an indirect externality, because they are not directly caused by renewable energy sources but represent avoided external effects of conventional sources of electricity. In the Swiss energy context, one of the major indirect externalities of renewable energy sources is the avoidance of nuclear risk. Until now, the effect of avoiding nuclear risk on public risk perception and preferences for renewable energy has not been studied in the valuation literature. Hence, this PhD thesis contributes to the existing literature by its central hypothesis, which postulates that public preferences for expanding hydropower production are linked to public preferences for avoiding nuclear risk. To this end, a choice attribute related to nuclear risk is included in the DCE. Hartmann et al. (2013) is the only study that explicitly investigates the relationship between public attitudes and perceptions of nuclear power and preferences for the adoption of green electricity. However, in contrast to Hartmann et al. (2013), this thesis focuses on this relationship based on stated preference research.

The main objective of the DCE is to investigate a number of axioms and common assumptions made in consumer choice theory (e.g. Jehle and Reny, 2001; Mas-Colell and Whinston, 1995). The underlying theoretical framework of DCEs

is provided by Lancaster's theory of consumer demand (Lancaster, 1966), and by random utility theory (McFadden, 1974; Thurstone, 1927). Lancaster's theory of demand states that utility is not derived from goods directly, but from their individual characteristics. Random utility theory has its roots in the rapidly increasing availability of survey data in the 1960s, which created the need for linking observed behavior to existing microeconomic consumer theory (McFadden, 2001). Random utility theory assumes that utility functions exist, and that respondents choose in accordance with their utility functions. Therefore, the standard economic axioms and assumptions of consumer theory as outlined, for example, in Jehle and Reny (2001), are maintained in the random utility framework. This PhD thesis tests some of these axioms and assumptions. Additionally, it tests an important assumption about choice behavior in Kahneman and Tversky's (1979) prospect theory.

First, the standard economic axiom of monotonicity and the conventional assumptions of stable and known preferences are investigated. This is accomplished by testing the null hypothesis that preferences are known, consistent, and monotonic, and by examining the determinants of choice certainty, choice consistency, and choice monotonicity and their impact on choice behavior. The contribution of this PhD thesis to the existing literature is that this thesis investigates choice certainty, consistency, and monotonicity simultaneously, using the same choice responses. This allows for the identification of both common and idiosyncratic drivers of these constructs.

Second, the axiom of continuous preference relations is tested by analyzing attribute non-attendance (ANA). Continuous preference relations imply continuous indifference curves, and hence assume that choice participants adopt compensatory decision-making rules when making choices in a DCE (e.g. Lagarde, 2010). The existence of ANA violates the continuity axiom. This thesis assesses how a novel methodology to capture visual ANA can contribute to a better understanding of ANA behavior. Specifically, the common approach for analyzing ANA in the existing literature through stated or inferred ANA information is extended with a novel, visual approach for capturing ANA behavior based on mouse-tracking.

Finally, this dissertation studies the dependence of preferences on reference points, which is an important assumption of choice behavior in prospect theory.

In contrast to large parts of the valuation literature, the original text of Kahneman and Tversky (1979) states a variety of possible reference points that do not have to coincide with an individual's status quo. Drawing on prospect theory, this PhD thesis examines the possibility that comparative risks displayed on a risk ladder may serve as reference points and have an impact on an individual's choice in a DCE. The majority of the DCE literature on reference points focuses on reference points that are linked to the characteristics of the choice tasks (e.g. their baseline levels). In contrast, the last chapter of this thesis contributes to the DCE literature by exploring the role of reference points which are induced independently and prior to the actual choice tasks.

The main research questions addressed in the thesis can be summarized as follows:

1. What are the main determinants of the non-market values for hydropower externalities?

2. What are the common and idiosyncratic determinants of choice certainty, choice consistency, and choice monotonicity in DCEs, and what is the role of choice complexity?

3. How does visual ANA data obtained from mouse-tracking perform in explaining ANA behavior compared with stated and inferred ANA?

4. Do comparative risks shown on risk ladders serve as reference points and influence preferences for a change in risk?

1.3 Data collection and econometric analysis

Two data collection processes took place for the purpose of this PhD thesis. First, a database was created based on secondary data derived from existing SP studies and publications for the meta-analysis, and second, a survey including a DCE was conducted to collect primary research data. A database of existing research that values the external effects of hydropower was constructed in order to identify the main determinants of the economic values for hydropower externalities (research question 1). The created database consists of 29 international studies, which together generate 81 observations. Three different meta-regression

models are applied. A baseline model is estimated using weighted least squares regression analysis. The observations are weighted by the sample size of the surveys in the original studies. This procedure controls for differences in the variances of the values in the database by assuming that variances are smaller for observations that are obtained from surveys with larger sample sizes. Two other models control for systematic differences in mean welfare estimates between the studies, and for differences in the influence of the regressors on the dependent variable.

The DCE that follows the global meta-analysis elicits public preferences for an expansion of hydropower in Switzerland specifically, and aims to generate data on public preferences for hydropower expansion. This serves to answer the methodological research questions 2 to 4. The DCE was implemented among 1,000 households that constituted a representative sample of the German- and French-speaking Swiss population (roughly 95% of the total population of Switzerland, the remaining 5% live in an Italian-speaking region). Survey pretesting included 20 face-to-face interviews and two rounds of online pretests with 220 and 350 respondents. For the final DCE, the respondents were split into four different, independently recruited representative samples, each comprising ca. 250 households. Each sample received a slightly different questionnaire version in order to be able to answer the different research questions. Compared with the baseline version, the three other versions differed with respect to: the presence of questions on choice certainty; the monitoring of the respondents' information acquisition process by mouse-tracking; and the reference points included in a risk ladder representing the changes in hydropower and nuclear power risk under valuation.

Different econometric techniques are applied. For the purpose of answering question 2, binary logit models and random-effects ordered logit models are estimated. Binary logit models are used to regress choice consistency and choice monotonicity on possible explanatory variables, and random-effects ordered logit models are employed to identify drivers underlying stated choice certainty. To answer research questions 3 and 4, mixed logit (MXL) models are estimated. In contrast to the fixed effects multinomial logit model, MXL models allow for random taste heterogeneity across individuals and correlation between unobserved factors over alternatives and choice tasks. Question 3 is addressed

by running MXL models with attribute parameters for respondents who state non-attendance to an attribute restricted to zero. The same procedure is applied for analyzing visual ANA information. Inferred ANA is assessed using equality-constrained latent class (ECLC) models. Each class in this model describes a specific pre-defined pattern of ANA behavior. MXL models are also used in order to identify the effects of different risk ladders on choice behavior (research question 4).

The Swait and Louviere (1993) test procedure is applied in the course of answering the research questions 2 and 4. For research question 2, the tests assess whether there are statistically significant differences between the choice behavior of respondents who are (un)certain about and (in)consistent in their choices. Furthermore, the effect of including follow-up questions on choice certainty and including the same choice task in a different position in the choice-task sequence is examined using the same procedure. In answering research question 4, the Swait-Louviere test is applied to compare two split-samples of respondents who were shown risk ladders that differ with respect to the ranges of probabilities of comparative risks.

1.4 PhD thesis outline

Chapter 2 aims to answer research question 1. This study was first presented at the 22nd Annual Conference of the European Association of Environmental and Resource Economists in Zurich in June 2016, and has been published as Mattmann, Logar, and Brouwer (2016a) in Energy Economics. It presents a meta-analysis of existing SP research on the economic value of the positive and negative external effects of hydropower. For this purpose, a database with the economic values of the non-market impacts of hydropower electricity generation is constructed. The main aim of the meta-analysis is to quantify and explain the economic values for positive and negative hydropower externalities. Different meta-regression model specifications are estimated to test the robustness of the determinants of these non-market values. The impact of key methodological features of the valuation studies on the results is also investigated.

Chapter 3 attempts to answer research question 2. It focuses on the consumer theory axiom of monotonicity and the assumptions that consumer preferences

are known and stable. More specifically, Chapter 3 tests whether choices are based on known, stable, and monotonic preferences, and investigates the common and idiosyncratic determinants of choice certainty, consistency, and monotonicity based on the results of the DCE. For this purpose, choice certainty, consistency, and monotonicity are regressed on possible drivers. In doing so, two different measures of choice task complexity are compared: The entropy of a choice task, and the utility difference between the alternative that is chosen and the second-best alternative. Moreover, this chapter tests the equality of choice behavior of respondents who differ with respect to choice certainty and consistency. It also investigates the effect of including choice certainty follow-up questions after each choice task, and compares the choice behavior of respondents who were shown a repeated choice task in a different position in the choice task sequence.

Chapter 4 answers research question 3 and investigates the standard economic axiom of continuity. This chapter was first presented at the 23rd Annual Conference of the European Association of Environmental and Resource Economists in Athens in June 2017. It presents the first application of mouse-tracking to analyze ANA in DCEs. Mouse-tracking is applied to record the frequency and duration of uncovering attribute information in the choice process. Mouse-tracking functions similarly to eye-tracking, but can be applied online and allows for a larger sample size. The information obtained from mouse-tracking is used to generate a visual definition of ANA, while stated ANA information is collected by means of a follow-up question after the DCE. The performance of choice models based on stated, inferred, and visual ANA information is compared.

Chapter 5 focuses on research question 4 and assesses a key assumption of prospect theory: the dependence of preferences on reference points. This chapter argues for the existence of multiple reference points. The DCE values the changes in the risk of dying caused by a hydropower and a nuclear power accident. Risk ladders are used to communicate the risk information to respondents. Two different risk ladders are presented to two independent samples of respondents. The risk ladders differ with respect to the range of risk probabilities that serve as a benchmark for the risks being valued. One sample is shown a risk ladder with a high reference point, that is, a risk ladder with a wide range of comparative risk probabilities that include high risk events, whereas the other

sample is shown a risk ladder with a low reference point, i.e. a risk ladder with a narrow range of comparative risk probabilities that encompass lower risks. On both risk ladders, the change in risk that is being valued is identical for both samples. Chapter 5 hypothesizes that, in addition to the status quo probability of the valued risks, comparative risks presented on the risk ladders represent reference points that influence the valuation of risk changes.

Chapter 6 discusses the results that are presented in the Chapters 2, 3, 4, and 5 and concludes. This chapter also identifies the need for further future research, and summarizes policy-relevant insights.