Chapter 2

Hydropower Externalities: A Meta-Analysis[1]

2.1 Introduction

As a result of both, increasing efforts to decarbonize economies and substantially diminished social and political acceptance of nuclear energy production following the 2011 accident in Fukushima, Japan, renewable energy sources are set to play a more prominent role worldwide. This is reflected in various national energy policies. Germany and Switzerland, for example, decided to phase out nuclear energy production and replace its share in national electricity production primarily with renewable energy sources (SFOE, 2013). Renewable energy sources avoid many negative externalities of conventional energy production based on fossil or nuclear fuels, which typically involve long-term consequences such as the impacts of greenhouse gas emission on climate change or the accumulation of radioactive waste. However, renewable sources of energy often operate with lower energy densities than non-renewable energy carriers, which results in spatially larger production facilities (Wüstenhagen, Wolsink, and Bürer, 2007). As a consequence, other types of externalities such as threats to biodiversity or aesthetic impacts occur.

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Much of the existing research related to the economic valuation of renewable energy focuses on the newer technologies of wind, solar, biomass and biofuel. Recent examples include studies which value externalities from: wind power generation (Alvarez-Farizo and Hanley, 2002; Ek, 2006; Ek and Persson, 2014; Ladenburg and Dubgaard, 2007); biomass (Susaeta et al., 2011); or a mixture of various renewable energy sources (Bergmann, Colombo, and Hanley, 2008; Bergmann, Hanley, and Wright, 2006; Komarek, Lupi, and Kaplowitz, 2011; Kosenius and Ollikainen, 2013; Ku and Yoo, 2010; Longo, Markandya, and Petrucci, 2008). In contrast, the amount of research that has been conducted on the effects and economic values of more established technologies such as hydropower is rather limited. Since the role of hydropower as a source of renewable energy is expected to expand further worldwide (e.g. Jacobson and Delucchi, 2009), an understanding of individuals' preferences for its effects on the environment, recreational activities, and aesthetic values is of crucial importance to inform an effective and efficient energy transition.

Hydropower is a renewable source of energy with a long history (Paish, 2002). The product of hydropower generation is electricity, a standard market good that can be sold directly to electricity consumers, and it is therefore usually not considered in valuation studies. The same holds for the employment effects of hydropower operations. However, hydropower electricity production typically generates a number of positive and negative side effects that affect different groups of stakeholders, for which they are, in most cases, not (directly) compensated. These effects of hydropower depend not only on the size of operation and the geographical location, but also on the type of hydropower facility. That is, run-of-the-river facilities, usually operating with constant water flows and generating electric base load, have different effects than storage plants that depend on dams to store water, which is released at times of peak demand. The effects of storage plants with natural water feeding can differ again from the effects of pumped-storage plants that pump water from a lower to a higher reservoir. In general, most of the external effects of hydropower are caused by hydropeaking and disconnected water bodies. Reduced connectivity refers to the disconnection of water bodies caused by hydropower dams and run-of-the-river facilities. Changes in flow (hydropeaking) occur only in the case of storage hydropower plants. Hydropeaking causes non-natural flow patterns, i.e. high variability in discharge, water levels, and flow velocity of water bodies. The various effects caused by different types of hydropower plants will be briefly summarized below.

Recreation is an important service provided by aquatic ecosystems (Boyd and Banzhaf, 2007), which may be impaired by hydropower. Examples of such services affected by hydropower operations include various types of recreational activities such as kayaking or rafting (Aravena, Hutchinson, and Longo, 2012; Hynes and Hanley, 2006), fishing (Filippini, Buchli, and Banfi, 2003; Gogniat, 2011; Håkansson, 2009; Loomis, Sorg, and Donnelly, 1986; Navrud, 2004; Robbins and Lewis, 2009) or visiting waterfalls (Ehrlich and Reimann, 2010). Most studies observe that these recreational activities are negatively influenced by hydropower due to hydropeaking and the disconnectivity of water bodies, both of which impede water sports and endanger fish populations, thereby reducing the value of angling. It is, however, conceivable that hydropower may also generate positive effects on recreational opportunities: for example, by creating artificial lakes suitable for water sports. Getzner (2015) empirically compares the recreational value of free-flowing sections of a river with dammed stretches and finds higher recreational benefits on free-flowing sections than on dammed stretches of rivers for a variety of recreational activities.

The environmental effects of hydropower are manifold. A positive environmental externality of hydropower electricity production is lower greenhouse gas emission compared with most other sources of electricity production (see Weisser (2007) for a literature overview of greenhouse gas emissions by different electricity production technologies). The reduction in the emission of greenhouse gases depends, however, on reservoir size and type, the extent of flooded vegetation, soil type, water depth, and climate conditions. Especially methane emission can form a significant source of greenhouse gas release in the case of the hydropower reservoirs of storage plants in tropical regions (e.g. Barros et al., 2011; Delsontro et al., 2010). Pumped-storage plants without natural water feed are used for load balancing only, and do not directly reduce greenhouse gas emissions since they consume more electricity than they generate.

Negative environmental externalities of hydropower also stem from either reduced connectivity of aquatic systems or altered flow regimes. Reduced connectivity especially affects the migration of fish and other animal species. Changes in flow patterns (hydropeaking) change sedimentation levels, and can lead to rapid changes in water temperature. Both of these effects have an impact on invertebrates, which are usually very sensitive to altered temperature and sediments (e.g. Bruno et al., 2009). In addition, non-natural hydropower flow patterns may endanger floodplains, threaten fish and bird species, and cause erosion.

Hydropower projects, especially the construction of dams, artificial lakes and reservoirs, may also affect artifacts of important cultural, historical and geological value that are flooded during the construction phase of hydropower storage plants (Han, Kwak, and Yoo, 2008; Lienhoop and MacMillan, 2007; Navrud, 2004). Direct, potentially negative, aesthetic impacts of hydropower often stem from hydropower-related facilities such as dams, access tracks, pipelines, buildings, and the lack of vegetation due to these installations (Hanley and Nevin, 1999). Run-of-the-river plants cause aesthetic degradation as well. It has been shown that free-flowing rivers have higher aesthetic value compared with rivers affected by hydropower facilities (Born et al., 1998). Furthermore, pylons connecting remote hydropower plants might adversely affect views and scenery (Aravena, Hutchinson, and Longo, 2012).

The main objective of this paper is to synthesize the empirical evidence on the economic valuation of hydropower externalities in a meta-analysis. In contrast to a recent meta-analysis on the willingness-to-pay for green electricity (Sundt and Rehdanz, 2015), we focus explicitly on hydropower and its externalities. This is, to our knowledge, the first study to conduct such an analysis. A main research question addressed in this paper is whether the positive hydropower externalities outweigh the negative ones. The purpose of the meta-analysis is not only to review and evaluate the existing literature, but also to explain study-to-study variation by focusing on differences between valuations for various positive and negative types of hydropower externalities, as well as on key methodological characteristics such as sensitivity to scope. In order to do this, the external effects of hydropower production are first identified and classified. Next, the drivers of welfare estimates for the non-market effects of hydroelectric production technology are examined in a meta-regression model.

The remainder of this paper is structured as follows. Section 2.2 describes the search procedure and selection of studies included in the meta-analysis. Section

2.3 explains the main econometric issues in meta-modeling and the estimated models. Section 2.4 considers the factors that influence the economic values of hydropower externalities. The results of the estimated meta-regression models are presented in Section 2.5 followed by conclusions in Section 2.6.

2.2 Study selection and characteristics

The non-market valuation of the externalities of hydropower production constituted the main criterion for a study to be included in the meta-analysis. More specifically, all studies that generated primary valuation data of the non-market impacts of electricity production by hydropower were considered for inclusion. We included all studies in which hydropower production was identified as a source of the externalities. This involves studies that valued the externalities of hydropower exclusively (roughly 80% of all observations), as well as studies which value the external effects of renewable energy in general, but explicitly mention hydropower to be one of these (20 of the observations included). For example, a study that values increased water flows due to modified hydropower operation schemes would be included in the analysis, whereas a study that estimates the value of increased water flows without explicitly specifying that these changes in water flows are caused by hydropower operation would not be included. Applying this selection criterion ensured that individuals took their preferences for hydropower into account when valuing the external effects.

The search procedure was conducted in 2014. Online databases that were browsed included Google Scholar, Scopus, Econlit and RePEc. ProQuest was used to search specifically for relevant PhD theses. The search included both published and unpublished papers, working papers, conference papers, PhD theses, Master’s theses, government and non-government reports. Keywords that were used in the search process included, among others, the following terms and combinations thereof: hydropower, hydroelectric, stated preferences, revealed preferences, contingent valuation, conjoint analysis, choice experiment, travel cost, hedonic pricing, externalities, dams, and recreational benefits.

Table 2.1 provides a list of the studies included in the meta-analysis collected by the search and selection procedures described above. Most of the studies obtained are articles published in international peer-reviewed journals, but there are also two reports, two working papers, one conference paper, a PhD thesis, and two Master's theses. Three reports could not be obtained despite an extensive search procedure. Other studies that were excluded to avoid double counting analyzed data that had already been used in one or more other relevant publication. Five papers valued the externalities of renewable energy in general without explicitly mentioning hydropower, and thus the economic values of the effects could not be ascribed to hydropower. Furthermore, two publications reported only aggregated economic values for the relevant population that could not be transformed to individual welfare estimates.

The earliest study was carried out in 1983, while the other studies were conducted over a period of 18 years between 1993 and 2011. The majority of the studies were carried out in Europe (70%), followed by South America (13%), the United States (9%), and Asia (9%). With respect to the valuation methods, most studies applied stated preference methods, such as contingent valuation (CV) or discrete choice experiments (DCE); two studies used revealed preference methods (travel cost method (TCM)); and three combined revealed and stated preference approaches, using the hypothetical TCM (HTCM). Out of a total of 29 studies, 81 observations could be used in the subsequent meta-analysis. 15 studies contributed only one observation. Studies provided more than one observation when using different samples of respondents (for example, distinguishing between users and non-users of a resource) or because they valued various combinations of hydropower externalities. A few studies also varied the methodological aspects in split samples. The number of respondents underlying each observation varies considerably (between 45 and 1933), with an average of 361 respondents per observation. Eight observations (9.9%) included respondents who were directly affected by hydropower externalities. These are, for example, anglers, who were asked to value the number of fish in a river affected by hydropower. Peer-reviewed papers included in the analysis received, on average, 39 citations measured by the Google Scholar citation index, with one study having a maximum of 136 citations (up to December 2014). Finally, the share of hydropower in total national electricity production (in the year of the survey) was included as a measure for the energy mix in a country (IEA, 2014a,b). National shares of hydropower vary widely, with an average of 38% of electricity produced by hydropower in the countries where the surveys were conducted.

TABLE 2.1: Studies collected in the selection and search procedure (ordered by study year)

#	Study year	Authors (years of publication)	Type of publication	Country	Nat. hydro. share^a	Valuation Method^b	N^c
1	1983	Loomis, Sorg, and Donnelly (1986)	Journal article (Journal of Environmental Management)	USA	13.7%	CV	1
2	1993	Kosz (1996)	Journal article (Ecological Economics)	AUT	71.5%	CV	1
3	1993	Navrud (1995, 2001)	Report & Journal article (Hydropower and Dams)	NOR	99.6%	CV	2
4	1994	Biro (1998)	Journal article (Ambio)	TUR	39.1%	CV	1
5	1996	Loomis (1996)	Journal article (Water Resources Research)	USA	9.6%	CV	3
6	1997	Hansesveen and Helgas (1997)	Master's Thesis	NOR	99.3%	CV	3
7	1998	Bergland (1998)	Report	NOR	99.4%	CV	3
8	1998	Filippini, Buchli, and Banfi (2003)	Journal article (Applied Economics)	CHE	53.7%	HTCM	1
9	1998	Hanley and Nevin (1999)	Journal article (Energy Policy)	GBR	1.4%	CV	1
10	1998	Loomis (2002)	Journal article (Water Resources Research)	USA	7.8%	HTCM	1
11	2002	Han, Kwak, and Yoo (2008)	Journal article (Environmental Impact Assessment Review)	KOR	1.0%	DCE	1
12	2002	Sundqvist (2002)	Doctoral Thesis	SWE	45.2%	DCE	1
13	2003	Bothe (2003)	Working Paper	ISL	83.4%	CV	1
14	2003	Hynes and Hanley (2006)	Journal article (Land Use Policy)	IRL	2.4%	TCM	1
15	2003	Bergmann, Colombo, and Hanley (2008)	Journal article (Ecological Economics)	GBR	0.8%	DCE	6
16	2004	Håkansson (2009)	Journal article (Journal of Environmental Planning and Management)	SWE	39.6%	CV	8
17	2004	Navrud (2004)	Report	NOR	98.8%	CV	1

#	Study year	Authors (years of publication)	Type of publication	Country	Nat. hydro. share[a]	Valuation Method[b]	N[c]
18	2005	Longo, Markandya, and Petrucci (2008)	Journal article (Ecological Economics)	GBR	40.5%	DCE	4
19	2006	Kataria (2009)	Journal article (Energy Economics)	SWE	43.1%	DCE	7
20	2006	Robbins and Lewis (2009)	Journal article (Journal of the American Water Resources Association)	USA	6.8%	TCM	2
21	2006	Ku and Yoo (2010)	Journal article (Renewable and Sustainable Energy Reviews)	KOR	0.9%	DCE	3
22	2008	Aravena, Hutchinson, and Longo (2012)	Journal article Energy Economics)	CHL	40.5%	CV	1
23	2008	Ponce et al. (2011)	Journal article (Water Resources Management)	CHL	40.5%	CV	10
24	2008	Kosenius and Ollikainen (2013)	Journal article (Energy Policy)	FIN	22.1%	DCE	1
25	2009	Ehrlich and Reimann (2010)	Journal article International Journal of Geology)	EST	0.4%	CV	1
26	2010	Guo et al. (2014)	Journal article (Energy Policy)	CHN	17.2%	CV	2
27	2011	Gogniat (2011)	Master's Thesis	CHE	51.5%	HTCM	1
28	2011	Klinglmair and Bliem (2013)	Conference Paper	AUT	55.0%	DCE	3
29	2011	Klinglmair, Bliem, and Brouwer (2012)	Working Paper	AUT	55.0%	DCE	10

Notes: [a] IEA (2014a,b).
[b] CV: Contingent Valuation; CE: Choice Experiment;
HTCM: Hypothetical Travel Cost Method; TCM: Travel Cost Method.
[c] Number of observations included in the meta-analysis.

2.3 Meta-model

2.3.1 Treatment of heterogeneity, heteroskedasticity, and non-independence

Meta-regression models can be classified according to the way they address and treat data heterogeneity, heteroskedasticity of effect-size variances, and non- independence of observations from the same studies (Nelson and Kennedy, 2008). This section explains these three issues and how they are tackled in our study.

Data used in a meta-analysis come from a variety of papers, authors, and countries. Furthermore, there are often individual-specific differences between survey participants, and the effect-size that forms the dependent variable in a meta-analysis might suffer from inconsistencies between studies (Smith and Pattanayak, 2002). In other words, studies may differ with respect to their design elements, but they may also differ regarding their examined effect-size (Ringquist, 2013). Apart from enhancing the comparability of effect-sizes by adjusting available data from primary studies and dropping observations that lack comparability, the standard treatment of data heterogeneity in economic studies is to control for differences in effect-size by including independent variables (Nelson and Kennedy, 2008; Smith and Pattanayak, 2002). In this study, control will be included for the differences between the types of hydropower externalities valued, the sample characteristics, and the methodological features of different studies.

The primary studies used in meta-analysis usually do not have the same (estimated) variances owing to differences in study-specific characteristics (Nelson and Kennedy, 2008). The standard assumption of the ordinary least squares (OLS) estimator of homogeneity is thus in general violated (Ringquist, 2013). In order to mitigate heteroskedasticity of effect-size variances and to control for differences in the quality of study results, the observations are ideally weighted by the inverse of their variances, resulting in weighted least squares regression (e.g. Lipsey and Wilson, 2001). By applying weights in this manner, more accurate studies with lower variances receive higher weights in the meta-analysis. Since, in this study, we only have information available about estimated variances of a fraction of the primary studies, we weight the individual observations by the square root of the study sample sizes, as is commonly done in the meta-regression literature (see Nelson and Kennedy (2008) for an overview on studies which apply this procedure). This ensures that studies with larger sample sizes (and therefore, as expected, also lower variances) receive more weight in the analysis. As a consequence, the issue of heteroskedasticity is mitigated, and we ensure that the observations which we consider to be more reliable receive higher weights in the analysis.

It is common procedure in meta-analysis to draw several effect-sizes from each study. Since observations drawn from the same study usually share some common characteristics, it must be assumed that there is within-study correlation between observations (Nelson and Kennedy, 2008). Various procedures exist to mitigate this issue, such as including only one observation per study, or including only mean values of various observations from the same study. However, since the number of primary studies, and hence observations that are used in a meta-analysis, may be limited, it is in many cases unavoidable to use all the observations obtainable from each study. Furthermore, the use of several observations from the same study provides some estimation leverage because many elements of the research design of these observations remain the same (Ringquist, 2013). If various observations per study are used, it is necessary to control for within-study correlation by explicitly taking the hierarchical data structure into account. This can be done, for example, by using panel data models or calculating cluster-robust standard errors (Nelson and Kennedy, 2008). Both approaches are applied in this study.

2.3.2 The meta-regression models

We apply a variety of different approaches to address the issues described in Section 2.3.1, resulting in three different models. In Model 1 we use cluster-robust standard errors, where studies are set as clusters. This enables us to take the correlation between value estimates from the same studies into account. Cluster-robust standard errors assume independent observations across, but not within, clusters. Model 2 is a random-effects panel model with individual studies defined as cross-sectional units. Model 3 is an extension of the random-effects model that allows not only intercept coefficients, but also slope parameters to be random (Cameron and Trivedi, 2005).

The baseline model (Model 1) is estimated by weighted least squares, and is specified as follows (e.g. Harbord and Higgins, 2008):

$$y_i = x_i'\beta + \varepsilon_i \text{ with } \varepsilon_i \sim [0, \frac{\sigma^2}{w_i}], \tag{2.1}$$

where y_i denotes the dependent variable, i.e. the welfare estimates for hydropower externalities; x_i is a vector of regressors; and β is a vector of associated coefficients. The observations are weighted by the square root of their respective sample size in this model. This was incorporated by using analytic weights which assume an error term with mean equal to zero and weighted variance of σ^2/w_i, where σ^2 is an unknown variance estimated in the regression, and w_i denote the known weights. Variances are assumed to be smaller for observations that are based on a larger sample size. Cluster-robust standard errors are applied in order to control for within-study correlations of observations.

The model above serves as a baseline case and is compared with more elaborate models (Models 2 and 3). Despite the advantage of the fixed-effects model that allows for correlation between unobservable study-specific effects and independent variables, such a specification is not feasible in our case because there is a substantial number of studies which provide only one observation. Model 2 therefore incorporates random-effects and is estimated using the maximum likelihood estimation procedure:

$$y_{ij} = x'_{ij}\beta + \mu_j + \varepsilon_{ij} \text{ with } \mu_i \sim [\mu, \sigma^2_\mu] \text{ and } \varepsilon_{ij} \sim [0, \sigma^2_\varepsilon]. \tag{2.2}$$

Model 2 incorporates two error terms: ε_{ij} denotes the standard error term, while μ_j is a random variable that varies across j studies, but is assumed to be distributed independently of the regressors (Cameron and Trivedi, 2005). Both the random effects and the error term are assumed to be identically and independently distributed (iid).

Model 2 is a more realistic specification compared with Model 1 because it allows systematic differences in mean welfare estimates between studies to be captured. However, an even more elaborate model would make it possible to control for differences in the influence of regressors on the dependent variable between studies. Such differences can be modeled by taking into account not only random intercepts, but also random slope parameters. This results in a mixed-effects model (Model 3)[2], which can be described as follows (Cameron and Trivedi, 2005):

$$y_{ij} = x'_{ij}\beta + z'_{ij}\mu_j + \varepsilon_{ij} \text{ with } \varepsilon_{ij} \sim [0, \sigma^2_\varepsilon], \tag{2.3}$$

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[2] Depending on the context of application, such models are also called hierarchical, multilevel, random coefficients, or variance components models.

where x_{ij} denotes, as before, the regressors; z_{ij} is a vector of observable characteristics (a subset of x_{ij} that includes the variables in the random part); μ_j is a random vector; and ε_{ij} is the standard error term. Mixed-effects models allow for the estimation of both fixed-effects and random-effects. Fixed-effects in this context describe the ordinary effects of regressors on the dependent variable. Their slope and intercepts describe the sample as a whole. These are the main effects of interest. Random-effects are the intercepts and slope parameters that vary across studies, and capture the heterogeneity between studies. Random-effects are usually not estimated directly, but their variances are calculated instead. The size and standard errors of these variances indicate whether there are significant variations between studies in the slope coefficients of the regressors that are assigned to the random part (Hamilton, 2012).

2.4 Selection and definition of variables

The main goal of the meta-analysis presented here is to explain variations in effect-size estimates between different studies, that is, variation in the dependent variable of interest, here welfare estimates for the positive and negative externalities associated with hydropower. The value function that serves as a conceptual basis for the different categories of factors which explain variations in effect-size estimates can be specified as follows:

$$Welfare\ estimate_i = f(Q_i; R_i; S_i), \tag{2.4}$$

where the estimated economic value obtained from study i represents the effect-size of interest, i.e. the dependent variable whose variation we aim to explain. Q denotes the type of externality that is valued in study i. Of importance here is not only the externality itself, but also the size of change in the provision or quality level of the externality (i.e. the difference between Q^1 in a new state and Q^0 in the status quo). The various externalities (Q) valued were divided into the following five categories: (1) landscape and vegetation; (2) wildlife; (3) greenhouse gas emission; (4) recreation; and (5) aesthetics. Additionally, sample characteristics (R) and methodological features of the studies (S) are theoretically expected to play a significant role in explaining effect-size estimates. Sample characteristics (R) refer to the socio-economic characteristics of survey respondents, and methodological features (S) refer to the methods and procedures used to elicit and analyze the welfare estimates.

Table 2.2 provides a full list of the regressors included in the meta-regression model. The directions of the valued effects are also indicated, i.e. whether they describe improvements, mitigations, or deteriorations. Mitigations include policies such as restoring rivers or dismantling hydropower dams, all of which may mitigate the negative impacts of hydropower operation on landscape and vegetation, wildlife, recreation, and aesthetics. Mitigations thus describe the positive changes of negative hydropower externalities. In contrast, improvements refer to welfare measures for the positive changes of the positive externalities of hydropower. Since low greenhouse gas emissions are the only positive externality of hydropower valued in our data set, improvements refer exclusively to reducing greenhouse gas emissions. Negative changes in externalities, such as a negative change of aesthetic values, are described as deteriorations. The different directions of the valued effects are captured by separate externality-specific variables[3]. The dummy variables for deteriorations in landscape and vegetation and wildlife were merged into one variable due to perfect collinearity between the two (all observations that valued deteriorations in landscape and vegetation also valued deteriorations in wildlife).

TABLE 2.2: Explanatory variables included in the meta-analysis

Variables	Description	Coding of variables
Type of externality and size of change valued		
Landscape & Vegetation (mitigation)	Mitigation of negative impacts on landscape & vegetation such as forests, flora species, or river-margin vegetation	Dummy: 1= Mitigation of negative impacts on landscape & vegetation valued; 0=Otherwise
Landscape & Vegetation and Wildlife (deterioration)	Deterioration of landscape & vegetation as well as deteriorations of wildlife	Dummy: 1=Deterioration of landscape & vegetation and wildlife valued; 0=Otherwise
Wildlife (mitigation)	Mitigation of negative impacts on fauna, especially populations of fish, birds and invertebrates (e.g. improving fish passage)	Dummy: 1= Mitigation of negative impacts on wildlife valued; 0=Otherwise
Greenhouse gas emission (improvement)	Reduction of greenhouse gas emission	Dummy: 1=Reduction of greenhouse gas emission valued; 0=Otherwise

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[3] No control was included for differences in welfare measures (compensating or equivalent surplus measures) due to multi-collinearity, although the direction of the valued effects does not necessarily coincide with these welfare measures. A mitigation of an effect, for example, can be assessed by both a compensating and an equivalent surplus, depending on whether the mitigation is framed as an actual improvement or an avoided deterioration.

Variables	Description	Coding of variables
Recreation (mitigation)	Mitigation of negative impacts on recreational amenities affected by hydropower production, e.g. kayaking, river rafting, hunting or visiting a waterfall	Dummy: 1= Mitigation of negative impacts on recreation valued; 0=Otherwise
Aesthetics (mitigation)	Mitigation of negative visual impacts, such as visibility of access tracks, pipelines and pylons or general aesthetic perception of water bodies that are used for hydropower	Dummy: 1= Mitigation of negative visual impacts valued; 0=Otherwise
Aesthetics (deterioration)	Deterioration of visual impacts such as visibility of access tracks, pipelines and pylons or general aesthetic perception of water bodies that are used for hydropower	Dummy: 1=Deterioration of visual impacts valued; 0=Otherwise
Size of change	Variable describing the size of an impact of a valued externality	Dummy: 1=Small change valued; 0=Medium or large change valued
Methodological variables		
Valuation method	Describes the valuation method applied: discrete choice experiment (DCE), contingent valuation (CV), or travel cost methods (TCM or HTCM)	Dummy: 1=DCE; 0=CV, TCM or HTCM
Survey mode	Describes the survey administration mode, e.g. mail, mail & phone, online, or face-to-face survey	Dummy: 1=Face-to-face survey; 0=Other survey mode (mail, mail & phone, online)
Payment vehicle	Characterizes the payment vehicle used, e.g. tax increase, electricity costs, water costs, entrance fees, etc.	Dummy: 1=Increase in taxes; 0=Other payment vehicles
Payment duration	Variable describing the duration of the payment that is presented to participants in the valuation procedure	Dummy: 1=Payment duration is limited (one-off or one year); 0=Unlimited payment duration (infinite)
Sample characteristics		
North and South America	Continent of survey implementation	Dummy: 1=North or South America; 0=Elsewhere
Asia	Continent of survey implementation	Dummy: 1=Asia; 0=Elsewhere
Hydropower share	Share of hydropower in national electricity production	Continuous variable (%)
Users	Describes whether participants in the valuation exercise are direct users of the resource being valued (mainly anglers)	Dummy: 1=Users; 0=Non-users

Variables	Description	Coding of variables
High income	Median disposable household income of all studies in 2013 USD (adjusted for GDP purchasing power parities)	Dummy: 1=Income above the median of all studies; 0=Income below the median
Year of study	Year of survey implementation	Continuous variable (1983-2011)

With respect to the dependent variable, only mean welfare estimates of DCEs, that is, welfare estimates for scenarios entailing combinations of changes in externalities to assess the trade-offs involved, can be compared with the values obtained from CV and TCM studies. Marginal estimates of welfare obtained from DCEs were therefore excluded from the analysis. Mean welfare measures may represent slightly different concepts, depending on whether stated or revealed preference methods are used (Hicksian or Marshallian surplus measures). However, for low income elasticities of demand for the externalities valued (and there is some evidence that income elasticities of demand for environmental goods are below unity: see, for example, Hökby and Söderqvist (2003)), Marshallian and Hicksian measures of surplus are similar, and it is therefore considered reasonable to use both measures in the same analysis.

The effect-size estimates of the various studies also had to be made comparable. For this purpose, all estimates of welfare were expressed in 2013 USD by adjusting for annual consumer price inflation and the GDP purchasing power parities (PPPs) of the countries where the studies were conducted (OECD, 2014). The same procedure was applied to the income variable. An additional important adjustment was to express all the welfare measures on an annual basis to the degree that this was possible. Welfare estimates obtained from publications that defined the payment vehicle as a payment "per trip" were adjusted by the average annual number of trips where possible, and excluded from the analysis otherwise. One observation defined the payment vehicle as an increase in electricity costs per kWh. Since the survey sample of this study is representative of the national population, we transformed this welfare estimate to an annual electricity cost, using the average kWh consumption per household per year in the country where the study was conducted (IEA, 2014a,b). In most of the studies, the duration of the payment was specified as indefinite. However, 24 observations include one-off payments or payments of limited duration (one, five, or ten years). To control for payment duration, a dummy variable which distinguishes between short- and long-term payments was created. Short-term payments are defined as payments with a duration of up to one year. All durations longer than one year are subsumed in the dummy for long-term payments. This approach is supported by experimentally observed discounting strategies, such as hyperbolic discounting, that suggest high mental discounting rates in the short run and low behavioral weight of the future (e.g. Kirby and Herrnstein, 1995).

The size of the change that is valued and the related notion of sensitivity to scope is a key conceptual issue accounted for in our meta-analysis. Sensitivity to scope describes the existence (or lack) of variation in economic values due to changes in the magnitude of an environmental good being valued (Carson, 1997). Sensitivity to scope was identified as one of the crucial criteria for valid and reliable stated preference research by the NOAA Panel (Arrow et al., 1993). Although there is an extensive literature on this issue, the results are somewhat inconclusive, and it is not always evident what an adequate response to scope would be. In general, most of the research concerning the existence and impact of scope effects has taken place in CV studies (see Desvousges, Mathews, and Train (2012) and Ojea and Loureiro (2011) for meta-analyses of the existing literature). This is also because DCEs, in contrast to CV, implicitly test for scope effects. The size of the change variable included in this study distinguishes between small, medium and large changes. Classification of the size of change was done based on the baseline and policy scenarios descriptions provided in the individual studies. This classification is available from the authors upon request.

Special care was taken in the process of selecting variables to ensure that the conceptually most-relevant variables are included in the meta-analysis, and at the same time multicollinearity is avoided. For example, the dummy for the TCM cannot be included in the regression model as it is highly correlated with the dummy for direct users of a resource because TCM assesses only the values of users. The dummy for users, therefore, also captures a large part of the effect of using the TCM. As a consequence, the dummy for DCEs (1 if a DCE is applied, 0 for other valuation methods) can be interpreted as capturing the effect of using DCEs compared with using CV only. Similarly, the dummy variable for recreational amenities excludes fishing, because recreational fishing is highly correlated with the dummy for users, i.e. anglers in most cases. Dummy variables describing the payment unit (household versus individual), type of welfare measure (compensating or equivalent surplus), and cultural heritage values also caused multicollinearity issues (in addition to not turning out to be significant in any model), and were hence not included in the analysis. The same holds for the variable which tests for differences in values for the externalities of existing and planned hydropower facilities.

2.5 Results

2.5.1 Descriptive statistics

Table 2.3 shows the cross-tabulation of the mean economic values across the main explanatory variables considered for the meta-regression models. The last row summarizes the welfare measure for the overall sample. Since a test of the equality of economic values between studies which value externalities of hydropower production exclusively and studies which include other renewable energies as well showed that these two welfare measures do not differ significantly, both categories of studies were included for the descriptive statistics and meta-regressions. Furthermore, no significant differences were found between the values associated with storage plants (27% of all observations), run-of-the-river plants (46%), and observations that do not distinguish between these different types of hydropower plants (27%). The estimates obtained from different hydropower types are therefore pooled in our analysis. It is not meaningful to disentangle the economic values estimated for different categories of externalities, since most of these values represent a combination of attributes.

The results of the Kruskal-Wallis test indicate that the welfare measures differ significantly between continents, as well as between valuation methods. The mean values for different regions show that surveys conducted in North and South America result in a significantly higher PPP adjusted welfare value than in Europe or Asia. They also show that welfare estimates in Asia are generally the lowest. Note, however, that the number of observations in Asia is limited, and the standard error is high. The same applies to the relatively high values found for North and South America. Contrary to expectations, the TCM generates the highest values of the three valuation methods. Here also the results have to be interpreted with caution because of the low number of observations and the relatively high standard errors for TCM. The observed differences in welfare estimates between different survey administration modes, types of welfare measures and size of change categories are not statistically significant.

The variable that captures the sensitivity to scope (i.e. the size of change) indicates that values increase when the size of change shifts from small to medium, but slightly decrease again for shifts from medium to large changes in externalities. This result might suggest insensitivity to scope or at least diminishing marginal utility of individuals when moving from small to medium and then to large impacts of hydropower.

TABLE 2.3: Cross-tabulation of mean values of hydropower externalities across groups of explanatory variables

	Mean value (2013 USD)	**Std. Err.**	**Min. value**	**Max. value**	**N^a**	**Kruskal-Wallis test statistic**	
Continents						χ^2=6.60	p=0.04
North and South America	275.1	401.9	87.7	1841.2	18		
Europe	146.9	164.3	3.9	1033.8	56		
Asia	94.3	166.9	14.8	471.8	7		
Valuation techniques						χ^2=22.24	p=0.00
DCE	152.6	106.6	14.8	487.6	36		
CV	97.6	94.1	3.9	471.8	39		
TCM	732.7	603.7	337.1	1841.2	6		
Survey administration						χ^2=1.87	p=0.39
Face-to-face	131.5	105.8	10.9	471.8	35		
Mail & mail/phone combined	215.3	361.0	3.9	1841.2	32		
Online	167.7	99.7	15.1	370.6	14		
Welfare measures						χ^2=0.93	p=0.34
Compensating surplus	174.2	272.1	3.9	1841.2	61		
Equivalent surplus	160.7	108.0	10.9	471.8	20		
Size of change						χ^2=0.51	p=0.78
Small	124.2	96.5	6.5	252.5	12		
Medium	182.4	202.6	5.8	1033.8	31		
Large	176.2	298.7	3.9	1841.2	38		
Mean economic value	170.9	241.5	3.9	1841.2	81		

Note: ^{a}Number of observations.

2.5.2 Meta-regression results

The dependent variable was adjusted using a Box-Cox power transformation in order to reduce its skewness (Box and Cox, 1964). The Box-Cox transformation estimates a parameter λ from the data that minimizes the skewness of the variable that is to be transformed (x):

$$B(x,\lambda) = \begin{cases} \frac{x^\lambda - 1}{\lambda} \text{ if } \lambda \neq 0 \\ \ln x \text{ if } \lambda = 0. \end{cases} \tag{2.5}$$

By setting a specific value for λ, the Box-Cox transformation can incorporate many traditional transformations such as square, cubic or fourth root, as well as logarithmic transformations (Osborne, 2010). For example, λ=0 would indicate a natural logarithmic transformation to fit the data best. In our case the transformation of the dependent variable resulted in λ=0.17, implying that such a Box-Cox transformation is an even better fit for the data than a logarithmic transformation.

Table 2.4 presents the outcomes of the three models described in Section 2.3.2. All models perform well with an R^2 of 0.77 for the first model and a pseudo-R^2 of 0.358 and 0.409 for Models 2 and 3, respectively. However, the pseudo-R^2 lacks the explanatory power interpretation of the R^2 for Model 1, and is therefore not directly comparable. Nevertheless, the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) show that there is a slight improvement when moving from Model 2 to Model 3.

The coefficients for the types of externalities confirm that the deterioration caused by hydropower production is valued, as expected, highly negative. This is evident from the significant negative coefficients for the deterioration of landscape, vegetation, and wildlife in all three models. The coefficients for aesthetic deterioration are negative in two out of three models but only reach significance in Model 3. Mitigating negative hydropower externalities does not seem to affect economic values substantially. The coefficients for mitigations of landscape and vegetation, as well as for wildlife, are not significant in two out of the three models. Furthermore, the coefficients for the deterioration of landscape, vegetation, and wildlife are much higher in absolute numbers than the estimates for mitigating these effects. Mitigation of aesthetic and recreational effects do not impact economic values significantly either.

The coefficient for reducing greenhouse gas emissions through hydropower is not significant. However, when interacting the dummy for greenhouse gas reduction with the share of hydropower in national electricity production, the coefficient of the interaction term is positive and highly significant. This means that reducing greenhouse gas emissions is valued positively and significantly more in countries with a higher share of hydropower in electricity production. A possible explanation for this result may be that awareness levels with respect to the positive effect of hydropower on greenhouse gas emission are higher in countries with a higher dependence on this renewable energy source.

In order to assess the trade-offs between positive and negative externalities more quantitatively, an alternative version of Model 1 was estimated by applying a logarithmic transformation of the dependent variable. This produces qualitatively similar results as shown in 2.4, but allows for a more straightforward interpretation of the different coefficients. According to this model specification, the deterioration of landscape, vegetation, and wildlife results, ceteris paribus, in a reduction of the estimated economic value by 136%. In contrast, the positive externality of avoiding greenhouse gas emissions in combination with the national hydropower share has a much weaker impact on the estimated non-market values. For each percentage point increase in the national hydropower share, avoiding greenhouse gas emissions results in a roughly 2.3% increase of the economic value. The relative change in the share of hydropower would have to be at least 60 percentage points in order to compensate for the valued negative externalities of hydropower production.

Because the values of the medium and large specification of the scope variable are the same and not significantly different, a dummy variable is included for small changes only. The sign and significance of this variable in Models 2 and 3 provide evidence for economic values being sensitive to scope. The results obtained in this study therefore support the existing evidence on sensitivity to scope in the economic valuation literature (see, among others, Bateman and Brouwer, 2006; Carson, 1997; Carson and Mitchell, 1993; Ojea and Loureiro, 2011; Smith and Osborne, 1996). In contrast to most of the existing literature on scope sensitivity, and especially the comprehensive meta-analysis of Ojea and Loureiro (2011), the sensitivity to scope detected in this study is not restricted to CV and nor does it apply only to changes in a specific environmental good. This was further tested by interacting the scope dummy with the types of externalities and the valuation methods. For the interaction terms that resulted in a sufficient number of positive observations for valid analysis, this did not generate any significant effects, and is therefore not shown here. Although we are able to provide evidence for sensitivity to scope, we could not address the adequacy of scope sensitivity, i.e. whether the magnitude of response to a change in scope is appropriate. This is still a rather unresolved issue in scope sensitivity research (Desvousges, Mathews, and Train, 2012).

The evidence for the impact of methodological variables on economic values is somewhat mixed. A clear result is provided by the coefficient for DCEs, indicating that DCEs result, ceteris paribus, in a higher economic value than CV and TCM. This finding is supported by some of the empirical evidence on the differences between values obtained by DCEs and CV (e.g. Hanley, Wright, and Adamowicz, 1998; Ryan and Watson, 2009). From a discounted utility point of view, assuming that the future has at least an infinitesimal weight, one would expect short-term payment durations to have a positive effect on economic values compared with long-term payments (Samuelson, 1937). However, the dummy for short-term payment durations does not turn out to be significant in any of the models. These results clearly indicate insensitivity to payment duration. A sensitivity analysis shows that this result remains robust when, in addition to payments of up to one year duration, payments that are limited to five and ten years are also defined as short-term payment durations, and only infinite payments are treated as long-term payments. This result may be interpreted in various ways. It might be that individuals have extremely high discount factors, and future costs therefore do not have an impact on their utility, even when these costs occur in the immediate future. However, even considering the high discount rates that are usually observed in economic experiments (for example, Harrison, Lau, and Melonie (2000) report annual discount rates close to 30%), it is still difficult to fully explain the non-significance of this variable. An alternative explanation could be that respondents simply do not consider longer payment durations during the surveys, and therefore show insensitivity to this factor.

In contrast to the findings in Section 2.5.1, the models show that neither Asian nor American respondents attach significantly different values to hydropower externalities than European respondents, once control is included for other influencing factors. The share of hydropower in the countries where studies were carried out does not seem to influence the economic values associated with hydropower externalities in the majority of models, although this variable is significant in Model 3. The dummy for users is positive and highly significant in all regression models, indicating that survey respondents who are direct users of the good that is affected by hydropower operation (mainly anglers who value the benefit of higher water flow of a river) are willing to pay significantly more than other respondents to mitigate the effects on a resource (or to avoid its deterioration). Furthermore, the variable indicating the year when the survey was conducted (set to 0 for the earliest survey in 1983) is significant and positive in the three models, which suggests a significant time trend of increased economic values for the resources affected by hydropower over the years. This may be due to the growing scarcity of environmental goods or an increasing awareness in more recent years about the impacts of hydropower production. The dummy for income levels above the median is only significant in Model 3. This result points to a low income elasticity of demand with respect to hydropower externalities.

Various combinations of random-effects have been tested in the mixed-effect Model 3. However, most of the variances of the random terms did not turn out to be significant. Likelihood-ratio tests indicated that the allocation of these terms to the random-effect part does not improve the model specification in most cases. Hence, the majority of variables are specified as fixed-effect terms. Only the inclusion of the dummy for the mitigation of the negative impacts on wildlife as a random term results in a significant model improvement. The variance of the variable is more than three times as large as its standard error. This suggests that there are significant differences with respect to the slope of the wildlife variable between studies. In other words, there are significant differences of the impact of valuing wildlife on welfare estimates between the studies, although the fixed-effect term of the same variable is not significant.

TABLE 2.4: Meta-analysis regression models

	Model 1: WLS		**Model 2: Random-effects**		**Model 3: Mixed-effects**	
Variables	**Coeff.**	**s.e.**	**Coeff.**	**s.e.**	**Coeff.**	**s.e.**
Constant	0.689	1.137	1.981	1.470	0.304	0.951
Type of externality and size of change valued						
Landscape & Vegetation (mitigation)	1.123	0.821	0.489	0.394	0.832**	0.331
Landscape & Vegetation & Wildlife (deterioration)	-3.057***	0.562	-3.454***	0.359	-3.606***	0.363
Wildlife (mitigation)	-0.273	0.763	-0.038	0.483	0.205	0.749
Greenhouse gas (improvement)	-0.658	1.072	-1.489	0.906	-0.037	0.401
Greenhouse gas (imp.)$*$Hydropower share	0.049**	0.024	0.075***	0.023	0.028***	0.010

	Model 1: WLS		Model 2: Random-effects		Model 3: Mixed-effects	
Variables	**Coeff.**	**s.e.**	**Coeff.**	**s.e.**	**Coeff.**	**s.e.**
Aesthetics (mitigation)	0.257	0.979	1.116	0.984	-0.454	0.391
Aesthetics (deterioration)	-0.282	0.780	1.019	0.853	-0.855**	0.353
Recreation (mitigation)	-0.413	1.122	0.211	0.501	-0.285	0.522
Size of change (small)	-0.788	0.500	-0.761***	0.280	-0.670*	0.365
Methodological variables						
Valuation method (DCE)	3.234***	0.851	3.193***	0.843	3.598***	0.690
Survey mode (face-to-face surveys)	0.886	0.836	0.597	0.722	1.135***	0.422
Payment vehicle (tax increase)	1.709	1.040	1.433	0.957	0.923	1.019
Payment duration (short-term)	-1.315	0.835	-0.936	0.934	-0.203	0.74
Sample characteristics						
North and South America	1.204	0.821	1.064	0.972	0.318	0.623
Asia	-2.393	1.451	-1.418	1.280	-0.880	0.654
Hydropower share	0.010	0.013	0.004	0.013	0.014**	0.007
Users	6.556***	1.364	6.561***	0.957	6.174***	0.885
High income (>median)	0.006	0.593	0.248	0.440	1.009***	0.258
Year of study	0.150***	0.046	0.104**	0.051	0.132***	0.026
Random-effects (group variable: studies)						
$\sigma^2_{\text{wildlife (mitigation)}}$					5.387***	1.736
$\sigma^2_{\text{constant}}$			1.869***	0.634	3.6e-25	
$\sigma^2_{\text{residual}}$			0.635***	0.175	0.500***	0.135
Model characteristics						
Log-likelihood			-124.743		-114.922	
AIC			293.485		273.844	
BIC			346.163		326.522	
R^2 (Pseudo-R^2)	0.770		(0.358)		(0.409)	
Number of observations	81		81		81	

Note: ***p<0.01, **p<0.05, *p<0.1.

2.5.3 Cross-validation

In order to compare Models 1, 2 and 3 and test for over-fitting of the data, a cross-validation procedure was carried out. Cross-validation is a statistical technique similar to bootstrapping and jackknifing but serving a different purpose. The main purpose of cross-validation is to obtain estimators of a model's prediction error, and compare the predictive power of various models (Efron and Gong, 1983). This procedure consists of several steps. First, 80% of the data points are randomly selected (the training set). Each model is then estimated based on the training set. Next, the values for the dependent variable of the remaining 20% of the data (the testing set) are predicted. The predicted values are compared with the actual values, and a standard error of the prediction is calculated. Formally, the prediction error has the following form:

$$\text{Prediction error } = \frac{1}{\sqrt{N}} \sqrt{\sum_{i}^{N} (y_i - \hat{y}_i)^2}, \tag{2.6}$$

where $\hat{y}_i$ denotes the predicted economic values that are compared with the actual values y_i; and N is the number of observations included in the testing set. The procedure described above was repeated 10,000 times for all three models, resulting in a distribution of the prediction errors as depicted in Figure 2.1.

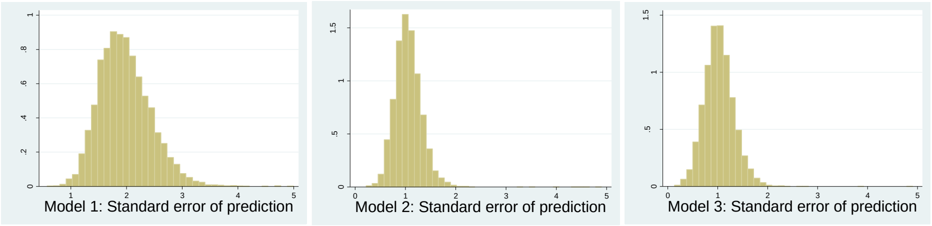

FIGURE 2.1: Histograms of the standard errors of model predictions based on 10,000 iterations

The mean value of the transformed dependent variable equals 7.01. The mean standard error of the prediction of Model 1 is 2.05, which is substantially reduced in Models 2 and 3 to 1.06 and 1.04, respectively. As expected, a panel specification substantially improves the predictive power of the model. Allowing between-study slopes of the wildlife mitigation regressor to vary results in a further reduction of the prediction errors, although the difference with Model 2 is small. The results of this cross-validation procedure provide evidence that Models 2 and 3 perform the best and Model 1 the worst out of the three model specifications.

Further evidence confirming the superiority of Models 2 and 3 is obtained by simulating the expected error when applying the estimated meta-regression model for benefit transfer purposes. This is done by estimating the model based on n-1 observations, and predicting the observation that is left out (e.g. Brander, Brouwer, and Wagtendonk, 2013). Comparing the predicted and the actually observed value, a prediction error can be calculated. This is then averaged across all observations. For the first model, this error amounts to 24%. On average, Model 1 applied to another context would thus result in an error margin of 24%. This error is considerably reduced in Model 2 (13%) and Model 3 (12%). Compared with the benefit transfer errors found in the literature, the simulated values obtained in this analysis are promising (e.g. Brouwer, 2000; Rosenberger and Stanley, 2006). However, the standard errors of this measure of prediction error have similar magnitudes as the prediction errors themselves.

2.6 Conclusions and discussions

This paper has applied meta-analysis, and estimated a meta-regression model in order to identify the factors that explain the variation in welfare estimates for the positive and negative external effects of hydropower production and to test for possible sensitivity to scope. The results revealed that welfare estimates for the external effects of hydropower are dependent on the type of externality assessed, as well as on whether deterioration or mitigation and improvements are valued. There is strong evidence for public aversion towards deteriorations in landscape, vegetation, and wildlife caused by hydropower. On the other hand, mitigation of the effects on these resources do not affect welfare measures significantly in most of the estimated models. The benefits of avoided greenhouse gas emissions are only significant in combination with the national share of hydropower in energy production. Sensitivity to scope is detected across externalities and valuation methods.

The insights provided by this study are of considerable relevance for policies which aim to reduce the negative externalities of existing hydropower facilities, and for the planning processes of prospective hydropower plants. The importance of negative externalities and the lack of significant economic values for mitigating such effects constitute a rather unfavorable result for the future development and expansion of hydropower. This suggests the need for a strong public focus on the negative effects of hydropower, and a very limited willingness-to-pay for avoiding such effects. Hydropower projects in areas where the potential for negative externalities is high (e.g. in conservation areas) are therefore likely to meet with public resistance. Instead, hydropower plants will have to be planned in areas where they have as little impact as possible on the surrounding landscape, vegetation, and wildlife. Claiming public financial resources for mitigating the effects of hydropower on environmental assets is hard to justify, in view of the fact that public willingness-to-pay for offsetting these externalities is so low.

Furthermore, an expansion of hydropower has a higher chance of success when the positive externalities of avoiding greenhouse gas emissions are sufficiently large to compensate for the negative externalities of the energy source. This is more likely to be the case in countries with an already high share of hydropower in electricity production. Presumably, the populations in these countries have a higher level of awareness regarding the expected consequences of hydropower on greenhouse gas emissions. Only in those cases can the positive externality of hydropower production outweigh its negative effects. However, we showed that the relative change of the share of hydropower has to be in the order of at least 60 percentage points to compensate for the negative externalities, and there are not many countries in the world which could achieve such an expansion.

Finally, aesthetic considerations do not seem to play an important role for the successful expansion of hydropower. This is in contrast to the key factors that drive public acceptance of other renewable sources of energy, in particular wind turbines. The visual effects of wind turbines have been identified as the key determinant of the public acceptance of wind power (e.g. Devine-Wright, 2005; Johansson and Laike, 2007; Warren et al., 2005; Wolsink, 2000). Although the literature on the factors which determine the acceptance of solar power is more limited, there is evidence that aesthetic considerations are also important for the case of photovoltaics (e.g. Faiers and Neame, 2006). This depends on whether photovoltaic structures are installed on existing artifacts, in which case they are not perceived as negative from an aesthetic point of view (Helena et al., 2015). Hence, it seems that each renewable energy source may have its own idiosyncratic factors that need to be considered in expansion planning processes, and what may be crucial for the development of one source of electricity may not be relevant for another.

The average values obtained in our analysis seem generally applicable for benefit transfer purposes in cost-benefit analyses involving hydropower projects for a number of reasons. First, we find sensitivity to scope that is not limited to specific externalities or valuation methods. Secondly, the economic values do not differ significantly neither between different types of hydropower plants nor between already existing and hypothetical new facilities. Finally, the prediction and transfer errors of our models are relatively low compared with those reported in the existing benefits transfer literature.

Having said that, the general applicability of the results found in this study may be limited due to other factors that are likely to play a role in the probability of successfully expanding hydropower. Such factors include the topographical characteristics of regions where hydropower projects are planned, and the remaining share of free-flowing rivers in a country. Owing to data limitations, we could not control for either of these variables in our models. Furthermore, the non-representative country selection in our database is an issue to keep in mind. Specifically, developing countries are underrepresented, with China and Chile contributing only two studies and 13 observations to the data set. These two countries are considered as developing economies by the International Monetary Fund (IMF, 2014). Moreover, no low-income countries are included. Nevertheless, we were able to control for continent of study origin which did not have a significant influence in any model specification.

Finally, there are a number of methodological issues that need to be taken into account when interpreting the outcomes of this research. First of all, there is considerable heterogeneity with respect to the effects measured between the observations. Although an extensive number of independent variables were included in order to control for variations between the studies, and the explanatory and predictive power of the models is relatively high, it cannot conclusively be ruled out that there may be other factors that drive the valuation results. Furthermore, the number of observations in the meta-regression is low, which is often the case in meta-analysis research. The trade-off between the conceptual homogeneity of the data studied and the amount of data points available for analysis is a general issue in meta-analysis research. The relative scarcity of studies on the effects of hydropower and their valuation also shows that this is a rather underinvestigated area that calls for further research.

2.A Studies included in the meta-analysis

#	Study
1	Loomis, J., Sorg, C., & Donnelly, D. (1986). "Economic Losses to Recreational Fisheries due to Small-head Hydro-power Development: a Case Study of the Henry's Fork in Idaho". *Journal of Environmental Management* 22 (1), pp. 85–94.
2	Kosz, M. (1996). "Valuing riverside wetlands: the case of the "Donau-Auen" national park". *Ecological Economics* 16, pp. 109–127.
3	Navrud, S. (1995). *Hydro Fuel Cycle. Part II (p.127-249) in European Commission DG XII Science Research and Innovation (1995): ExternE: Externalities of Energy. Volume 6: Wind and Hydro. EUR 16525 EN, European Comission Publishing.* Luxembourg.
	Navrud, S. (2001). "Environmental costs of hydro compared with other energy options". *Hydropower and Dams* 8 (2), pp. 44–48.
4	Biro, Y. E. K. (1998). "Valuation of the Environmental Impacts of the Kayraktepe Dam/Hydroelectric Project, Turkey: An Exercise in Contingent Valuation". *Ambio* 27 (3), pp. 224–229.
5	Loomis, J. (1996). "Measuring the economic benefits of removing dams and restoring the Elwha River: Results of a contingent valuation survey". *Water Resources Research* 32 (2), pp. 441–447.
6	Hansesveen, H., & Helgas, G. (1997). "Environmental Costs of Hydropower Development - Estimering av miljokostnader ved en vannkraftutbygging i Ovre Otta". Norwegian University of Life Sciences, As, Norway.
7	Bergland, O. (1998). *Valuing Aesthetical Values of Weirs in Watercourses with Hydroelectric Plants - Verdsetjing av estetiske verdiar i tilknytning til tersklar i regulerte vassdrag*. Oslo: Norwegian Water Resources and Energy Directorate (NVE).
8	Filippini, M., Buchli, L., & Banfi, S. (2003). "Estimating the benefits of low flow alleviation in rivers: the case of the Ticino River". *Applied Economics* 35, pp. 585–590.
9	Hanley, N., & Nevin, C. (1999). "Appraising renewable energy developments in remote communities: the case of the North Assynt Estate, Scotland". *Energy Policy* 27 (9), pp. 527–547.
10	Loomis, J. (2002). "Quantifying recreation use values from removing dams and restoring free-flowing rivers: A contingent behavior travel cost demand model for the Lower Snake River". *Water Resources Research* 38 (6), pp. 2–1–2–8.
11	Han, S.-Y., Kwak, S.-J., & Yoo, S.-H. (2008). "Valuing environmental impacts of large dam construction in Korea: An application of choice experiments". *Environmental Impact Assessment Review* 28 (4-5), pp. 256–266.
12	Sundqvist, T. (2002). "Power Generation Choice in the Presence of Environmental Externalities". PhD Thesis, Lulea University of Technology, Lulea, Sweden. Retrieved from `https://pure.ltu.se/portal/files/153854/LTU-DT-0226-SE.pdf`
13	Bothe, D. (2003). *Environmental Costs due to the Karahnjukar Hydro Power Project on Iceland*. University of Cologne: Department of Economic and Social Geography, Cologne, Germany.
14	Hynes, S., & Hanley, N. (2006). "Preservation versus development on Irish rivers: whitewater kayaking and hydro-power in Ireland". *Land Use Policy* 23 (2), pp. 170–180.
15	Bergmann, A., Colombo, S., & Hanley, N. (2008). "Rural versus urban preferences for renewable energy developments". *Ecological Economics* 65, pp. 616–625.

#	Study
16	Håkansson, C. (2009). "Costs and benefits of improving wild salmon passage in a regulated river". *Journal of Environmental Planning and Management* 52 (3), pp. 345–363.
17	Navrud, S. (2004). *Environmental Costs of Hydropower, Second Stage - Miljøkostnadsprosjektet Trinn 2*. EBL report 181.
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