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Hydropower externalities: A meta-analysis

Matteo Mattmann [a,b,*], Ivana Logar [a], Roy Brouwer [c,a]

[a] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland
[b] Department of Environmental Economics, Institute of Environmental Studies, VU University Amsterdam, The Netherlands
[c] The Water Institute, Department of Economics, University of Waterloo, Canada

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ABSTRACT

This paper presents a meta-analysis of existing research related to the economic valuation of the external effects of hydropower. A database consisting of 81 observations derived from 29 studies valuing the non-market impacts of hydropower electricity generation is constructed with the main aim to quantify and explain the economic values for positive and negative hydropower externalities. Different meta-regression model specifications are used to test the robustness of significant determinants of non-market values, including different types of hydropower impacts. The explanatory and predictive power of the estimated models is relatively high. Whilst controlling for sample and study characteristics, we find significant evidence for public aversion towards deteriorations of landscape, vegetation and wildlife caused by hydropower projects. There is however only weak evidence of willingness to pay for mitigating these effects. The main positive externality of hydropower generation, the avoidance of greenhouse gas emission, positively influences welfare estimates when combined with the share of hydropower in national energy production. Sensitivity to scope is detected, but not linked to specific externalities or non-market valuation methods.

1. Introduction

Due to 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 in the future worldwide. This is reflected in various national energy policies. Germany and Switzerland, for example, decided to phase-out nuclear energy production and to 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 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 et al., 2007). As a consequence, other types of externalities such as threats to biodiversity or esthetic impacts occur.

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 valuing externalities from wind power generation (Alvarez-Farizo and Hanley, 2002; Ek and Persson, 2014; Ek, 2006; Ladenburg and Dubgaard, 2007), biomass (Susaeta et al., 2011) or from a mixture of various renewable energy sources (Bergmann et al., 2006, 2008; Komarek et al., 2011; Kosenius and Ollikainen, 2013; Ku and Yoo, 2010; Longo et al., 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) understanding individuals' preferences for its effects on the environment, recreational activities and esthetic 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 is therefore usually not considered in valuation studies. The same holds for 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 not only depend 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

* Corresponding author at: Eawag, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland.
E-mail address: matteo.mattmann@eawag.ch (M. Mattmann).

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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 et al., 2012; Hynes and Hanley, 2006), fishing (Filippini et al., 2003; Gogniat, 2011; Håkansson, 2009; Loomis et al., 1986; S. 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 to 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 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 stem as well from either reduced connectivity of aquatic systems or altered flow regimes. Reduced connectivity especially affects 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 et al., 2008; Lienhoop and MacMillan, 2007; Navrud, 2004). Direct, potentially negative, esthetic 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 esthetic degradation as well. It has been shown that free-flowing rivers have higher esthetic value compared to rivers affected by hydropower facilities (Born et al., 1998). Furthermore, pylons connecting remote hydropower plants might affect views and sceneries (Aravena et al., 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. The purpose of this 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 describes the search procedure and selection of studies included in the meta-analysis. Section 3 explains the main econometric issues in meta-modeling and the estimated models. Section 4 presents the factors that influence the economic values of hydropower externalities. The results of the estimated meta-regression models are presented in Section 5 followed by conclusions in Section 6.

2. Study selection and characteristics

The non-market valuation of 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 externalities of hydropower exclusively (roughly 80% of all observations) as well as studies which value 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 published as well as unpublished papers, working papers, conference papers, PhD theses, Master 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 1 provides the list of 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 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 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 was carried out in Europe (70%), followed by South America (13%), the United States (9%) and Asia (9%). With