Environ Dev Sustain (2018) 20:S145–S162
https://doi.org/10.1007/s10668-018-0169-0

Discrete-choice experiments valuing local environmental impacts of renewables: two approaches to a case study in Portugal

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Received: 1 September 2017 / Accepted: 12 May 2018 / Published online: 16 May 2018

Abstract Despite the often mentioned environmental benefits associated with transition from fossil fuels to renewable energy sources, their use for electricity production has non-negligible negative environmental impacts. The most commonly mentioned in surveys concern different types of landscape impacts, impacts on the fauna and flora, and noise. These impacts differ by size and location of plants, and by source of energy, rendering the policy decision complex. In addition, there are other welfare issues to take into consideration, as positive and negative environmental impacts are not evenly distributed among population groups. This paper proposes to compare the welfare impacts of renewable energy sources controlling for the type of renewable as well as the specific environmental impact by source. To this end, two discrete-choice experiments are designed and applied to a national sample of the Portuguese population. In one case, only individual negative impacts of renewables are used, and in another case, the negative impacts interact with a specific source. Results show the robustness of discrete-choice experiments as a method to estimate the welfare change induced by the impacts of renewable energy sources. Overall,

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respondents are willing to pay to reduce the environmental impacts, thus making compensation for local impacts feasible. Moreover, the estimations reveal that respondents are significantly sensitive to the detrimental environmental effects of specific renewable energy sources, being willing to pay more to use these sources of energy relative to others.

Keywords Renewable energy sources · Discrete-choice experiments · Environmental impacts · Public attitudes

1 Introduction

The European Union has set a target of 20% of renewables in the final energy consumption by 2020 with differing country targets (EU 2009). In the EU28, between 2005 and 2015, renewable primary energy production increased 71%, averaging an annual growth rate of 5.5%, comprising around 29% of total primary energy production in 2015 (http://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics). In Portugal, renewable energy sources (RES) accounted for 29.4% of annual electricity production in 2006 and 54.1% one decade later in 2016 (DGEG 2015, 2017). The development of RES power plants has among other causes been motivated by the threat of climate change and the need to reduce CO2 emissions produced namely by the burning of fossil fuels. Other non-environmental externalities often invoked for supporting RES include energy security and the creation of green jobs.

There is clear evidence of the positive effects of RES when used as substitutes for fossil fuel sources for electric production (Borenstein 2012). There are, however, negative welfare impacts of RES. The issue has been raised for example by the IEA/OECD acknowledging that renewables impose environmental burdens that need to be addressed if "renewables are to fulfil their full potential as part of an integrated energy system" (1998, p. 13). Therefore, if there are non-negligible environmental impacts these need to be accounted for in the design of policies promoting RES. Furthermore, the impacts differ by source of energy, location and size of power plant, among other factors. Many of these impacts are experienced locally by communities neighbouring RES facilities (Botelho et al. 2016b), while the benefits of using RES are of a public good nature, which raises equity issues. This issue is seldom acknowledged in the literature.

In this paper, we propose to focus on local environmental impacts from the operation of RES electricity production plants by applying an economic non-market valuation method to attribute an economic value to those impacts. Specifically, we consider several types of impacts of RES and design discrete-choice experiments to elicit the corresponding economic value from a random sample of national residents in mainland Portugal.

We wish to explore whether beneficiaries from the use of RES acknowledge the negative impact of RES on local communities, namely environmental impacts, and to such end, we consider both different renewable sources and different types of environmental impacts. Two types of discrete-choice experiments were developed, namely one specific to each of the three main RES (wind, hydropower and solar photovoltaic), and one to compare globally across energy sources. In both cases, the design controls for the environmental impacts specific to each energy source in addition to common types of environmental effects. This study thus combines two approaches previously used when stated preference methods are applied, namely either focusing on the choice between different RES or focusing on the impacts of a specific renewable. In the case of

Portugal, Botelho et al. have reported on the economic valuation of specific RES such as solar photovoltaic (2016c), hydropower (2015) or forest biomass (2016a), from the perspective of national residents faced with trade-offs as to the specific local environmental impacts. However, the analyses have been made within a RES not across RES, with the exception of Botelho et al. (2016c) that elicit the economic valuation across energy sources but from the perspective of local residents in terms of compensation for actual damages and inconvenience experienced.

Furthermore, other discrete-choice experiments on renewables have either focused just on the choice of source, as are the cases of Borchers et al. (2007) and Cicia et al. (2012). Other studies consider a combination of the source of energy with the location of the power plant (Gracia et al. 2012) or the share of renewables in the energy mix (Yang et al. 2016). In terms of impacts, other DCEs outline several types of impacts (e.g. Kosenius and Ollikainen 2013 include as environmental attribute carbon emissions, and for localized impacts the effects on local jobs and biodiversity; Komarek et al. 2011 explore greenhouse gas emissions and the timeframe for emissions reductions).

To the best of our knowledge, ours is the first study to on the one hand combine both energy-specific approaches and a global multi-RES approach and on the other hand to focus on local environmental impacts.

Discrete-choice experiments technique is a revealed preference method commonly used in Economics to value attributes of goods or services that have no direct market expression (e.g. Johnston et al. 2017). In the case of renewables, each RES can be modelled as consisting of several attributes, i.e. in this study, local environmental impacts, which affect individuals' utilities differently. A feature of the method is that individuals are presented with scenarios where they have to trade off those attributes for monetary gains or losses.

As a consequence, this paper contributes to illustrate the pertinence of stated preference methods, in particular DCE, to the study how the public perceives the trade-offs implied by energy policy choices. There is seemingly contradictory evidence from surveys in that the general public supports RES for electricity production over the alternatives, but is less supportive of concrete power plants. For example, the Eurobarometer (European Commission 2014) finds 90% of European support government policies setting target to further increase renewable usage until 2030. As Wolsink (2007) illustrates for wind power, "public attitudes towards wind power are fundamentally different from attitudes towards wind farms." Some authors have opted to design public opinion surveys taking a different approach than simply gauging support. For example, Batel and Devine-Wright (2015) present acceptance questions to the public placing the infrastructure investment in the vicinity of respondents, while Sütterlin and Siegrist (2017) explicitly describe the burdens imposed by specific RES investments. The methodological option in this paper forces respondents to make trade-offs between specific sources of renewables or environmental impacts in monetary terms. As a consequence, the survey does not elicit abstract and unconditional support but rather explicitly makes respondents consider the costs of renewables. We argue this type of empirical study can thus provide a more realistic portrait of public perceptions of RES by taking into account specific local environmental impacts.

The remainder of the paper is organized as follows. Section 2 reviews the evidence on local environmental impacts of RES. Section 3 briefly presents the methodology applied and the specificities of the present case study. Section 4 presents the main results, and Sect. 5 concludes as well as discusses the main methodological and policy implications from the present study.

2 Local environmental impacts of RES

The IEA/OECD (1998, p. 16) considers the potential environmental burdens of RES as "typically small, site-specific and local in nature and usually involve a loss of amenity (e.g. visual or noise impacts)". When considering the negative externalities from fossil fuel power plants or nuclear plants (Welsch 2016), the negative impacts of RES are indeed small, as the former create both local and global public bads, and the latter essentially local impacts. Nonetheless, the consideration of the local impacts can influence sitting decisions of RES power plants and even compensatory measures to the local populations and can be non-negligible.

In this study, we explore the local environmental impacts of RES from the perspective of beneficiaries of renewables use and compare the economic valuation of specific types of impacts related generically to RES and alternatively to specific RES. A brief overview of the literature on environmental burdens of RES is presented that corresponds to the typology of impacts that is usable in the empirical case study, namely impacts on *landscape* and *heritage*, *fauna and flora*, and *noise*. To limit the scope of the empirical analysis, we focus on *hydropower*, *wind* and *solar photovoltaic*.

The use of hydropower for electricity generation involves the construction and operation of dams whose several impacts have been documented in the literature (e.g. Botelho et al. 2017b; Siciliano et al. 2015; Tilt et al. 2009). Small-scale projects are considered to be have minimal visual impacts (IEA/OECD 1998), but that is not the case of larger scale installations which can involve the flooding of nearby areas and can have different impacts on the *landscape* (e.g. Bergmann et al. 2006; Ponce et al. 2011; Rosenberg et al. 1995; Zhao et al. 2012). Additionally, some projects also impact on built *heritage* such as historical sites (e.g. Costa et al. 2016; Ferreiro et al. 2013; Gunawardena 2010). Furthermore, hydropower also impacts biodiversity, the *fauna and flora* (e.g. Bakken et al. 2012, 2014; Han et al. 2008).

Wind energy for electricity generation is the more widely studied RES in terms of environmental impacts. Wolsink (2007) and Devine-Wright (2005) consider that the impacts on *landscape* are the most relevant factors in explaining opposition to wind farms. Several aspects of landscape alterations are cited when local residents are consulted such as the visibility of the wind farms impacting the scenery, aesthetics impacts or the disturbance from the lights (Bergmann et al. 2006; Firestone et al. 2015; Scherhaufer et al. 2017). Another relevant environmental impact of wind farms concerns *noise* and how it can create annoyance for local populations (e.g. Bakker et al. 2012; Botelho et al. 2017a; Pedersen et al. 2007).

Furthermore, wind farms can have impacts on *fauna/flora* in particular wildlife such as bats or birds (e.g. Wang et al. 2015 for a recent summary of evidence). These negative impacts are often invoked as one justification for the opposition to wind farms (e.g. Enevoldsen and Sovacool 2016; Scherhaufer et al. 2017). As noted by Langer et al. (2016), acceptance of wind energy can be partly explained by perceived side effects.

As for solar photovoltaic energy, the impacts during operations depend on the size of the plant and the location (Tsoutsos et al. 2005). Given relatively high land requirement of photovoltaic farms, one relevant local impact concerns *landscape* and land use (Chiabrando et al. 2009; Lackner and Sachs 2005; Mérida-Rodríguez et al. 2015; Torres-Sibille et al. 2009). Furthermore, these farms can also interfere with biodiversity and the local *fauna and flora* (e.g. Gasparatos et al. 2017; Lovich and Ennen 2011).

Finally, some photovoltaic farms create a *glare* effect that can inconvenience locals (e.g. Chiabrando et al. 2009; Ho 2013; Rose and Wollert 2015).

3 Methodology

3.1 Discrete-choice experiments

To address the economic value of local environmental impacts of three important sources of renewable energy for electricity production, and to elicit respondents' preferences towards the energy sources and its impacts, we resort to economic non-market valuation methods. These methods can be applied when there is no market for the impacts considered although there are welfare impacts. Specifically, we apply a survey-based stated preference method.

While different perspectives and methods can be applied to the problem outlined, we focus on the one hand on the economic value attributed by national residents to the environmental impacts on communities that neighbour RES facilities. Non-market valuation methods can thus be applied to elicit the willingness-to-pay (WTP) of national residents to compensate local communities for the impacts endured. On the other hand, we opt to define the local environmental impacts in terms of commonalities across RES by focusing not on the impacts of specific facilities but on types of impacts. These types of impacts are more generally referred to as attributes of the non-market good or service under valuation.

Therefore, the stated preference method used in this study is the discrete-choice experiment (DCE). DCE was developed based on the theory of preferences by Lancaster (1966), whereby individuals demand attributes of goods rather than the goods in themselves. Therefore, changes in levels of attributes affect consumers' welfare levels. Specifically in a DCE, respondents are presented with a several choice tasks which vary in the level of the attributes. In order to estimate a monetary value of respondents' welfare change by changes in attribute level, a monetary WTP variable or price is included as an attribute (Bateman et al. 2002; Hanley et al. 1998, 2001; Johnston et al. 2017; Pearce et al. 2006).

Some studies have applied the DCE methodology to study public perceptions concerning RES, as reviewed for example in Soon and Ahmad (2015) and Sundt and Rehdanz (2015) for a total of 8 studies. In general, studies consider sources of renewables but seldom consider the specific local environmental impacts. In Portugal, Botelho et al. (2016c) have focused on local environmental impacts of renewables from the perspective of local population in terms of compensation for the damages sustained. Botelho et al. (2017c) compare valuations when it is elicited as a willingness-to-accept measure of compensation to local residents or as a willingness-to-pay by national residents, but only for the case of photovoltaic farms. Using a similar methodology, Botelho et al. (2015) report on the economic valuation of local environmental impacts for the specific case of hydropower and in Botelho et al. (2017c) for forest biomass.

The present study is broader in scope as it complements the valuation of specific RES in terms of local environmental impacts with a multi-RES questionnaire also offering the option concerning the renewable energy. Specifically, DCEs are used to compare the welfare effects of three sources of renewable energy, namely solar photovoltaic, hydropower and wind. The elicitation of respondents' willingness to avoid specific environmental impacts by energy source is performed under two approaches, namely a RES-specific approach and a global approach. Under a RES-specific

Table 1 Attributes and levels by survey version

Attributes (levels)	Wind survey (W)	Hydropower survey (H)	Photovoltaic survey (PhV)	Global survey (G)
Significant effect on landscape (present/absent)	✓	✓	✓	✓
Significant effect on fauna and flora (present/absent)	✓	✓	✓	✓
Significant effect on heritage (present/absent)		✓		✓
Glare effect significantly affecting population (present/absent)			✓	✓
Noise significantly affecting population (present/absent)	✓	✓		✓
Energy source (wind power/hydropower/solar photovoltaic)				✓
Price (4/8/12 Euros)	✓	✓	✓	✓

approach, we design a DCE for each RES (solar photovoltaic, hydropower and wind) and present each DCE to a different group of respondents. In this case, each group is presented with trade-offs between alternative combinations of environmental impacts for a given energy source. Under a global approach, a fourth group of respondents simultaneously reveal their preferences for energy sources and environmental impacts of the RES considered. This paper thus reports results on four different but comparable surveys, identified by W (wind energy), H (hydropower), PhV (solar photovoltaic), and G (global survey, which covers all three energy sources simultaneously). The global survey allows us to interact the energy source with the environmental impacts for a richer model.

In general, the design of a DCE proceeds in the following steps: selection of attributes and levels; construction of the experimental design; and survey design (Champ et al. 2003; Johnston et al. 2017). The selection of attributes in the present paper was based on an extensive literature review, and validated in focus groups. The final design of the surveys was also run through a series of think-aloud sessions described in Botelho et al. (2014). Table 1 presents the attributes selected and the corresponding surveys where they were included.

The choice task presented to each respondent consisted of choosing between two alternative ways of producing electricity using a RES. In the case of surveys W, H and PhV, respondents were asked whether they would prefer form A or B of producing electricity through the use of either W, H or PhV energy, with a different combination of environmental and price attributes. In the global survey, respondents choose also between a form A or B, but in this case the energy source is also an attribute of each alternative (Table 2 provides examples of the choice sets from the RES-specific survey in panel (a), and from the global survey in panel (b).

Each survey is organized in four sections. The first section addresses environmental problems and energy sources in general, namely familiarity with RES and how respondents perceive their importance and impacts. The second section corresponds to the economic valuation exercise. Given the number of attributes considered in each survey, the number of choice questions differs by version: survey W and PhV have six choice set questions; survey H has eight and survey G nine choice set questions. Section three includes a few questions on opinions on RES. The final section collects socio-demographic.

Table 2 Choice sets examples

(a) Choice set example from the surveys focusing exclusively on one RES (in this case wind power). Consider the choice between form A of electricity generation through wind power and form B of electricity generation also through wind power. Tick your preferred option

	Form A	Form B
Significant impact on the landscape	Yes	No
Significant impact on the fauna/flora	Yes	No
It produces noise affecting population	Yes	No
Increase in the monthly electricity bill €	4	8
Your choice	▭	▭

(b) Choice set example from the global survey. Consider the choice between form A and B of electricity generation. Tick your preferred option

	Form A	Form B
Significant impact on the landscape	Yes	Yes
Significant impact on the fauna/flora	No	No
It harms heritage	No	No
It produces noise affecting population	No	No
Source of energy	**Wind power**	**Solar photovoltaic**
Increase in the monthly electricity bill €	4	8
Your choice	▭	▭

3.2 Implementation and sample

Surveys W, H and PhV were administered to a national sample of 250 respondents each, while survey G was administered to a sample of 800 respondents. Surveys were administered through face-to-face interviews to increase information quality during the first half of 2014.[1] The sampling process was by quotas with respect to district of residence, age, sex, and education level and within the quotas, sampling was random. A firm specializing in surveys was hired to administer the questionnaires, using quotas by districts, gender, age and education in mainland Portugal. Respondents were randomly selected from the telephone directory. The empirical study only concerns mainland Portugal.

Table 3 presents summary statistics by survey type. However, given the sampling process, significant differences between samples are not expected *ex-ante*. The average age of respondents is roughly 50 years, and the majority of respondents are married and have at least post-secondary education.

Concerning electricity expenditures, respondents pay on average 65 Euros for the monthly electricity bill (varying between 60 and 79 Euros). This was the vehicle chosen to create a credible payment method for the WTP in the DCE.

To understand respondents' environmental concerns, they were presented with a question regarding the relevance of several environmental problems in Portugal. Most respondents find air pollution, water pollution and waste as the most significant.

[1] The surveys were administered as part of a broader research project on renewables in Portugal (in accordance with the acknowledgement included in this paper).

Table 3 Sample characteristics

Variable	Description	Mean/frequency				Variable	Description	Frequency			
		W	PhV	H	G			W	PhV	H	G
Age	Age of respondent	52 (18)	50 (17)	50 (17)	47 (16)	Familiarity with RES	Wind	98%	96%	100%	99%
Employment situation	Unemployed	11%	18%	14%	11%		Hydropower	96%	99%	98%	93%
	Unpaid family worker	5%	0%	7%	1%		Forest biomass	51%	52%	57%	51%
	Student	7%	7%	9%	4%		Solar Photovoltaic	92%	99%	99%	93%
	Retired	38%	35%	26%	16%		Geothermal	49%	61%	57%	57%
	Self-employed	12%	7%	9%	11%		Wave energy	68%	69%	79%	67%
	Employed	27%	32%	36%	58%	Respondent sees RES power plant		21%	18%	21%	34%
Marital status	Married	73%	67%	73%	59%	If yes	Sees WF	77%	78%	69%	69%
	Divorced	5%	4%	6%	6%	If yes	Sees HP	4%	13%	25%	13%
	Single	14%	22%	17%	32%	If yes	Sees FB	0%	2%	2%	3%
	Widower	8%	8%	4%	3%	If yes	Sees PV	37%	16%	12%	42%

Table 3 (continued)

Variable	Description	Mean/frequency				Variable	Description	Frequency			
		W	PhV	H	G			W	PhV	H	G
Education	Primary school (years 1–4)	23%	19%	18%	7%	If yes	From residence	81%	42%	58%	45%
	Preparatory school (years 5–6)	4%	8%	5%	4%	If yes	From work	38%	22%	77%	13%
	Secondary school (years 7–9)	19%	17%	14%	9%	If yes	During daily commute	38%	56%	40%	60%
	Post-secondary (years 10–12)	28%	29%	26%	31%	Environmental problems	Climate change	39%	42%	44%	48%
	Undergraduate degree	23%	24%	31%	39%		Air pollution	55%	55%	59%	42%
	Master degree	2%	3%	3%	9%		Water pollution	40%	57%	48%	50%
	PhD	1%	0%	*1%*	*1%*		Over-exploit. natural resources	3%	6%	7%	12%
	Other	0%	0%	*1%*	*0%*		Decreased biodiversity	5%	14%	13%	20%
Electricity bill	Monthly electricity bill (in euros)	70 (82)	75 (44)	77 (78)	61 (63)		Waste	45%	65%	41%	44%
							Other	4%	2%	5%	4%

For numeric variables the table presents means and standard deviation in parentheses. For categorical variables, relative frequencies are presented

Specifically in terms of renewables, when asked about their knowledge, the majority of respondents are familiar with wind, hydropower and solar photovoltaic energy sources, which are the object of this paper. However, other renewables, such as forest biomass or geothermal, present lower frequencies. On average, 28% of respondents indicate that a RES facility is observable daily, more frequently from home or during the daily commute. Furthermore, the most frequently stated type of facility is wind farms.

4 Results

Using survey data, we are able to analyse respondents' WTP to prevent certain environmental impacts of RES which are included in the DCE choice sets. Under the DCE structure, each respondent trades off monetarily attributes of RES in terms of local environmental impacts. To estimate WTP, we can restrict to a particular RES using the RES-specific surveys (W, H, and PhV) or address RES in general using the global survey (G), which considers a particular source for each option within a choice set.

To investigate both preferences for environmental impacts and for energy sources, two sets of models are estimated. Using data from the G survey, we estimate respondents' preferences for RES and their impacts, and test whether the impacts are valued differently by source (Table 4); Using surveys W, PhV and H, WTP is estimated and compared to the results from survey G (Table 5).

The analysis of DCE choices is based on Random Utility theory which assumes that the individuals faced with a choice within a set of mutually exclusive alternatives will choose the one that maximizes its utility. The utility function is composed of an observed component x (vector of explanatory variables that are observed by the researcher) and a stochastic component, ε. Let U1 and U2 represent an individual's utility of two alternative choices, namely alternative 1 and 2: $U1=\beta 1'x+\varepsilon 1$ and $U2=\beta 2'x+\varepsilon 2$, respectively. Alternative 1 will be selected if $U1>U2$. Assuming that random components of the utility are independent and identically distributed (iid) extreme value type 1, the binary logit model follows, based on the logistic distribution. Allowing a more flexible distribution of the random terms specified by the researcher, the random parameters logit (RPL) model (e.g. Hensher and Greene 2003; McFadden and Train 2000; Revelt and Train 1998) captures sources of unobserved heterogeneity and takes into account the panel data nature of the DCE in which several observations per respondent are gathered which cannot be assumed to be independent. In this model, the individual specific parameter vector, β_n, is defined by $\beta_n = \beta + \sigma v_n$, where β is the population mean and v_n represents the individual specific heterogeneity, σ is the standard deviation of the distribution of β_n around β (Greene 2012).

In the present application, the choice between the two generic alternatives of energy production by respondent n in choice set t is analysed through the specification of a RPL model. Assuming a linear additive utility function, the utility that respondent n derives from the choice of the form i (of production of electricity) in choice set t is written as:

$$U_{nit} = \beta_n' X_{nit} + \alpha P_{nit} + \varepsilon_{nit},\ i = 1,2 \tag{1}$$

where X_{nit} = attributes of the alternatives (impacts on landscape, impacts on fauna/flora, impacts on heritage, noise, glare, and alternative energy sources), P_{nit} = Price attribute (Increase in the monthly electricity bill)

$$\beta_n' = (b' + s'\eta_n)$$

Table 4 Random parameter logit—global survey

		Model 1			Model 2		Model 3		Model 4	
		Coeff.	SE	WTP	Coeff.	SE	Coeff.	SE	Coeff.	SE
Random parameters										
Landscape	Mean	−0.08**	0.037	0.42**	−0.52	0.34	−0.25**	0.1	−0.52***	0.09
	SD	0.46***	0.06		0.47***	0.06	0.47***	0.06	0.47***	0.06
Fauna/flora	Mean	−1.4***	0.06	7.5***	−1.5***	0.1	−1.5***	0.35	−1.5***	0.06
	SD	1***	0.06		1***	0.06	1***	0.06	1***	0.06
Noise	Mean	−0.27***	0.04	1.4***	0.28**	0.12	−0.5***	0.08	−1.8***	0.33
	SD	0.29***	0.11		0.27**	0.11	0.27**	0.1	0.27**	0.1
Heritage	Mean	−0.39***	0.05	2.05***	−0.5***	0.06	−0.5***	0.06	−0.5***	0.06
	SD	0.018	0.1		0.01	0.09	0.01	0.09	0.01	0.09
D1 (hydropower = 1)	Mean	−0.3***	0.05	1.6***	−0.7***	0.23	−0.7***	0.25	−0.7***	0.1
	SD	0.03	0.1		0.03	0.09	0.026	0.099	0.03	0.09
D2 (wind power = 1)	Mean	0.11*	0.07	0.6*	−1.39***	0.33	0.7***	0.25	0.7***	0.14
	SD	0.02	0.15		0.03	0.18	0.03	0.18	0.03	0.18
Fixed parameters										
Price	Mean	−0.19***	0.007		−0.18***	0.008	−0.12***	0.02	−0.18***	0.007
Interactions										
Landscape * hydropower					0.004	0.43				
Landscape * wind power					2.1***	0.52				
Fauna/flora * hydropower							0.78	0.5		
Fauna/flora * wind power							−1.3***	0.4		
Noise*Hydropower									2.08***	0.44
LL_{Model} −3594.7					−3583.6		−3583.6		−3583.6	
Pseudo R^2 0.2796					0.28		0.28		0.28	
BIC/*N* 1.015					1.014		1.014		1.013	

Table 4 (continued)

	Model 1			Model 2		Model 3		Model 4	
	Coeff.	SE	WTP	Coeff.	SE	Coeff.	SE	Coeff.	SE
Chi-squared 2790.46 [13 *df*] $p=0.00000$				2812.8 [15 *df*] $p=0.00000$		2812.8 [15 *df*] $p=0.00000$		2812.8 [14 *df*] $p=0.00000$	

***, ** and *, respectively, represent that the significant is under the level of 1, 5 and 10%

Table 5 Random parameter logit—energy specific surveys

		Model 5 wind			Model 6 photovoltaic			Model 7 hydropower		
		Coeff.	SE	WTP	Coeff.	SE	WTP	Coeff.	SE	WTP
Random parameters										
Landscape	Mean	−0.31***	0.07	1.95***	−1.1***	0.1	4.2***	−0.32***	0.06	4.8***
	SD	0.02	0.18		0.56***	0.16		0.19	0.2	
Fauna/flora	Mean	−0.75***	0.09	4.73***	−1.29***	0.1	4.9***	−0.78***	0.09	11.7***
	SD	0.69***	0.12		0.7***	0.14		1***	0.09	
Noise	Mean	−0.78***	0.09	4.9***				−0.59***	0.07	8.8***
	SD	0.7***	0.12					0.02	0.15	
Glare	Mean				−0.67***	0.08	2.5***			
	SD				0.008	0.08				
Heritage	Mean							−0.19***	0.05	2.8***
	SD							0.003	0.08	
Fixed										
Price	Mean	−0.16***	0.01		−0.26***	0.05		−0.07***	0.011	
LL0	−1039				−1039.7			−1386.3		
LL_{Model}	−882.6				−701.2			−1182.8		
Pseudo R^2	0.15				0.33			0.15		
BIC/*N*	1.155				0.97			1.163		
Chi-squared	312.9[7 *df*] $p=0.00000$				677[7 *df*] $p=0.00000$			407[9 *df*] $p=0.00000$		
N (*n*)	1500 (250)				1500 (250)			2000 (250)		

***, ** and *, respectively, represent that the significant is under the level of 1, 5 and 10%

b' = population mean; $s'\eta_n$ = independent random deviates representing the deviation from the mean; η = randomness in the coefficients, assumed to be random and normally distributed,[2] implying that $\beta \sim N(b, s^2)$.

Tables 4 and 5 report the estimation results of the RPL model (NLOGIT® Econometric Software, Inc., version 5.0) with simulated maximum likelihood using Halton draws with 250 replications.

Using data from the global survey, we estimate the effects of both the environment impacts and of the type of RES. Table 4 reports the estimation results. Four models are estimated for robustness, namely Model 1 which considers the impact of each attribute and RES in isolation; Models 2 through 4 allow environmental impacts to differ depending on RES, by introducing interaction terms. Model 2 considers the hypothesis that effects on landscape vary by energy source; Model 3 considers the effects on fauna and flora and Model 4 considers the effects of noise. In addition to the coefficients, Table 4 reports willingness to pay estimates to avoid the environmental impacts and to have one particular source of energy relative to other source (solar photovoltaic).

As reported in Table 4, the means of the random parameters are statistically significant at explaining the choice of a specific form of producing electricity through RES. The non-random parameter, Price, is also statistically significant and negative, indicating the disutility of choosing alternatives with higher prices. Models 2–4 estimates reveal that respondents perceive differently the impacts on landscape, fauna/flora, and noise differently depending on the energy source considered, as most coefficients of the interaction terms are statistically significant. In some cases, the direction of the effect is different as is the case of wind power, which has a positive coefficient in Model 1, when it is included as a dummy variable. In Model 2, the impacts of wind power on respondents' utility are different across impacts, being less detrimental in the case of impacts on landscape, then in relation to other type of impacts. This is corroborated in Model 3 where a dummy variable captures the interaction between wind power and impacts on fauna/flora, and in this case, the effect on fauna/flora is distinct from the impact of other effects.

These results are consistent with willingness to pay estimates. Respondents are, on average, willing to pay 1.6 Euros to have electricity produced with hydropower relative to photovoltaic, and 0.6 to have wind generated electricity relative to photovoltaic; thus, most preferred source is hydro, followed by wind and lastly photovoltaic. Regarding their sensitivity to the environmental impacts of, fauna/flora is the most valued impact, followed by heritage.

Regarding the effects of environmental attributes on the welfare space by source, Table 5 reports estimated WTP considering attributes that are RES-specific, as is the case of the inconvenience caused by the glare effect for solar photovoltaic, heritage impacts for hydropower, noise production for wind and hydropower.

Table 5 presents the comparison between respondents' willingness to pay to avoid environmental effects of wind, hydro and photovoltaic energy for electricity production. Comparing respondents' WTP to avoid effects on landscape and on fauna/flora across sources, results show that these effects are most significant in the case of hydropower; noise is also most significant for hydropower, compared with wind power.

[2] As the direction of the preferences is not clear (the parameters may have positive or negative values), the impact attributes are specified as normally distributed. As a conventional procedure, the price attribute will be specified as a fixed or non-random parameter.

It is thus clear that the use of RES for electricity production implies statistically significant welfare losses from the point of view of national residents. Furthermore, those losses are energy-source-specific, independently of considering a context of choice of impacts and energy source (as translated into the global survey DCE), or just environmental impacts conditioned on source of energy (as in the case of each energy-specific DCE). Finally, respondents not only express preferences over the source of energy, but also over the pair (impact, energy source). This result highlights the relevance that social factors should play upon deciding the construction and the specification of electricity generation plants. The source, the location, and the size of the plant are, as shown, relevant in welfare space.

5 Conclusions and discussion

It is undeniable that RES can play an important role in contributing to a more sustainable lifestyle in the future in terms of energy production. The lower environmental impacts of using renewable energy sources relative to fossil fuels make them a preferred choice by policy makers and the public in general. However, the operation of RES power plants also generates negative environmental impacts albeit local in their scope. A full consideration of costs and benefits of RES clearly favours them over fossil fuels, but should not neglect the local impacts. For example, as argued by Gasparatos et al. (2017, p. 175), "nonlinear effects can emerge during scaling up and that seemingly low impacts could become considerable when renewable energy technologies are deployed at a scale commensurate to achieve a transition towards a Green Economy".

In particular, the benefits of RES are of a global public good nature, so it is pertinent to ask if the beneficiaries of using RES are willing to compensate those directly affected. We approach this issue in the empirical study by exploring whether national residents are willing to pay to compensate for certain specific negative local environmental impacts.

We argue this type of empirical study can provide a more realistic portrait of public perceptions of RES. The methodological option in this paper forces respondents to make trade-offs between specific sources of renewables or environmental impacts in monetary terms. As a consequence, the survey does not elicit abstract and unconditional support but rather explicitly makes respondents consider the costs of renewables. Some authors have opted to design public opinion surveys taking a different approach than simply gauging support. For example, Batel and Devine-Wright (2015) present acceptance questions to the public placing the infrastructure investment in the vicinity of respondents, while Sütterlin and Siegrist (2017) explicitly describe the burdens imposed by specific RES investments.

The estimations reveal that respondents' are significantly sensitive to the detrimental environmental effects of renewable energy sources, being willing to pay more to use some sources than others. In addition, respondents are willing to pay to reduce their environmental impacts. Results illustrate the robustness of discrete-choice experiments as a method to estimate the welfare changes induced by the impacts of RES electricity production. DCE thus allows decision-makers to gauge whether and how beneficiaries from RES value impacts on local communities.

For policy purposes, the results show that in choosing size, location and type of energy sources, decision-makers should not ignore that there are welfare effects of each particular renewable source. Moreover, in deciding the mix of energy sources, citizens' preferences for the source of energy can be taken into consideration as these clearly differ. Furthermore, stated preference studies such as the present study can be designed to estimate an equity-enhancing compensation from the beneficiaries of RES to the affected local residents.

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