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Anabela Botelho
Lina Lourenço-Gomes
Lígia Pinto
Sara Sousa
Marieta Valente

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Botelho, Anabela [a], Lourenço-Gomes, Lina [b], Pinto, Lígia [c], Sousa, Sara [d], Valente, Marieta [e]

[a] *DEGEIT and GOVCOPP, University of Aveiro, 3810-193 Aveiro, Portugal, anabela.botelho@ua.pt*

[b] *CETRAD and DESG, University of Trás-os-Montes and Alto Douro, 5000-801 Vila Real, Portugal, lsofia@utad.pt*

[c] *EEG and NIMA, University of Minho, 4710-057 Braga, Portugal, pintol@eeg.uminho.pt,*

[d] *ISCAC, Polytechnic Institute of Coimbra, 3040-316 Coimbra, Portugal, ssousa@iscac.pt*

[e] *EEG and NIMA, University of Minho, 4710-057 Braga, Portugal, mvalente@eeg.uminho.pt [corresponding author]*

Abstract

Renewable energy sources for electricity generation are unequivocally more environmentally friendly than the traditional sources, but are not impact-free. Given the potential for solar photovoltaic energy to contribute to the energy mix in some countries, it is timely to carefully consider the potential environmental costs of operation of photovoltaic farms, which are experienced by the local population, while the general benefits accrue to all. These adverse impacts should be identified and acknowledged. This paper proposes and applies economic valuation methods to estimate the value of those environmental impacts. We apply the contingent valuation method to a sample of local residents close to three selected photovoltaic farms in Portugal. We design a discrete choice experiment to elicit the valuation of specific adverse impacts of electricity generation through photovoltaic energy by national residents. Our results show that the value elicited in the vicinity of the photovoltaic farms is non-negligible and national residents value positively and differently the different adverse local impacts. Both of these estimates, in conjunction or independently, can be used to fully account for this often neglected cost of solar energy. The asymmetric equity implications of photovoltaic projects should not be neglected when deciding their construction and location.

Keywords: Photovoltaic Farms; Stated Preference Methods; Contingent Valuation; Discrete Choice Experiments; Environmental Impacts.

1. Introduction

Renewable energy sources (RES) present undeniable advantages over other energy sources ranging from national energy security to reduced environmental impacts in terms of air pollution, including greenhouse gas emissions. Notwithstanding the many advantages of RES, they are not entirely "environmentally benign" in that they also damage the environment and impact individuals negatively (OECD/ IEA, 1998). This occurs specifically as a consequence of the operation of the power facilities and the damages are mostly experienced locally. As a consequence, the benefits of RES are shared by the population in general, but the negative impacts are mostly experienced by communities neighbouring the RES facilities. In this case study we focus on solar photovoltaic farms (henceforth PVFs) and how the impact of their operation is monetarily valued by the two groups of stakeholders to firstly establish how stated preference methods in economic valuation can be applied to enrich benefit-cost analysis concerning future developments, and secondly to check whether a compensation is feasible from the beneficiaries to the affected.

PVFs have been increasingly used to produce electricity in the last years with decreasing fixed and variable costs (Baker *et al.*, 2013). Being "one of the most promising emerging technologies", the International Energy Agency predicts that the share of photovoltaic (PV) energy will account for 16% of the global electricity production by 2050 (IEA, 2015). In general, solar energy has the potential to reduce greenhouse gas emissions and help in the transition towards a green model of growth less dependent on fossil fuels and more sustainable (OECD, 2012). As such, not only do PV developments allow countries to comply with national goals for international agreements, and increase national energy independence, but also contribute towards local economic development.

While contributing to local economic development, it is also a fact that the operation of PVFs causes local negative impacts. When making a decision about a new energy project, all benefits and costs need to be accounted for, so that an efficient decision from an economic perspective is made and economic welfare maximized. As a consequence, in the particular case of PV energy, the costs imposed by the daily operation of the farms on the local population need to be accounted for. Furthermore, given that the stakeholders who benefit and those who incur the above mentioned costs are not the same, equity considerations also call for including and measuring the impacts on the local population.

We propose that stated preference methods can be used to assign a monetary value to the local impacts, so that they can be included in the decision-making process concerning aspects such as the location and size of the farm, as well as ultimately the efficiency of its development and operation. Specifically we first apply the contingent valuation method (CVM) to local residents of specific PVFs in Portugal, so as to value economically the impact of the operation of their neighbouring farm. We then use the discrete choice experiments (DCE) method on a random sample of the national population to elicit the value of specific impacts of PVFs. The application of these techniques to different groups of stakeholders highlights how they can be used to inform the decision-making process. In particular, this study illustrates how the two techniques can be used either autonomously or complementarily, given that they are used to economically value local impacts of PVFs, which do not have a market value, but from two different perspectives.

This study also highlights that the impacts on local residents are non-negligible and that PV energy, as well as other RES, is not entirely "environmentally benign" (Botelho *et al.*, 2016). There is however potential for compensation *ex-post*, minimizing social equity issues. Alternatively, at least all costs should be accounted for during the *ex-ante* project evaluation, and to that end having monetary estimates of the local damage is desirable, either in terms of use values by local residents or in terms of total economic value by all national beneficiaries.

The paper is organized as follows. Section 2 reviews the evidence on local negative impacts of PVFs. Section 3 describes the methodology by discussing the two valuation methods used. Section 4 presents the results from the two valuation case studies as well as a comparison of results. Section 5 draws the main conclusions.

2. Local Negative impacts of PVFs

Notwithstanding the many benefits of using solar power in general and PVFs in particular, there are different types of non-negligible environmental burdens. The IEA/ OECD (1998) consider that potential burdens are mostly small, with the exception of visual intrusion of large-scale projects. The OECD/IEA (1998) mostly identifies life-cycle emissions as the main environmental impact caused by RES, namely in what concerns the development, production, and decommissioning processes, rather than the daily operation of PVFs. Dubey *et al.* (2013) also highlight potential consequences for workers, as well as the environment, during the life cycle of the technology. There are however technological developments that potentially reduce the impact for instance at the recycling stage (Fthenakis, 2000).

Several studies concerning the operation of PVFs have identified environmental burdens, most of them inconveniencing neighbouring populations. These depend on the size of the plant and are location-specific (Tsoutsos *et al.*, 2005).

There are important impacts in terms of land use (Lackner & Sachs, 2005, Chiabrando *et al.*, 2009). Large areas may be required to accommodate PVF projects, which as noted by Chiabrando *et al.* (2009) explains recommendations to utilize photovoltaic energy on roofs before developing large-scale PVFs. On the other hand, PVFs may displace food crops and replace cultivable land (Tsoutsos *et al.*, 2005) which contributes to the ongoing "food vs. fuel" controversy (Srinivasan, 2009). Chiabrando *et al.* (2009, p. 2445) identify a potential for fragmentation of the countryside in that "the PV system may deplete the unitary characteristic of a specific countryside" with negative impacts on nature conservation and biodiversity.

Torres-Sibille *et al.* (2009) explore the visual impact on the landscape of often rural areas both objectively through expert assessments and subjectively through public perceptions, focusing on the impacts due to the visibility of the plant in relation to the total landscape area, colour, fractality (i.e., the contrast in shapes relative to the surrounding environment) and concurrent use of different types of panels in one plant.

Thermal pollution is as a potential effect from the impact on the thermal balance of the surrounding area (Gunerhan *et al.*, 2008), as well as impact on the climate of the site (Chiabrando *et al.*, 2009; Neff, 1981). Issues about the impact on fauna and flora have also been raised (e.g. Chiabrando *et al.*, 2009), as well as potential discharge of pollutants (Gunerhan *et al.*, 2008), although abnormal but still risky for locals and workers (Tsoutsos *et al.*, 2005).

Several authors have studied the negative impacts of the glare effect due to reflection of sunlight (Chiabrando *et al.*, 2009; Ho, 2013; Rose & Wollert, 2015) and this is potentially a major source of inconvenience given that it can directly affect the wellbeing of local residents on a daily basis, rather than indirectly as with the other impacts identified above.

3. Methodology

3.1. Overview of both studies

Nonmarket valuation techniques are used when the market cannot provide decision-makers with price information about goods or services (Carson, 2000). In what concerns the environment, it is often the case that environmental goods and services are either public or common goods and do not have a market expression. This is the case of eliciting welfare changes caused by the operation of PVFs, since these impacts are not "traded" in markets.

Furthermore, when undertaking benefit-cost analysis about renewable energies, information about all costs imposed by the development and operation of energy plants is required. As argued above, the impacts of specific RES on specific locations and the local communities should not be forgotten when all costs and benefits are computed. Thus a monetary valuation of those impacts needs to be provided so that these local impacts are considered in equal (i.e. monetary) terms as other costs or benefits. This calls for an economic valuation exercise to be undertaken, and this is where nonmarket valuation techniques can help (e.g. Atkinson & Mourato, 2008; Menegaki, 2008).

Total economic value of an environmental good or service comprises both use and non-use values (Pearce & Turner, 1990). Use value includes the direct, indirect and option values. In the case of valuing local impacts of PVFs by eliciting from the local population their willingness to accept (WTA) to endure a welfare loss, it is use values that are being elicited. As for non-use values these concern essentially existence value, whereby the individual for whom these are elicited has no prospect of directly or indirectly benefiting from the good or service in question. When eliciting the willingness of national respondents to compensate local residents for local impacts, what is being analysed is the willingness to pay (WTP) of non-use values.

In this study we apply two nonmarket valuation techniques, namely two stated preference techniques that will complementarily value local and global impacts from the perspective of local residents or national residents. The contingent valuation method (CVM) will be used to survey the former and a discrete choice experiment (DCE) will be applied to the welfare impacts from the perspective of the general population. Either measure of economic value can be used if the objective is to come up with a monetary estimate. It should however be acknowledged that, as in the case of the present study, these measures correspond to different value components. In our study, we are not interested in providing a definitive valuation for compensation purposes, but rather in assessing first if the value of local impacts is non-negligible, and second how the two measures compare, so as to assess the viability of a welfare-enhancing transfer between stakeholders.

Both methods are discussed next.

3.2. CVM and the local population questionnaires

The CVM consists of applying a questionnaire where a hypothetical market scenario is described (Bateman *et al.*, 2002). A panel of experts provided guidelines for application, legitimizing the CVM, in that it can even "produce estimates reliable enough to be the starting point of a judicial process of damage assessment" (Arrow *et al.*, 1993, p. 4610)[1].

We designed a contingent valuation scenario to estimate the WTA of the local population for the negative impacts caused by the PVF's operation nearby. The questionnaire had the conventional four parts (Whitehead, 2006) with firstly questions about RES in general and secondly questions about on the production of electricity through PVFs, including the valuation question. The third part included questions about perceptions about energy sources, including non-renewables and the final part gathered information about respondents' socio-economic characteristics (e.g., gender, education, family, income). The questionnaire was iteratively reviewed using pilot studies (Botelho *et al*., 2014).

The valuation question was formulated as an open question and the payment vehicle identified in the question was the monthly electricity bill. Three specific locations and PVFs were selected to administer the questionnaires in Portugal, located in the region of Alentejo, which is the region that accounts for about one third of the installed capacity of solar photovoltaic power in Portugal in 2015 (DGEG, 2016). Furthermore, the region of Alentejo is one of the regions in Europe with the highest photovoltaic solar electricity potential (European Union, 2012). In terms of occupied area, the PVF in *Amareleja* (Location A) is the biggest (250 ha), followed by *Ferreira do Alentejo* (Location B with a total of 94 ha, which correspond to three smaller PVFs with 58 ha, 31 ha and 5 ha) and *Hércules* (Location C with 60 ha).

The valuation question used was:

> Taking into account your income and your usual expenses, answer the following question: What is the minimum amount that you would be willing to receive as compensation for the inconvenience that the presence of the photovoltaic farm causes you? The amount would be credited to your monthly electricity bill.

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[1] The interested reader is referred to Champ *et al.* (2003) for more detailed information about stated preference methods.

You would be willing to receive _____________ Euros per month.

3.3. DCE and the national population questionnaires

DCE is a survey-based non-market valuation method that, rather than using a hypothetical scenario which is marginally altered, identifies the value of a non-market good or service as the value of its underlying attributes. This empirical method is based on the economic theory of Lancaster (1966) whereby goods or services are not valuable in themselves but because of their composing characteristics or attributes. To elicit the welfare changes experienced by the general population due to PVFs, we apply DCE and identify the main attributes involved in the impacts of PVFs. We design a series of sets of alternatives involving different levels of attributes and a corresponding cost. In each choice set, respondents choose the preferred combination of attributes and monetary cost, and we can thus identify how attribute levels are traded off against different costs, and infer the value of each attribute (Hanley *et al*., 1998; Hanley *et al*., 2001; Pearce *et al*., 2006). Champ *et al.* (2003) provide as more detailed information in terms of empirical application and estimation for the interested reader.

In our study we identified through focus groups and pilot studies three main attributes pertinent to PVFs namely an impact on the landscape, and impact on the local fauna and flora and a glare effect impact on the population. These attributes were traded off against a monetary cost. Similarly to the CVM questionnaire, we opted for a payment vehicle through the monthly electricity bill.

The DCE questionnaires consisted of four parts, namely the first addressed questions about renewable energy sources. The second part included the DCE with six choice sets, with a choice set described as the example in Table 1 with two alternative ways of producing electricity using PV energy and a corresponding cost. The third part assessed respondents' preferences and attitudes towards energy sources and the fourth part included generic background questions. The questionnaire design resulted from an interactive test and review process using pilot studies.

Table 1: Choice Set Example

Consider the choice between form A of electricity generation through photovoltaic energy and form B of electricity generation also through photovoltaic energy. Tick your preferred option:

	Form A	Form B
Significant impact on the landscape	Yes	Yes
Significant impact on the Fauna/Flora	No	Yes
Produces glare affecting population	Yes	No
Increase in the monthly bill €	12	8
Your choice	☐	☐

4. Results

4.1. Local Residents

4.1.1. Sample description

In terms of implementation, the administration of the local residents' questionnaire took place in May 2014 with a total of 61 questionnaires collected (22 in location A: Amareleja, 15 in location B: Hércules, and 24 in location C: Ferreira do Alentejo)[2].

In the sample there are 27 women and 34 men. The average age is 53 years old (standard deviation 17.7) with a minimum of 21 years and maximum of 87, and with 31.2% of individuals in retirement. In terms of qualifications, 26.7% of respondents had only primary school level, 20% held a bachelor or undergraduate degree, and the remaining respondents completed intermediate levels of education.

In terms of involvement with the local PVF, 36.1% reported they either worked in the PVF (4.9%) and/ or had family and acquaintances working there (36.1%).

Concerning the environmental and energy questions, 82% of respondents acknowledged that fossil fuel energy caused environmental problems. Also, they were asked whether they believed that RES in general were beneficial for the population and 85.2% agreed.

[2] **The questionnaires administration was part of a broader research project concerning RES in Portugal as per the acknowledgment at the end of the paper.**

In terms of electricity consumption, the average monthly bill was €78 considering the 58 respondents who supplied this information (with a minimum of €15 and a maximum of €300). It should be noted that these values were in most cases verified by the interviewers. Also, about half of respondents consider that it is (very) important to know the type of renewable energy that is included in electricity production.

4.1.2. WTA analysis and estimation

In terms of the elicited WTA, the values range from 0 to €300 with an overall average value of €29.20. Considering only positive WTA, the average is €45.68 for the 39 respondents. Relative to the monthly household electricity bill these WTA values range from 0% to 400% (all responses are below the totality of the electricity bill, except for six responses which correspond to 100% for four individuals, 111% and 400% for the other two respondents).

We apply regression analysis to the distribution of WTA and use several variables to explain the WTA. We propose that the decision process concerning the WTA takes place in two stages. In the first stage respondents are faced with the hypothetical valuation scenario and decide whether or not they are entitled to compensation. Once they decide they should be compensated, then in the second stage, they determine how much. In our valuation questions, only nonnegative integer values are admissible. It is common in valuation exercises such as this, for many individuals to answer zero, and this high frequency of zeros needs to be accounted for. In this study there are indeed 21 zero responses. As such, we propose that a two-part model is fitted to the data to take these features into consideration. Furthermore, the zero-inflated negative binomial allows for the two stages to be modelled separately (Cameron and Trivedi 2009).

We hypothesize that the WTA is site-specific given that different PVFs impose different types of costs to the local population. As such we include dummies for the two locations, and use *Location A (Amareleja)* as the omitted category. Given that this is also the largest plant of the three, it is likely the local residents are more inconvenienced in this location than in the other locations, thus generating both a higher probability of stating a non-zero WTA and a higher WTA conditional on asking for compensation.

The first stage model considers that the entitlement to compensation and we include several factor which may increase or decrease the probability of feeling entitled. On the one hand, the perception of nuisance from the glare effect is likely to impact the probability positively, given that this is the local effect that directly affects the population wellbeing. This nuisance corresponds to a dichotomous variable to capture whether or not the individual is annoyed by the glare effect or not (*Glare effect nuisance*).

On the other hand, if RES or the PVF are perceived as positive, individuals are less likely to feel compensation is required. As such we include a dummy for whether individuals consider that RES benefit the population (*RES benefit population*) and a dummy to capture whether the respondent or family/acquaintances work at the PVF (*Self-interest*). We hypothesize that an individual involved economically directly or indirectly with the PVF is less likely to state a positive WTA.

In the second stage, we model the WTA conditional on being positive on an ordinal variable capturing the degree of nuisance from the glare effect (*Glare effect nuisance level*) and hypothesize that all things being equal, the more the stated experienced nuisance the higher the required compensation.

For the regressions in both stages, we control for gender, age, whether the respondent is retired (*retired*) and per capita household income (*income pc*). Table 2 presents the results from the zero-inflated negative binomial model.

Table 2: Zero-inflated negative binomial model

VARIABLES	(1) WTA (yes/no)	(2) WTA
Glare effect nuisance (yes/no)	-1.284	
	(0.975)	
RES benefit population (yes/no)	-0.249	
	(1.654)	
Self-interest (yes/no)	0.579	
	(1.032)	
Glare effect nuisance level (--1 to 5++)		0.372***
		(0.115)
Location B (Hercules)	-20.79***	-0.898***
	(1.837)	(0.298)
Location C (Ferreira)	2.843***	-0.607**
	(1.050)	(0.307)
Retired	-3.742***	0.909**
	(1.441)	(0.459)
Gender (1 female/ 0 male)	-0.446	-0.00447
	(0.917)	(0.284)
Age	0.0477	-0.0365***
	(0.0370)	(0.0103)
Income pc	0.00236*	-0.000750
	(0.00138)	(0.000483)
Constant	-3.912	5.430***

	(2.842)	(0.569)
Ln(alpha)	-0.567*	
	(0.309)	
*N: 61 (zero=39); Wald chi2(4) 40.68****	61	61

Notes: Robust standard errors in parentheses; significance levels: *** p<0.01, ** p<0.05, * p<0.1; dichotomous variables take value 1 if "Yes" and 0 if "no"; Location A (Amareleja) is the omitted category. Estimation using STATA® software, version 13.

According to the results presented in table 2, for the first stage, the entitlement to compensation depends essentially on the location of the PVF. Relative to *Location A (Amareleja)*, local residents are less likely to ask for compensation in *Location B*, which is the smallest, and more likely to ask for compensation in *Location C*, all else being equal.

In terms of controls, the coefficient on the variable that captures whether the respondent is retired is statistically significant and negative, so all else being equal, a retired individual is less likely to ask for compensation. As for the other statistically significant coefficient, on the per capita income, it is economically irrelevant.

Concerning the WTA in the second stage, the degree of experienced nuisance from the glare effect affects positively the amount of stated compensation. The locations are also statistically significant in terms of effects with negative signs, implying that relative to *Location A*, both locations separately elicit lower compensations. Based on the regression in the second stage, we predict the amount of compensation demanded on average by the local residents in *Location A (Amareleja)* to be the highest (€53.24 per month), followed by *Location B (Hercules)* €21.34 and *Location C (Ferreira do Alentejo)* with €12.16. It should be noted that these compensation amounts differ and are site-specific. Furthermore, while we do not have observations from other PVFs to infer causality, we can see that these amounts are positively correlated to the size of the individual PVF (while Location C has the intermediate total area, it is composed of three smaller plants and it is likely that the impact experienced by local residents comes from one of the smaller plants).

4.2. National sample (non-residents)

4.2.1. Sample description

The national population sample was collected during the first half of 2014 and is composed of 250 residents of Mainland Portugal. In terms of sample composition, there are 117 (46.8%)

men and 133 women (53.2%). The mean age is 50.2 years old (with standard deviation of 17.3 years, and minimum of 18 and maximum of 85) and in terms of occupation, 35.3% are retired. Inspecting the qualifications in the sample, 18.5% only have primary schooling, 27% hold a degree (bachelor, undergraduate or master) with about half the sample indicating in-between qualifications.

As for environmental and energy perceptions, 69% of respondents agree that energy from fossil fuels causes environmental problems, and 91.6% that RES benefit the population in general. In terms of how friendly RES are perceived, 92.8% and 92.4% of respondents consider that wind and solar energy are (very) environmentally friendly.

Some questions concerned actual electricity consumption. The average monthly household electricity bill was 75 euros (with standard deviation of €43.6 and minimum €20 and maximum €250). The majority of the respondents (72.4%) agreed that knowing the energy mix in terms of renewables used in the production of their consumed electricity was (very) important.

4.2.2. WTP analysis and estimation

Given the setup of the choice experiment discussed above, there are eight choice sets with two options available, corresponding to 16 choice decisions per respondent. In total there are 4000 distinct observations that have a data structure similar to panel data. There was a question to ascertain how respondents made their choices and 42.4% indicated that for their choices they had considered all attributes, while the remaining had considered only some of the attributes.

In terms of regression model, we use a binary logit model (with cluster correction). Each choice set is characterized by a combination of attributes, meaning that respondents choose levels of attributes. Table 3 presents the estimated partial effects of each attribute on each individual's choice. In the last column we report respondents' predicted willingness to pay (WTP) to avoid each environmental impact.

Table 3 Binary logit model (with cluster correction)

VARIABLES (attributes)	Partial effects (stdev)	Mean WTP (stdev)
Landscape	-0.312***	7.124***
	(0.022)	(0.749)
Fauna/Flora	-0.371***	8.129***

	(0.024)	(0.849)
Glare	-0.185***	4.837***
	(0.014)	(0.579)
Price	-0.040***	------
	(0.002)	
Log likelihood function	-1531.532***	

Notes: Robust standard errors in parentheses; significance levels: *** p<0.01, ** p<0.05, * p<0.1; Estimation using STATA® software, version 13.

As per Table 3, the estimates for the coefficients of all attributes are statistically significant and different. Each attribute separately has a negative impact on the probability of choosing a particular form of electricity producing using PVFs. When the attribute in question corresponds to impacts on fauna and flora, respondents were 37.1 percentage points (p.p) less likely to choose that form of production. Respondents are also 31.2 p.p. less likely to choose a production form that impacts the landscape. Finally the glare effect reduces the probability of a form of production generating it being chosen in 18.5 p.p..

When estimating the WTP for each attribute separately, we find that respondents are on average willing to pay €8.13 per month to avoid an impact on fauna and flora, €7.12 to avoid impacts on landscape and less importantly €4.84 to prevent impacts from the glare effect.

4.3. Discussion

The previous sections report on the application of stated preference methods to estimate welfare effects of the local operation of PVFs. By eliciting the economic values from two different groups of shareholders, the estimates thus correspond to different components of the total economic value. The CVM was used to elicit the valuation of local residents of the WTA, while a DCE was implemented for national residents to value what is essentially a non-use value.

In the former study, we selected three locations for PVFs which differ in terms of total area and land use. Location A (Amareleja) is the biggest PVF and in fact the average estimated WTA is the largest in comparison to the other two (€53.24 per month). In Location B (Hercules), local residents are less likely to indicate a positive WTA than in A and on average the estimated WTA is lower (€21.34). Location C (Ferreira do Alentejo) has the intermediate total area of the study, but consists of three smaller plants, and in fact residents are more likely to feel entitled to compensation than in A, but demand a lower on average compensation (€12.16). Given the reduced number of locations we can only speculate that a more scattered sitting in Location C affects more residents, but reduces the individual nuisance.

The DCE elicited the valuation from a national sample of the local environmental impacts experienced by local residents. The results from the estimation show that all attributes considered were statistically significant and valued differently, ranging from€4.84 to €8.13 per month.

The estimates from the application of the CVM to local residents represent a monetary value for the different dimensions of nuisance caused by the proximity of a specific local PVF. On the other hand, the approach of the DCE does not consider specific locations, but rather different attributes impacted by PVFs. Both approaches allow decision-makers to consider all costs of the operation of PVFs albeit from different perspectives, and can thus be used in isolation or complementarily. Furthermore, the comparison of these estimates can be used to estimate the potential for compensatory transfers between the two types of stakeholders, namely those directly affected and the beneficiaries. Given that the number of local residents in comparison to the number of beneficiaries, it is safe to conclude that the welfare benefits more than compensate the costs, and, before taking into consideration equity issues, PVFs are potentially welfare-enhancing.

5. Conclusion

When making decisions about sitting of RES projects, policy makers should considers all costs and benefits to arrive at efficient decisions. In the case of PVFs they are normally considered environmentally friendly, but in fact are not impact-free. The environmental impacts are mostly experienced locally, while the benefits from cleaner energy are shared by all. This study applies two economic nonmarket valuation techniques to estimate the local environmental impacts, namely the CVM and DCE, targeting two groups of stakeholders, local residents and national residents respectively. With a local resident sample, we estimate the minimum monetary compensation for the experienced local impacts. With a national sample we elicited the economic value attached to avoiding specific local impacts in the generation of electricity trough PVFs. This study highlights that these local impacts are indeed non-negligible and should be included in a thorough cost-benefit analysis. Furthermore, there is scope for a welfare-enhancing transfer between the two groups of stakeholders.

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References

Arrow, K., Solow, R., Portney, P. R., Leamer, E. E., Radner, R., & Schuman, H. (1993). Report of the NOAA panel on contingent valuation. *Federal register, 58*(10), 4601-4614.

Atkinson, G., & Mourato, S. (2008). Environmental cost-benefit analysis. *Annual review of environment and resources, 33*, 317-344.

Baker, E., Fowlie, M., Lemoine, D., & Reynolds, S. S. (2013). The Economics of Solar Electricity. *Annual Review of Resource Economics, 5*(1), 387-426. doi: 10.1146/annurev-resource-091912-151843

Bateman, I. J., Carson, R. T., Day, B., Hanemann, M., Hanley, N., Hett, T., . . . Ozdemiroglu, E. (2002). *Economic valuation with stated preference techniques: a manual*. Cheltenham, UK: Edward Elgar Publishing.

Botelho, A., Pinto, L. M. C., Lourenço-Gomes, L., Valente, M., & Sousa, S. (2016). Social sustainability of renewable energy sources in electricity production: An application of the contingent valuation method. *Sustainable Cities and Society, 26*, 429-437. doi: http://dx.doi.org/10.1016/j.scs.2016.05.011

Cameron, A. C., & Trivedi, P. K. (2009). *Microeconometrics using Stata*. College Station, Texas: Stata Press.

Carson, R. T. (2000). Contingent Valuation: A User's Guide. *Environmental Science & Technology, 34*(8), 1413-1418. doi: 10.1021/es990728j

Champ, P., Brown, T., & Boyle, K. (2003). Primer on Nonmarket Valuation. The Economics of Nonmarket Goods and Resource., V. 3: Kluwer Academic Publishers.

Chiabrando, R., Fabrizio, E., & Garnero, G. (2009). The territorial and landscape impacts of photovoltaic systems: Definition of impacts and assessment of the glare risk. *Renewable and Sustainable Energy Reviews, 13*(9), 2441-2451. doi: http://dx.doi.org/10.1016/j.rser.2009.06.008

DGEG. (2016). Renováveis - Estatísticas rápidas n. 141 junho 2016, available at www.dgeg.pt: Direção Geral de Energia e Geologia.

Dubey, S., Jadhav, N. Y., & Zakirova, B. (2013). Socio-Economic and Environmental Impacts of Silicon Based Photovoltaic (PV) Technologies. *Energy Procedia, 33*, 322-334. doi: http://dx.doi.org/10.1016/j.egypro.2013.05.073

European Union. (2012). *Photovoltaic Geographical Information System (PVGIS) - Photovoltaic Solar Electricity Potential in European Countries*: European Commission Joint Research Centre,.

Fthenakis, V. M. (2000). End-of-life management and recycling of PV modules. *Energy Policy, 28*(14), 1051-1058.

Gunerhan, H., Hepbasli, A., & Giresunlu, U. (2008). Environmental impacts from the solar energy systems. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 31*(2), 131-138.

Hanley, N., Mourato, S., & Wright, R. E. (2001). Choice Modelling Approaches: A Superior Alternative for Environmental Valuatioin? *Journal of Economic Surveys, 15*(3), 435-462.

Hanley, N., Wright, R., & Adamowicz, V. (1998). Using Choice Experiments to Value the Environment. *Environmental and Resource Economics, 11*(3-4), 413-428. doi: 10.1023/A:1008287310583

Ho, C. K. (2013). Relieving a Glaring Problem. *Solar Today, April 2013*, 28-31.

IEA. (2015). *Solar Photovoltaic Energy*: OECD Publishing.

Lackner, K. S., & Sachs, J. (2005). A robust strategy for sustainable energy. *Brookings Papers on Economic Activity, 2005*(2), 215-284.

Lancaster, K. J. (1966). A New Approach to Consumer Theory. *The Journal of Political Economy, 74*(2), 132-157.

Menegaki, A. (2008). Valuation for renewable energy: A comparative review. *Renewable and Sustainable Energy Reviews, 12*(9), 2422-2437. doi: http://dx.doi.org/10.1016/j.rser.2007.06.003

Neff, T. L. (1981). *The social costs of solar energy: A study of photovoltaic energy systems*. MIT, Cambridge, MA: Pergamon Press.

OECD. (2012). *Energy - OECD Green Growth Studies*: OECD Publishing.

OECD/ IEA. (1998). Benign energy? The environmental implications of renewables: Organisation for Economic Co-operation and Development and International Energy Agency.

Pearce, D., Mourato, S., & Atkinson, G. (2006). *Cost Benefit Analysis and the Environment: Recent Developments*: SourceOECD Environment and Sustainable Development.

Pearce, D., & Turner, R. K. (1990). *Economics of Natural Resources and the Environment*. Baltimore: The John Hopkins University Press.

Rose, T., & Wollert, A. (2015). The dark side of photovoltaic — 3D simulation of glare assessing risk and discomfort. *Environmental Impact Assessment Review, 52*, 24-30. doi: http://dx.doi.org/10.1016/j.eiar.2014.08.005

Srinivasan, S. (2009). The food v. fuel debate: A nuanced view of incentive structures. *Renewable Energy, 34*(4), 950-954. doi: http://dx.doi.org/10.1016/j.renene.2008.08.015

Torres-Sibille, A. d. C., Cloquell-Ballester, V.-A., Cloquell-Ballester, V.-A., & Artacho Ramírez, M. Á. (2009). Aesthetic impact assessment of solar power plants: An objective and a subjective approach. *Renewable and Sustainable Energy Reviews, 13*(5), 986-999. doi: http://dx.doi.org/10.1016/j.rser.2008.03.012

Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy Policy, 33*(3), 289-296.

Whitehead, J. (2006). A practitioner's primer on the contingent valuation method. In A. Alberini & J. Kahn (Eds.), *Handbook on contingent valuation* (pp. 66-91). Cheltenham, UK: Edward Elgar.