Identification and assessment of the environmental impacts associated with wind energy

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Abstract

Electricity is an essential commodity in modern societies. Over time, the sources of electricity have changed. Wind energy is currently one the most important energy sources in the production of electricity. The main objective of this study is to identify and assess the environmental impacts associated to the wind energy. To achieve this goal, we use the Contingent Valuation Method to elicit the value of the environmental damage caused by the production of electricity through wind energy. Damages are elicited from three different but complementary perspectives: local residents, residents in a nearby town and residents outside de area. The results obtained demonstrate the relevance of identifying the different groups that may be affected by the construction and operation of wind farms, the difference obtained for the WTP and WTA illustrates this result. In addition, the values obtained in our study go in line with previous literature, illustrating the robustness of the methodology used

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1 – Introduction

In recent years, renewable energy investments in Portugal, with regard to wind energy, made Portugal a world reference. In 2011, Portugal's capacity for producing wind energy was 4372.8MW (INEGI and APREN, 2011). Portugal imports coal, oil and gas to produce electricity because it has very little in the way of conventional energy sources, this imports represent around half of its trade deficit. So to reduce this deficit Portugal heavily invested on renewable sources of energy. Portugal has geographic and geomorphologic characteristics that beneficiate the production of wind energy (DGEG, 2012). Wind energy has presented the biggest growth of the installed power level in the EU (Sahin, 2004). In the European Union (EU) wind energy investments are mostly offshore, but in Portugal all energy is produced onshore. Portugal have only installed one turbine offshore (project "windfloat") that will be commercialized between 2015 and 2020 (Azau, 2011).

With the increasing development of wind farms is important to identify the environmental impacts considered most important by the Portuguese population, where information is scarce. The main objective of this paper is to identify and assess the environmental impacts associated to the wind energy. The wind farm of "Terras Altas de Fafe" is the basis of the study. To compute the economic valuation of environmental impacts, we resorted to the Contingent Valuation Method (CVM) to estimate the willingness to pay (WTP) and the Willingness to accept (WTA) of each subsample.

2 – Previous wind energy valuation studies

Wind power is considered a "clean" energy source, environmentally friendly and sustainable when compared with other renewable (Saidur et al., 2011), however it also is associated environmental impacts, mainly during the energy production stage. The literature indicates that the most common environmental impacts of electricity production are related with the changes of the physical environment: visual impact, noise impact, impacts on fauna and flora (Álvarez-Farizo and Hanley, 2002; Menegaki, 2008; Bergmann et al 2006; Mendes et al 2002; Saidur et al. 2011). The valuation of the environmental impacts, which are considered as non-market goods, can be attained by two major classes of methods: direct methods and indirect methods. Direct methods are based on stated preferences and indirect methods in revealed preferences (Adamowicz et al., 1994; Garrod and Willis, 1999). For our study we chose the Contingent Valuation Method (CVM), because is the best suited and recommended by the National Oceanic and Atmospheric Administration (NOAA) panel to determine the use value and non-use of natural resources. Given the growing importance that renewable energy sources have gained, there is a considerable number of studies that analyze these impacts on the environment, as for example, Abdullah and Jeanty (2011), Yoo and Kwak (2009), Koundouri et al. (2009), Kumbaroglu et al. (2008), Groothuis et al. (2008), Wiser (2007), Nomura and Akai (2004) and Hanley and Nevin (1999).

Abdullah and Jeanty (2011) in their study analyzed the expansion of electricity access in rural Kenya, using the CVM to determine the WTP of individuals to obtain electricity from two mechanisms, grid electricity and photovoltaic electricity (renewable energy). Two types of payment were used: a lump sum (one time) or monthly (60 months). The main conclusions regarding the WTP, revealed that individuals with higher incomes who had business interests presented a higher WTP. On the other hand, the WTP is lower for households in which the head of household is older and spends more time at the place of residence. This result is observed both in the case of grid electricity and photovoltaic electricity, regardless of the type of payment. A conclusion also interesting was that the WTP for grid electricity is superior to the photovoltaic regardless of the payment type, in other words, the WTP for grid electricity with lump sum payment and with a monthly amount is \$ 235 and \$ 126, respectively, while the WTP for photovoltaic for a fixed amount is \$ 222 and for a monthly amount is \$ 98. In this sense, the WTP for a monthly payment is almost half of the lump sum. The authors also concluded that the government should subsidize connection costs for both power systems (grid and photovoltaic).

Koundouri et al. (2009) aimed to analyzed individuals' preferences regarding renewable energy and provide useful guidance for potential investment in renewable energy in Greece. The application of CVM intends to analyze the WTP of individuals to build a wind farm, as well as estimate the supply function and perform cost-benefit analysis of the project. In the study, 30% of respondents have a zero WTP for the construction of the wind farm. Furthermore, respondents who stated a positive WTP for the construction of the wind farm (70%), contributed to an average WTP of € 8.86 (the payment vehicle was the bimonthly electricity invoice). The study also concludes that the WTP is negative for families with more children and full-time workers, in contrast, the WTP is positive for cases in which individuals are more informed about the economic effects for the region and for individuals with higher education and also for people who live in rural areas.

Yoo and Kwak (2009) obtained the WTP of respondents for green electricity (renewable energy) and analyze the economic benefits of increasing the percentage of green energy consumed by Korean households. The WTP to have "clean" energy increases largely due to the rise of concern, among individuals, with energy. Consequently, the lack of information on renewable energies ultimately leads individuals with lack of knowledge to be against paying for healthy energy. The monthly average WTP as well as annual benefits for residents, were statistically significant. Using parametric methods the predicted WTP was $ 1.8 (KRW 1681) and using non-parametric was $ 2.2 (KRW 2072).

Groothuis et al. (2008) collected the WTA to measure the compensation needed to allow the construction of wind turbines in the mountains of North Carolina. The opposition of individuals to the generation of electricity from wind is based, in large part, on the negative externalities that these sites may cause, as for example, visual impacts, noise and shadows and lighting effects. It was found that individuals who are willing to participate in green power programs require a lower monetary value of compensation. The WTA compensation was $ 23 by family per year for the location of the wind farm. In the study, it was concluded that compensation could be used to reduce the NIMBY effect (Not In My BackYard).

Kumbaroglu et al. (2008) presents a study that analyzes the interest of Turkey's population to reduce CO_2 emissions and invest more in renewable energy technologies. Using the MVC they determine the WTP for reducing CO_2 emissions, and determine a value that defines the level of installation of renewable energy technologies. Thus, the payment would be a mandatory surcharge on electricity consumption. This study also concluded that reductions of CO_2 emissions significantly affect economic growth and consequently there is an incentive to shift to renewable technologies. Another interesting conclusion is that with the increase of individual income, the WTP increases encouraging the use of new technologies.

Wiser (2007) used the CVM to analyse the willingness to pay of consumers for renewable energies in the US. He found that the WTP varies according to payment vehicle and with renewable energy supply. When respondents are confronted with collective payment mechanisms, in which all individuals and companies are obliged to pay, respondents have a higher WTP than when confronted with voluntary payments.

This occurs because when payments are voluntary, individuals with a higher WTP believe that other individuals will also have this sensitivity, which is not always the case and originates a free-riding behaviour. Also relevant in explaining individuals WTP were the demographic and socioeconomic variables: high income households have a higher WTP, and women also show a greater willingness to pay in the case of voluntary payments. Another variable that equally manifests a higher WTP is education, the higher the educational level the greater will be the WTP of individuals.

Nomura and Akai (2004) analyze the willingness of Japanese households to pay, in the form of a flat monthly surcharge, for renewable energy (photovoltaic and wind). The WTP found was $ 17 per month per household. In this regard, individuals who consider that renewable energy technologies will be used in the future have a higher WTP. Therefore, the WTP also increases if the renewable energy system becomes more familiar.

Hanley and Nevin (1999) evaluated the economic value and elicited individual preferences regarding the construction of a wind farm (three turbines), a small-scale hydro and a biomass equipment. The CVM was used to obtain the WTP and WTA of benefits/environmental costs perceived by local residents (North West of Scotland). Thus, for the wind farm, 78% of residents support the development of the wind farm, with a WTP of £ 87 per year. In opposition, of the 10 residents who do not accept the construction of the wind farm, just one states that compensation for a reduction in annual electricity invoice would change his mind, with a minimum reduction of £ 140 per year.

3 – Methodology

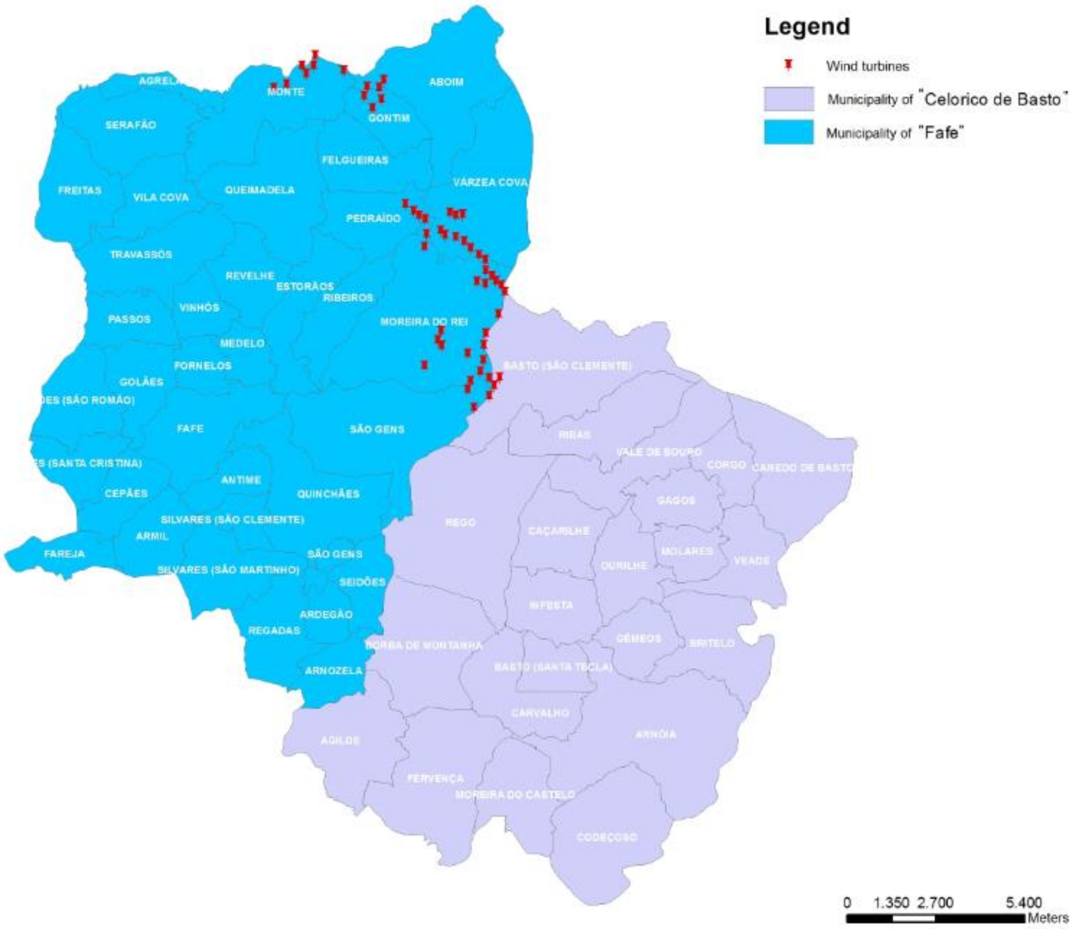
The CVM has been applied in various areas, when it comes to environmental issues it cover a wide range of situations: water quality, air quality, outdoor recreation, the preservation of species and cultural heritage, among others (Carson, 2000; Pearce et al., 2006, Department of Environment, 2008; Mendelsohn and Olmstead, 2009). With the development of the NOAA panel in 1993, the MVC was seen as a model that produces reliable enough estimates to be able to be the starting point for the determination of lawsuits involving damage to natural resources (Portney, 1994; Carson, 2000, Pearce et al. 2006). This method allows to measure, in monetary values, the impact on welfare level resulting from a quantitative or qualitative variation of environmental amenities, by directly asking individuals about their WTP or WTA. The CVM has the particularity of being applicable in project evaluations *ex-ante* and *ex-post*, so it can capture the use and non-use values of environmental goods and services (Pearce et al., 2006). In assessing environmental goods and services the NOAA panel determined that the total value is a more accurate measure of the value and that the MVC is the best method to reveal these values (Arrow et al., 1993). In some cases the non-use value can be a very important issue in social evaluation (Olmstead and Mendelsohn, 2009). The MVC describe the goods or services to value in detail and then ask consumers about the value they attach to the environmental good or service, through careful research (Mendelsohn and Olmstead, 2009). To determine the value assigned to the good, a valuation measure must be specified, ie, the WTP and WTA. Although the MVC is a simple, flexible, and largely applied, this method is also subject to some criticisms (Venkatachalam, 2004). The most important concern is the hypothetical nature of the valuation exercise (Pagiola, 1996; Garrod and Willis, 1999; Department of

Environment, 2008). Addressing the hypothetical bias requires a careful design of the survey and the appropriate statistical analysis.

4 – Description of the case study site

The wind farm of the "Terras Altas de Fafe" is composed by 53 wind turbines of 2MW power (ECOSSISTEMA and ARQPAIS, 2003). It is located in the district of Braga, in the municipalities of Celorico de Basto and Fafe (Figure 1), in the area of the “Serra do Monte do Marco”, with an extension of 20 Km approximately (ECOSSISTEMA and ARQPAIS, 2003). According to the details provided by the INEGI and APREN report (2011), in 2004 was connected the first wind turbine to the network (the park started its operations on December 28, 2004) in 2005 the remaining 39 were connected, summing the 40 turbines pre-defined in the project and referred in the Environmental Impact Study (EIS). In 2008, 13 more wind turbines were installed, totalizing 53 wind turbines, as currently listed. The turbines were manufactured by Gamesa, G87 model, giving a total power of 106 MW. The estimated annual production is of 213 GWh, a production that approaches the energy consumed by the residents of the municipalities of Fafe, Celorico de Basto and Cabeceiras de Basto (about 90 000) (Pinto, 2009). According to the EIS (ECOSSISTEMA and ARQPAIS, 2003), the foundation of each turbine occupies an area of 150 m^2, and each turbine consists of a multiplier and an electric generator located on the top of the tower. The towers, carbon steel, have a height that varies between 60 and 78 meters. Each of the blades is 39 meters long. As for the substation, it occupies an area of 8300 m^2 (ECOSSITEMA and ARQPAIS, 2003). The construction potentially generates environmental impacts as suggested by the literature previously analyzed.

Figure 1 - Municipality of Fafe and Celorico de Basto with the location of wind turbines of the wind farm "Terras Altas de Fafe”



Source: CAOP, 2013

5 – Design of the questionnaire

In the present application we developed three different valuation scenarios for each of the three groups interviewed: Local Residents (LR), Residents in the vicinity (Fafe) (RF) and Non-Residents in Fafe (NRF). LR were asked the minimum amount they would require as compensation for the damages imposed by the wind turbines. Residents in Fafe were asked their willingness to pay to prevent the construction of a wind farm, the payment vehicle was the household electricity bill; Non-Residents in Fafe were asked how much they would be willing to pay for the constitution of a compensation fund for local people affected by the impacts of construction and operation of the wind farm. The aim of this study was to identify and assess the environmental impacts associated with wind energy, based on the wind farm "Terras Altas de Fafe", considering the three groups representing three types of victims.

5.1 – Survey information and design

The application of the questionnaires was preceded by a pre-test (LR, RF and NRF) to see if the questions were clear and complete and if any question should be reformulated. Only small text changes resulted from this interaction. The questionnaires were composed of four sections, although the most common structure for such surveys is three (Bateman et al. 2002). The introductory section is intended to give an idea of the respondent's familiarity with renewable energy, the second section is devoted to the assessment, this section differs between the three versions of the questionnaire. The valuation section primarily consists of an informative text that introduces the topic, the renewable energy sources used to produce electricity, with a special emphasis on wind energy, which is the only one present in the region. For RF and NRF images were also exhibit, Figure 2 shows a pre and post-change landscape, to elucidate the hypothetical scenario proposed. In the third section questions to determine respondents' knowledge about wind energy and the environmental impacts they consider to be the most important and which affect them either positively or negatively, were included. Finally, the fourth section collects demographic data (gender, age, education, profession, current work situation, residence, income and number of members of the household).

The valuation question for the three cases was divided in two steps. A simple dichotomous choice question asked the respondents if they were willing to pay/accept for the scenario proposed; if respondents answered yes, then they were asked an open-ended question on how much they would be willing to pay/accept; if respondents answered no to the first question they were asked to indicate the reason for their response from a set of possible causes.

The questionnaires were implemented during the months of May and June 2012. The questionnaires for local residents and residents in Fafe were done through personal interviews, questionnaires for non-residents in Fafe were mostly done by email (71%). In total 204 usable questionnaires were obtained.

Figure 2 – Manipulated photographs

5.2 – Sample description

The total sample is composed of 36% of LR, 32% of NRF and 31% of RF; 96% of those interviewed have heard of the problems of climate change that are associated with the use of energy from fossil fuels. Regarding their knowledge of renewable energy, wind energy, solar energy and hydropower are the most popular, with 100%, 99% and 90%, respectively. For 46% of sample interviewed within the renewable energy, wind energy is the most frequently used in Portugal. The majority of respondents (96%) believe that renewable energy is our future. Most respondents are not friends or family of people working in the wind farm (71%). Analyzing with more emphasis the wind power, according to the sample Portugal has natural conditions for producing wind energy (97%) and this brings benefits to the population (90%). Thus, for wind power, the fact that it is a renewable energy, reduces contribution to global climate change and does not produce harmful emissions or toxic wastes, these are the benefits most frequently reported by respondents. The environmental impact that negatively affect respondents are visual impacts (61%), the impact of noise (43%), the impact on flora (31%) and the impact on the fauna (22%). Respondents consider the creation of new jobs as the impact that affect them positively. Table 1 shows the socio-demographic information of the sample.

6 – Results and discussion

6.1 – Descriptive Statistics

According with Table 1, the mean WTP per year of RF to prevent the construction of wind farm suggested by the hypothetical scenario was € 9.56 (only 4% of the no-answers referred the project as not credible, which shows some successful in the construction of the scenario and choice of payment vehicle). The WTP by year of NRF for the constitution of a compensation fund was € 24.38 (only 2,5% of the no answers object to the credibility of the scenario and payment vehicle proposed).

Table 1 - Sample characteristics

Age (mean years)		**Income (mean)**		**Household size**	
LR	41.6	LR	1050.76 €	1	11.33%
NRF	27.2	NRF	1371.36 €	2	16.75%
RF	36.2	RF	1113.37 €	3	34.98%
				4	31.03%
				5	4.43%
Total	35.0	Total	1178.50 €	More than 5	1.48%
Education		**Current situation of the work**			
Primary	13.72%	Employed	58.82%		
Basic	33.33%	Unemployed	11.28%		
Secondary	17.64%	Students	19.12%		
University	35.29%	Retired	7.35%		
		Housewife	3.43%		

Moreover, the WTA of LR for the compensation for environmental damage caused by the wind farm was situated at € 19.98 per year. Thus, the WTA compensation of local residents is higher than the WTP of RF to prevent the construction of a wind farm, but it is lower than the WTP of the NRF for the constitution of a compensation fund indicating that the creation of this fund would be viable.

6.2 – Econometric Analysis

Using the information collected, we then estimate the valuation functions for each sub-sample and also study the determinants of the decision to pay/accept. To this end we specify a *Tobit* model for the valuation function, given the censured nature of the dependent variable; for the decision to pay/accept we specify a *Probit* model as we are dealing with a binary qualitative variable. The independent variables considered in the regressions, are the same whenever that was possible. In some cases the included variables lacked statistical significance and were substituted by others that were thought to represent the influence of the same theoretical variable. Socio-demographic variables such us *gender*, *higher_education*, *employed*, and *income_pc* were included. Apart from these, there are others that are specific to the models of each subsample.

- *Gender*: Gender of respondent, 0 if female, 1 if male.
- *Higher-education*: Respondents with higher education, 0 if other levels of education, 1 if higher education.
- *Employed*: Respondents employed, 0 if other employment situations, 1 if one employee.
- *Income_pc*: Income per capita.
- *Employed_inc*: Per capita income of the employed.

• *Wenerg_cont_prbl*: Wind energy contributes to the resolution of the energy problems, 0 if not, 1 if yes.

• *Fav_employment*: Favourable employment and creating jobs, 0 if not, 1 if yes.

• *Fam_friends_wemp*: Do you have friends or family working on the wind farm, 0 if not, 1 if yes.

• *Imp_visual*: Visual Impacts important, 0 if not, 1 if yes.

• *Neg_imp_noise*: Impact of noise is negative, 0 if not, 1 if yes.

• *N_emissions_pst*: It not produces dangerous emissions or toxic solids, 0 if not, 1 if yes.

• *Pos_creation_emp*: Creating of new jobs is positive, 0 if not, 1 if yes.

• *Pos_red_climate_chande*: Reduction of global climate change is positive, 0 if not, 1 if yes.

• *Answer_question*: How easy was the answer to the question of valuation, 0 if Very difficult or difficult, and 1 if Very Easy or easy.

Table 2 - Estimated Marginal Effects and Standard Errors for Probit and Tobit models

	Willingness to Pay/Accept					
	WTP				**WTA**	
	Non_ Resid_Fafe		**Resid_Fafe**		**Local_Resid**	
	Marginal Effects					
Identification of models	**Probit**	**Tobit**	**Probit**	**Tobit**	**Probit**	**Tobit**
Independent Variables						
Socio-demographic Variables						
Gender	-0,1099 (0,1546)	-6,6012 (10,5641)	0,0619 (0,1360)	3,5231 (4,8554)	0,0994 (0,0988)	0,8003 (3,2832)
Higher-education	0,3712*** (0,1161)	23,3381* (13,9788)	-0,0487 (0,1471)	-0,4973 (5,4295)	-0,2071 (0,1883)	-5,1568 (6,0399)
Employed	0,3191** (0,1376)	25,5632*** (10,3426)	-0,6599*** (0,2546)	-14,2463 (9,1947)	-0,0714 (0,0924)	0,0636 (3,3446)
Income_pc	-0,0003 (0,0002)	-0,0308** (0,0161)	-0,0002 (0,0004)	0,0014 (0,0168)	0,0000 (0,0002)	-0,0033 (0,0043)
Employed_inc			0,0009* (0,0005)	0,0211 (0,0194)		
Knowledge variables of wind energy						
WEnerg_cont_prbl	0,2143 (0,1786)	26,4750* (16,2110)				
Fav_employment						4,8738 (3,2127)
Fam_friends_Wemp	-0,1935 (0,1339)	-17,2432* (9,9648)				
Imp_visual	0,0401 (0,1425)	-8,5031 (9,5266)	0,2302*** (0,0902)	13,0499* (6,8494)	0,2675** (0,1326)	6,5199* (3,7562)
Neg_imp_noise			0,3029 (0,2529)	9,9156 (6,8935)	0,1921 (0,1687)	7,1110* (4,3575)
N_emissions_pst	0,3527** (0,1160)	27,9333*** (11,4428)				
Pos_creation_emp			0,0039 (0,1214)	0,3872 (4.1621)		
Pos_red_climate_change			-0,1764 (0,1604)	-2,2824 (4,1342)		
Answer_question			0,1705*** (0,0696)	5,9842** (2,4362)		
Percentage correctly predicted/amount predicted (Tobit)	35,14%	12,91	21,56%	3,25	82,94%	11,64
Log-pseudolikelihood value	-33,0792	-140,8018	-29,4587	-86,8448	-32,2446	-182,5482
P-values (global significance)	0,0004**	0,0221**	0,0334**	0,0115**	0,0604*	0,1091*

Note: standard errors in parentheses; *Significance level of 10%; ** Significance level of 5%; *** Significance level of 1%.

The variable *employed_inc* is only used in connection with the RF designs, since this control for the income levels (suggested by economic theory) has proved more effective in this way.

According to the econometric analysis we can conclude that the willingness to pay of Fafe Residents was €3.25 and for Non-residents was €12.91. The willingness to accept compensation by Local Residents was €11.64 (Table 2). Thus, the mean predicted value for compensation is lower than the mean value to pay for the compensation fund. Predicted participation in the compensation fund is 35% approximately; for residents in Fafe the probability that they are willing to pay some amount to prevent the construction of a wind park is 22%, approximately; The comparison of these two predicted probabilities seems to indicate that subjects more easily pay to compensate damages to local population, than to prevent the construction of a wind farm, which may indicate that they are sensitive to the damages caused but still want wind energy to be used to produce electricity. The predicted probability of a Local Resident being willing to receive some amount as compensation for the damages caused by the wind farm is 83%.

The variables included in the models were dictated by the theory and by previous studies on environmental valuation. Notice, however, that in some instances the questionnaire provides more than one indicator for each theoretically or empirically motivated variable. In such cases the choice was guided by individual statistical significance. Moreover, even if individually not significant, variables were kept if they contributed to overall significance. All regressions are globally statistically significant at 5%. In turn, the *Tobit* model of LR for the same significance level is assumed to be marginally significant (p-value = 0.1091), the *Probit* is globally statistically significant at 6%, as can be seen in Table 2.

Considering the regressions presented in Table 2, we draw the following conclusions. First, E*mployed* increases the probability of being willing to pay for NRF and also increases the average amount they are willing to pay; for RF it decreases the probability of being willing to pay for avoiding the construction of the wind farm. This difference may be explained by the fact that the scenario posed is different, and subjects may be willing to pay to compensate for damages but at the same time want to have the farm built. Second, the most important impact determining the decision to pay and the amount paid are visual impacts. The variable is significant and positive in all regressions except for NRF. For the group of non-residents the fact that wind energy does not produce harmful emissions is the most important variable in the group of attitudinal variables.

The results obtained are in line with previous studies in several aspects. Ladengurg and Dubgaard (2007) concluded that there is a positive WTP to reduce visual desaminidades of wind farms, and it is expected that respondents show a higher WTP. We obtain the same result for RF and LR, for NRF the variable is not statistically significant. Income is not statistically significant in most regressions; however the variable *Employed* is and has the expected positive sign in the tobit regression for NRF. The decision to contribute by RF is negatively influenced by the variable *Employed*, but is positively influenced by the income of those employed (*Employed_inc*).

When it comes to the WTA it is common that the results are higher than the WTP (Horowitz and McConnell, 2002), but what we see in this study is that the WTA of LR is greater than the WTP of RF but lower than the WTP of NRF. It should be stressed that the comparison between the mean WTP for Non-residents and for Residents cannot be made as the scenario posed is not the same, in the first case subjects are asked how much they would be willing to contribute to a compensation fund, while in the second case they are faced with the possibility of avoiding the construction of a wind farm, which for many respondents is seen as a desirable endeavour as it avoids harmful air emissions and reduces the national dependency of foreign energy sources.

7 – Conclusions

In this paper, we use the conditional valuation method for valuing environmental impacts that are associated with wind energy and wind farms. We estimated the willingness to pay of NRF for a compensation fund for local residents, the willingness to pay of RF to prevent the construction of a wind farm and the willingness to accept of LR for compensation for environmental impacts caused by the wind farm. The estimates obtained are interesting and reveal that the amount needed to compensate local residents for the negative impacts caused by the wind farm could be raised by the constitution of a compensation fund paid by non-residents.

The results obtained also demonstrate the relevance of identifying the different groups that may be affected by the construction and operation of wind farms, the difference obtained for the WTP and WTA illustrates this result. In addition, the values obtained in our study go in line with previous literature, illustrating the robustness of the methodology used.

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