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Valuing the Attributes of Renewable Energy Investments

ABSTRACT

Increasing the proportion of power derived from renewable energy sources is becoming an increasingly important part of many countries's strategies to achieve reductions in greenhouse gas emissions. However, renewable energy investments can often have external costs and benefits, which need to be taken into account if socially optimal investments are to be made. This paper attempts to estimate the magnitude of these external costs and benefits for the case of renewable technologies in Scotland, a country which has set particularly ambitious targets for expanding renewable energy. The external effects we consider are those on landscape quality, wildlife and air quality. We also consider the welfare implications of different investment strategies for employment and electricity prices. The methodology used to do this is the choice experiment technique. Renewable technologies considered include hydro, on-shore and off-shore wind power and biomass. Welfare changes for different combinations of impacts associated with different investment strategies are estimated. We also test for differences in preferences towards these impacts between urban and rural communities, and between high-and low-income households.

***Keywords*: Renewable Energy; External Costs and Benefits; Choice Experiments**

1. Introduction

Increasing the proportion of power derived from renewable energy sources is becoming an increasingly important part of many country's strategies to achieve reductions in greenhouse gas (GHG) emissions. However, renewable energy investments can often have external costs and benefits, which need to be taken into account if socially optimal investments are to be made. This paper attempts to estimate the magnitude of these external costs and benefits for the case of renewable technologies in Scotland, a country which has set particularly ambitious targets for expanding renewable energy. The external effects we consider are those on landscape quality, wildlife and air quality. Unlike other papers in the literature, we do not restrict our investigation to the effects of particular technologies (such as hydro or wind, Alvarez Farizo and Hanley, 2002; Hanley and Nevin, 1999), but consider impacts applicable to a wide range of renewable technologies. We also consider the welfare implications of alternative investment strategies for employment and electricity prices. The methodology used to do this is the choice experiment (CE) technique. Renewable technologies considered include hydro, on-shore and off-shore wind power and biomass. Welfare changes for different combinations of impacts associated with different investment strategies are estimated. We also test for differences in preferences towards these impacts between urban and rural communities, and between high and low-income households.

In what follows, Section 2 sets out some background detail on energy policy in Scotland. Section 3 provides a brief overview of the CE method, whilst in Section 4 we outline the design and conduct of our empirical study. Section 5 presents results from data analysis, including the conditional logit models estimated from the CE data. Section 6 evaluates the welfare effects of alternative investment strategies in renewables, whilst the final section presents some conclusions.

2. Scotland as a Case Study

Scotland has recently started down a new path in how it generates electricity (ROS, 2002). The Scottish Executive has set two challenging targets for use of renewable pow- er sources in the next 20 years:

- by 2010, 18% of electricity consumed should come from renewable generation,
- by 2020, that portion should rise to 40%.

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Currently only 10% of the electric energy produced in Scotland comes from renewable sources such as wind energy, hydro and waste-to-energy plants. These targets are thus ambitious, as the potential for large-scale hydro is close to fully developed, and as wave energy technology has not yet been adequately tested on a commercial scale. The 400% increase in clean electricity production will have to come from new energy projects and new technologies. The 2020 goal is three times larger than the negotiated portion Scotland has committed to as its contribution the UK's reduced GHG obligation. Denmark, with a 79% renewable electricity goal by 2030, is the only European Union member with comparable voluntary goals (de Vries et al., 2003).

The major political reasons for promoting renewable energy are external to Scotland. The UK has accepted a legally binding target of reducing emissions of a bundle of GHGs by 12.5% below 1990 emission levels by 2008–2012, as its share of the European Union negotiated target of an 8% reduction in GHGs under the Kyoto Protocol. The Energy White Paper "Our energy futurecreating a low carbon economy", published in February 2003 by the British Government, includes an even more ambitious path of reducing CO2 emissions by some 60% of current levels by 2060 (DTI, 2003). Currently, the UK Renewables Obligation-a requirement on power supply companies to meet certain minimum fractions of total supply from renewables-has set a target of 10.4% by 2010–2011.

The economic reasons for Scotland developing renew-ables are multifaceted. The first reason is that renewable energy projects by their very nature should be highly sustainable. There is minimal or no resource depletion due to the use of renewables technologies, as compared to gas-, oil- and coal-based energy. Renewable energy projects, as with traditional fossil fuel projects, tend to be capital intensive, so the opportunity to develop and manufacture renewable energy equipment for domestic use and international export exists. In 2001, Vestas, a major manufacturer of wind turbines, announced a manufacturing facility would be opened in Scotland (Scottish Executive, 2001), although most capital equipment is currently imported. There is the potential to transfer some of the job skills learned in the North Sea oil industry to the marine renewables sector, which includes tidal, wave, and ocean current power generation technologies, as the off-shore oil industry declines (a European Marine Energy Centre (EMEC, 2004) was opened on Orkney in 2004 to assist in the advancement of marine energy). Off-shore wind farm development may need this skilled labour pool. England and Wales will have a more difficult time building sufficient renewables capacity to provide adequate non-fossil fuel energy that their populations will need to meet domestic targets (OXERA, 2002). Scotland, on the other hand, has some of the greatest renewables potential in all of Europe, and therefore may have sufficient excess supplies to trade south of the border. Finally, rural areas of Scotland, with some of the greatest needs for economic development, will be the location of most all land-based renewable energy projects (Hassan et al., 2001). These rural communities may well reap benefits from these long-term projects.

A fundamental restructuring of the power industry will need to be undertaken to achieve these renewable targets. Since the 1880s in Scotland, as in the rest of the world, the power industry has been organised with a centralised hierarchical technological and management structure. Ever-larger generating facilities based on fossil fuels and nuclear power, and a unified transmission network to distribute the electricity over hundreds of miles, were the model of development. The nature of land-based renewable energy projects makes this development style technically impossible at this time. Current scale economies dictate that projects like wind farms and biomass generation plants be 3–5% the size of a traditional 1200 MW coal-fired plant. Even the largest wind farms being planned today are only 20% of this size. Also, because of the intermittency problems of renewable sources, greater quantities (measured by megawatt capacity) of generating assets are needed because of the lower average usage of this capacity. Renewable energy projects normally require large amounts of space to capture the energy in wind, water or solar radiation in sufficient quantity to be commercially viable. Dozens of communities in Scotland will therefore likely be impacted by renewable energy projects that will need to be constructed to meet the Scottish Executive's clean energy goals. As noted above, only 10% of electricity in Scotland is currently generated from renewable sources, mainly from hydro power stations (Scottish Executive, 2002b). The biggest current share of generation (44%) is from nuclear stations: however, all of these are planned to close by 2023 (NIA, 2003), and no new nuclear plants are likely to be commissioned.

The primary policy instrument being utilised by the Scottish Executive to motivate what is thus a very large expansion of renewable energy sources is the Renewables Obligation (Scotland) (ROS). The ROS has combined a demand-push legal requirement for renewable power usage with a supply pull financial incentive programme to reward private industry for constructing and investing in new renewable energy generation projects. The ROS compels licensed electricity suppliers to source specific quantities of eligible renewable energy for sale to all customers (residential, commercial and industrial), or face financial penalties for the shortfall. The associated increase in electricity costs is shared by all consumers and avoids the free-rider problem (Rose et al., 2002). The original minimum supply of renewable power by retailers, by quantity, was set at 3% for2002–2003, rose to 4.3% for 2003–2004, and will rise annually to 10.4% in 2010–2011. During the 18 months since the ROS was implemented in April 2002, significant increases in renewable generation projects have applied for or are moving towards application and planning consent. In all, 1500 MW of capacity has sought consent and another 2500 MW of capacity is near requesting consent (BWEA, 2003).

The financial incentives for private investment in renewable power facilities are created by the use of the renewable obligation certificates (ROCs). Electricity suppliers use these certificates as evidence that the required percentage of sales is matched with eligible green power production. The ROCs are traded separately from the actual electricity being generated and had a market price of £45–50 per megawatt during the first year of the ROS. This money is earned by the renewable power generating company and represents revenue above the value of the electricity being sold to the power market. Renewable power generators earned £63–75 per megawatt of production during the 2002–2003 period as compared to £17–25 per megawatt paid for fossil fuel-powered production.

3. The Choice Experiment Method

Renewable energy investments in Scotland are thus expected to grow rapidly in the near future. These investments will produce a series of potential impacts on the environment, price of electricity and employment. Environmental impacts will include landscape effects, effects on wildlife and changes in air pollution (e.g. waste to energy plants emit air pollution). Exactly what environmental impacts occur, what happens to electricity prices through changes in cost, and any changes in employment, will depend on the exact investment mix (e.g. the balance between on-and off-shore wind farms; the extent of hydro developments). Taken together, environmental effects, price effects and employment effects can be thought of as the attributes of a renewable energy strategy. Knowing something about the relative economic values of these attributes is important if we wish a renewables strategy to (i) take some account of public preferences and (ii) take some account of economic efficiency (benefit-cost) concerns. Choice Experiments are an economic valuation method which enables this kind of information to be produced.

3.1 The Characteristics Theory of Value and Random Utility Theory

CEs are based on two fundamental building blocks: Lancaster's characteristics theory of value, and random utility theory (RUT). Lancaster (1966) asserted that the utility derived from a good comes from the characteristics of that good, not from consumption of the good itself. Goods normally possess more than one characteristic and these characteristics (or attributes) will be shared with many other goods (Lancaster, 1966). The value of a good is then given by the sum of the value of its characteristics.

RUT is the second building block. RUT says that not all of the determinants of utility derived by individuals from their choices is directly observable to the researcher, but that an indirect determination of preferences is possible (McFadden, 1974; Manski, 1977). The utility function for a representative consumer can be decomposed into observable and stochastic sections:

$$U_{an} = V_{an} + e_{an}, \tag{1}$$

where Uan is the latent, unobservable utility held by consumer n for choice alternative a, Van is the systemic or observable portion of utility that consumer n has for choice alternative a, and ean is the random or unobservable portion of the utility that consumer n has for choice alternative a. Research is focussed on a probability function, defined over the alternatives which an individual faces, assuming that the individual will try to maximise their utility (Bennett and Blamey, 2001; Louviere et al., 2000). This probability is expressed as

$$P(a \setminus C_n) = P[(V_{an} + e_{an}) > (V_{jn} + e_{jn})] \quad \forall a \neq j \tag{2}$$

for all j options in choice set Cn, a and n are as previously described, or

$$P(a \setminus C_n) = P[(V_{an} + V_{jn}) > (e_{jn} + e_{an})] \quad \forall a \neq j \tag{3}$$

To empirically estimate (3), and thus to estimate the observable parameters of the utility function, assumptions are made about the random component of the model. A typical assumption is that these stochastic components are independently and identically distributed (IID) with a Gumbel or Weibull distribution. This leads to the use of multinomial (sometimes called conditional) logit (MNL) models to determine the probabilities of choosing a over j options (Hanley et al., 2001):

$$P(U_{an} + U_{jn}) = \frac{\exp(\mu V_a)}{\sum j \exp(\mu V_j)} \quad \forall a \neq j \tag{4}$$

Here, μ is a scale parameter, inversely related to the standard deviation of the error term and not separately identifiable in a single data set. The implications of this are that the estimated β values cannot be directly interpreted as to their contribution to utility, since they are confounded with the scale parameter. When using the MNL model choices must satisfy the independence from irrelevant alternatives (IIA) property, which means that the addition or subtraction of any option from the choice set will not affect relative probability of individual n choosing any other option (Louviere et al., 2000). Modelling constants known as alternative specific constants (ASCs) are typically included in the MNL model. The

ASC accounts for variations in choices that are not explained by the attributes or socio-economic variables, and sometimes for a status quo bias (Ben-Akiva and Lerman, 1985).

The estimated coefficients of the attributes can be used to estimate the tradeoffs between the attributes that respondents would be willing to make. The price attribute can be used in conjunction with the other attributes to determine the willingness-to-pay of respondents for gains or losses of attribute levels. This monetary value is call the "implicit price" or part-worth of the attribute:

$$part-worth=-\left(\frac{\beta\ \ non-market\ attribute}{\beta\ monetary\ attribute}\right) \tag{5}$$

The scaling problem noted above is resolved when one attribute coefficient is dividing by another, as in the part-worth equation, since the scale parameter cancels out.

4. Study Design and Implementation

To meet Scottish Executive targets, hundreds of renewable energy projects of all sizes and types of technology have been proposed. These range from large wind farms and new hydroelectric schemes that have significant impacts on the countryside and local communities, to small changes like the addition of solar panels to rooftops and district heating plans with impacts that may only be felt by the immediate residents. This paper's objective is to estimate the value of positive and negative impacts arising from the kind of renewable energy projects that will be developed over the coming years.

4.1 Designing the Choice Experiment

In any CE, attributes must be chosen which meet a number of requirements. These are that they are:

- relevant to the problem being analysed,
- capable of being understood by the sample population, and
- of applicability to policy analysis.

Identifying the set of attributes and the levels these take is a key phase in CE design. To this effect, focus groups were conducted with members of the general public (Dewar, 2003). The objective set to each group was to identify the 'characteristics' of 'green' electric energy production that were regarded as 'good' or 'bad'. The facilitator had each group identify all the types of renewable power technologies that they could, and then discuss the good or bad characteristics of each type of energy project. Technologies that were identified were: windmills, hydro schemes (run of river and reservoir), tidal and wave power, solar (photovoltaic and hot water panels) geothermal, various types of biomass or waste combustion like burning municipal solid waste, wood burning, animal and organic waste, natural gas from landfills and fermentation of organics. After identification of the attributes of each technology, the groups were requested to separate into smaller sections of two or three persons, and rank these attributes by importance to them. After that exercise, individuals were asked to indicate their personal choices for which characteristics were most important or of concern to them. Three characteristics that dominated all others were revealed by the focus groups. One was that renewable energy projects have a low environmental impact, and should reduce how we change or pollute the environment. Another was that the projects be aesthe- tically pleasing. This characteristic was a little more contentious because some group members felt that both windmills and reservoirs are pleasing to observe, while other members felt that large man-made structures took away from nature's scenic beauty. The final dominant characteristic was that wildlife should not be harmed any further and that projects that improved wildlife should be supported. Other less significant characteristics mentioned by individuals or groups were the creation of jobs, the effect on electricity prices, the abundance and sustainability of the resources, and more localised control and responsibility for the project.

Five key attributes were then chosen, based on these focus groups responses, and also on government statements (e.g. Scottish Executive, 2002b) and the literature. The attributes chosen were:

- impacts on the landscape,
- impacts on wildlife,
- impacts on pollution levels, in particular, air pollution,
- creation of long-term employment opportunities, and
- potential increases in electric prices to pay for renewable sources.

Once these attributes were determined, a questionnaire was constructed that presented the context of renewable energy development in Scotland. The national commitment by the UK to reduce production of GHGs was explained. Survey participants were told that the survey was not concerned with any specific type of renewables technology, but with the impacts that could result from development of any renewable energy resource. The five attributes noted above were described, with examples being given to clarify each type of impact.

SPSS (VERSION 10.0) was used to select a set of optimal choice profiles, which were then combined to make up the choice sets used in the experiment. Table 1 shows the attributes and levels as used in the final design. Given the five attributes and 17 associated levels, 1800 possible profiles exist, which was an unfeasible number to employ in the survey. We thus used a fractional factorial design to reduce this full factorial to 24 profiles that could be used to estimate main effects. This smaller set was also

Table 1. Attributes and attribute levels

Attribute	Description	Levels
Landscape impact	The visual impact of a project is dependent on a combination of both the size and location	None, low, moderate, high
Wildlife impact	Change in habitat can influence the amount and diversity of species	Slight improvement, no impact, slight harm
Air pollution	Many types of renewable energy projects create no additional air pollution, but some projects do burn non-fossil fuels. These projects produce a very small amount of pollution when compared to electricity generated from coal or natural gas	None, slight increase
Jobs	All renewable energy projects will create new local long-term employment to operate and maintain the projects. Temporary employment increases during the construction phase are not being considered	1–3, 8–12, 20–25
Price	Annual increase in household electric bill resulting from expansion of renewable energy projects. An average household pays £270 a year (£68 per quarter) for electricity	£0, £7, £16, £29, £45
Alternate specific constants		
ASC-A	Takes value of 1 for Plan A, 0 otherwise. Acts to represent variations that cannot be explained by the attributes or socio-economic variables	
ASC-B	Takes value of 1 for Plan B, 0 otherwise. Acts to representvariations that cannot be explained by the attributes or socio-economic variables	

designed for orthogonality, which is a desirable, but not a required, mathematical characteristic of choice set construction. Twenty different choice sets were thus designed and used in the questionnaire, blocked into sets of four (that is, each respondent worked there way through four choice tasks). Combined plans were alternated in the order in which they appeared as a choice set and the order of the individual plans were alternated between the first or second within the choice set. This was done to avoid any bias from the ordering of choices.

Choice sets were then presented, and the survey participant was requested to indicate their preference. Each set contained three options. Plans A and B were possible renewable energy projects, each with different attribute levels. A third option of choosing neither was given. This ‘neither’ option, commonly called the opt-out or status quo option, stated that there would be no increase in renewable energy, that alternative programmes would be implemented to avoid climate change, and that North Sea natural gas usage would be expanded to provide for future electricity generation. Figure 1 gives an example choice set. The final page of the questionnaire was concerned with collecting standard socioeconomic information about the participant. Information was requested about location of household, number of children, employment in the energy sector, membership in a conservation group, age, household income, education attainment and amount of last electric bill.

Because of budgetary constraints, the design was selected to estimate principal effects only. No secondary cross-effects can be determined from the choice design being used. The sample size requirements grow too rapidly when cross-effects are to be studied. The questionnaire and accompanying cover letter were then submitted to a small pretest with regard to their clarity and usefulness of the information contained. Feedback from this process lead to a revised and shortened version of the cover letter, clarification of some terminology and changes in how the socio-economic information was requested in the questionnaire. The questionnaire and other survey materials can be found in Hanley et al. (2004).

4.2 Sample Selection

The sampling frame for this project was the Scottish general public. Our sample population was randomly selected from the list of registered voters in eight council districts of Scotland. The districts are Aberdeenshire, Highlands and Islands, Western Isles, Edinburgh, Glasgow, Stirling, Borders and Dumfries and Galloway. Approximately 250 names were from Glasgow and Edinburgh, 80 from Aberdeenshire and 30–45 names from each of the other districts.

A mail survey was used due to constraints imposed by project funding. Some 547 names were selected and mailed survey packages with a cover letter during the first week of September 2003. As an incentive to participate a £20 prize draw was offered. Three weeks later a follow-up postcard was mailed to encourage the completion and return of the survey. By October 2003, 219 households had returned surveys, a 43% response rate after undeliverables are considered. Two hundred and eleven surveys were received in time to be part of the sample set. Eight surveys were returned too late to be included. Two hundred and eighty-seven households did not respond. This response rate is acceptable, and comparable to other studies (Ek, 2002; Hanley et al., 2001) that had response rates ranging from 44% to 56%, for a survey mailed to the general population. Mail surveys tend to have the lower response rates than telephone or face-to-face interviews (Bateman et al., 2002). The sample group of respondents should also be tested for any self-selection bias, which could result in a biased MNL estimates and WTP amounts.

5. Data Analysis

To model the information collected from the question-option example

	Plan A	Plan B	Neither
LANDSCAPE visual impact caused by location and/or size	HIGH	NONE	No increase in renewable energy
WILDLIFE health of habitat	SLIGHT HARM	SLIGHT HARM	Alternative climate change programs used
AIR POLLUTION	NONE	NONE	
EMPLOYMENT new jobs in local community	8-12 JOBS	1-3 JOBS	North Sea gas fired power stations instead
PRICE OF ELECTRICITY additional rates per year	£16 per year	£7 per year	
YOUR CHOICE: (please tick one only)	A ☐	B ☐	I would not want either A or B ☐

Figure 1. Example choice set

naire, each choice set has three lines of code that combines the attribute levels, ASCs and socio-economic variables (Bennett and Blamey, 2001). The data matrix appeared in the form:

alternative plan A :

$$V_a = ASC_a + \beta_{attributes} X + \beta_{soci-econ} Y,$$

alternative plan B :

$$V_b = ASC_b + \beta_{attributes} X + \beta_{soci-econ} Y,$$

no renewables option : $Vn = \beta_{attributes} X + \beta_{soci-econ} Y$, (the neither=opt-out plan)

where V is the conditional indirect utility, $ASC_{a,b}$ are the alternative specific constants for each choice plan, $\beta_{attributes}$ is a vector of coefficients associated with the attributes X and levels, and $\beta_{socio-econ}$ is a vector of coefficients associated with the socio-economics descryptors Y of the respondents.

NLOGIT 3.0/LIMDEP 8.0 econometric software was used to estimate the MNL model. Attributes were effect coded, rather than being coded using dummy variables, as this will provide estimates that are uncorrelated to the intercept of the model (Louviere et al., 2000). Effect coding means that at least one level of each attribute is not included as an identified variable: thus a three-level attribute generates two variables. The excluded level is coded as negative one. The attributes levels chosen for exclusion were the ones hypothesised to have the most negative effect on environmental amenities. Therefore, the estimated coefficients for each of the remaining levels indicate the value respondents placed on the change from the lowest valued (omitted) level to the level of greater utility. The omitted levels were: high landscape impact, slight wildlife harm and slight increase in air pollution. The effect of these omitted levels on utility is given by the negative of the sum of the coefficients on all the included levels.

5.1 Descriptive Statistics

Any mail survey has the risk of self-selection bias. Comparing the socio-economic information collected on the 211 respondents used in the CE against the statistical profile of the Scottish population is one test for such a bias: the null hypothesis that the experiment population is equal to the national population must be rejected for bias to be suspected. In our sample, respondent's income and location of residence are different from the national distribution at 10% level. Our sample is thus lower income than the national average, and more rural. These two descriptors are in fact correlated with each other. Rejection of the null hypothesis means that the estimated coefficients and the calculated WTP values may not be statistically valid representations of the whole Scottish population.

5.2 Model estimation and results

Results for all 211 respondents from the MNL model are shown in Table 2. The ''simple'' model shows results when only the CE attributes are included in the regression. The coefficients are interpreted as the parameters of the indirect utility function, although the fact that they are confounded with a scale parameter means that one cannot directly interpret their numerical value (the scale parameter cancels out when calculating implicit prices or welfare measures). Coefficient signs show the influence of attributes on choice probabilities: here, all attribute coefficients have the expected signs. The signs of all but the price attribute are positive, as consumer preference theory predicts, since these attributes are coded to show an increase in environmental quality, which should lead to increased utility. Price is negative and therefore also in accord with standard economic theory. All of the environmental attributes are significant determinants of utility at some level: changes in air pollution, landscape effects and wildlife effects. However, employment creation is not a significant attribute.

A series of socio-economic variables were proposed for inclusion in an ''expanded'' model based on standard consumer theory. The Student's t-test and log-likelihood tests were then used to determine acceptance or rejection of each variable. The rejected descriptive variables were: does the respondent have children, employment in the energy sector, membership in a conservation group, amount of last electric bill, age by five categories and education by three categories. The covariates used in the "expanded" model in Table 2 thus show either statistical significance or are included on theoretical grounds. Education and age are in the former class, while income is the latter case.

A likelihood ratio test was used to compare the "simple" and "expanded" models, and rejected the null hypothesis that the parameter values of the two models are equal at the 95% significance level. Implicit prices derived from the two models are not statistically different. Simple visual examination of this is confirmed by the large overlap of the confidence intervals (95% level) of implicit prices of both models (the delta method was used to calculate the confidence intervals). The adjusted

Table 2. Multinomial model results

Model	Model: expanded model w/covariates				Simple model: attributes only			
Descriptor	Coefficient	Implicit price (£)	(std. error)	(95% confidence interval)	Coefficient	Implicit price (£)	(std. error)	(95% confidence interval)
Moderate Landscape	0.29	5.58	(2.99)	(0.28–11.44)	0.20	4.07	(2.99)	(–1.79–9.93)
Low Landscape	0.15	2.82	(3.56)	(–4.16–9.79)	0.16	3.21	(3.56)	(–3.77–10.19)
None Landscape	0.42*	8.10*	(1.94)	(4.30–11.90)	0.39*	7.88*	(1.94)	(4.08–11.68)
None Wildlife	0.22**	4.24**	(2.18)	(–0.03–8.51)	0.27*	5.51*	(2.18)	(1.24–9.78)
Improved Wildlife	0.63*	11.98*	(1.88)	(8.30–15.66)	0.50*	10.11*	(1.88)	(6.43–13.79)
None Air pollution	0.74*	14.13*	(1.88)	(10.45–17.81)	0.71*	14.40*	(1.88)	(10.72–18.08)
Employment	0.02	0.32	(0.22)	(–0.11–0.66)	0.01	0.23	(0.22)	(–0.20–0.66)
Price	–0.05*			(0.0065)	–0.05*			(0.0058)
ASCA	2.80*				2.96*			
ASCB	2.73*				2.80*			
IncomeA	–0.01							
IncomeB2	–0.01							
Higher educationA	0.99*							
Higher educationB2	0.85*							
Under age 40-A	1.06**							
Under age 40-B	0.88***							
Log-likelihood	–434				–509			
No. of observations	739				836			
Pseudo-R2	0.31				0.29			

*Significant at 1% level, **significant at 5% level and ***significant at 10% level. Bold indicates monetary implicit values.

Table 3. Implicit prices from the model with covariates

Landscape impact	Households are WTP £8.10 to decrease high impact landscape changes to having no landscape impact
Wildlife impact	WTP of £4.24 to change a slight increase in harm to wildlife from renewable projects to a level that has no harm. However, households would be WTP £11.98 per annum to change a slight increase in harm to wildlife from renewable projects to a level that wildlife is improved from the current level
Airpollution impact	Households are WTP £14.13 to have renewable energy projects that have no increase in air pollution, compared to a programme which results in a slight increase in pollution

McFadden pseudo-R2 is also improved with the addition of the covariates. Louviere et al. (2000) state that a McFadden statistic in the 0.20–0.30 range is comparable to an ordinary least square (OLS) adjusted-R2 of 0.70–0.90. Therefore, the expanded model with covariates is deemed the superior model, and implicit prices from this are used in the following discussion. Implicit prices ("part-worths") are interpreted as the incremental willingness-to-pay through an increase in electricity charges per annum per household for a change in any of the attributes. They reveal the following (Table 3).

Looking closer at landscape impacts, moderate and low landscape impacts were not statistically significant compared with a high impact. Respondents thus only seem WTP to reduce high landscape impacts, but not to reduce low or moderate impacts. One very interesting finding is that employment effects are not statistically significant determinants of choices or of utility: respondents as a whole did not seem to care about employment effects to a significant degree.

An internal validation question was included in the questionnaire to test for consistency of these results. Respondents were asked to indicate which single attribute was most important to them. The ordering of the attributes by votes from respondents was: air pollution, wildlife, electricity price, landscape and employment. This shows consistency with the preference results shown in Table 2. Also, there is inferred consistency of the indirect utility measurement of individuals as the implicit prices are in the same rank order. Consistency with preference theory is also demonstrated by the estimated willingness-to-pay increasing with increased improvement of the qualitative attributes (for instance, with regard to wildlife effects).

5.3 Heterogeneous Preferences

One important factor that may determine one's attitudes to renewable energy projects is where one lives, in particular whether one lives in the countryside or not. A way of testing this in our survey is to examine whether there is a statistical difference between rural and urban estimated MNL coefficients and implicit prices. To do this, the sample was partitioned according to place of residence as disclosed in the questionnaire. The sample population was thus segregated into two groups, those located in villages or the countryside and those who reside in towns and cities. Separate MNL models were then run for each group (Table 4). A likelihood ratio test rejected the null hypothesis that the segregated subsets were equal at the 5% level. Moderate landscape impacts now register as significant in the rural model, as do jobs. Jobs remain insignificant in the urban sample, but become strongly significant in the rural model: this is perhaps unsurprising given most peoples' likely expectations about where jobs would be created. Note that the McFadden pseudo-R2 for the rural subset has increased to 0.34 from the 0.29 level with the complete sample.

Another reason why attitudes towards renewable energy investments might vary across people is their income: either because environmental concern is a "luxury" (Hokby and Soderqvist, 2003), or because rising energy prices hit poorer households disproportionately hard. To test this hypothesis, the sample was split by annual household income level into two subsamples: low income (£16,000 or less per year) and higher income (greater than £16,000 per year). The log-likelihood ratio test failed to reject the null hypothesis that the two subsets were equivalent to the complete sample set: there are no significant differences in preferences therefore between these two income groups.

6. Welfare Analysis for Alternative Investment Plans

One of the strengths of CEs is that estimated coefficients of the attributes maybe used to estimate the economic value of different ways in which the attributes can be combined. In the context of this paper, alternative renewable energy investments may be compared in terms of the welfare changes that they are associated with. To determine the change in economic surplus from possible alternative projects in a multi-attribute MNL model, a "utility difference" is calculated as

$$enonomics\ surplus = -(1/\beta_{monetary})(V_i^1 - V_i^2), \quad (6)$$

where V_i is the conditional indirect utility associated with alternative i. The superscript 1 is the base case-here defined as an expansion of an existing fossil fuel power plant-and superscript 2 is the alternative renewable energy case (Bennett and Blamey, 2001). Four different energy project scenarios were considered:

- Large off-shore windmill farm: a 200 MW, 100 turbines each at 80 m nacelle hub height, 6–10 km from shore.
- Large on-shore windmill farm: 160 MW, 80 turbines each at 80 m nacelle hub height.
- Moderate windmill farm: 50 MW, 30 turbines each at 60 m nacelle hub height.
- Biomass power plant: 25 MW, emissions stack height up to 40 m, portions of building up to 30 m, fuelled by energy crops.

Table 5 gives results for the welfare change of each investment scenario relative to the case, using Equation (6).

The above values can be interpreted as the price that households are willing-to-pay (or would have to be offered in compensation in case B) on an annual basis to have renewable energy projects with the indicated attribute levels, rather than the base case expansion of fossil fuel power. These Scottish households place the greatest value on off-shore wind farms, with the major determinant of the prospective welfare change being the absence of landscape impacts. This result matches with prior public opinion research in Scotland (Scottish Executive, 2003). The next most valued type of energy project is biomass generation. The major determinant for this type of project being highly valued is the amount of employment that is associated with plant operation and agricultural production of the energy crops; and with the wildlife benefits associated with this expansion in biomass production. Most significant of the results presented in Table 5 are the large and substantial negative value placed on large on-shore wind farms by our sample households in Scotland. The high level of landscape intrusion and the low amount of other beneficial attributes make the promotion and construction of large-scale windmill farms a poor social welfare choice, other things being equal. The negative monetary value indicates that households would have to be compensated in excess of £19 per year for the construction of this type of project, if their utility is to be held constant.

It is important, however, to note several caveats. These alternative projects do not produce the same amount of electric power. As an example, two moderately sized wind farms would have to be constructed to generate similar quantities of electricity each year as a biomass generating plant. Quantifying the cumulative effect of numerous projects being constructed in a region is, however, beyond the scope of this paper.

7. Conclusions

Renewable energy offers a partial solution to the problem of reducing greenhouse gas emissions whilst meeting future energy needs. Yet different renewable energy projects can have varying external costs in terms of impacts on the landscape, wildlife and air pollution. In addition, strategies vary in their likely impacts on jobs and electricity prices. The choice experiment method used in this paper enables these effects to be jointly evaluated in wel-

Table 4. Implicit prices of attributes comparing rural, urban and all respondents

Model: attributes only (standard error and 95% confidence intervals) Full sample set Descriptor	Rural subset Implicit price (£)	Urban subset Implicit price (£)	Implicit price (£)
Moderate Landscape	**4.07**(2.99) (–1.79–9.93)	**12.15****(6.3) (–0.196–24.5)	**0.50**(3.31) (–5.99–6.98)
Low Landscape	**3.21** (3.56) (–3.77–10.19)	**–5.68** (7.09) (–19.58–8.20)	**7.15** (4.03) (–0.74–15.04)
None Landscape	**7.88*** (1.94) (4.08–11.68)	**5.32** (3.32) (–1.18 to –11.83)	**8.73*** (2.41) (4.01–13.45)
None Wildlife	**5.51*** (2.18) (1.24–9.78)	**6.18** (3.71) (–1.08–13.45)	**4.43** (2.69) (–0.83–9.70)
Improved Wildlife	**10.11*** (1.88) (6.43–13.79)	**15.23*** (3.16) (9.04–21.49)	**7.62*** (2.42) (2.87–12.36)
None Air pollution	**14.40*** (1.88) (10.72–18.08)	**19.08*** (3.73) (11.77–26.39)	**11.77*** (2.08) (7.70–15.85)
Employment	**0.23** (0.22) (–0.20–0.66)	**1.08*** (0.44) (0.20–1.95)	**–0.19** (0.26) (–0.69–0.32)
Log-likelihood	–509	–200	–290
No. of observations	836	349	475
Pseudo-R^2	0.29	0.34	0.27

*Significant at 1% level and **significant at 5% level. Bold indicates monetary implicit values.

Table 5. Welfare change for alternative energy projects

Scenario	Base case Fossil fuel power station expansion	A Large off-shore wind farm	B Large on-shore wind farm	C Small on-shore wind farm	D Biomass power plant
Attribute levels					
Landscape	Low	None	High	Moderate	Moderate
Wildlife	None	None	None	None	Improve
Air pollution	Increase	None	None	None	Increase
Employment	+2	+5	+4	+1	+70
Welfare change (£/hsld/yr)		+£6.60	–£19.40	+£2.40	+£4.60

fare-consistent terms. This enables conclusions to be drawn about the net social benefits of different renewables investment strategies.

Reviewing our main results, we found a substantial sensitivity to the creation of projects that will have a high impact on landscapes. Conversely, there seems to be no sensitivity, or at least no positive mean willingness-to-pay, to reduce landscape impacts if the projects are designed to have moderate or low levels of landscape effects. Wildlife is highly valued by our sample group and avoiding impacts on wildlife comes out as being as important as avoiding impacts on landscape. The implicit price to maintain a neutral impact on wildlife is 75% of the price households would pay to reduce landscape impacts from high to none. Any project that creates the potential to harm wildlife thus needs to have large offsetting benefits. The converse of this is the growing of coppiced willow as biomass for use in energy production is expected to create greater bio-diversity on farmland. Our results show that such increases in wildlife attract a high economic value. We have not included benefits related to the carbon sequestration function of biomass growth, but this might be an important part of the overall case for promoting biomass generation. Conversely, avoiding air pollution from renewable energy investments was highly valued by our respondents. This would add to the case against burning biomass for power.

Investing in renewable energy might well result, at least over the short to medium term, in an increase in electricity prices. Our results show that, unsurprisingly, increases in prices reduce consumer utility, since the coefficient on price in all of our models is negative and significant. However, we do not find in the survey sample that income groups differ in their preferences towards renewable energy. However, this study did not have a sufficiently large sample to test for those households near the 'energy poverty' level. This is an issue for further research.

Turning to spatial issues, there are important differences between urban and rural responses in this choice experiment. There is some evidence that accepting negative environmental impacts from the development of projects (e.g. landscape impacts) is more acceptable to the rural population: the rural sample show no willingness-to-pay for reducing landscape impacts from high to none. Conversely, rural people value wildlife benefits and reductions in air pollution more highly than their urban cousins (this latter may be due to a perception that biomass combustion was more likely in rural areas, i.e., close to the supply of such material). Finally, we found that employment creation is a statistically and economically significant attribute to the rural sample, but not to the urban sample. Rural respondents would be willing-to-pay an additional £1.08 per year from each household for each additional full time job created by the renewable projects.

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