Marine trade-offs: comparing the benefits of off-shore wind farms and marine protected areas

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Abstract:

The drive to increase renewable electricity production in many parts of Europe has led to an increasing concentration of location of new sites at sea. This results in a range of environmental impacts which should be taken into account in a benefit-cost analysis of such proposal. In this paper, we use choice modelling to investigate the relative gains and losses from siting new windfarms off the coast of Estonia, relative to the option of creating a new marine protected area. Methodologically, the paper makes a contribution by showing the ability of the latent class mixed logit model to represent both within-and between-class preference heterogeneity, and thus its power to provide a more sophisticated representation of preference heterogeneity than latent class or mixed logit approaches. The paper is also the first to use the latent class mixed logit in willingness-to-pay space for environmental goods.

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Highlights:

- We analyse the trade-offs between wind energy production and the designation of marine protected areas in Estonia
- Discrete choice modelling is used to estimate the relative welfare effects of 3 design options in two locations
- A methodological enhancement to choice modelling is introduced, namely the latent class mixed logit model in willingness to pay space
- The model shows distinct preference heterogeneity both within and between latent classes of respondents
- On average, people prefer "eco" windfarms to conventional windfarms or marine protected areas

Keywords: discrete choice experiment, off-shore wind energy, marine protected areas, willingness to pay, renewable energy

JEL classification: Q51, O13, Q56, Q58, Q42, Q48, Q25, Q28

1. Introduction

European climate and energy policies require both the reduction of member states' emissions of CO_2 and an increase in the share of renewables in their energy mix (Böhringer *et al.*, 2009). One of the means of moving towards the achievement of such targets is through utilizing wind energy, especially in countries with relatively lower solar or hydro energy potential. Because wind turbines require space and are often contested by local inhabitants due to noise and visual dis-amenity (Meyerhoff *et al.*, 2010), there is a growing interest in locating new windfarms off-shore, away from inhabited areas, although economic valuation studies show both support for and opposition towards off-shore renewable installations (Ladenburg, 2010; Krueger *et al.*, 2011). Such preferences for and against particular renewable technologies and locations for such technologies (Bergmann *et al.*, 2008) needs to be seen in the context of a general overall support for the development of renewable energy sources, and wind power in particular, by the general public (Kosenius and Ollikainen, 2013).

Any new investment in off-shore wind energy is thus likely to give rise to both economic benefits (for those who support the expansion of renewables in this way, along with the value of electricity produced and the savings in CO_2 and other pollutant emissions), and economic costs to those who oppose specific investments. The balance of benefits and costs is likely to be highly case-specific. However, a further complication arises from the potential choice between designating an area of the sea for renewable energy investments relative to designating the same area as a Marine Protected Area, which could exclude such investments. MPAs are now seen as an important tool of ecosystem-based marine spatial management that can be employed to maintain marine ecosystems in a healthy, productive and resilient condition by balancing the increasing diversity and intensity of human activities with the sea's ability to provide ecosystem services (Olsen *et al.*, 2013). A number of empirical studies report respondents' positive willingness to pay (WTP) for establishing marine protected areas (MPA), typically with preferences for more stringent restrictions on allowed uses of these areas (Wallmo and Edwards, 2008; Gillespie and Bennett, 2010; Wattage *et al.*, 2011; Aanesen *et al.*, 2015). EU law does not compel the use of cost-benefit approaches in the designation of MPAs, but economists would argue that such evidence is a useful input to the policy process (Hanley *et al.*, 2014).

In the case of marine shoals (sand banks and reefs), wind farms and marine areas protection are competing uses of these scarce resources. On the one hand, such sites provide a good opportunity for installing wind turbines, and on the other they are typically ecologically valuable, e.g., providing rich spawning areas for fish and good habitat for bird and mammal species. Siting wind farms in such areas can damage their ecological quality.

In this study we apply stated preference methods to investigate the general public's preferences for developing Estonian shoals into marine protected areas, wind farms, or "eco wind farms" (wind farms which are built with increased care for the environment and which include environmentally-friendly characteristics: Westerberg *et al.*, 2013). On the one hand, the installation of off-shore wind farms would contribute to Estonia's energy security and potentially reduce the environmental impacts caused in particular by the use of oil shale for energy production. On the other hand, the installation of off-shore wind farms could cause negative impacts on the marine environment, although knowledge about these impacts is limited (see, for example, the limited literature on the effects of wind farm construction on sea birds: Furness *et al.*, 2013).[4]

In this paper we provide evidence about how the general public is impacted in economic terms by alternative uses (renewable energy and biodiversity conservation) of these marine areas. Results from a choice modelling exercise are then used to estimate the benefits of alternative scenarios for the development or protection of a specific coastal area in Estonia. The paper is organized as follows. In Section 2 we describe the study location as well as the design and implementation of the survey. Section 3 introduces the econometric approach used, namely the latent class mixed logit model. We present the results in Section 4, including the estimated welfare changes resulting from implementing a particular policy. Section 5 summarizes and concludes.

2. Empirical study

2.1. The study site

Our empirical investigation concerns shallow marine areas north-west of Hiiumaa island in Estonia (Figure 1). Hiiumaa is Estonia's second-largest island, situated on the west part of Estonian archipelago and the shoals are situated 15-25 kilometers north of the island. These shoals are ecologically valuable because of the reef and sandbank habitats present in some areas. Both reef and sandbanks habitats are represented on

[4] Research shows mixed impacts on marine mammals from off-shore wind turbines. Noise pollution from the construction process is likely to have negative effects on seals and cetaceans; but once constructed, wind turbines provide a habitat enhancement through the creation of artificial reefs. No-fishing regulations around windfarms also benefit marine mammals.

both of the shoals, but there are relatively more sandbank habitats on the Apollo shoal (8% of the area of the shoal) and relatively more reef habitats on the Western shoal (30% of the area of the shoals). Reef habitats are relatively rare in the Baltic and they are biodiversity hot spots. The most important shoal from a seabird perspective is the Apollo. It provides a habitat for many bird species, including the long-tailed duck. The long-tailed duck is the most numerous wintering water bird in Estonia. However, their numbers have been in decline (for example, from 1993 to 2007 numbers of long-tailed duck in Baltic Sea region decreased by 65%). For this reason, it has been proposed to develop Apollo differently from the rest of shoals.

The shoals are currently to a large extent undisturbed, however, a wind energy developer is planning to construct wind energy farms there. In total, approximately 200 wind turbines could be erected on all of the shoals. This investment would increase Estonian energy security – the annual electricity production there could reach as much as 22% of Estonian total electricity production in 2011. It could also have environmental benefits – even though Estonia has already reached the EU target of 20% of energy coming from renewable sources by 2020, the main source of energy is still oil shale which is causing several environmental problems such as the necessity to store dangerous waste, conventional pollutants and greenhouse gases emissions, pollution of water, and the decline of ground water levels during oil shale extraction. Increasing the share of renewable energy sources in the national energy mix could thus help with these problems. On the other hand, construction of the wind farm would cause temporary but major pressures on the marine environment of Hiiumaa shoals. This means that bottom habitats would be strongly affected during construction; marine mammals, fish and birds would all be disturbed. During the operation phase, the impact on marine life is unclear. However, use of the shoals by birds in the event of significant wind turbine construction would probably be limited.

In response to the plans of building the wind farm it has been proposed to establish marine protected area on Apollo shoal. Currently about 27% of marine waters in Estonia are under some form of regulated use (i.e. no fishing, mining or installation of wind turbines is allowed). If the shoals were designated as marine protected areas, this would allow marine mammals, birds and fish to thrive in these areas and conserve their habitats. Finally, some of the development plans include building an "eco wind farm" – essentially a wind farm which would strive to minimize environmental pressures. The wind turbines would be located in areas where valuable bottom habitats are not present. The number of wind turbines would decrease while the power capacity of each turbine would increase allowing the production of the same amount of electricity with an expanded space for birds. The producer would also have to use the best available techniques in order to minimize the effects on the environment both during construction and operation phase. This environmentally-friendly windfarm development is used as a third option alongside the setting up of a new marine protected area and the construction of a conventional and thus less-environmentally-friendly offshore windfarm in the stated preference exercise reported below.

2.2. Experimental design

Stated preference methods are now widely used as a method to estimate the economic benefits and costs associated with environmental change (Hanley and Barbier, 2009). One of the more common stated preference methods is known as contingent valuation, where respondents are asked to state their maximum willingness to pay for an environmental improvement, or maximum willingness to pay to avoid an environmental degradation. Willingness to Accept Compensation measures can also be used. In the contingent valuation study reported below, we utilized the discrete choice experiment method to elicit peoples' preferences and their willingness to pay for the support of different development options of the shoals (Carson and Czajkowski, 2014). The development options under consideration for the Apollo and the Western Shoals included a 'status quo' (no change over present) alternative, a marine protected area (MPA), a new off-shore windfarm (WF) as well as the eco windfarm option (ECO-WF). Table 1 provides a summary of the attributes and attributes levels.

Participants of the survey were provided with objective scientific information about economic uses and the ecological importance of the shoals. After they were familiarized with the current situation, we asked them to participate in a discrete choice experiment which elicited their preferences for each of the development options. The choice tasks included the status quo (no change) and two other alternatives, representing potential development scenarios and the associated cost. The experimental design was generated to minimize the D-error of a multinomial logit (MNL) model, using Bayesian priors obtained in a pilot study, and was updated during data collection. Each respondent was presented with 12 choice tasks. An example of a choice card is provided in Figure 2. The survey was developed in 2012-2013 in close cooperation with marine scientists, environmental organisations and the off-shore wind energy developer. The survey went through a thorough pretesting process, including the use of verbal "think-out-loud" protocols, consultations with stakeholders and a pilot study administered to a random sample of 100 respondents. The questionnaire was available in Estonian or Russian.

2.3. Data collection

The main data collection took place in August 2013. The survey was administered using computer-assisted web interviews to a representative sample of 700 adult citizens of Estonia. Since there were no changes needed in the contingent scenario, descriptions or attributes and their levels for the main survey, the observations from 100 respondents obtained in the pilot were included in the main survey dataset which was used for analysis. The overall sample was quota-controlled for gender, age, nationality and place of residence. Table 2 presents the comparison of the characteristics between the sample and the target population and illustrates that the sample can be considered representative.[5]

3. Econometric approach

In what follows we infer respondents' preferences from the choices they made in the choice experiment. Theoretical foundations for quantitative modelling of consumers' utility functions are provided by the random utility theory (McFadden, 1974). Simple applications of this approach (e.g., the multinomial logit model) assume all individuals have the same preferences. More elaborate methods allow for unobserved preference heterogeneity in the form of membership in latent classes of preferences (the latent class multinomial logit model), or else allow parameters of respondents' utility functions to be random and to follow particular parametric distributions (the mixed logit model). We combine these two approaches by allowing the population's utility function parameters to come from latent groups of random parameters, known as a Latent Class Mixed Logit (LCMXL) model.

The LCMXL allows for both segmentation of respondents into classes with similar preferences, and unobserved preference heterogeneity *within* these classes, the latter introduced via random parameters. The model is relatively new and so far has rarely been used. It allows for highly flexible, possibly multi-modal distribution of respondents' preferences. It permits more flexibility in representing preference heterogeneity than the standard latent class model or the mixed logit model. Greene and Hensher (2012) apply LCMXL to analyze preferences for freight distribution trips and Xiong and Mannering (2013) use it to investigate the influence of guardian supervising on adolescent drivers' car crashes. Hess *et al.* (2013), Yoo and Ready (2014), and Campbell *et al.* (2014) use the LCMXL model to investigate attribute non-attendance by constraining parameters associated with specific attributes to zero in some of the latent classes.

[5] Internet coverage in Estonia was estimated at 80% in December 2013, indicating that the web-based administration of the survey is not a major source of error (for comparison, the EU average in the same period was 76.5%).

Formally, in the LCMXL model individual i 's utility resulting from choosing the alternative j at choice occasion t, conditional on individual *i* belonging to class *c* out of *C* classes can be expressed as:

$$V_{ijt}^{c} = a_i^c p_{ijt} + \mathbf{b}_i^{c\prime} \mathbf{X}_{ijt} + e_{ijt}^{c}, \qquad (1)$$

where the utility expression is separable in price, p_{ijt}, and other non-price attributes, $\mathbf{X}_{ijt}$, a and $\mathbf{b}$ are the associated parameters and e_{ijt}^{c} is a stochastic component allowing for other factors than those observed by an econometrician to affect individuals' utility and choices.

Two things in the above specification need to be noted. First of all, a_i^c and $\mathbf{b}_i^c$ are individual-specific, thus the index *c* seems to be irrelevant as every respondent belongs to only one class. However, the researcher does not know to which class each individual belongs, so a probabilistic framework is applied which assumes that every respondent belongs to every class with some probability which has to be estimated. These probabilities describe *between*-class heterogeneity, while a_i^c and $\mathbf{b}_i^c$ represent *within*- class heterogeneity.[6] Secondly, the stochastic component of the utility function (e_{ijt}^{c}) is of unknown, possibly heteroskedastic variance $\left(\operatorname{var}\left(e_{ijt}^{c}\right) = (s_i^c)^2\right)$, which can also differ between classes for a given individual. Identification of the model is typically assured by normalizing this variance, such that the error term $\varepsilon_{ijt}^{c} = e_{ijt}^{c}\, \pi \big/ \left(\sqrt{6} s_i^c\right)$ is identically and independently extreme value type one distributed (with constant variance $\operatorname{var}\left(\varepsilon_{ijt}^{c}\right) = \pi^2 \big/ 6$), leading to the following specification:

$$U_{ijt}^{c} = \sigma_i^c a_i^c p_{ijt} + \sigma_i^c \mathbf{b}_i^{c\prime} \mathbf{X}_{ijt} + \varepsilon_{ijt}^{c}. \qquad (2)$$

Note that due to the ordinal nature of utility, this specification still represents the same preferences as in (1). The estimates $\sigma_i^c a_i^c$ and $\sigma_i^c \boldsymbol{b}_i^c$ do not have direct interpretation anyway, but if interpreted in relation to each other the scale coefficient ($\sigma_i^c = \pi \big/ \left(\sqrt{6} s_i^c\right)$) cancels out.

[6] It is typically assumed that individual parameters in each class follow particular parametric distributions (possibly multivariate distribution, allowing for non-zero correlations of model parameters). Assuming that the parameters are the same for all respondents in a class leads to the basic latent class multinomial logit model (LCMNL).

Finally, given the interest in establishing estimates of WTP for the non-monetary attributes $\boldsymbol{X}_{njt}$, it is convenient to introduce the following modification which is equivalent to using a money-metric utility function:

$$U_{ijt}^{c} = \sigma_i^c a_i^c \left(p_{ijt} + \frac{\mathbf{b}_i^{c\,\prime}}{a_i^c} \mathbf{X}_{ijt} \right) + \varepsilon_{ijt}^{c} = \sigma_i^c a_i^c \left(p_{ijt} + \boldsymbol{\beta}_i^{c\prime} \mathbf{X}_{ijt} \right) + \varepsilon_{ijt}^{c}. \tag{3}$$

Note that under this specification (which is similar to WTP-space mixed logit: Train and Weeks, 2005), the vector of parameters $\boldsymbol{\beta}_i^c$ is now (1) scale-free so that (3) can be directly interpreted as a vector of implicit prices for the attributes $\boldsymbol{X}_{ijt}$. An additional advantage of this specification is that the econometrician is able to specify a particular distribution of WTP in a given class (by specifying the distribution of $\boldsymbol{\beta}_i^c$) rather than the distribution of the underlying taste parameters ($\boldsymbol{b}_i^c$).

An individual chooses alternative *j* if $U_{ijt}^c > U_{ijt}^c$, for all $k \neq j$, and therefore the probability of respondent's choices conditional of his membership in class *c* is given by:

$$P(y_i \mid \mathbf{X}_i, \boldsymbol{\Omega}^c, class = c) = \int \prod_{t=1}^{T_i} \frac{\exp\left(\sigma_i^c a_i^c \left(p_{ijt} + \boldsymbol{\beta}_i^{c\prime} \mathbf{X}_{ijt} \right) \right)}{\sum_{k=1}^{C} \exp\left(\sigma_i^c a_i^c \left(p_{ikt} + \boldsymbol{\beta}_i^{c\prime} \mathbf{X}_{ikt} \right) \right)} d(a_i^c, \boldsymbol{\beta}_i^c), \tag{4}$$

where $\boldsymbol{\Omega}^c$ contains all parameters which define $\boldsymbol{\beta}_i^c$ and a_i^c distributions. The $\boldsymbol{\beta}_i^c$ and a_i^c are not directly observed in data, so they have to be integrated out to obtain an unconditional probability. The probability of respondent *i* being a member of class *c* is given by the logit formula[7]:

$$\pi_c = \frac{\exp\left(\boldsymbol{\theta}_c' \mathbf{Z}_i \right)}{1 + \sum_{k=1}^{C-1} \exp\left(\boldsymbol{\theta}_k' \mathbf{Z}_i \right)}, \tag{5}$$

[7] For $c = 1, \ldots, C-1$. π_C is defined so that $\sum_{c=1}^{C} \pi_c = 1$.

where $\mathbf{Z_i}$ is a vector containing a constant and possibly other explanatory variables of class membership, such as respondents' socio-demographic characteristics. This leads, finally, to the following formula for the probability of observing individual *i*'s choices y_i:

$$P(y_i \mid \mathbf{X}_i, \mathbf{Z_i}, \mathbf{\Omega}) = \sum_{c=1}^{C} \pi_c P\left(y_i \mid \mathbf{X}_i, \mathbf{\Omega}^c, class = c\right), \tag{6}$$

where $\mathbf{\Omega}$ contains all parameters associated with $\mathbf{\Omega}^c$ and $\boldsymbol{\theta}_c$.

The model can be estimated using the maximum likelihood method. Since there is no closed form solution to the multiple integral provided in (4), simulation-based optimization methods must be used.

4. Results

We now apply the model described in the previous section to the discrete choice data collected in our empirical study in order to gain an insight into respondents' preferences and whether we are able to identify distinct groups of respondents who are similar with respect to their preferences. Overall, this exercise provides an overview of the social preferences for marine protected areas compared to wind farms, using the Estonian shoals as the case study.

Table 3 presents the estimation results of the LCMXL model[8,9] – the estimates of utility function coefficients (means and standard deviations of normally distributed parameters) are shown for each of the three latent classes of preferences.[10] Since the model was estimated in WTP-space, the coefficients can readily be interpreted as the respondents' marginal willingness to pay for the program attributes. Overall, the model exhibits a very good fit to the data. We found that this specification outperformed other models, such as the latent class model with non-random parameters and the mixed logit model with or without

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[8] The model was estimated using custom code in Matlab. Translation of the original questionnaire, dataset and software codes are available online at czaj.org.

[9] The maximum likelihood function was simulated using 10,000 Sobol draws (_ENREF_6). As an aside, we found that using more draws for the simulation facilitated identification of the global maximum of the log-likelihood function more efficiently that using multiple starting points with only a few hundred draws (_ENREF_4).

[10] We also tried models with a different number of classes, the model presented here, however, provided the most reliable results both in terms of satisfying convergence criteria and interpretability of the results.

correlations, showing that the LCMXL specification provides a useful tool when distribution of respondents' preferences in the population is highly heterogeneous and possibly multi-modal.

The three latent preference classes we were able to identify can be conveniently interpreted with respect to what kind of policies respondents appreciate the most. The first major difference between the classes is the perception of the status quo (*SQ*). Respondents with class 1 preferences are generally dissatisfied with the status-quo policy (they would be WTP 2.06 EUR per year on average to change it), while class 2 respondents are happy with it (they would be WTP 1.56 EUR per year to retain the status quo), whilst class 3 respondents are indifferent (since the mean of the *SQ* parameter is not significantly different from zero). It is worth noting that there is a high variation with respect to how satisfied / dissatisfied with the current management policy respondents are, as shown by high standard deviations of the *SQ* with respect to their means.

With regard to willingness to pay for establishing marine protected areas, Class 1 respondents are the most keen on this change (shown by a WTP of 1.25 and 1.46 EUR for the Apollo and Western Shoals respectively). Their next-preferred option is an 'eco' wind farm on Apollo Shoal (0.76 EUR) and a conventional wind farm on the Western shoals (1.23 EUR). In contrast, Class 2 respondents are generally against establishing wind farms on any of the shoals (-3.30 and -6.14 EUR for Apollo and Western Shoals, respectively) but they would be indifferent, on average, with respect to establishing 'eco' wind farms, and they do not approve of establishing a marine protected area in the Apollo shoals (WTP of -3.05 EUR). Class 3 respondents are somewhat similar to respondents represented by class 2 with respect to their perception of wind farms (-5.75 and -2.35 EUR, respectively), however, they seem to prefer establishing an 'eco' wind farm on Apollo Shoal (0.71 EUR) and a marine protected area in the Western Shoals (1.50 EUR).

The results described in the preceding paragraph concern the means of the distributions of WTP for each of the attribute in each class. It is worth noting, however, that there is also significant and relatively large preference heterogeneity *within* each class with respect to how the attributes are viewed. This can be seen by consulting the standard deviation column of parameters for each latent class. Furthermore, each respondent's preferences are represented with a class membership probability-weighted set of preferences for each of the three classes. To illustrate the extent of preference heterogeneity our model allows for, and the possible multi-modality of the distributions of individual-specific (posterior) WTP-space parameters we calculated these estimates for each of the choice attributes.[11] The kernel densities of the marginal WTP distributions are provided in Figure 3. These results demonstrate that the model indeed allows for a very

[11] This is possible by combining the information about the overall distribution of preferences in the population with the knowledge of each respondent's choices using Bayes' formula.

large extent of preference heterogeneity, and possibly multi-modal distributions of posterior estimates of individual-specific preference parameters (WTPs). Interestingly, the results also show that for most attributes, there are conflicting views. There are groups of respondents who value them positively, as well as groups who would not want to see a policy implemented.

Finally, in order to provide clearer policy recommendations, we simulated the aggregate non-market net benefits associated with three policy options:

(1) converting all the shoals into marine protected area;

(2) establishing conventional wind farms in each location; and

(3) establishing 'eco' wind farms in each location.

To do this, we took 10^7 draws from the multivariate normal distribution described by the coefficients estimated and their associated variance-covariance matrix. For each set of parameters (i.e., each draw) we calculated the welfare measures associated with the policy options. The results are presented in Table 4. The results show that developing the Estonian Shoals into 'Eco' Wind Farms would provide the highest non-market benefits of on average 4.65 EUR per year per household. Such a policy would also constitute an improvement with respect to the status quo.

5. Summary and Conclusions

Many countries world-wide face the dual needs of expanding the fraction of electricity generated from renewable energy, and cutting greenhouse gas emissions. Wind power has been a major element of the increase in renewable energy capacity in Europe, but the siting of new wind farms creates economic costs in terms of dis-amenity and effects on wildlife. The move to site new wind capacity off-shore changes and shifts these land-based externalities spatially, but does not avoid them. Moreover, such investments create trade-off situations where governments must evaluate the relative environmental and economic benefits and costs of new off-shore wind farms against other policy options such as the creation of marine protected areas.

In this paper, we use choice modelling to investigate the relative gains and losses from siting new windfarms off the coast of Estonia, relative to the option of creating a new marine protected area. The focus is on shoals which are high biodiversity locations, but also locations of high potential for wind energy. A finding which emerges is that citizens prefer environmentally-friendly new windfarms to new marine protected areas being designated, but would also be willing to pay to avoid the siting of conventional windfarms in these shoals. Considerable differences also emerge in the willingness to pay for each of these three options between the two areas within the case study site, namely the Apollo and Western Shoals, as may be seen by comparing the mean WTP estimates in Table 3 and the distributions of WTP values shown in Figure 3.

Since many governments incentivize new wind energy investments in a way which leads developers to prefer locations and designs which maximize private returns, it is unlikely that the market-driven investment outcome would be in accord with the ranking of options shown in Table 4 in terms of welfare change. Thus, the government would need to re-align incentives such as feed-in tariffs or green certificates, or add additional planning restrictions, for the environmentally-friendly" option to be also that preferred by developers. Moreover, designation of marine protected areas comes at an economic cost to producers whose activities are thus restricted (e.g., energy firms, fisherman, oil and gas firms). Such costs would need to be weighed against the benefits to citizens from MPA creation in order to determine which action maximizes net social benefits over time. That is not a comparison we were able to make in this paper.

Methodologically, the paper makes a contribution by showing the ability of the latent class mixed logit model to represent both within-and between-class preference heterogeneity, and thus its power to provide a more sophisticated representation of preference heterogeneity than latent class or mixed logit approaches. The paper is also the first to use the latent class mixed logit in willingness-to-pay space for environmental goods. This is valuable since researchers have long argued that willingness-to-pay space models have several advantages over preference space models in the context of simpler mixed logit approaches.

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Table 1. Attributes and attribute levels used in the discrete choice experiment

Attribute	Attribute level	Description
Apollo shoal	*A-SQ*	No change, status quo is maintained (reference level)
	A-MPA	Establishing a marine protected area
	A-WF	Developing a wind farm
	A-ECO-WF	Developing an 'environmentally friendly' wind farm
Western shoals	*W-SQ*	Status quo is maintained (reference level)
	W-MPA	Establishing a marine protected area
	W-WF	Developing a wind farm
	W-ECO-WF	Developing an 'environmentally friendly' wind farm
Cost	0 (SQ alternative only), 2, 5, 10, 20	Annual cost to each Estonian household (EUR per year)

Table 2. The comparison of sample and target population characteristics

	Sample	**Target population**
Male	46.0%	46.4%
Age 15-34	34.0%	34.2%
Age 35-49	27.0%	26.8%
Age 50-74	39.0%	39.0%
Nationality – Estonian	67.4%	68.3%
Nationality – non-Estonian	32.6%	31.7%
Residence – North Estonia	43.0%	43.2%
Residence – West Estonia	11.0%	11.2%
Residence – Central Estonia	10.0%	9.6%
Residence – North-East Estonia	11.0%	11.4%
Residence – South Estonia	25.0%	24.6%
Total	800 respondents	1 300 000 citizens

Table 3. The results of the latent class mixed logit (LCMXL) model used to investigate preferences for developing Estonian shoals into marine protected areas or wind farms; the model was estimated in WTP-space – coefficients can be interpreted as marginal WTPs in EUR

	Latent class 1		**Latent class 2**		**Latent class 3**	
Preference parameters						
	mean	**st. dev.**	**mean**	**st. dev.**	**mean**	**st. dev.**
Maintaining the status quo (***SQ***)	-2.0598***	10.9643***	1.5633**	2.0847***	-0.4883	2.4237***
	(0.5770)	(1.3589)	(0.6342)	(0.4626)	(0.3465)	(0.3701)
Marine Protected Area on Apollo Shoal (***A-MPA***)	1.2524***	0.6176***	-3.0545**	0.0152	-0.5163	3.0320***
	(0.1643)	(0.2673)	(1.5545)	(5.4415)	(0.3610)	(0.4646)
Wind Farm on Apollo Shoal (***A-WF***)	0.4129***	0.4201***	-3.3037***	0.0014	-5.7554***	0.9864**
	(0.1243)	(0.1883)	(1.1253)	(2.7963)	(0.6947)	(1.0006)
'Eco' Wind Farm on Apollo Shoal (***A-ECO-WF***)	0.7651***	0.0030	0.1419	0.4185***	0.7052**	2.4150***
	(0.1488)	(0.7130)	(0.2043)	(0.1871)	(0.2910)	(0.3038)
Marine Protected Area on Western Shoals (***W-MPA***)	1.4627***	0.1003	-3.8098	0.7686	1.4953***	1.6112***
	(0.1340)	(0.6403)	(2.4283)	(3.9884)	(0.3052)	(0.2970)
Wind Farm on Western Shoals (***W-WF***)	1.2325***	0.0002	-6.1435**	3.0870***	-2.3494***	3.9747***
	(0.1425)	(0.7925)	(2.5840)	(1.2036)	(0.4688)	(0.5454)
'Eco' Wind Farm on Western Shoals (***W-ECO-WF***)	0.6597***	0.2181	-0.2490	0.1739	0.0107	2.3697***
	(0.1286)	(0.2971)	(0.1482)	(0.2967)	(0.3579)	(0.2916)
Annual cost per household (***COST***)[12]	-0.7337***	0.9452***	1.6460***	1.4580***	-0.2449**	0.3022***
	(0.1002)	(0.1247)	(0.5461)	(0.5803)	(0.1064)	(0.1403)
Average class probabilities						
	0.4188		0.3288		0.2524	
Model characteristics						
Log-likelihood (constants only)			-9508.16			
Log-likelihood			-5901.28			
McFadden's pseudo-R^2			0.3794			
AIC/*n*			1.2399			
n (observations)			9600			
k (parameters)			50			

***, **, * Significance at 1%, 5%, 10% level, respectively; standard errors provided in parentheses

12 Preference space equivalent. Parameters of the underlying normal distribution are reported.

Table 4. Simulated welfare change associated with implementing a uniform policy (*Marine Protected Area*, *Conventional Wind Farm*, or *'Eco' Wind Farm*) on all of the shoals (values are EURO per year per household)

	Marine Protected Areas	*Conventional Wind Farms*	*ECO-Wind Farms*
mean (st.error)	2.3654 (1.1545)	-1.8234 (1.3529)	4.6539 (0.9519)
95% c.i.	(0.10 ; 4.63)	(-4.48 ; 0.83)	(2.79 ; 6.52)

Figure 1. Planned locations of off-shore wind energy farms or new marine protected areas on Hiiumaa shoals (marked yellow)

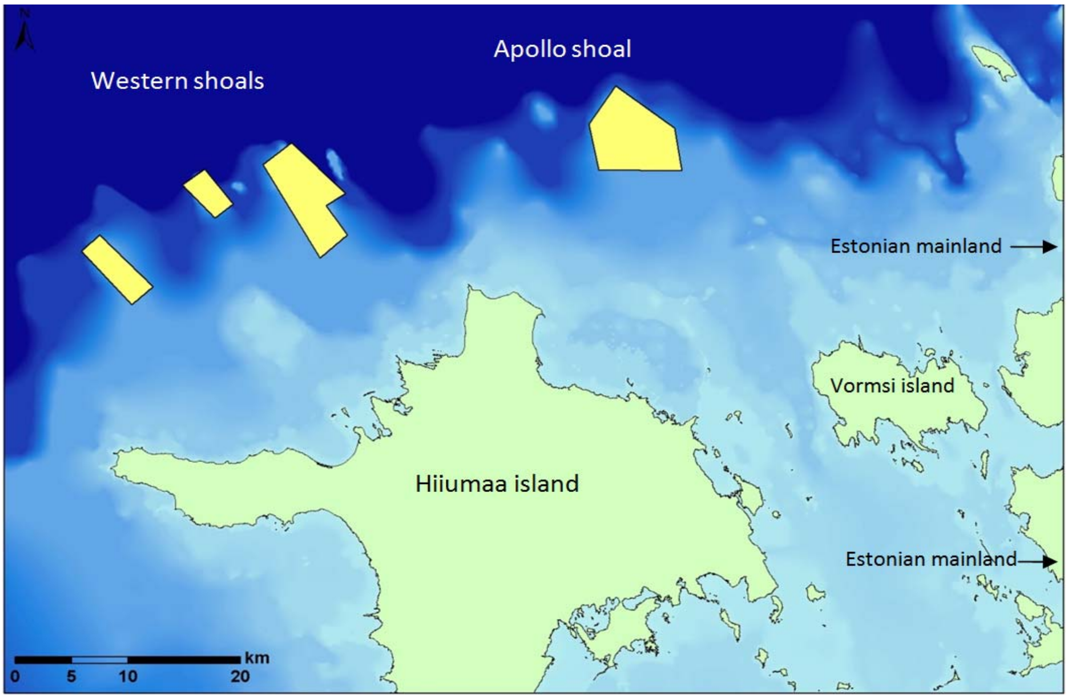

Figure 2. An example of a choice card (translation)

Please choose the alternative which is the most preferable for you:

	Status Quo	**Alternative A**	**Alternative B**
Apollo shoal	No change	ECO-WF	MPA
Western shoals	No change	WF	No change
Cost to your household (EUR per year)	0	10	5
YOUR CHOICE	☐	☐	☐

Figure 3. Kernel smoothing density function plots representing the distribution of individual-specific (posterior) preferences (mean WTP) for the policy attributes