Review

How Spatial Relationships Influence Economic Preferences for Wind Power—A Review

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Abstract: An increasing number of studies in the environmental and resource economic literature suggest that preferences for changes or improvements in environmental amenities, from water quality to recreation, are spatially heterogeneous. One of these effects in particular, distance decay, suggests that respondents exhibit a higher willingness to pay (WTP) the closer they live to a proposed environmental improvement and vice versa. The importance of spatial effects cannot be underestimated. Several of these studies find significant biases in aggregate WTP values, and therefore social welfare, from models that disregard spatial factors. This relationship between spatial aspects and preferences, however, remains largely ignored in the non-market valuation literature applied to valuing preferences for renewable energy, generally, and wind power, specifically. To our knowledge, fourteen peer-reviewed studies have been conducted to estimate stated preferences (SP) for onshore and/or offshore wind development, yet less than half of those utilize any measure to account for the relationship between spatial effects and preferences. Fewer still undertake more robust measures that account for these spatially dependent relationships, such as via GIS, outside incorporating a single 'distance' attribute within the choice experiment (CE) referenda. This paper first reviews the methodologies of the SP wind valuation studies that have integrated measure(s) to account for spatial effects. We then categorize these effects into three dimensions—distance to a proposed wind project, distance to existing wind project(s), and cumulative effects—supporting each with a discussion of significant findings, including those

found in the wind hedonic and acceptance literature. Policy implications that can be leveraged to maximize social welfare when siting future wind projects as well as recommendations for additional research to control for preference spatial heterogeneity in wind CEs are also posited.

Keywords: wind power; stated preference; revealed preference; spatial heterogeneity; distance decay; cumulative effects

1. Introduction

A cost-efficient transition to larger wind power capacities in the electricity generation mix requires prioritization of the least cost wind power locations. Accordingly, an energy planning authority's goal is to create a policy scheme to ensure costs are minimized relative to the generation output. This cost minimization problem involves the trade-off between, on one hand, exploiting the sites with best wind regimes, and on the other hand developing sites with the least costs given available technology. A simplified generation cost function (GCF) of wind power can therefore be defined as:

$$GCF = Cost_{\text{Turbine}} + Cost_{\text{Grid}} + Cost_{\text{Operation}} + Cost_{\text{External}} \tag{1}$$

where $Cost_{\text{Turbine}}$ is a function of the power capacity and type of the turbine, tower height and the foundation type, while $Cost_{\text{Grid}}$ is a function of the length and type of both (a) the inter-array (within wind farm) cabling; and (b) the cable to the grid as well as grid investments, such as transmission or substation upgrades [1]. The third element, $Cost_{\text{Operation}}$, or operation cost, includes the cost of turbine maintenance, upkeep, and repair [1]. Together, these cost components are spatially dependent upon the quality, speed and frequency of the wind resource in a given area. Accordingly, the choice of wind farm location and configuration or layout of a project's individual wind turbines affects the generation cost function. This spatial dependency is a function on the cost of wind power development at both a micro as well as macro level. The final component in the cost function is the external cost, which we will elaborate on in the section below.

External Costs

Depending on the location of wind turbines within projects and the locations of the wind farm relative to the grid, spatially induced external costs are likely to emerge on a micro and macro scale. The specific placement of wind turbines at a project scale in the vertical and horizontal dimensions can influence overall generation output and efficiency within the wind farm (micro scale). Vertically speaking, deployment of turbines with varying rotor diameters and hub heights in a single wind farm can reduce wake effects and turbulence, thereby improving generation efficiency [2–4]. Proximal obstructions (*i.e.*, natural ground cover, vegetation and/or the built environment) can negatively impact optimal wind characteristics depending on their physical magnitude and location relative to the project site. So, horizontally speaking, spatially dispersing wind turbines onshore, either to account for landscape restrictions or wake effects in both onshore and offshore settings, has also been found to increase efficiency [4,5].

On a macro scale, perhaps the strongest spatial driver of development, and subsequently costs, are the available wind resources across different locations. All else equal, this factor will result in a concentration of wind farms at locations with the highest average wind speed, which is optimal from an investor's point of view. However, though generation output is maximized, concentrating wind turbines in few locations might not be optimal from a welfare economics perspective due to external production costs associated with higher power production fluctuations and consequently a need for further investments in baseload capacity or storage. For example, using Germany and southern Iberian Peninsula as cases, Grothe and Schnieders [6] and Santos-Alamillos *et al.* [7], respectively, find that optimizing the spatial allocation of onshore and offshore wind projects (and individual turbines) can stabilize the generation output and in some cases contribute to baseload. Accordingly, by taking into account the spatial and geographic variation in wind resources in combination with leveraging existing grid connections, more optimal wind power deployment can be achieved.

In the same line of thinking, the distance to a stable grid is also a spatial driver when choosing locations to build wind projects. As argued in Rahmann and Palma-Behnke [8], locations with favorable wind regimes might be located in weak or challenged transmission areas, whereas less favorable wind regime locations might be near a stronger transmission area that is also close to load (demand) centers. In that case, the location with favorable wind conditions might exhibit higher generation costs relative to sites with less favorable wind conditions. In addition, adding an additional wind turbine at the margin to the generation portfolio could increase the need for investments in a stronger grid and potentially also backup generation capacity for periods with unfavorable wind conditions [9–11].

Finally, wind projects built in offshore environments face additional spatially induced considerations for expenditures. Initial capital investment costs, such as turbine foundations, installation and grid costs, increase linearly as distance from the shore increases but exponentially as water depths increase [12]. For example, holding distance from the shore constant, an increase in water depth from 10–20 m to 30–40 m increases investment costs by around 25% [12]. As greater distances from the shore are generally associated with increased water depths and deeper bathymetry, costs, therefore, can increase substantially if an attempt is made to site wind farms further offshore out of view.

These spatial relationships solely focus on generation and maximising the associated power production related to the technical inputs and characteristics of the generating units in the system. The energy planner could exclusively leverage these elements to identify the socially optimal locations for wind-powered electricity production. However, the spatial properties of wind power development are inherently not restricted to the technical aspects or investment decisions alone. Public preferences to deploy particular energy technologies often have nothing to do with the aforementioned cost generation considerations but can be significantly related to public appetites for electricity price premiums. As discussed in the reviews by Ladenburg *et al.* [13] and Ladenburg and Möller [14], the attitude toward and acceptance of wind power are significantly related to the spatial location of wind turbines relative to places of residence. Along the same line, Ladenburg [15] reviews and finds evidence that spatial interaction with energy sources influence preferences for different energy types. Furthermore, the vast literature on preferences for improvements in or amenities provided by the environment display significant spatial patterns which have an influence on both their distribution and supply (see, for example, the special issues in Resource and Energy Economics [16] and Ecological Economics [17]).

Incorporating spatial aspects can help explain preferences for environmental goods, broadly speaking, and renewable energy generation initiatives. The aim of the present article is, therefore, to review and discuss the findings of studies that estimate spatial relationships between individuals and their preferences for on- and offshore wind power, generally; consider preferences for the location of wind power projects, specifically; and detail how the results can be used in order to increase a cost efficient transition to increased wind generation capacities. These spatial issues related to preferences for onshore and offshore wind farms can be grouped around three core elements in the environmental economic literature and are related to distance dependency (travel distance) to the nearest existing wind project, distance dependency to the nearest proposed wind development, and cumulative daily exposure and impacts from wind turbines.

2. Spatial Methods Review: Stated Preferences for Onshore and Offshore Wind Farms

To the authors' knowledge, stated preferences for wind power development have been elicited through fourteen peer-reviewed choice experiment (CE) studies over the past decade. Of those, eight tested for spatial aspects either by including this dimension explicitly as an attribute within the CE or as a more discrete measure outside the CE (see Table 1). Those eight studies along with unpublished results from one analysis [18] and three graduate theses/dissertations [19–21] are summarized below with an emphasis on the spatial variables. For further methodology details on some of these peer-reviewed studies, see Ladenburg and Lutzeyer [22]. Although some of the following studies received low response rates, the main focus in this section is to overview both the experimental designs and the methods of estimation for spatial effects influencing stated preferences for wind power.

Table 1. Peer-reviewed choice experiment studies estimating stated preferences (SP) for onshore and offshore wind power. Adapted from Ladenburg and Dubgaard [23] and Strazzera *et al.* [24].

Study	Wind Project Location	CE Attributes	Attribute Levels	Significant WTP (€/year)	Significant Spatial Variables
Ek and Persson [25]	Onshore or offshore (30 turbines)	(1) Landscape; (2) ownership; (3) consultation; (4) 5% of annual revenue transfer to defined party	(1) Offshore, open/plains, mountains or forest; (2) state, municipality, private, or cooperative; (3) mandatory or extended; (4) municipality or local community	Mountainous area (−2.42), Offshore (2.59), Cooperative (0.65), Municipality (1.1), Private (−3.09), Earmarked (0.77), Extended consultation (0.32) [a]	N/A
Mariel *et al.* [26]	Onshore	(1) Decline in red kite population; (2) **minimum wind farm distance to residential areas;** (3) size of wind farm; (4) maximum turbine height	(1) 5%, 10% or 15%; (2) **750, 1100 or 1500 m;** (3) small, large or medium; (4) 110, 150 or 200 m	(LC Model, Class 3) (Small wind farm) 1.88; (Red low, high) 1.66, −2.14; (Minimum distance medium, high) 2.72, 2.85	**Minimum distance, medium and high (LC model, Class 3)**
Vecchiato [27]	Onshore or offshore	(1) Wind turbine location relative to plains baseline; (2) turbine height relative to 50 baseline; (3) no. of turbines per project; (4) **minimum distance from town center**	(1) Mountains/hills or sea; (2) 50, 120 or 200 m; (3) 4, 15 or 50; (4) **100, 250 or 1000 m**	N/A, 96.5; −29.4, N/A; −13.3, N/A; 47.1, 78	**Minimum distance from town center**
Westerberg *et al.* [28] *	Offshore (108 MW = 30 turbines)	(1) **Wind farm distance from shore;** (2) wind farm recreation opportunities; (3) adoption of local environmental policy	(1) **5, 8, 12 km**; (2) yes/no; (3) yes/no	(LC Model, Segment 1 aka Loyal LR tourists in WTP, [WTA]) WF 5, 8 & 12 km (−29.3, [8.8]; 24.1, [10.1]; 1.4, [4.2]), WF recreation opp. (21.9, [4.5]), Environmental policy (39.2, [2.7])	**Distance from shore; group of respondents live far from project and close to project in latent class model (discrete)**

Table 1. *Cont.*

Study	Wind Project Location	CE Attributes	Attribute Levels	Significant WTP (€/year)	Significant Spatial Variables
Ladenburg *et al.* [29] [b]	Offshore 500 MW (100 turbines)	(1) **Distance from shore relative to 8 km baseline**	(1) **12, 18, or 50 km**	18, 50 km (162, 275)	**Distance from shore**
Landry *et al.* [30] *	Offshore (3 MW turbines)	(1) No trip; (2) park fee; (3) congestion; (4) **location in ocean;** (5) **location in sound**	(3) medium or high; (4) **4 or 1 miles**; (5) **1 or 4 miles**	341.3, 12, N/A, 104.7, 102.5, N/A, N/A, N/A	**Location**
Strazzera *et al.* [24] [c]	Onshore	(1) beach SI and beach MC; (2) archeology impact (close to site, away from site); (3) property; (4) services	(1) well visible, not well visible, not visible; (2) close to site or away from site; (3) private, public regional, or public local; (4) no services, training, training and microcredit	(Willingness to accept) 166.45, 233.12, 165.91, 44.2	N/A
Krueger *et al.* [31]	Offshore (500 turbines)	**Distance from shore (0.9, 3.6, 6 or 9 miles)** in inland, bay, and ocean		Inland (18.9, 8.7, 0.8, 0); Bay (34.4, 11.1, 5.8, 2.1); Ocean (80.0, 68.8, 35.1, 26.6)	**Distance from shore**
Meyerhoff [32]	Onshore	Effect on red kite population (5%, 10%, 15% decline); **minimum wind farm distance to residential areas (750, 1100, 1500 m)**; size of wind farm (small, large, medium); maximum turbine height (110, 150, 200 m)		−6.24 and −5.52; 38.16 and 46.44; 45.72 and 51.72, N/A/, N/A	**Minimum distance to residential areas**

Table 1. *Cont.*

Study	Wind Project Location	CE Attributes	Attribute Levels	Significant WTP (€/year)	Significant Spatial Variables
Dimitropoulos and Kontoleon [33]	441 MW	(1) Number of turbines; (2) turbine height; (3) conservation status of the site; (4) participatory planning		18.7, −439.6, −718, −854.5	N/A
Ladenburg and Dubgaard [34]	Offshore, 3600 MW	(1) **Distance from shore relative to 8 km baseline**; (2) number of turbines; (3) total number of projects to be built	(1) **12, 18, or 50 km**	47, 98, 125, N/A, N/A	**Distance from shore**
Bergmann *et al.* [35]		(1) Landscape impacts; (2) wildlife impacts; (3) air pollution; (4) employment benefits		−12, 6, 20, N/A	N/A
Alvarez-Farizo and Hanley [36]		(1) Protection of an environmental feature	(1) cliffs, habitat and flora, or landscape	22, 38, 37	N/A
Ek [37]	Onshore and offshore	(1) Turbine location; (2) size of project in # of turbines; (3) sound impacts; (4) size of turbine	(1) mountains, onshore or offshore; (2) single, <20, 10–50	0, 12, 29, 10, 20, 0, N/A, N/A	N/A

Notes: * Denotes recreation study; [a] Presented in marginal WTP estimates in Öre/kWh; [b] Measured in marginal WTP/household/year in DKK; [c] The bid values were measured in willingness to accept (WTA).

2.1. Abay

Abay [19] is a master's thesis. Abay employed a web-based CE to estimate the relative preferences for onshore compared to offshore wind farms using location-specific settings. The distance was specifically tested both as an *onshore* attribute with two levels (0.5 or 1 km from the nearest residential area) and an *offshore* distance attribute with levels of 8, 12, 18, and 50 km from shore. In the choice scenario, 450 MW of wind power must be built either onshore or offshore. For onshore, the preamble stipulated that the power capacity would be built through municipal-scale projects (3 MW each) across 150 locations. If offshore, the power generation capacity would be built within a single 450 MW wind farm (containing 90, 5 MW turbines) in only one of 5 possible offshore locations. This CE design allows testing onshore and offshore specific attributes while holding the wind power development capacity fixed, allowing the scenario to be independent of "installed capacity demand effects" [22]. For onshore development, variables tested in addition to the distance attribute included size and number of turbines (1 × 3 MW, 2 × 1.5 MW and 4 × 750 kW) and number of residents in the nearest residential area (below 10, 11–100 or more than 100 persons). For offshore, a geographical location attribute for the proposed wind farm was also included in addition to the four offshore distances. The potential offshore sites in Denmark were Southeast (Bornholm and Moen), Northeast (Anholt), Northwest (Jammerbugten) or West (Vesterhavet). An included map showed the location and the size of the proposed and existing Danish offshore wind farms. The cost attribute was common for both onshore and offshore wind alternatives at a fixed, annual increase in the electricity bill (0, 50, 100, 300, 600 and 1200 DKK/household/year). Visualizations were included for both onshore and offshore wind farm alternatives. The sample of 2331 respondents was drawn as a quota on geography, gender and education, yielding in a response rate of 8.6%, not uncommon for web surveys.

2.2. Knapp et al.

Like Krueger *et al.* [31] and Ladenburg and Dubgaard [34], Knapp *et al.* [20] spatially elicited preferences by testing three offshore project locations: 4.8, 9.7, and 16.1 km (distances in the study were shown to respondents in miles at 3, 6 and 10, respectively). This CE was just one of a few to employ both WTP and WTA measures through a dichotomous choice of whether respondents would be supportive of the project with an opt-out alternative, similar to Westerberg *et al.* [28]. Data for this master's thesis was collected from a sample split in two coastal, Lake Michigan communities (USA) through a web-based survey. For each distance, respondents were shown corresponding visualizations of a 400 MW wind farm consisting of 80 turbines. Each choice question was followed with a 0–10 scale, prompting respondents to denote their certainty for each vote. Whereas one half of the sample (Michigan, response rate = 13%, *n* = 208) saw a randomized order of the visualizations, the other (Illinois, response rate = 7%, *n* = 122) saw each distance in ascending order starting with the 3-mile scenario. For the entire sample, pre-determined bid prices were randomly assigned to each respondent but remained internally constant across the three choice sets.

2.3. Krueger et al.

Using a CE, Krueger *et al.* [31] utilized distance from shore as the spatial attribute to estimate demand for reducing offshore wind farm visual disamenities. Specifically, the preamble stipulated a scenario in which a wind farm with 500 turbines was slated to be built 1.44, 5.76, 9.6, 14.4 km or too far to see from shore (the original distances are defined as 0.9, 3.6, 6 and 9 miles, respectively) depicted with corresponding visualizations at each of the five distances. Besides the distance attribute, the study also discretely accounted for spatial effects though stratification of the sample based on how close each household was located to the coast, and thus the site (and view) of the proposed wind farm. Respondents were geographically divided from closest to the furthest in the Ocean ($n = 182$), Bay ($n = 203$), and Inland ($n = 564$) samples. This geographic stratification compares preferences for respondents in the different stratum that are close and far from the wind farm, discretely capturing a spatial dimension through expected exposure to the wind farm. In addition, the choices designated the wind farm might be located off of one of three Delaware (USA) beaches (either Delaware, Rehoboth or Fenwick Beach)—another attribute capturing some element of spatial and possibly place-based characteristics. Three choice sets per respondent included one opt-out with two offshore development options. The opt-out informed respondents that fossil fuel (natural gas and coal) power would be increased and no wind farms would be developed offshore. Other attributes included a renewable energy fee on the ratepayer's monthly electricity bill up to three years (bids were 0, 1, 5, 10, 20 and 30 \$USD/month); the amount of a royalty payment from the project developer to a fund (1, 2 or 8 million \$USD); and the fund's purpose (beach nourishment, renewable energy development or general). This analysis received a high 52% response rate.

2.4. Ladenburg and Dubgaard

Ladenburg and Dubgaard [23,34] were the first economic valuation studies to address preferences for the reducing visual disamenities of offshore wind farms and were part of a larger study on offshore wind farms [38,39]. These studies tested the spatial attributes of offshore wind power locations as a distance attribute (12, 18 or 50 km relative to 8 km from the coast) and how the spatial location of offshore wind farms influence the preferences for the distance attribute (see later). The CE valuation scenario stipulated an increase of 3600 MW in power produced by offshore wind farms. Each respondent evaluated three choice sets consisting of two hypothetical wind farm layouts (varied in distance to shore as well as by the number of turbines per wind farm) with no opt-out alternative along with a fixed increase in the household electricity bill. In addition to the spatial dimension represented by the distance attribute, the researchers include a qualitative spatial variable in the form of whether or not an offshore wind farm was located in the respondents' residence or summerhouse view. Using visualizations of 5 MW turbines (the turbines had a 100 m nacelle and 60 m blades = 160 m in total), a wind farm at 50 km would not be visible from the coast, and the locations were not site specific. The other attributes in the CE were "wind farm size" and "total number of wind farms to be erected". In total, ($n = 375$) of 700 respondents that were initially randomly drawn from a national Danish Civil Registration System survey responded, equaling a 53.6% response rate.

2.5. Ladenburg et al.

Estimating WTP to reduce the visual disamenities of offshore wind farms in Denmark, Ladenburg *et al.* [29] only tested for spatial dimensions by included an attribute for an offshore wind farm's distance from shore. The authors also tested the effect of "Cheap Talk" [40,41], a method that has shown evidence in reducing hypothetical bias in stated preference studies. The wind farm scenario stipulated the development of 7 wind farms with 100, 5 MW turbines in each project, equaling a total capacity of 3500 MW to simulate the 3600 MW government target. For the proposed offshore wind development alternatives, the projects could be located at 12, 18 or 50 km from the coast, representing reductions in the visual impacts compared to the status quo projects. It was indicated that projects in this status quo alternative were located at 8 km from shore with no additional cost to the household, ensuring that the estimated demand to reduce visual disamenities would not be confounded with a general preference for wind energy (as is the case when the choice is given between a wind turbine alternative relative to a non-wind turbine alternative). At 50 km, a wind farm with 5 MW turbines (the turbines had a 100 m nacelle and 60 m blades = 160 m total) would not be visible from the coast. For the payment vehicle, an annual fixed increase in the household electricity bill was used of either 100, 400, 700 or 1400 Danish Kroner (DKK)/household/year, equaling 13.4, 53.7, 94 and 187.1 €/household/year. Respondents each faced a total of six choice sets; each included visualizations of the wind farm scenarios in addition to a map showing the location of existing offshore wind farms and the expected location of the proposed offshore wind farms. Respondents were randomly sampled from a nationwide, Danish internet panel consisting of approximately 17,000 people.

2.6. Ladenburg and Knapp

To the authors' knowledge, Ladenburg and Knapp [18] is the first analysis that estimated preferences for offshore wind farm locations by addressing the spatial relationship between the location of proposed offshore wind farms and the respondents' residences as well as the cumulative effects from the number of turbines seen. In addition, the study tested viewshed effects for onshore and offshore wind farms but found no significant results. Ladenburg and Knapp [18] employed the Cheap Talk (CT) data sample from Ladenburg *et al.* [29] (see Section 2.5). The properties of the study design are thus equivalent to Ladenburg *et al.* [29]. To obtain 350 respondents in both the CT sample, 619 respondents were e-mailed an invitation to participate in the survey. There were 338 respondents, equal to a response rate of 54.6%.

2.7. Landry et al.

Landry *et al.* [30] was one of the few recreational demand studies to estimate SP and changes in future beach visitation (*n* = 118) given an offshore wind farm was built adjacent to North Carolina beaches (USA). A spatial attribute for distance was included in the CE, prompting respondents to choose their trip at a site-generic beach with a wind farm located either in the Atlantic Ocean or in inland, sound waters. For the sound and ocean waters, the view varied in three dimensions in that it was either unobstructed with no wind turbines or had a wind farm sited either 1.6 or 6.4 km from shore (the distances were presented in the CE at distances of 1 and 4 miles, respectively). Other attributes included number of people for beach congestion, the travel distance to the beach from the respondent's

home, and a parking fee. The preamble scenario prompted respondents to complete six choice sets with corresponding visualizations of the ocean *vs.* sound views, each having three beach vacation options with an opt-out choice to stay home. The scenario did not stipulate the amount of generation (power capacity) to be built, the number of turbines and their specific location where they were to be erected, nor the specific places of the beaches.

2.8. Lutzeyer

Part of a Ph.D. thesis, Lutzyer [21] carried out both a General Population (GP) and a Vacation Rental (VR) study to garner preferences for offshore wind farms and their locations. The spatial attributes in both mail surveys included the number of turbines visible from shore (64, 100 and 144) and their distance to shore (5, 8, 12 and 18 miles). Both studies stipulated the development a 720 MW wind farm with 144, 5 MW turbines (measuring approximately 104 m to the nacelle with 69 m blades) and respondents were asked to rank the three alternatives in each of eight choice sets: two wind development alternatives and a status quo. Additional attributes included in the GP study included a CO_2 emission reduction equivalence (100,000; 200,000; 300,000; 400,000 and 500,000 cars), number of jobs created (500, 800, 1100 and 1400 jobs) and cost/addition to the electricity bill ($2, $5, $8, $12, $16, $20, $25 and $30 USD). Meanwhile, the objective for the VR study was to elicit preferences for beach vacation sites near an offshore wind project. In addition to the number of turbines and their distance, the VR study included an attribute noting a change in the vacation rental price (+5%, 0%, −5%, −10%, −15%, −20% and −25%). While visualizations for each alternative were included in both studies, one unique aspect about the VR design is that it included both daytime and nighttime visualizations. The GP survey received a response rate of 33% ($N = 1050$, $n = 303$) while the VR survey received a 62.3% response rate ($N = 792$, $n = 484$).

2.9. Meyerhoff; Mariel et al.

Meyerhoff [32] tested for spatial relationships in an interview-based CE ($n = 353$) by denoting the minimum distance of the turbines to onshore, residential areas. A second spatial variable was incorporated ex-post using GIS to estimate respondents' distance to nearby turbine(s), and other spatial characteristics such as nearby turbine density, as a proxy for experience with wind turbines. This CE investigated whether different degrees of exposure and experiences with existing wind turbines influenced preferences for additional wind development in Westachsen, Germany. Three proposed development programs were laid out in the choice sets. The first proposed how wind power would develop through 2020 (that is, no-cost status quo). The remaining programs stipulated that wind power would also develop through 2020 but each with different restrictions on one of the CE attributes. These options also included a monthly ratepayer surcharge due to higher costs as a result of those restrictions. In addition to the spatial attribute tested within the CE, the other attributes included the size of wind farms, the maximum height of the turbines, and impact on the red kite population (*Milvus milvus*, a bird of prey). Mariel *et al.* [26] used the same dataset as Meyerhoff [32].

2.10. Vecchiato

Similar to Abay [19], Vecchiato [27] carried out a CE prompting respondents to choose between onshore or offshore projects in Italy (*n* = 383). The web-based instrument controlled for spatial effects by including a distance attribute measuring the minimum distance of the wind farm, presented in three levels: 0.1, 0.25, or 1.0 km from the nearest town or coast (if sited offshore). The preamble thoroughly describes the policy motivation, informing the respondent that Italy plans to increase its current renewable generation from 5.2% to 17% by 2020, increasing annual renewable energy output from ~4 MWh to 10 MWh. Other attributes tested in the CE include "position" of the wind project on the landscape/seascape (mountain/hills, offshore, or plains), height of the wind turbines, and number of wind turbines per project while the cost bids varied from 20, 50, 100, or 150 €/year. Respondents were shown eight choice tasks containing three alternatives—two new wind development options of varying attribute-level combinations plus one opt-out status quo alternative at a 0 €/year cost. Visualizations of what each project might look like in the various environments were not shown.

2.11. Westerberg et al.

Following Landry *et al.* [30], Westerberg *et al.* [28] examined offshore wind development impacts using a coastal, recreational demand model in the Languedoc Roussillion region of the French Mediterranean. The authors estimated WTP and WTA for coastal recreation, defined in the payment vehicle as a change in the accommodation price, near a proposed 108 MW offshore wind project (consisting of 30 × 3.6 MW turbines, typically 80 m nacelle and 55.5 m blades =133.5 m total) using an explicit distance attribute at five, eight or twelve km from shore. The following WTA and WTP levels were used (in €/per week): −200, −50, −20, −5, +5, +20, +50 and +200. An additional (discrete) spatial variable was estimated upon analysis in the latent class model (LCM), discussed in Section 3. Non-spatial attributes also tested in the CE included either permitting or not permitting the public to partake in associated tourism opportunities created by the project's foundation (boating, scuba and skin diving and possibly angling) and whether or not the adoption of local environmental policy would be promulgated alongside the wind development (a policy that would favor additional bike lanes, public transport, solar panels, *etc.*). Each respondent evaluated eight choice sets consisting of two hypothetical alternatives (with visualizations) and an opt-out alternative defined as the current vacation destination and conditions (*i.e.*, no offshore wind farm, associated recreation activities, or municipal environmental policy). Respondents were sampled and personally interviewed on nine different beaches along the coastlines of two locations. Approximately 50% of tourists asked were willing to participate, resulting in an effective sample of *n* = 339.

3. Spatial Drivers of Preference Heterogeneity

Over the past decade, spatial effects have been shown to significantly affect preferences for improvements in environmental goods and services [42–44]. Accordingly, how the benefits resulting from protecting amenities—or improving their quality—are spatially supplied is far from irrelevant through an economic welfare perspective. In the next three sections, the spatial properties tested in the stated and revealed preference literature for wind power are presented.

3.1. Distance to an Existing Wind Project

The environmental economics literature has several findings of how preferences for amenities are influenced by the distance to existing amenities/substitute goods. Pate and Loomis [45] was the first study that addresses this issue in the economic literature, but lately a relatively large number of studies have been undertaken (see for example [42,46,47]). Accordingly, we observe that proximity to substitute goods reduce the demand for the amenity improvement in question. This relationship also demonstrates a relevant spatial element in preferences for the preferred location of wind turbines.

3.1.1. Distance to the Nearest Wind Project (or Substitute), Stated Preference Studies

Generally speaking, people consider the visual aspects of wind farms to be a disamenity. Accordingly, the presence of an existing wind farm at a relatively close distance to a residence might have different effects on preferences for the location of additional wind turbines. For example, people who live far from an existing wind farm, *i.e.*, those without a view from their home of any wind turbines, might find the impacts of a proposed wind farm more negative compared to people who live relatively close to a wind farm. Conversely, people who have a wind farm close to their residence might have more negative experiences and thus also might perceive the impacts as more negative compared to individuals with less experience by physical proximity. Meyerhoff [32] supports the latter argument and finds that individuals living closer to existing onshore wind turbines are less likely to prefer additional onshore wind development.

In addition to Meyerhoff [32], Ladenburg and Möller [14] find that the distance to existing offshore wind farms negatively influences respondents' acceptance of existing offshore wind farms. Additionally, they find that respondents living within 30 min of driving distance from an existing offshore wind farm are significantly more adverse toward existing onshore wind farms. However, as highlighted in the review by Ladenburg and Möller [14], the distances to existing wind projects might not be unidirectional. Ladenburg [15] finds that respondents with a view of a large, near-shore wind farm compared to a wind farm of similar size further away have weaker preferences for wind power relative to biomass and solar energy.

3.1.2. Distance to the Nearest Wind Project (or Substitute), Revealed Preference Studies

An increasing number of hedonic price method (HPM) [48] house studies have analyzed whether home values are influenced by the proximity of wind turbines. If such post-development effects are found, this finding would suggest that the location of wind turbines influence the preferences and subsequently residential spatial sorting. Typically these studies have combined both qualitative measures (whether the property has a view to wind turbines) and quantitative measures (the quantitative distance to wind turbines). Overall, the results are mixed. The majority of the studies have found that onshore wind farms either exhibit no negative net effects on nearby home values [49–55] or even slightly increase property values [56]. Several studies suggest, however, that distance-related attributes, tested either by the ability to see a nearby wind project from the residence or as an interactive effect of the visual attribute with distance from the project, exhibit negative effects on revealed preferences and home values either in the short run or when considering net impacts [57–59]. These findings of distance decay for RP are summarized in Table 2. Finally, it is critical to note that no peer-reviewed RP studies, to the authors'

knowledge, have been undertaken to estimate impacts on property values for homes located in areas adjacent to *offshore* wind projects, either existing or proposed; therefore, preferences for offshore wind farms have only been estimated using SP.

3.2. Distance to a Proposed Wind Project

The second spatial element takes into account that the preferences for siting new wind farm(s) might be a function of the distance that people live from its proposed location. This expectation takes the point of origin first described by Sutherland and Walsh [60] who find that WTP for river quality is a function of the visit rate to the river. The authors find that the visit rate decreases with the distance to the river. Grounded in distance dependency of residents' distance to the good in focus, this relationship can be applied to non-market valuation for wind power by using the distance or travelling time to the nearest potential onshore or offshore wind farm site. The aggregate consumers' WTP for a particular site is critical because the location of wind projects has a substantial influence on the electricity generation costs—and ultimately how much the end user pays for the energy consumed.

Studies examining spatial preferences for proposed wind farm locations can be divided in two approaches, presented below. The first tests for a spatial relationship by including a distance attribute in the CE design. This distance measure typically represents the distance of the proposed wind project to the nearest residential 'area' (for onshore) or the shore (for offshore). The second tests for a spatial relationship by explicitly analyzing if the actual distance between the respondents' homes and the proposed project influences preferences for the potential wind turbine locations.

Table 2. Hedonic results estimating distance dependence of revealed preferences (RP) for onshore wind farms.

Study	Location	Variable(s) Estimated Distance Dependency	Property Distance from Turbine(s)	Sample size (N = # properties)	Key Conclusions
Jensen *et al.* [57]	Denmark	Wind turbine visibility; interaction of visibility with distance to wind turbine	≤2.5 km	12,640 across 21 municipalities	Up to 10% of home values can be explained by sound and visibility. Negative price impact lessens with increased distance from the nearest wind turbine.
Lang *et al.* [61]	Rhode Island State (USA)	Proximity to turbines; viewshed (None, Minor, Moderate, High, or Extreme)	Homes within 0–0.8, 1–1.61, 1.6–3.2, 3.2–4.8 km (relative to 4.8–8 km)	48,554 single-family home sales near ten sites (3254 are <1.61 km from wind turbine)	Negative short-term effects on home values close to turbines. No significant effects on long-term or net property values.
Gibbons [58]	England and Wales	Wind turbine visibility; distance	0–1 km, 2–4 km, 4–8 km, 8–14 km	38,000 quarterly housing price observations	Analyzing visual impacts for small rural wind projects, found negative long-term or net effects. Home price decreases approximately 7% if within 1 km of a wind turbine but less than 1% if home is beyond 4 km.
Heintzelman and Tuttle [59]	New York State (USA)	Distance to nearest turbine [a]; number of turbines in distance bands	0–0.5, 0.5–1, 1–1.5, 1.5–2, and 2–3 miles	11,331 properties	Wind projects significantly reduce net or long-term property values in 2 of three 3 counties for homes with wind turbine visibility *versus* homes with no visibility.

Notes: [a] Used as a proxy for viewshed effects.

3.2.1. Spatial Preferences Related to Distance Attributes

Spatial preferences estimated using a pre-defined distance attribute in the CE have been analyzed for onshore wind farm development [19,26,27,32]. Generally, individuals prefer onshore wind farms to be located at greater distances from residential areas. Abay [19] finds that the distance effect is significantly influenced by the size and number of wind turbines. In that study, the respondents have particularly strong preferences for several, smaller turbines to be built 1 km (relative to 0.5) from nearby residential areas relative to one or two larger (1.5–3 MW) turbines. Vecchiatio [27] finds distance from the nearest homes/coast (1 km relative to 0.1 km) was the second most influential attribute related to wind choices and preferences in the CE. This study also estimates a significant, non-linear distance decay effect, or a declining marginal utility to site the wind project further from the nearest town/coast. Respondents exhibit a WTP of 47 € to move the project from 0.1 to 0.25 km and 78 € from 0.1 to 1 km. Meyerhoff [32] also finds that the respondents prefer wind farms to be located at the greatest distance from residential areas. However, noteworthy preference heterogeneity seems to be present in that minimum wind farm distance from the nearby residential area is not statistically significant for Class 2 ("moderates"), comprising 26% of the sample [32].

For offshore, Ladenburg and Dubgaard [34] was the first study to test spatial preferences in the CE using the distance to the coast as an attribute. Subsequently, a range of SP studies have tested attribute-specific spatial preferences for offshore wind farms locations [18–21,28–31]. Together, the studies generally suggest that there are significant preferences for building offshore wind farms some distance away from the coast. However, as put forward in the review by Ladenburg & Lutzeyer [22], there is likely substantial preference heterogeneity in that some share of the coastal population might even have positive preferences, or a WTP, to build offshore wind farms closer to shore.

3.2.2. Spatial Preferences in a Distance Decay Approach

Whether there exists a spatial relationship with preferences for a proposed wind farm given its actual distance from respondents has so far only been explicitly tested in Ladenburg and Knapp [18]. To estimate this variable, they use travel time via roads from the respondents' zip code area to the nearest proposed site for an offshore wind project. This individual travel time is then used to test if preferences are spatially dependent on the whether the respondents have short or long travelling time to the nearest proposed development area. Through this approach, they find respondents exhibit a lower WTP to reduce anticipated visual disamenities the further away they live from the closest proposed offshore wind farm development site. In other words, respondents exhibit a lower WTP to move the project away the longer travelling time the respondents live from that site. Furthermore, the authors find indications that this estimated distance decay effect is non-linear. They test several distance decay functions, including linear and quadratic, but find that that a spline-threshold approach to be the most appropriate. Specifically, they find that the 60th percentile of respondents with the shortest travel time to the nearest proposed offshore wind farm sites is significantly less adverse to the cost attribute compared to the respondents that live further away. From an economic perspective, this finding suggests that respondents in the 0–60th percentile have a 37% higher WTP for the proposed offshore wind farm to be located at 12, 18 or 50 km, relative to eight km, compared to the respondents in the 61–100th percentile.

In addition, Krueger *et al.* [22] and Westerberg *et al.* [28] control for spatially distributed preferences. Krueger *et al.* [22] find indications that respondents in the subsample furthest from the area designated for offshore wind power development exhibit the weakest preferences to reduce visual impacts from those offshore wind farms. These results are somewhat supported by Westerberg *et al.* [28]. Compared to segment 3 in their latent class model, segment 2 respondents contain a significantly higher number of respondents from northern Europe, and thus they live far from the French coastline with the proposed wind development of interest. Segment 2 respondents appear to hold relatively weaker preferences for visual impact reductions compared to tourists from southern France that physically live, and perhaps work, much closer to the proposed site. This finding could suggest that people living far from the area of attention have weaker preferences for reducing the visual disamenities in terms of the level of compensation required to stay for a week of vacation. However, the respondents in segment 1 also have weaker preferences compared to segment 2 and this segment does not have a significantly higher ratio of respondents from northern Europe as in segment 2. Furthermore, it is also important to note potential cultural effects in this relationship.

3.3. Cumulative Effect

The final spatial element associated with wind power preferences is the influence of the number of turbines that respondents see cumulatively during their daily traveling patterns and routines. Capturing cumulative effects expands the traditional, one-dimensional distance decay function in the sense that the distance to the good in focus/substitutes alone might not be the sole driver of preferences. Rather, the number of substitutes, and the distances to those cumulatively, might drive preferences, particularly if respondents feel surrounded by turbines. Jorgensen *et al.* [44] illustrate this multidimensional effect, finding that the distance to both seawater and fresh water substitutes have a significantly negative effect on preferences for river restoration, suggesting respondents show weaker preferences the closer to, and higher availability of, substitutes. The cumulative effect of both proposed, and existing, development on preferences is perhaps the least tested spatial attribute discussed in the literature. Such an effect, if present, would suggest that the location individual wind turbines coupled with the spatial location of other wind turbines drive external welfare costs.

Respondents have been found to prefer larger but fewer wind projects [27,62]. Development through such an approach may be a way to potentially minimize the spatial inundation of the turbines across concentrated areas. Ladenburg and Dahlgard [63] and Ladenburg *et al.* [13] find evidence that the higher (stated) number of turbines seen day-to-day decreases acceptance for onshore wind power. Similarly, Ladenburg [64] finds some support that respondents who see twenty or more turbines on a daily basis are more negative toward existing offshore wind farms relative to respondents who see only 0–5 turbines in a given day. However, additional evidence suggests that a higher number of cumulative sightings of wind turbines does not have an impact on the relative attitude towards additional onshore and offshore wind farms [65]. Ladenburg and Knapp [18] test but do not find significant cumulative effects on preferences for offshore wind farms. Specifically, respondents that encounter more than twenty turbines daily do not have significantly different preferences for siting offshore wind farms at distances beyond eight km than respondents who see five or fewer turbines daily. Abay [19] also tests the cumulative effects regarding preferences for both onshore and offshore wind farms. Interestingly, while Abay [19]

finds that the number of turbines seen daily does not influence the preferences for the spatial attributes of onshore and offshore wind turbines, respondents that see more wind turbines on a daily basis exhibit stronger preferences to develop the proposed 450 MW of wind power in a single, large offshore wind farm relative to 150 onshore locations. More specifically, respondents who see 1–5, 6–15 or 15+ turbines daily have 21%, 36% and 44% higher WTP to build the 450 MW offshore relative to onshore, compared to respondents who see no turbines daily. These results are thus in contrast to the related results and attitudes in Ladenburg [65].

4. Qualitative Spatial Impacts

In the wind power perception literature, many studies use information on either whether respondents have ever seen a turbine/wind farm or have a wind farm in their viewshed (see Ladenburg and Möller [14] for a review). While these qualitative variables are not related to a particular quantitative spatial dimension *per se*, they nevertheless capture spatial relationships between the respondents and the location of wind farms. For example, respondents that have a wind farm in view from their home live closer to wind turbines compared to those who do not. Significant spatial relationships in these qualitative dimensions thus provide valuable insight regarding spatial effects on quantitative WTP estimates.

Having a viewshed with offshore wind farms is used as a determinant of preferences to reduce associated visual disamenities in Ladenburg and Dubgaard [34]. In their model, they find that respondents with a view of an offshore wind farm from their residence or summerhouse exhibit significantly stronger preferences to locate the project farther from shore. Their WTP is a factor of 2.1–3.6 larger for siting offshore wind farms at 12, 18 or 50 km from the shore, relative to the respondents without an offshore wind farm in view. However, as the authors mention, this estimated effect is based on the stated preferences for 17 respondents and is only significant on a 90 percent level of confidence and should therefore be interpreted with caution.

Given that caveat, these results should be interpreted in context with two recent studies that also estimate Danish preferences to reduce visual diamenities. The first study, Ladenburg and Knapp ([18], unpublished results), is based on a Danish survey from 2006. The results do not suggest that respondents with an offshore wind farm near either their residence or summerhouse demonstrate a higher WTP to reduce offshore wind farm visual disamenities. The second, Abay [19], is based on a survey from 2011 to 2012 and finds that respondents with an onshore or offshore wind farm located in their home's viewshed exhibit stronger preferences to build 450 MW of wind power in locations offshore relative to onshore. More specifically, the WTP to build the 450 MW offshore is nearly 16% and 38% higher among respondents who can see an onshore or offshore wind farm from their residence or summerhouse, respectively.

It is once again important to stress that both of these papers use data from relatively few respondents that actually have a view of an offshore wind farm from their residence or summerhouse. Nevertheless, the more recent studies point towards having a viewshed with an offshore wind farm might not be uniform compared to Ladenburg and Dubgaard [34]. A potential explanation could be that Ladenburg and Knapp [18] and Abay [19] include a map of Denmark that denotes existing and proposed offshore wind farms whereas the geographical location of offshore wind farms in Ladenburg and Dubgaard [34] was not specified. The results in Ladenburg & Dubgaard [34] could thus potentially be explained in that

respondents with a view of an offshore wind farm are willing to pay an additional risk-premium to site offshore wind farms further from the shore given the specific geographic location for the proposed development is not identified; therefore, they might be more risk-averse to having future, additional offshore wind farms possibly sited close to the project already in sight. Another possible explanation might also be that individual preferences have changed over time with increased development onshore and offshore. However, the data in the Ladenburg and Knapp [18] is from 2006 and, thus, only a few years after Ladenburg and Dubgaard's [34] research was carried out.

As illustrated in Ladenburg [15], another explanation could also be that that the type of wind farm of which respondents have a view is relevant. This paper focuses on the preferences for power production from wind relative to biomass or solar energy in Denmark. Though the preferences are not estimated monetarily, the paper offers insight on some meaningful viewshed and spatial relationships. First, a respondent with view of an onshore wind turbine from his or her residence or summerhouse has lower preferences for wind power, while having the project offshore appears to increase preference for wind power (significant at a 90% confidence level). This study takes advantage of a pseudo-natural experiment by including preferences for the relative renewable generation technologies of two distinct populations: on adjacent to the Nysted offshore wind farm and the other to the Horns Rev project. What makes these samples unique is that while the two wind farms were built at approximately the same time, the otherwise highly similar wind farms (72–80 tall turbines; a height of 110 m) were built at different distances from the coast: the Nysted project is located approximately 6–10 km from the coast whereas Horns Rev is 14–17 km. Consequently, these projects provide distinct impacts on the view of the seascape. Accounting for the differences in experience, Ladenburg [15] finds that the respondents with the closer offshore wind farm (Nysted) in their viewshed exhibit significantly weaker preferences for wind power compared to respondents who see Horns Rev in their view. Finally, Ek and Persson [25] also inquire about experience with wind farms (that is, whether or not a respondent has wind turbines in sight of their residence or cottage), but interestingly this variable had no effect on latent class membership.

Finally, it is worth highlighting that several related non-economic surveys have also found spatial effects for wind power and energy development [66–68]. While these studies do not quantitatively elicit WTP estimates, and consequently do not define the spatial dimensions through which social welfare could be maximized, they do estimate significant spatial parameters related to individual wind power attitudes, beliefs and perceptions. Moreover, these findings suggest siting wind farms offshore tends to be preferred, generally speaking. Together, these studies suggest that attitudes toward and economic preferences for wind power are interlinked and influenced by both the spatial attributes of the development itself and interaction of the individual with the technology.

5. Conclusions and Policy Prospects

This article has reviewed the relevant literature on economic preferences for wind power, both on and offshore, while focusing on the spatial dimensions that influence those preferences. Together, these studies make the case that spatial effects significantly contribute to preference heterogeneity. In addition to 14 CE stated preference analyses, several unpublished studies also find evidence suggesting that spatial elements affect preferences for wind development.

The reviewed papers thus clearly indicate that stated preferences for wind farm locations are spatially distributed with regard to the location of wind turbines within a specific area via the distance attributes. Preferences are also spatially distributed in regard to the respondents' homes and their distances to the proposed wind development site. To this end, the review demonstrates that when confronted in a CE with direct trade-offs between costs, various wind farm attributes, and a distance attribute, respondents significantly associate a higher utility with alternatives at greater distances. This finding naturally lends valuable information in relation to the relative societal welfare gains associated with the spatial distribution of wind turbines within a specific area designated for wind power development.

The review thus demonstrates a significant gap in that outside specifically testing a pre-defined spatial attribute within the CE, aside with a few examples of discrete measures via sample stratification, controls for spatial effects on SP in an actual distance decay framework are almost non-existent. Clearly more studies are needed that address how individuals trade-off the actual distance/travelling time to proposed wind farm sites and their willingness to pay to reduce its visual impacts or to even build the project. Following the findings in Ladenburg and Knapp [18], such spatially distributed preferences might have a significant influence on the choice of wind farm locations, resulting in trade offs between potentially higher technical costs associated with deploying the projects further from shoreline populated areas and the social welfare benefits that accrue as a result of such actions. There thus remains a significant opportunity moving forward to test for spatial dimensions explicitly as attributes within a choice experiment, including controlling for travel time or distance to proposed projects using geographic information systems (GIS) software. Further research also should explore how ancillary dimensions influence WTP and welfare estimates such as directional effects as well as users *vs.* non-users of the space near or surrounding these projects given that potential conflicts between recreational and commercial users are likely to occur for offshore projects, especially. Previous evidence suggests users exhibit higher WTP for environmental amenities or WTP to avoid conflicts compared to non-users; similarly, use-status of areas valued for water quality improvements have been found to significantly affect welfare estimates in that users and non-users' distance decay functions take on different shapes (either linearly or logarithmically) with decreasing proximity [44,69].

Finally, governments across Europe as well as the United States have plans to proliferate their offshore wind capacity in the coming decade. It is therefore paramount to understand if and how preferences are spatially correlated with the proposed wind development locations or, for countries with substantial existing onshore and offshore wind capacity, if preferences for future projects are spatially correlated with the location of existing wind development. Both Ladenburg and Knapp [18] and Abay [19] provide strong, preliminary indications that cumulative effects in terms of the (stated) number of turbines seen on a daily basis significantly influence stated preferences. Though Ladenburg and Knapp [18] also test whether this cumulative effect is negatively correlated with an attitude towards additional offshore wind farms and find no significance, next research steps would be to include more objective measures to test for cumulative effects.

Acknowledgments

work is also part of her studies. The authors would like to thank Jeremy Firestone for his fruitful comments and initiative to extend an invitation to submit a paper focusing on the spatial preferences for wind power development. Any errors are, of course, the sole responsibility of the authors.

Author Contributions

The authors contributed, respectively, according to the order in which their names are listed. Lauren Knapp contributed the manuscript design, content, editing and final revisions. Ladenburg contributed to content as well as revisions.

Conflicts of Interest

The authors declare no conflict of interest.

Nomenclature

CT	Cheap talk
CE	Choice experiment
HPM	Hedonic price method
GCF	Generation cost function
LCM	Latent class model
MWTP	Marginal willingness to pay
RP	Revealed preference
SP	Stated preference
TCM	Travel cost method
WTP	Willingness to pay

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