A review of the criteria that influence choices concerning the location of onshore wind energy projects in Iceland



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1. INTRODUCTION

WIND ENERGY – BACKGROUND

Over the course of the 20th Century, the global use of onshore and offshore wind energy has continued to expand, especially in response to environmental, availability and price concerns about electricity generation derived from fossil fuel combustion (Kiunke et al., 2022; Msigwa et al., 2022). Today, wind energy constitutes the fastest growing technology in the renewable power industry, with almost 1,870 TWh produced in 2021, up 17% on 2020 generation (IEA, 2022). Total installed capacity from onshore and offshore sources in 2020 was 837 MW, more than half of which is sourced from China (GWEC, 2022). Approximately 6.7% of global electricity production was from wind energy in 2021 (BP, 2022). In the light of various nations' net zero greenhouse gas emissions commitments, the GWEC (2022) project rapid further expansion, anticipating an additional 557 GW of combined offshore and onshore capacity by the end of 2026.

Despite the various uses of wind power, its growing significance as a share of global electricity production, and environmental advantages in comparison to fossil fuel powered alternatives, the negative consequences of wind turbine installations and wind farms have often been to the fore in the public and planning discourse about the merits of the technology (Brannstrom et al., 2022; Graham et al., 2009; Langer et al., 2018). Hastik et al. (2015) provided a comprehensive analysis of the environmental and ecosystem service impacts of several renewable energy technologies. In the case of impacts located close to the site of onshore wind farms, the most often cited issues are negative effects on birds and bats (Husby and Pearson, 2022; Lintott et al., 2016; Wang et al., 2015), altered landscape aesthetics (Vlami et al., 2016), shadow flickering and safety risks (Karanikas et al., 2021), and health impacts from noise (Nazir et al., 2020). Offsite issues, such as the construction of access roads and power line infrastructure, often constitute additional concerns (Hastik et al., 2015). Connected to these various issues, several studies have also focused on the themes of social acceptance and how best to cultivate a social license to operate (Colvin et al., 2019; Frate et al., 2019; Walker and Baxter, 2019).

GIS MAPPING FOR LOCATING RENEWABLE ENERGY PROJECTS

The various environmental, social, and economic implications of renewable energy projects frequently demand advanced decision support platforms to determine the optimality of proposals. In recent years, an increasing number of studies have utilised Geographic Information System (GIS) mapping in tandem with MCDA to enrich the data pool available to decision-makers. The aim of GIS mapping is to store, retrieve, manipulate, analyse, and map geographical data (Church, 2002). The recent study by Cook and Pétursson (2023) appraised the increasingly significant role of GIS-based analysis, specifically connected to its use within MCDA. Although focused only on geothermal power, hydropower, and onshore wind energy, the study nevertheless revealed the breadth of focus of GIS-MCDA in the academic literature, particularly in relation to issues such as economic prospectivity, land-use trade-offs, visual impacts of erected infrastructure, and the social acceptability of proposals. A total of 41 articles were analysed, based on the most relevant publications in the period January 2017 to May 2023. These were split as follows: n = 13 for geothermal power, n = 9 for hydropower, and n = 19 for wind power.

As per the detailed Appendix C in the Cook and Pétursson (2023) study, the criteria evaluated in the GIS-MCDA literature on onshore wind energy projects includes the following:

- Environmental impacts (e.g., visual, noise, birds, bats, shadow flicker, soil texture, presence of geological formations, etc.).
- Location specifics (e.g., predicted productive capacity; relief and topography; other land uses; and distance to electricity sub-stations, powerlines, telecommunications, roads, tourist sights, cities, towns, railways, etc.).
- Land use and legal restrictions (e.g., protected areas, airports, military zones, forests, sand dunes, farms, vegetated areas, wetlands and rivers, urban locations, etc.).
- Socio-demographics (e.g., population density) and social acceptability of proposals.

ONSHORE WIND ENERGY DEVELOPMENT IN ICELAND

Onshore wind energy is a relatively new technology in Iceland, currently comprising a few off-grid turbines and contributing a token 0.03% of national electricity generation (NEA, 2023). However, given the strong productive potential of onshore wind power (Archer and Jacobson, 2005; Nawri et al., 2014) there are plans for expansion (Sæþórsdóttir et al., 2021). A 120 MW wind farm at Búrfellslundur in South Iceland, where two 0.9 MW test turbines have operated for a decade, will be the first major wind power project in Iceland, commencing operations within the next few years. Another project of ca. 100 MW at Blöndulundur in North Iceland is also planned and classed in the utilisation category by Iceland's Master Plan for Nature Protection and Energy Utilization (ramma.is, n.d.). In early 2025, 39 wind energy projects had been submitted for assessment in the Master Plan, a clear indication of the interest in wind energy development in the country.

AIMS AND STRUCTURE

This report has the following aims:

1) To consider how the various GIS-MCDA criteria for onshore wind energy projects, as identified by Cook and Pétursson (2023), could apply to the Icelandic context.
2) To evaluate the extent to which GIS-based analysis is already utilised in Iceland and what additional aspects could be considered, providing potentially useful information to aid Iceland's Master Plan for Nature Protection and Energy Utilization, and its Steering Committee and four Expert Groups.

Section 2 of this report provides a summary overview on how MCDA studies are typically structured and operate in a renewable energy project context. Sections 3 to 5 of this report consider the GIS-MCDA evaluative criteria identified in Cook and Pétursson (2023) with respect to onshore wind energy projects, outlining how these are likely to apply to the Icelandic case. Much of this content constitutes a synthesis of other work recently published in support of the Master Ploan's evidence base. Section 6 then provides a discussion, first reflecting on the extent to which such GIS-MCDA based evaluations are already undertaken in Iceland and then considering the main practical and policy-making implications of this study. Section 7 provides a short conclusion regarding the main findings.

2. MCDA AND LOCATION OF RENEWABLE ENERGY INFRASTRUCTURE

RENEWABLE ENERGY SITING VIEWED AS A MULTI-CRITERIA DECISION-MAKING PROBLEM

Decision-making concerning the optimal location of renewable energy projects and the scale of operations has frequently been viewed as a straight-forward identification of the sites that are most efficient, those possessing highest resource capacity and being least costly to develop (Shao et al., 2020). In recent years, though, there has been increasing recognition of the multifarious factors that can influence decision-making in this regard, including an array of technical, environmental, economic, and socio-cultural issues (Harper et al., 2019; McKenna et al., 2022). It is thus referred to as a Multi-Criteria Decision-Making (MCDM) problem, which has increasingly led to the deployment of structured methods which strive to resolve conflicts and trade-offs in a transparent manner. MCDA is one form of analysis, which employs multiple criteria or attributes to obtain an integrated decision-making result (Kumar et al., 2017; Shao et al., 2020).

HOW MCDA OPERATES – THE MAIN COMPONENTS

Although there are many different approaches to MCDA, there are several commonalities to such studies in an energy project context. Six main stages have been identified by Shao et al. (2020): (1) the formulation of alternatives; (2) criteria selection; (3) data normalisation; (4) criteria weighting; (5) alternative evaluation; and (6) result validation.

In this first stage, researchers identify the problem and the spatial scale of the study area, which can vary from being a very local focus up to a national level evaluation in the case of Iceland's Master Plan for Nature Protection and Energy Utilization. MCDM/MCDA problems generally comprise of five components, which are goal, decision-makers preferences, alternatives, criteria, and outcomes (Kumar et al., 2017).

In stage two, criteria are determined. This is an important and often lengthy process whereby exclusion criteria are defined, whilst evaluative criteria are identified that are deemed to have a particular significance on the suitability of sites for renewable energy projects. The process of determining the criteria can involve use of many different research methods and forms of evidence gathering, including literature reviews, interviews and focus groups with experts and affected stakeholders, and surveys and questionnaires. Exclusion criteria can include sites located in protected areas, on roads or in urban settlements, mountainous areas, at airports and military locations, on highly vegetated landscapes, or areas with high cultural heritage value, etc. The evaluative criteria are mainly divided into five aspects: technical, economic, environmental, social, and institutional criteria (Kumar et al., 2017). Sometimes specific criteria are both used for the purposes of exclusions and evaluation – for example, in the case of onshore wind energy projects, wind speed and slope are important technical factors, yet poor performance can prevent sites from being considered as suitable, even if all other evaluative criteria are assessed as being very positive.

Data normalisation occurs in stage three. The initial quantitative data collected by experts and expert groups are normalised so that they can be utilised in quantitative calculations. Normalisation of quantitative and qualitative criteria leads to directionless and dimensionless operable values. Although less commonly used in MCDA studies on energy projects, qualitative data is initially incommensurate with quantitative. A

simple normalisation method for qualitative criteria is expert scoring. In this scoring method, experts give the evaluation value of criteria according to their own experience and/or objective data to transform the criteria into a quantitative score. This process can realise the quantification, directionlessness and dimensionlessness of the qualitative criteria in one step.

In the fourth stage, weightings are applied to the coefficients of the evaluative criteria. It is nearly always the case in an energy project context that MCDA studies will apply different weights since the criteria are unlikely to be deemed as having an equal degree of importance. Three factors are usually considered to obtain such weights: the variance degree of criteria, the independence of criteria, and the subjective preference of decision-makers. Various weighting methods can be used for projects involving rank-order rather than equal weighting, which include but are not limited to the Analytical Hierarchy Process (AHP), the Analytic Network Process (ANP), linguistic quantifiers, fuzzy measures, and rank correlation analysis (Shao et al., 2020). Of these, the AHP is by far the most widely applied, involving two main steps: pairwise comparison and weighted linear combination (WLC). Pairwise comparison is used to weight the different criteria, while WLC is the final stage in the AHP evaluation of the alternatives. An AHP-based determination of weights includes two steps. The first step establishes a judgment matrix based on people's judgment of the relative importance of each criterion at a given level, which is usually scored according to a scale from 1 to 9. The second step calculates the weights based on the judgment matrix and conducts a consistency test to indicate whether the comparison made is reasonable.

Stage five applies exclusion criteria to sift out unsuitable options. Following this, for the remaining potential energy projects, aggregations leading to rankings of the locations are conducted, and a variety of methods can be applied. According to Shao et al. (2020), the WLC, the second stage in the AHP, is currently by far the most used method in MCDA studies on renewable energy site selection. However, alternative approaches, such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Translating Reality (ELECTRE), Ordered Weighted Averaging (OWA), and ""VIekriterijumsko Kompromisno Rangiranje" (VIKOR), are increasingly commonly used, with each method often integrating varying degrees of fuzzy logic. TOPSIS chooses the alternative of shortest the Euclidean distance from the ideal solution and greatest distance from the negative ideal solution. ELECTRE involves partial aggregation based on the construction of relations of comparisons of the performances of each pair of solutions. OWA is an aggregation operator that provides a parameterised family of aggregation operators between the minimum and the maximum. VIKOR is often applied when compromises are sought, based on a determination by experts of the 'maximum group utility' and 'the minimum individual regret' (Kumar et al., 2017; Shao et al., 2020).

The sixth stage reviews and verifies the results and further analysis is conducted. Often a sensitivity analysis of the results is applied considering the implications of slightly different weighting or aggregation methods.

3. ENVIRONMENTAL IMPACTS

VISUAL DISTURBANCES AND SHADOW FLICKER

Disturbance to the visual aesthetics of the surrounding landscape is often cited as the most prominent impact of onshore wind energy projects. Although there are some reports of positive visual impacts, most of the studies in the literature address negative perceptions (Tverijonaite and Sæþórsdóttir, 2023). The extent of the impacts relates mostly to the visibility of the turbines and hubs, the size and height of the turbines, the number of turbines, and the spatial arrangement of the array (Alphan, 2021; Diógenes et al., 2020; Sæþórsdóttir and Ólafsdóttir, 2020). Distance from turbines plays a major role in terms of the extent of the potential perceived visual blight (Bishop, 2002; Sullivan et al., 2012). The movement of the turbines also contributes to the visual impact, especially in the immediate vicinity of the infrastructure from the shadow flickering of rotating blades (Rudolph et al., 2017). In addition, a study by Bishop and Miller (2007) reported that the perceived size of rotating turbines is in the region of 10-20% greater than when they are stationary. A further source of visual intrusion concerns lighting, particularly aviation obstruction lights installed on wind turbines, with the most significant negative impacts from xenon lights rather than LED or colour markings on blades (Rudolph et al., 2017).

In the presence of good weather and clear visibility, the potential visual impact of onshore wind turbines has exhibited considerable variability from nation to nation. Hrabalíkóva et al. (2024) find that there are several objective factors that need to be considered when assessing the likely visual impact of an onshore wind power project, which include terrain conditions and landscape elements (including structures); the relative height of the observation point and the wind turbine in the terrain; the visibility, colour, proportions and appearance of the wind turbine; the layout and size of the project; and maximum visibility under optimal conditions.

The GIS-based study by Hrabalíkóva et al. (2024) into the visual impacts of onshore wind turbines has summarised the zones over which wind turbines are theoretically visible in different nations, and the extent of that impact on the landscape with respect to distance (see Table 1). Based on wind turbines of 150-metre height, which have been proposed in Iceland, the following impact zones are recommended: a near zone of 0-4.5 km; an intermediate zone of 4.5-10 km; and a remote zone of 10-16 km. In Table 1, the case of Denmark exemplifies these impact zones. Hrabalíkóva et al. (2024) describe the near zone as a region where the wind turbines are the dominant feature in the landscape, the intermediate zone as an area whereby the wind turbines are prominent but do not exceed the scale of other landscape elements, and the remote zone as an area with insignificant effects compared to other landscape elements. The delineation of these zones assumes clear visibility, and other factors can reduce the impact of the wind turbines, both when still and operational, on the surrounding landscape. These include the lighting and atmospheric conditions, and the colour of the wind turbines, which impact contrast effects (Hrabalíkóva et al., 2024).

Table 1. Overview of general perception of wind power projects in an open landscape in selected nations. (Sourced from Hrabalíkóva et al., 2024)

Perception		Description/definition	Radius of visibility (km)							
			CZ[1]	Scot[2]	NO[3]	DK[4]	CH[5]	DE[6]	AT[7]	US[8]
Near zone	**Strong visibility**	*Likely to prominent feature:* space where the technical elements of windfarm are noticeable and distinguishable from other elements of the landscape	0-3	0-2	0-1	0-4.5	0.5-2.5	0-1	0-2	0-3.2
Intermediate zone	**Clear visibility**	*Relatively prominent:* The area of the immediate influence of the wind farm. The wind turbine is clearly and undoubtedly visible in the landscape. Partially may be suppressed, or its manifestation influenced or mitigated by other predominantly more significant compositional elements of the landscape.	3-6	2-5	1-16	4.5-10	2.5-5	1-4.5	2-5	3.2-8.1
	Good visibility	*Relatively prominent, seen as a part of the wider landscape:* Area from where the wind turbine is not so dominant in the landscape, but it is visible, and other landscape elements mitigate its manifestation in direct view	6-10	5-15				4.5-7.5	5-10	8.1-16.1
Remote zone	**Poor visibility**	*A minor element in the landscape:* The area from which the building is no longer dominant and barely distinguishable to the naked eye; in ideal visibility, it may be slightly prominent.	10-20	15-30	16-20	10-16	5-10	7.5-10	10-30	16.1-32.2

[1] For one wind-turbine of 90-110 m hub height, Ministry of Environment of the Czech Republic (Věštník Ministerstva životního prostředí, 2018, p. 41)
[2] Source: PAN45(revised 2002)
[3] For one wind-turbine of 80-90 m hub height, Norwegian Directorate of water resources and energy (Visuelle virkninger av vindkraft, 2017, p. 12)
[4] Wind turbines up to 150 m of overall height, (Nielsen et al. 2007, pp. 51–59)
[5] Wind turbines between 110-170 m (Dominik Eggli, 2021)
[6] (Torkler & Zeidler, 2013)
[7] (Ian D Bishop, 2002)
[8] (Palmer, 2022)

As Table 1 testifies, the visual impact on the landscape thus appears to vary considerably from nation to nation. Guan (2021) asserts that the zone of theoretical visibility is only a starting point in gauging the likely impact of onshore wind power projects on the surrounding landscape. Other factors are equally important, such as the elements, structure, and functions of the landscape (Guan, 2021). Elements relate to the properties of the landscape in terms of aspects such as soils, texture, colour, and architecture. Structure pertains to the topography, relief, and shape of the landscape. Landscape functions are highly subjective and relate to perceptions about the beauty, naturalness, diversity, peculiarity, and coherence of the landscape (Guan, 2021). These factors correspond closely with the 22 attributes of landscape identified by Ostman (2020), which, in turn, vary in manifestation and magnitude with respect to landscape type.

In addition to the visual impacts of rotating wind turbines over an extended distance, these can often present a more local blight in the form of shadow flicker, which can induce health consequences such as epilepsy seizures in the most severe cases (Karanikas et al., 2021). The extent of the impact is proportional to the number of turbine blades and the speed of rotation. As the regulatory environment for wind energy projects is still in its infancy in Iceland, there are no formal distance requirements for settlements to be located away from onshore wind energy projects. However, an assessment by Haugen (2011) into the restrictions imposed by various nations found distances from towns in the range of only 200 metres (Portugal) up to 2,000 metres (Scotland). The northerly latitude of Iceland leads to a relatively low angle sun for several months of the year, increasing the likely depth of the shadow flicker effect. The study by Doheny (2015), based on the altitude and azimuth of the sun in Iceland, advocated wind turbine placement at no closer than 1,400 metre distance southwards of residential or commercial buildings. The same 1,400 metre threshold could be applied to roads to prevent any potential disorientation of drivers via shadow flicker effects. Besides the case of Scotland, this distance exceeds the threshold applied in the twenty-four nations and states assessed by Haugen (2011), being close to the 1,500-metre margin currently applied by Norway (Ekstern Rapport, 2022).

NOISE

Wind turbines produce sound via both mechanical and aerodynamic sources, with the latter the dominant source from modern upwind turbines. Aerodynamic sound is experienced by human beings in terms of its sound pressure level (loudness) and frequency (pitch) (CMOH, 2010). This is typically caused when rotating turbine blades encounter turbulence in the passing air, being low frequency in the range of 200-200Hz, with the loudness varying with respect to the distance from the wind turbines (Colby et al., 2009). Although a study by CMOH (2010) found no scientific evidence to indicate that low frequency sound from wind turbines causes negative health effects, a variety of negative health consequences have been reported in conjunction with exposure to the loudness of wind turbines. These include headaches, difficulty concentrating, fatigue, dizziness, tinnitus, sleep disturbances, and more (Chiu et al., 2021).

At very close distances of only a few metres, noise levels from wind turbines often reach over 100 dB (GE, 2023), however, the loudness drops rapidly with distance and rarely, if ever, exceeds 35 dB from more than 500-metres away. This is lower than the World Health Organization’s recommended safe level of 40 dB for outdoor noise, which is akin to the noise emissions at close range of the average domestic refrigerator (GE, 2023). A systematic literature review by Schmidt and Klokker (2014) into the health effects of wind turbines found evidence of increased risks of annoyance and sleep

disturbances, but that noise emissions were entirely tolerable to human beings around L_{Aeq} of 35 dB, with no or negligible effects at this loudness.

A separate yet rarely considered issue concerns the potential for electromagnetic noise, which is reflected by large towers, generators, and rotating wind turbines (Krug and Lewke, 2009). Electromagnetic noise generated by the wind turbines can affect weather radar, and therefore exclusion zones are often recommended to prevent disturbance. EUMETNET (2017) have studied the different types of impacts, which include blockage of radar beams and reflection of radar emissions, leading to disruptions in the measurement of precipitation and Doppler winds. Regarding the extent of exclusion zones, the World Meteorological Organization (2010) recommends a strict exclusion zone of up to 5 km in which wind turbines should not be installed. In this area, any wind turbine can completely or partially block radar, resulting in significant loss of data that cannot be recovered. A further exclusion zone of between 5 and 20 km is also often advisable given the potential for multiple reflection and multi-path scattering that can create false echoes and compromised Doppler velocity measurements. At distances of 20-45 km, only low or negligible effects are likely (World Meteorological Organization, 2010).

BIRDS

One of the major concerns regarding wind farms, both onshore and offshore, is the possibility of bird mortality. Bird collisions with wind turbines are induced by a variety of complex, often interacting factors, which include technological features (such as turbine type, configuration, and lighting), site specifics (for example, landscape, weather, food availability and flight paths), and species characteristics (for instance, abundance, sensorial perception, morphology, and phenology) (Marques et al. (2014). Although the consensus on bird mortality from wind turbine collisions is that there are zero or negligible impacts in most cases (Drewitt and Langston, 2006; Marques et al., 2021), there remains considerable evidence of instances of fatalities and bird displacement in certain cases. The recently published review by Balmori-de la Puente and Balmori (2023) analysed fatalities in wind farm collisions over the period 2001-2016. The authors reported that flight type was the most important variable affecting the likelihood of collisions, followed by the seasonal movement type. Those species with hovering, song-flights and active soaring flights were found to be more vulnerable to collisions, with seasonal movement also influencing the probability. There is evidence that raptor and cranes are the most vulnerable bird species to collisions, which can lead to fatalities (Martin et al., 2012). Raptors, such as sea eagles, kites, and falcons, have a narrow visual field and a blind spot above their heads. In addition, they forage from the air, looking downwards in search of prey. This can mean that they have a blind spot on the horizontal plane of travel (Linder et al., 2022).

In the literature review by Marques et al. (2021), 40.6% of 71 peer reviewed studies identified displacement effects, with 7.7% reporting increased abundance in the locality. In the US, bird mortality rates by virtue of collisions with onshore turbines have been reported for 300 bird species, with small passerines constituting 57% of all fatalities (Allison et al., 2019), and annual mortalities are estimated in the range of 140,000 to 679,000 across North America (Choi et al., 2020). Studies on the extent of bird displacement are rarer than mortality analyses, however, this can take place during both the construction and operations of onshore wind energy projects (Drewitt and Langston, 2006). Shaffer and Buhl (2016) conducted a before and after control impact assessment of the extent to which onshore wind turbines in native mixed grass

prairies contributed to the displacement of breeding grassland birds. The authors observed displacement for 7 of 9 bird species and attraction for 1 other species, with displacement and attraction occurring in the range of 100 to 300 metres distance from the turbines. These effects were first observed 1 year after construction and persisted for at least 5 years. In the review study by Coppes et al. (2019), in 15 of 35 studies, negative effects on grouse species were reported due to onshore wind energy installations, which included spatial avoidance and displacement of nesting sites, all at a distance of up to 500 metres from the turbines.

Regarding the earliest onshore wind energy project proposals in Iceland, much of the research into the likely environmental impact concerned threats to birds. Preliminary assessments by Landsvirkjun (2013a) into the potential impacts to birds at Bjarnalón and Hafið identified impacts to five bird species via density measurements, three of which were nesting locally. Flight monitoring detected 17 species, including the pink-footed goose, European golden plover, whimbrel, common ringed plover, less black-backed gull, and raven. Although the likelihood of collision was considered low when calculated for the pink-footed goose and European golden plover, the disturbance to the habitat of birds by Bjarnalón in the Hafið area was more substantial during the construction period (Landsvirkjun, 2013).

More recently, the Nature Research Centre of Northeast Iceland has studied birdlife in three parts of the country where wind energy projects are proposed, focusing particularly on the effects on nesting birds and the pathways of migratory species. The research on migratory species has included the gathering of information about the specific species flying to Iceland, the routes, number of birds and altitude (Nátttúrustofa Norðausturlands, n.d.). In addition, based on criteria for defining Important Bird Areas (IBAs) by BirdLife International, the Icelandic Institute of Natural History has defined 121 areas of international importance for the 81 species of birds that are breeding or regular visitors to Iceland, which fall into three categories: (a) seabird colonies, (b), rocky coast and shallow marine waters, and (c) wetlands and other inland areas. It is recommended by the Institute that onshore wind energy projects are planned in areas outside of their classification of important bird areas (Mannvit, 2020). Most of the IBAs in Iceland are important breeding sites, with a few having importance as staging, moulting, or wintering sites. Lake Mývatn and Breiðafjörður serve all four functions (Náttúrfræðisstofnun Íslands, 2016).

SITE DISTURBANCE

Some other environmental factors may need to be considered regarding the siting of onshore wind energy projects. These include some disturbances to specific local flora and fauna via the construction of a project, as well as impacts to cultural and geological heritage. Poorly located wind energy projects can degrade high carbon soils and habitats (Shepherd et al., 2021). It is also important to evaluate the suitability of the sub-surface soil for the construction of roads to the project site and turbine foundations, with the latter necessitating soil extraction. Proper soil condition classification and monitoring is essential for turbine foundation selection (Doheny, 2015).

OTHER ENVIRONMENTAL FACTORS

Given the cold climate of Iceland, the potential for wind turbine blade icing is pronounced (Kraj and Bibaeu, 2010). A study by IEA (2016) found that 30% of the total installed wind power capacity in the world was situated in cold climate locations that are vulnerable to icing. Gao et al. (2021) found that ice accretion on blade topics could

extent to a thickness of up to 30 cm at blade tips, leading to slower turbine rotation and ice-induced power losses of up to 80%. In some cases, turbines shut down completely. In addition, safety issues can arise due to the potential for ice-throw, whereby shards of ice are cast from the turbine (Ellenbogen et al., 2012).

4. LOCATION SPECIFICS

PRODUCTIVE CAPACITY AND ECONOMIC OPTIMALITY

The productive capacity of onshore wind energy projects is typically estimated by fitting wind speed data with a Weibull distribution (Deep et al., 2020). The calculation of the probability density function for the Weibull distribution requires data on average wind speed, scale, and locational parameters. Wind locations are classified by the American Wind Energy association according to their wind power density (Helgason, 2012). Wind power density is a measure of the kinetic power available per square metre for specific wind speeds. A further important consideration concerns the capacity factor – the proportion of the time during which turbines are operational. Since onshore wind energy is highly intermittent and wind turbines shut down at the highest speeds, these tend to be relatively low, typically in the global range of 20% to 50% (WE, 2023). Test onshore wind turbines in Iceland have reported capacity factors of 45%, at the upper end of the global range (Gísladóttir, 2016).

As is the case within Expert Group 4 of Iceland's Master Plan for Nature Protection and Energy Utilization, the economic performance of onshore wind energy farms is often estimated with respect to their levelized costs of energy generation (LCOE), which are an aggregation of all the likely costs of a project over its lifetime, discounted according to the time period of incidence, annualised over the assumed lifespan of the project, and averaged per unit of predicted annual power generation. As the technology has matured, the LCOE for onshore wind energy has fallen considerably around the world. In 2010, global weighted average LCOE for onshore wind energy was 9% higher than for fossil-fuel fired plants, yet by 2022, this figure was 52% lower (IRENA, 2023). Costs continue to fall – for newly commissioned onshore wind projects, the global weighted average LCOE fell by 5% between 2021 and 2022, from USD 0.035/kWh to USD 0.033/kWh (IRENA, 2023).

OTHER LAND USES

The impacts of onshore wind energy projects to other land uses can vary significantly. Wind turbines utilise relatively little of the land area. A survey in the US of large-scale wind energy facilities found that less than 0.40 hectares per MW is disturbed permanently, and less than 1.41 hectares per MW are disturbed during construction, with the rest of the land usable for multiple purposes, including grazing, agriculture, hiking trails, and highways (NREL, 2012). However, the perceived negative externalities of onshore wind energy projects are critical to any land use conflicts (Frantál et al., 2023). The greatest land-use impacts that have been reported in Iceland concern potentially negative impacts to tourism sites, which have been proposed in areas with a high wilderness value (Tverijonaite and Sæþórsdóttir, 2023). Moreover, the importance of wilderness to Icelanders was reinforced in a perception survey (n = 641) and scenario analysis by Ólafsdóttir and Sæþórsdóttir (2020). The authors found that nearly all of land above 300 metres in elevation is perceived by Icelanders to be wilderness, with the key characteristics of wilderness determined to be an open and vast landscape, uninhabited areas, and the absence of any anthropogenic interventions or features. Perceptions of wilderness diminished when scenarios presented in the survey included anthropogenic features other than those associated with archaeological remains. A separate study by Sæþórsdóttir (2014), entailing a survey of 1,710 tourists, 51 semi-structured interviews, and 30 diaries, had investigated the attitudes of foreign tourists when presented with scenarios involving

power plant projects in the central highlands of Iceland. The participants were of the view that the remote, uninhabited highlands were a major attractor factor, especially among the German, French and Dutch segments, and that if the pristineness of the wilderness was diminished via energy infrastructure, then the quality of the tourist experience would be undermined.

There are relatively few studies that have explored in-depth the implications of onshore wind energy projects concerning agricultural lands. The global review by Wang et al. (2015) reported a general tendency for there to be positive impacts to primary productivity and local air quality, but negative impacts sometimes to soils, water, and livestock. Most of the negative effects occurred during operations and decommissioning. Although more evidence is needed, a review study by Helmutsdóttir (2023) identified the likelihood in Iceland of large noise effects on grazing pigs and cattle at a distance of 1 km from a wind energy site, and large effects on roaming sheep and the habitats of reindeer due to the necessary construction of new roads. Equally, many disused agricultural sites are suitable for land-use conversion, which may be relevant in the context of Iceland's history of farm abandonment (Wilkinson, 2009). Around 7% of abandoned agricultural lands in Lithuania, which currently cover 373.6 km^2, were determined to be highly suited to onshore wind energy projects, with a further 18% deemed to have average suitability (Tumeliene et al., 2022).

Distance thresholds are typically applied between airports and military sites and the siting of onshore wind energy projects. Rotating wind turbines have sometimes interfered with radars (Losco and Collick, 2012). This has led to delays or the abandonment of several prospective wind energy projects, for example, between the years 2008 and 2010, such concerns in the US led to the curtailing of 20,000 MW of planned onshore wind energy capacity (Auld et al., 2013). Some authors, including Brigada et al. (2021) have emphasised that radar clutter problems can potentially be reduced through the adoption of a staggered wind turbine configuration, which does not undermine mean power density. Nevertheless, most nations continue to apply distance restrictions around airports and military sites. Germany recently relaxed one of the strictest exclusion zones around airports. Formerly a 15 km exclusion zone was placed around ground-based navigation facilities, which was reduced to 7 km in February 2023 by German air traffic control and the German Federal Ministries for Economic Affairs and Climate Protection and for Digital and Transport (DFS, 2023). In the UK, a safe distance threshold of 10km for civil/military radar is applied (CAA, 2016).

Planning guidelines and regulations typically prevent the erection of wind turbines in protected areas for reasons of landscape aesthetics and biodiversity preservation (Jung and Schindler, 2021). In the European Union, legislation does not specifically ban wind turbines within protected areas or their vicinity. However, this is typically the approach taken by member states based upon their interpretation of various forms of legislation. These include the EU Habitats Directive (1992), the EU Landscape Convention (2000), the global Ramsar Convention (1971), the Council of Europe's Bern Convention (1979), and the Kiev Protocol on Strategic Environment Assessment (2003) (Marsden, 2017). In Iceland, the established of a Protected Area generally prevents onshore wind farms.

DISTANCE TO ROADS

Van Haaren and Fthenakis (2011) assert that road proximity is an important factor in the feasibility of onshore wind energy project for multiple reasons, including ease of

access in construction and maintenance. Miller and Li (2014) also consider a distance of 1,000 meters to be reasonable, with the suitability of sites falling as distance from roads grows. At the same time, care must be taken when configuring wind energy projects to ensure that shadow flicker and noise impacts are not enlarged because of the presence of nearby roads.

AVAILABILITY OF GRID CONNECTIVITY AND BALANCING POWER

One of the main technical barriers to the wider use of onshore wind energy concerns the potential for a site to connect to the electricity grid (Jung and Schindler, 2021). Due to the intermittency of the wind resource, the integration of this technology into the power grid can lead to imbalances and management challenges relating to variations in voltage and overload of the network (Ahmed et al., 2020; Benzohra et al., 2020). Given this, a further complexity arises considering the importance of having available balancing power in electricity grids that are isolated from others. This is the case in Iceland, where there is no interconnector to mainland Europe or elsewhere, and grid strengthening is required. Furthermore, there is frequently extended distances in Iceland between a location and the electricity grid, necessitating long and expensive transmission lines.

Many studies involving the role of balancing power in conjunction with onshore wind farms explore the challenges in the delivery of sufficient balancing power due to the significant intermittency in wind energy generation. Kiviluoma et al. (2012) called for a need to have flexible plant facilities, increased demand-side management, and more interconnections, transmission lines, and larger balancing areas to address this challenge. Vandezande et al. (2010) referred to the importance of establishing well-functioning balancing markets for the periods when there is a shortfall in energy generation, which must be capable of allocating balancing costs to the responsible parties. All these aspects are likely to be significant considerations in Iceland, where the capacity factors of onshore wind energy sites are likely to be in the range of 40-45% (Landsvirkjun, 2021), and the challenges are currently significant concerning the availability of balancing power and the strength of the electricity grid.

5. SOCIO-DEMOGRAPHICS AND SOCIAL ACCEPTABILITY

POPULATION DENSITY

Onshore wind energy projects are typically sited some distance away from densely populated areas, not least due to the aforementioned visual impacts, which are often negative. The study by Peri and Tal (2020) uncovered that anthropocentric environmental impacts from turbines were found to be significant whenever sites were located less than 750 m from settlements. This is unsurprising, given that this distance is less than the typical visual impact near zone of 0-4.5 km described by Hrabalíkóva et al. (2024). In practice, nations have tended to apply exclusion zones more akin to the intermediate zone of 4.5-10 km, with some going even further. In 2016, the Hungarian Parliament enacted legislation that banned wind turbines within a 12-kilometre radius of populated areas, leading to no areas being suitable across the whole nation (IEA, 2023).

SOCIAL ACCEPTABILITY OF PROPOSALS

Closely tied to the issue of the visual impacts of onshore wind turbines is the notion of the social acceptability of proposals. The degree of acceptability often depends greatly on the stakeholders who are directly affected (Ólafsdóttir and Sæþórsdóttir, 2019). A survey of Icelanders by Landsvirkjun (2013b) found that 80% were broadly supportive of onshore wind energy development. However, this was prior to the development of any projects greater in scale than test turbines. Other studies have found that the siting of wind farms is often a complicated issue and afflicted by conflicts with various key stakeholders, such as tourist operators (Ólafsdóttir and Sæþórsdóttir, 2019). This is often described as the NIMBY (not-in-my-backyard) effect, whereby those directly affected by a forthcoming wind energy project are strongly against its development (Tverijonaite and Sæþórsdóttir, 2023). This aligns with the perspective of Devlin (2005), who articulated that although the benefits of wind energy projects are widespread, and even global in terms of combating climate change, the negative consequences are much more local and relate to the perceived implications of a degraded environment. In Iceland, where much of the tourist economy can be described as ‘nature-based’ (Sorrell and Plante, 2021), and there are barren and exposed landscapes, the negative economic consequences for the tourism industry could potentially be significant (Ólafsdóttir and Sæþórsdóttir, 2019).

The first proposal for a 200 MW wind energy project at Búrfellslundur was opposed by Iceland’s National Planning Agency on the grounds of potential impacts to tourists, given that it would have been highly visible to those travelling on the main edge-of-highland road to the popular recreational area of Landmannalaugar (Einarsdóttir et al., 2019). The study by Ólafsdóttir and Sæþórsdóttir (2019) reaffirmed that there are generally positive attitudes to onshore wind energy in general in Iceland, but with reservations about specific proposals for wind farm projects. The disturbance to the visual aesthetic was the greatest concern, given that much the landscape is considered by stakeholders to be wilderness despite several hydropower projects in the region, and the introduction of a large-scale wind energy project could represent a ‘triggering factor’ that would lead to the landscape being perceived by visitors and residents as anthropogenic rather than natural (Ólafsdóttir and Sæþórsdóttir, 2019).

The recent literature review by Tverijonaite and Sæþórsdóttir (2023) articulated that the social acceptance of wind energy projects should not be viewed as static but rather

developing according to a U-shaped trajectory. In the initial instance, general attitudes towards the technology are positive until specific proposals are outlined, at which point local attitudes tend to become negative. However, as found by Wolsink (2007), if the negative local perceptions can be satisfactorily mitigated, then they return to being positive within around a year from construction. Moreover, some stakeholders have reported positive local attitudes that increase in positivity over time due to new wind energy projects, with some individuals even choosing to live in communities nearby (Hoen et al., 2019). A number of factors seem to be central to fomenting positive local attitudes to onshore wind energy projects, which have been categorised by Leiren et al. (2020) as follows: (1) technical characteristics of the project, including turbine height and size, visibility, distance from residential areas and need for necessary infrastructure improvements, such as grid connections; (2) environmental factors, including impacts on the physical environment, ecology and greenhouse gas emissions; (3) societal factors, including impacts to human health, well-being, and quality of life; (4) economic impacts, including those on tourism, agriculture, and other forms of local income generation; (5) contextual factors, such as trust in key actors, regulatory frameworks, and the planning and permitting process; and (6) individual characteristics, for example, self-identity, place attachment, sense of place, and the political climate and various discourses surrounding wind energy.

In the Leiren et al. (2020) study, focused on six European regions, item (4), specifically impacts to tourism, were found to be barriers to social acceptance in four cases, while they were neutral considerations in the others. This echoes the findings of some research in Iceland – in the study by Sæþórsdóttir et al. (2021), concerns about the potential impacts of five proposed wind energy projects in Iceland were voiced by tourism service providers. These were based on the potential for the projects to degrade the aesthetics of the landscape, undermining the quality of the visitor experience, and potentially leading to reduced visitor numbers and income generation over time. A subsequent spatial assessment of the degree of perceived impact on tourism operators revealed considerable variability in the character of perceived impacts by tourist service providers in response to the current proposals for a 120 MW wind energy project at Búrfellslundur (Tverijonaite et al., 2022). Although the majority voiced negative concerns, predominantly due to visual and tourist mobility impacts which extended in some directions over a 100 km radius, some reported mixed or positive responses in the immediate vicinity. The mixed responses related to the perception that negative impacts were confined to visual aspects and would not affect tourist mobility, and the extent of the visual impacts would depend greatly on subjective factors, such as familiarity with wind turbines. The one positive tourist operator opined that the addition of a wind energy project was occurring in an area already influenced by many hydropower plants and would be a complementary feature (Tverijonaite et al., 2022).

There is also evidence that the perception of onshore wind energy projects depends not only on distance but the scale. A study by Betakova et al. (2015) found that not only did impacts to landscape aesthetics disappear at a distance of 5-10 km, but that a positive perception for one wind turbine decreased rapidly with increasing numbers. Part of this difference in perspective can be attributed to how the energy is being used – in the case of a single wind turbine, it would be perceived as being of local benefit, whereas a large-scale project is more likely to be predominantly of benefit to people and industries living elsewhere (Betakova et al, 2015).

6. GIS MAPPING IN ICELAND

GIS mapping has been undertaken by the Global Wind Atlas[9], which highlights the areas in Iceland with the greatest mean wind speed and mean power density. This provides a crude informative showing some of the locations that are likely unsuitable. Iceland-specific analysis was carried out by Nawri et al. (2014), using downscaling simulations with the Weather Research and Forecasting model ad local wind speed distributions derived from Weibull statistics. A further 14 test sites were selected for more detailed analyses using the Wind Atlas Analysis and Application Program (WAsP). Nawri et al. (2014) concluded that Iceland's potential wind energy sites were comparable to those in the highest wind energy class elsewhere in Europe, and that wind conditions were not a constraining factor on onshore wind energy production.

Much of the ongoing work in Iceland involving GIS analysis and onshore wind energy projects has investigated the extent of the visual impacts on surroundings. The recent work of Ostman and Árnarson (2021) evaluated the visual impacts of eight proposed onshore wind farms that were potentially going to be assessed in the fourth phase of Iceland's Master Plan for Nature Protection and Energy Utilization. The specific data collection locations for each windfarm project were dictated by the Icelandic Landscape Project (ILP) methodology, which uses GPS coordinates from a 5 x 5 km point-based grid system and has been applied in previous data collection phases for Iceland's Master Plan.

Using Viewshed Explorer, analysis of the collected data included the creation of a zone of theoretical visibility, which applied a maximum radius distance of 40 km in accordance with Scottish National Heritage guidelines. This was deemed appropriate given the sparseness, exposed and gently sloping nature of many of Iceland's landscape types. However, visible points within a 10 km radius of proposed onshore wind energy projects were determined to the outer limits of the intermediate zone, unless settlements or other sensitive areas were located between 10 and 40 km from the site (Ostman and Árnarson, 2021). In addition to the use of basic GIS-based analysis to determine zones of theoretical visibility and possible impacts on specific landscape types (Ostman and Árnarson, 2021), the use of photomontage (2D), 3D panoramic visualisations, weather, daylight, and line of sight analysis can help to similar the likely actual impact of wind turbines on the landscape, since theoretical analysis does not account for localised screening and magnitude of visual effects. Line of sight analysis investigates whether an object, in this case a wind turbine, is visible in a straight line from specific viewpoints. In GIS mapping, data points are typically classified as green if the wind turbine is visible from a specific location and red if not.

The study by Hrabalíkóva et al. (2024) refers to the ongoing development of a 3D map[10] of several potential wind power projects in Iceland, which, among other aspects, integrates GIS data on visual impacts to the landscape, inclusive of the effects of weather and daylight, and line of sight analysis to assess the likely visual impact of wind power projects and particular array formations. This will extend the degree of objectivity of GIS-based analysis in informing Iceland's Master Plan for Nature Protection and Energy Utilization beyond the level often found in academic GIS-MCDA studies, which generally rely only on zone of theoretical visibility assessments and/or

[9] See: https://globalwindatlas.info/en/area/Iceland
[10] See: https://hrabalikova.github.io/3d-map-test/

are restricted to distances to settlement locations, land use types (e.g. protected areas, airports, mining zones, etc.) and objects (e.g. radar and antennas) that are deemed most likely to be affected by an onshore wind power project (Peri and Tal, 2020; Sotiropoulou and Vavatsikos, 2021). Furthermore, the use of advanced 3D analysis increases the capacity to reduce the potential impact of onshore wind energy projects in Iceland through mitigative measures, which can greatly minimise the potential for human health to be harmed negatively via issues such as shadow flicker and noise. Given the local incidence of such effects, restriction zones can be applied via straight-forward 'distance to' analysis, as is commonly applied in academic GIS-MCDA studies on onshore wind energy projects (Peri and Tal, 2020). The study by Doheny (2015), based on the altitude and azimuth of the sun in Iceland, advocated wind turbine placement at no closer than 1,400-metre distance southwards of residential or commercial buildings. The same 1,400-metre threshold could also be applied to roads to prevent any potential disorientation of drivers via shadow flicker effects. Besides the case of Scotland, this distance exceeds the threshold applied in the twenty-four nations and states assessed by Haugen (2011), also being close to the 1,500-metre margin currently applied by Norway (Ekstern Rapport, 2022).

Regarding any potential negative impacts from the noise of rotating turbines, GIS analysis has been undertaken in Iceland to assess dB at various distances. An investigation by Landsvirkjun into the loudness of two test turbines in the Hafið area, near the soon-to-be constructed wind power project at Búrfellslundur, found noise levels in close proximity to the turbines of 103 dB, which reduced to only 45 dB at a distance of 340 metres. However, the loudness diminished to 36-40 dB at 500 metres from the turbines, which aligns with the World Health Organization's safe level of 40 dB (Landsvirkjun, 2013). Concerning electromagnetic noise from rotating wind turbines, as far as the authors are aware, no studies have been undertaken yet into its potential incidence in Iceland.

In recent years, GIS-based research on breeding birds has focused on gaining greater understanding in Iceland of the areas where the most common birds are likely to be present. A study by Mendéz and Gunnarsson (2020) estimated the likely presence of the 12 most common land birds in Iceland. This included the development of a species diversity map, which displayed the locations in Iceland where species diversity exceeds a threshold of 0.5, i.e., there is a greater than 50% likelihood that a particular species will be found in a plot. Although there are areas of considerable species diversity around Iceland, Mendéz and Gunnarsson (2020) found that these are most often observed in the southern areas of the nation, especially the flat lowlands which tend to be warmer and wetter. The southern region is also the area most associated with the migratory pathways of many bird species in the spring and autumn periods.

In relation to the specific vulnerabilities of bird species in Iceland, research in Germany has found that white-tailed sea eagles are one of the bird species that are most often killed by wind turbines. These are present in Iceland, with approximately 250 located in the area between the southern Westfjords and Snæfellsnes (Hansen et al., 2022; Krone, 2018). Krone (2018) suggests that to reduce the likely frequency of collisions, 3 km exclusion zones should be applied between wind turbines and known nests.

The icing potential of Icelandic wind energy projects has been modelled by the Icewind project, which has used GIS-mapping to develop an icing atlas for the Nordic nations. A map showing the maximum simulated ice load at the surface has been developed,

which demonstrated the locations in Iceland where ice load is particularly likely to negatively impact the power generation of onshore wind energy projects, which include mountainous areas in the Westfjords, northern parts of Iceland, the south-east, and East Fjords. The areas of least vulnerability included the Reykjanes peninsula, southern lowlands, Borgarfjörður, and Melrakkaslétta (Clausen and Giebel, 2017).

Regarding the social acceptability of onshore wind energy projects in Iceland, the spatial mapping study by Tverijonaite et al. (2022) provided a useful demonstration of the role that GIS mapping can play in indicating likely zones of negative impact from the perspective of specific stakeholders – Icelandic tourist operators in that case study. In addition, it is important that future onshore wind energy projects secure the backing of affected stakeholders, including the general Icelandic public. In tandem with GIS mapping, approaches such as the Public Acceptance Rating of proposals could be adopted. Hrabalíkóva et al. (2024) highlight how photomontage data can be used to determine relative acceptability via mean Public Acceptance Ratings of wind energy project configurations. Positive mean values signify acceptable proposals, with negatives equating to unacceptable impacts from a visual perspective. In theory, a survey-based approach could determine the perspectives of multiple different stakeholders using this method. Furthermore, similarly to the other forms of visual impact analysis being undertaken in Iceland, once more information is known about the preferences of various stakeholders concerning wind energy project proposals, such information could be used as the basis for informing design, either at that specific site or elsewhere. The Ministry of Forests, Lands and Natural Resource operations (2016) categorised four different sets of wind energy proposals in British Columbia: Class A (preservation), Class B (retention), Class C (partial retention), and Class D (modification). Of these, only Class D's proposals were found to have a negative Public Acceptance Rating, with the wind turbines appearing as large and distinctive features of the landscape. In the best case, Class A, they were barely visible. Such information, when gathered from multiple different distances and viewpoints, could be used to generate a GIS map of public acceptability, akin to the recent work of Tverijonaite et al. (2022) on the visual and tourism mobility impacts of the proposed wind farm at Búrfellslundur.

GIS-based tools can play an important role in the design of proposals and avoid the most unsuitable locations from the outset. They can also help to inform the public in this regard when maps are made available online. The mapping of various exclusion zones, such as residential or commercial buildings within 500 metres of wind turbines, 15 km of airports, or in protected areas, will support energy project developers in avoiding locations of immediate unsuitability. The capacity to access 3D visual analysis further extends the potential of GIS mapping in aiding pre-proposal design prior to assessment by the Master Plan. Cranmer et al. (2023) found that more immersive forms of media tended to lead to more positive impressions about wind energy projects in the US than 2D maps. Furthermore, both 2D and 3D mapping approaches enable some of the worst effects relating to the scale, size and configuration of a turbine array, or contrast effects, to be entirely prevented even prior to the detailed design phase when an Environmental Impact Assessment is required.

A further issue that is often ignored when considering the impacts of onshore wind energy projects concerns the decommissioning and potential recycling of turbine components at its end. This is likely to become a more significant issue in the future given the increasing prominence of the circular economy. Thus, future decision-making

may also wish to consider how best to mitigate the impacts of such projects over their entire lifecycle, reflecting on optimal locations with regards to the storage and recycling of decommissioned parts, or how they can be transported from the site with minimal environmental impact for re-use or recycling.

7. CONCLUSION

In the context of the global energy transition and the Icelandic government's pursuit of net zero carbon status by the year 2040, developing wind energy has been proposed as a way of dealing with climate change and reducing carbon dioxide emissions, additional to any expansion in the current utilisation of hydro and geothermal power. However, the location of placing onshore wind energy needs careful consideration. The important task of balancing wind energy development, environmental protection and other trade-offs can be informed through use of GIS-analysis in advanced planning instruments that can systematically evaluate likely impacts. As is increasingly carried out around the world, GIS-based Multi-Criteria Decision Analysis provides an advanced means of determining the optimal location of onshore wind power projects and has usefulness as an informative device within Iceland's Master Plan for Nature Protection and Energy Utilization. Efforts are already underway in Iceland to develop enhanced understanding of the likely visual impacts of proposed wind power projects in Iceland. This will be particularly helpful in developing an implementable and standardised 2D and 3D modelling approach for landscape visual impact evaluation, providing the capacity to evaluate changes to landscape quality before and after proposed wind power projects are introduced.

In Iceland, the regulatory framework for onshore wind energy is less developed than in many other countries where the technology has been much more widely adopted, and yet it is highly likely that wind energy will play a role in producing the increased renewable generation needing to support Iceland's transition to becoming a net zero carbon society by 2040. It is evident that GIS mapping can be very helpful in resolving some of the complex issues that still need to be resolved within Iceland's decision-making apparatus for locating onshore wind energy projects. As the report by Government of Iceland (2023) called for, areas should be determined where the installation of wind energy will be prohibited and where they are most suitable. GIS mapping can play a major role in not only determining optimal locations but helping to mitigate at the earliest design stage the potential social and environmental impacts of onshore wind energy proposals. This can aid the Icelandic government in developing the rules find the most suitable location for wind energy projects and avoiding conflicting locations in the country.

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