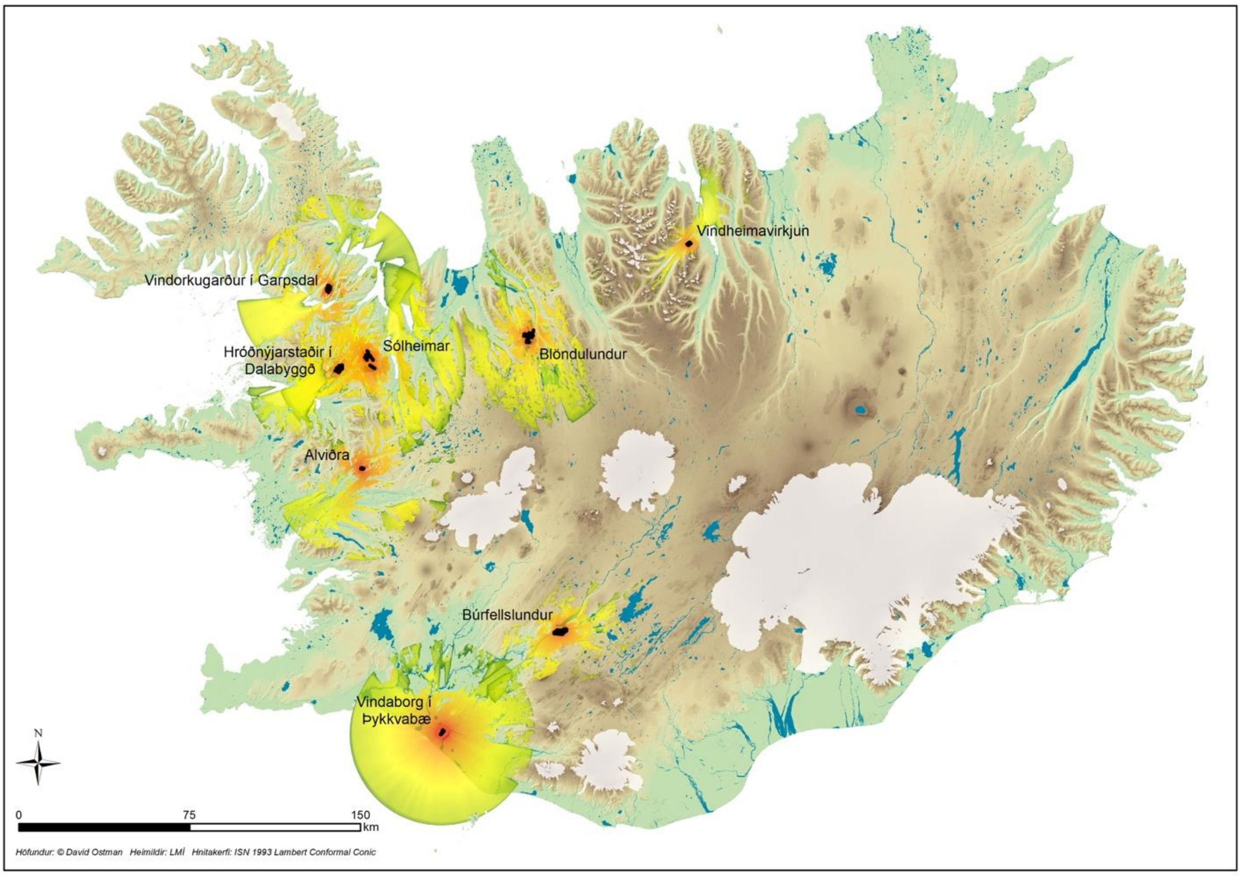
# Landslagsáhrif vindorkuvera - þróun aðferðafræði til greiningar og mats





**David C. Ostman og Þorvarður Árnason**

**Háskóli Íslands – Rannsóknasetur á Hornafirði**


HÁSKÓLI ÍSLANDS

Rammaáætlun

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Rannsóknasetur á Hornafirði

Höfn, desember 2021

Verkefni unnið fyrir Áætlun um vernd og orkunýtingu landsvæða (Rammaáætlun)

Titill: Landslagsáhrif vindorkuvera – þróun aðferðafræði til greiningar og mats

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Forsíðumynd: Kort um sýnileika þeirra átta hugmynda um vindorkuver sem rannsökuð voru í verkefninu, miðað við 40 km radius út frá verunum – © David C. Ostman (2021).

# Efnisyfirlit

# Formáli

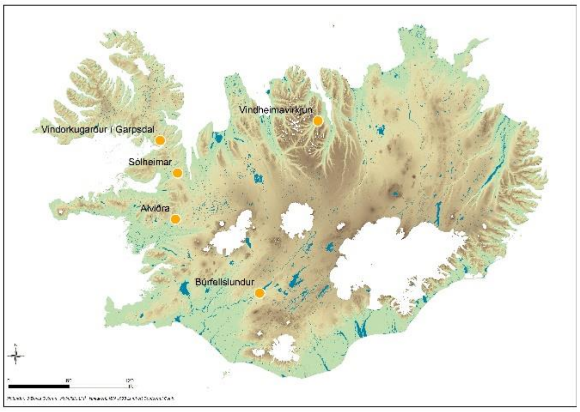
Skýrsla þessi er unnin á vegum faghóps 1 í fjórða áfanga *Áætlunar um vernd og orkunýtingu landsvæða* (Rammaáætlunar).[1] Fyrri áfangar Rammaáætlunar hafa fyrst og fremst fjallað um vatnsafls- og jarðvarmavirkjanir. Vindorkuver komu þannig ekki til skoðunar innan Rammaáætlunar fyrr en í 3. áfanga, en þar voru tvær tillögur um vindorkuver teknar til mats. Áhugi á nýtingu vindorku á Íslandi hefur farið stigvaxandi á allra síðustu árum, sem sést ef til vill best á því að 34 hugmyndir að vindorkuverum voru upphaflega lagðar fram til mats í 4. áfanga Rammaáætlunar. Í Kortasjá Orkustofnunar má finna nánari upplýsingar um þessar virkjanahugmyndir, og sjá fjölda þeirra og dreifingu um landið (Mynd 1).[2]


*Mynd 1: Tillögur að vindorkuverum sem lagðar voru fram til skoðunar í 3. og 4. áfanga Rammaáætlunar. Skjáskot af Kortasjá Orkustofnunar.*

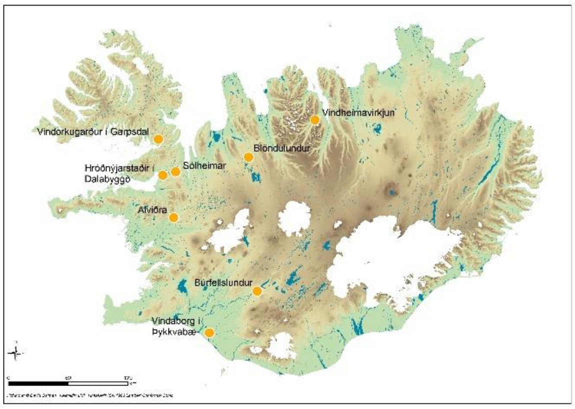
Aðeins hluti framlagðra hugmynda um vindorkuver uppfyllti þó skilyrði um nauðsynlegar grunnupplýsingar fyrir matsvinnuna og því komu á endanum aðeins fimm þeirra til formlegs mats í 4. áfanga Rammááætlunar: Alviðra, Búrfellslundur, Sólheimar, Vindheimaverkjun og Vindorkugarður í Garpsdal (Mynd 2). Þar sem þróunarverkefnið sem hér er til umræðu hófst áður en endanleg niðurstaða um mat á tillögum lá fyrir voru þrjú fyrirhuguð virkjanasvæði til viðbótar skoðuð í þróunarverkefninu: Blöndulundur, Hróðnýjarstaðir og Vindaborg í Þykkvabæ (Mynd 3).

[1] Sjá nánar: https://www.ramma.is/

[2] Sjá: https://map.is/os/#




*Mynd 2: Staðsetning tillagnana fimm sem teknar voru til mats í 4. Áfanga Rammaáætlunar.*




*Mynd 3: Rannsóknarsvæðin átta sem tekin voru til skoðunar í þessu þróunarverkefni.*

Matsvinna faghóps 1 byggir á aðferðafræði sem var að stofni til mótuð í 1. áfanga Rammaáætlunar.[3] Á meðal þeirra viðfanga (þ.e. einstakra náttúru- og menningarverðmæta) sem faghópunum ber að fjalla um eru landslag og óbyggð víðerni. Eitt af viðmiðunum sem huga þarf að við mat á landslagi er sjónrænt gildi. Aðferðafræði um almenna flokkun, greiningu og mat á landslagi var frágengin í 2. áfanga áætlunarinnar.[4] Sú aðferðafræði (sem byggir á kerfisbundinni söfnun upplýsinga um einkenni landslags á vettvangi) nýtist til mats á virkjunarhugmyndum, óháð tegund þeirra eða gerð. Áhrif vindorkuvera á landslag eru þó að verulegu leyti annars eðlis en áhrif vatnsafls- eða jarðvarmavirkjana. Síðartöldu virkjanirnar eru meira „jarðbundnar" en vindorkuverin þar sem langir spaðir, staðsettir á háum turnum, teygja sig til himins og geta þarafleiðandi verið sýnilegir mjög langt að. Þótt vindmyllur geti verið stakar er algengara að reisa töluverðan fjölda vindmylla nálægt hver annarra, þar sem aðstæður til vindorkunýtingar eru taldar hagstæðar. Vindorkuver geta þarafleiðandi teygt sig yfir talsvert stór svæði og eru því sýnilegri sem uppsettar vindmyllur eru fleiri. Jarðrask er vissulega einnig fyrir hendi, bæði vegna landsins sem tekið er undir undirstöður vindmyllanna og einnig vegna vegalagningar og annarra framkvæmda sem nauðsynlegar eru til þess að unnt sé að koma vindmyllunum fyrir. Hin fýsísku áhrif á landslag eru þó alla jafnan mun minni að vöxtum en áhrifin sem stafa af sýnileika þessara stóru og háu mannvirkja. Slík mannvirki eru því að stærstum hluta í „lóðréttu plani", á meðan mannvirki sem tengjast nýtingu vatnsorku eru fyrst og fremst í „láréttu plani". Jarðvarmavirkjanir hafa bæði þessi einkenni til að bera, þar sem gufustrókar standa iðulega upp af borholum og geta þarafleiðandi verið sýnilegir úr töluvert meiri fjarlægð en önnur dæmigerð mannvirki sem fylgja virkjun jarðvarmans.[5] Slíkir strókar ná þó ekki jafn hátt til lofts og stærstu vindmyllur og geta enn fremur verið mjög breytilegir bæði að hæð og lögun, eftir því hvaðan og hversu sterkt vindar blása.

Af ofangreindum ástæðum taldi faghópur 1 nauðsynlegt að þróa sérstaka aðferðafræði til að greina og meta landslagsáhrif af völdum vindorkuvera, sem notuð yrði samhliða eldri aðferðum.

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[3] Thóra Ellen Thórhallsdóttir (2007). Strategic planning at the national level: Evaluating and ranking energy projects by environmental impact. *Environmental Impact Assessment Review* 27(6): 545-568.

[4] Þóra Ellen Þórhallsdóttir, Þorvarður Árnason, Hlynur Bárðarson og Karen Pálsdóttir (2010). *Íslenskt landslag. Sjónræn einkenni, flokkun og mat á fjölbreytni*. Reykjavík: Háskóli Íslands.

[5] Sjá nánar: David Ostman (2015). *A New Approach for Assessing Landscape Impacts of Geothermal Power Plants: A Case Study of Hellisheiði*. Óbirt meistaraprófsritgerð við Háskóla Íslands.

# 1. Landscape data collection process

The latest rounds of landscape data collection for Rammaáætlun phase 4 (RÁ4) occurred during the summer of 2019, between August 7th and September 26th, and the summer of 2020, between July 19th and September 5th. The data collection was targeted based on the assessment areas of the power projects proposed for RÁ4 (Ostman, 2020). These included 8 windfarm projects: Blöndulundur, Vindaborg í Þykkvabæ, and Hróðnýjarstaðir í Dalabyggð, Alviðra, Vindheimavirkjun, Búrfellslundur, Sólheimar, and Vindorkugarður í Garpsdal, of which the latter 5 became priority projects for formal evaluation within RÁ4. Figure 1 shows the locations of all 8 windfarm projects for which fieldwork was conducted between 2019 and 2020.

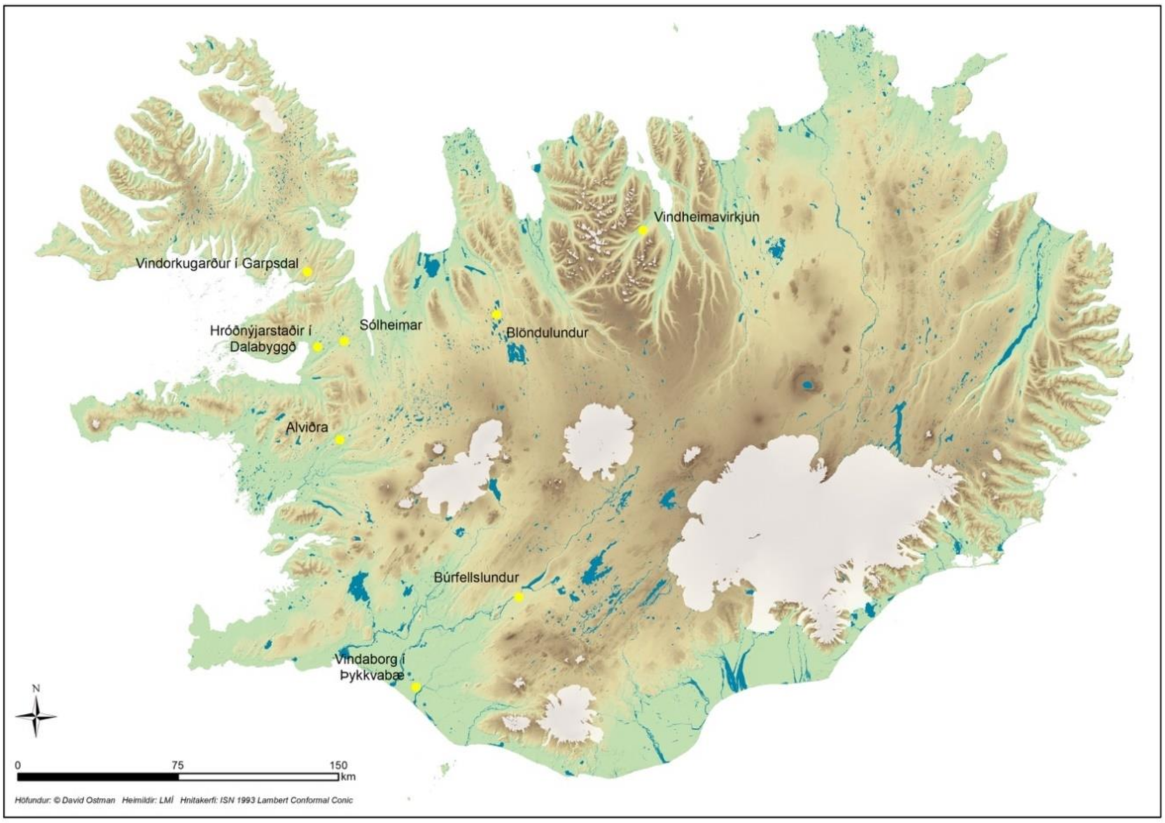



*Fig. 1. Locations of all windfarm projects for Rammaáætlun phase 4 for which fieldwork was conducted during the summers of 2019 and 2020*

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 (adopted originally from a 10 x 10 km grid from Náttúrufræðistofnun Íslands) and which has been used in previous Rammaáætlun data collection phases (Þórhallsdóttir, Árnason, Bárðarson & Pálsdóttir, 2010). Four types of data were gathered and recorded at each point: (1) Checklist of landscape characteristics (visual features), (2) Checklist of wilderness characteristics (manmade, structure-related variables and perceptual qualities), (3) 360-degree photography, and (4) 360-degree videography. Additional photographs and video were taken specifically in the direction of where the turbines would be built, with the intention to use theseto create photomontages of the respective windfarms.

A total of 65 individual data points was collected for the 8 windfarm projects visited in the summers of 2019 and 2020 (Figure 2). These newly-collected points were subsequently assessed in combination with all other data points that had already been collected as part of previous ILP fieldwork and Rammaáætlun phases.

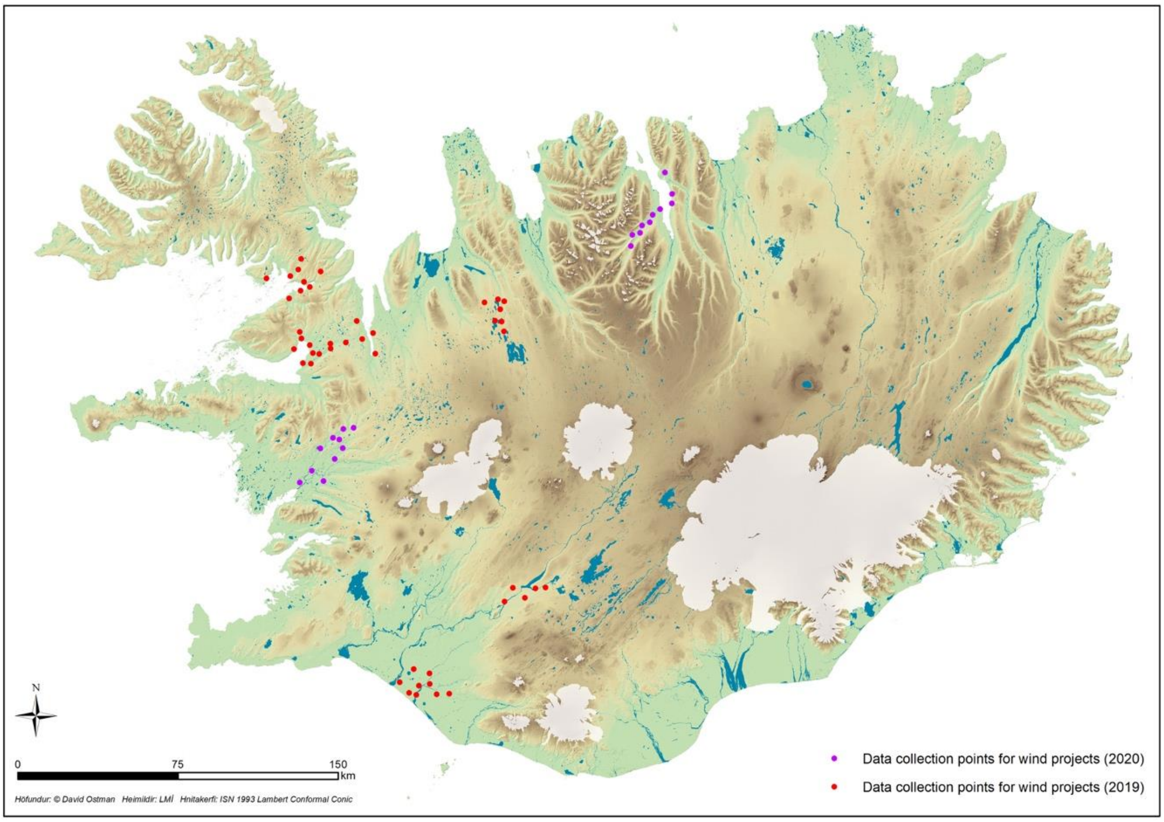



*Fig. 2. Fieldwork sampling points collected in the summers of 2019 and 2020 for windfarm projects*

In order to prioritize data points for the windfarm projects, grid points that fell within the potential visibility of the turbines had to be determined, so a zone of theoretical visibility (ZTV) map was created in a licensed visibility software, *Viewshed Explorer* (Carver, S. & Washtell, J., 2012), on all proposed windfarm projects prior to beginning fieldwork (Figure 3). This ~~new~~ visibility program is described in greater detail in section 3. A maximum distance radius of 40km was placed on the visibility analyses as recommended by the Scottish National Heritage guidelines based on the proposed turbine blade tip heights (Scottish National Heritage, 2017).

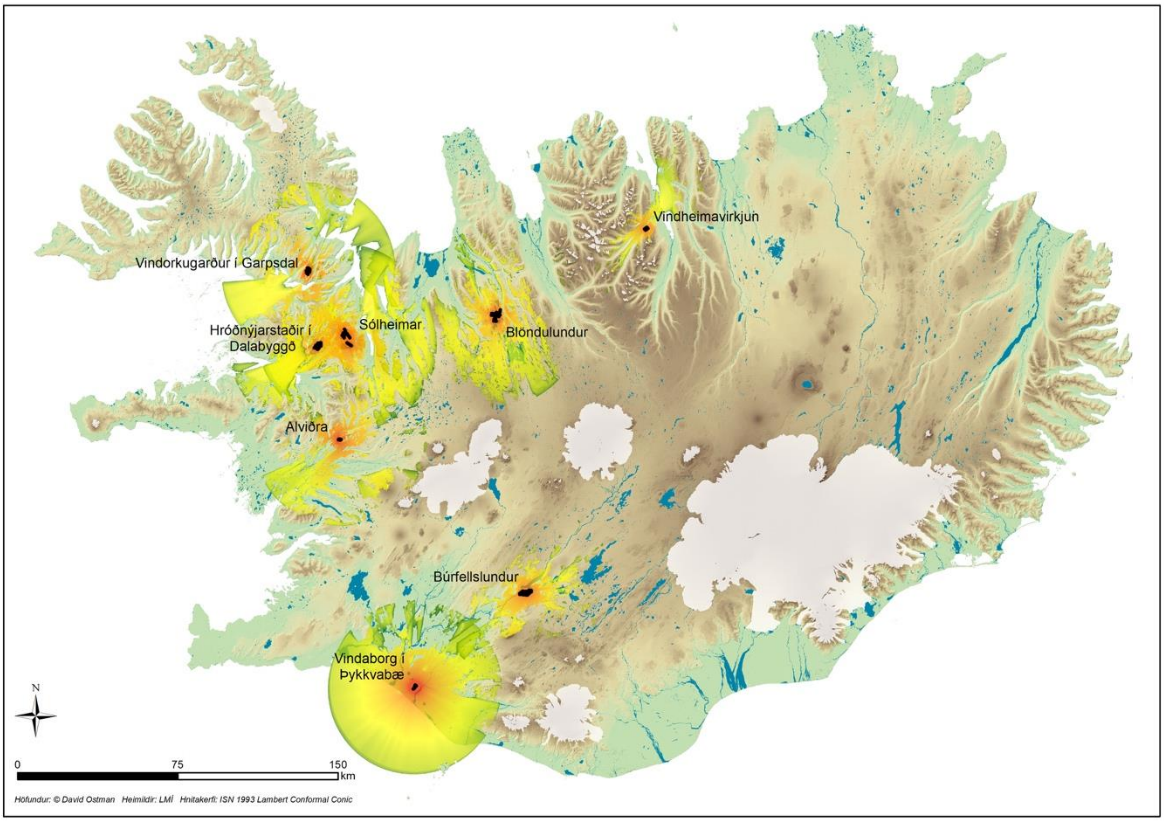



*Fig. 3. Visibility analyses conducted in Viewshed Explorer for proposed windfarm projects to target data collection points that fall within potentially visible areas. A 40km maximum distance radius was used for the visibility extent*

Visible points within a 10km radius of each project were given priority, as well as locations that fell within shared visibility amongst projects and those more easily accessible based on roads and terrain. Other points outside of the 10km radius were also targeted based on settlements and other sensitive areas (main roads, etc...) within the visibility zone. Figures 4 through 11 show the data collection locations - 2020 points and older - that were used in assessing each of the 8 projects, overlaid with the *Viewshed Explorer* ZTV layer.

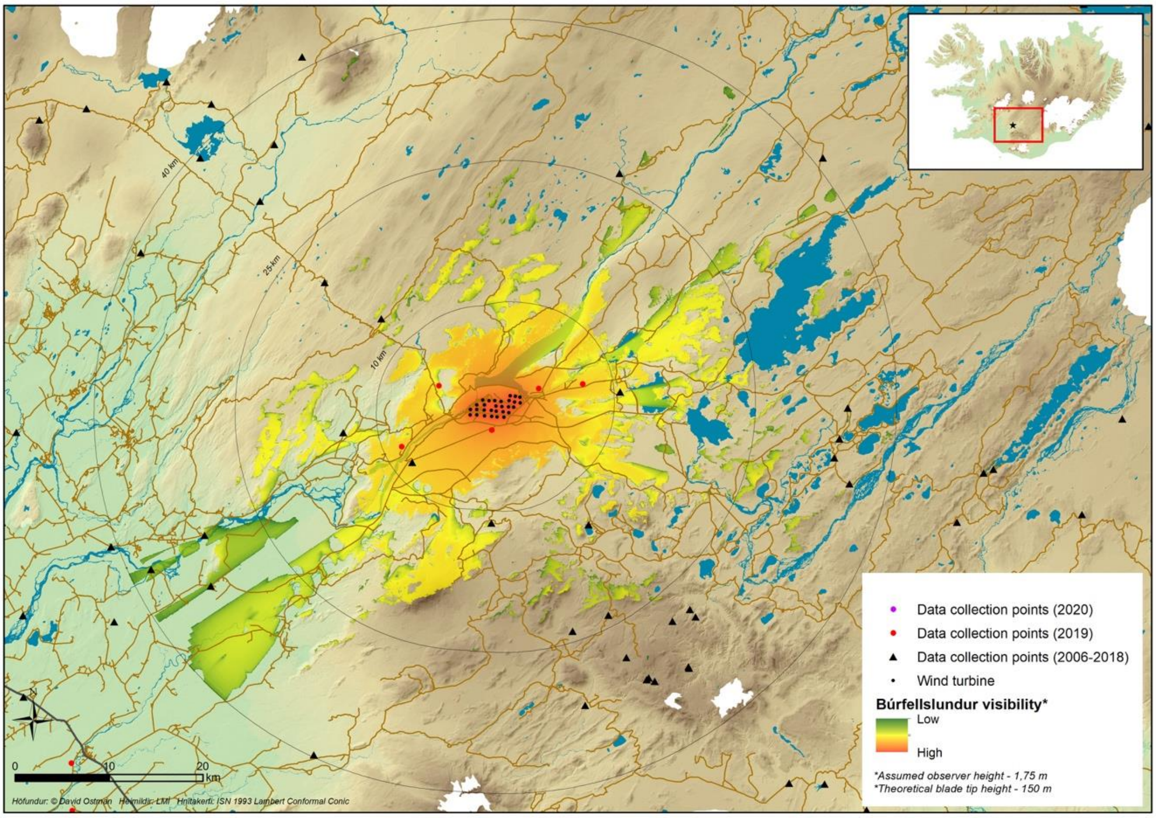



*Fig. 4. Data points for Búrfellslundur windfarm with Viewshed Explorer visibility*

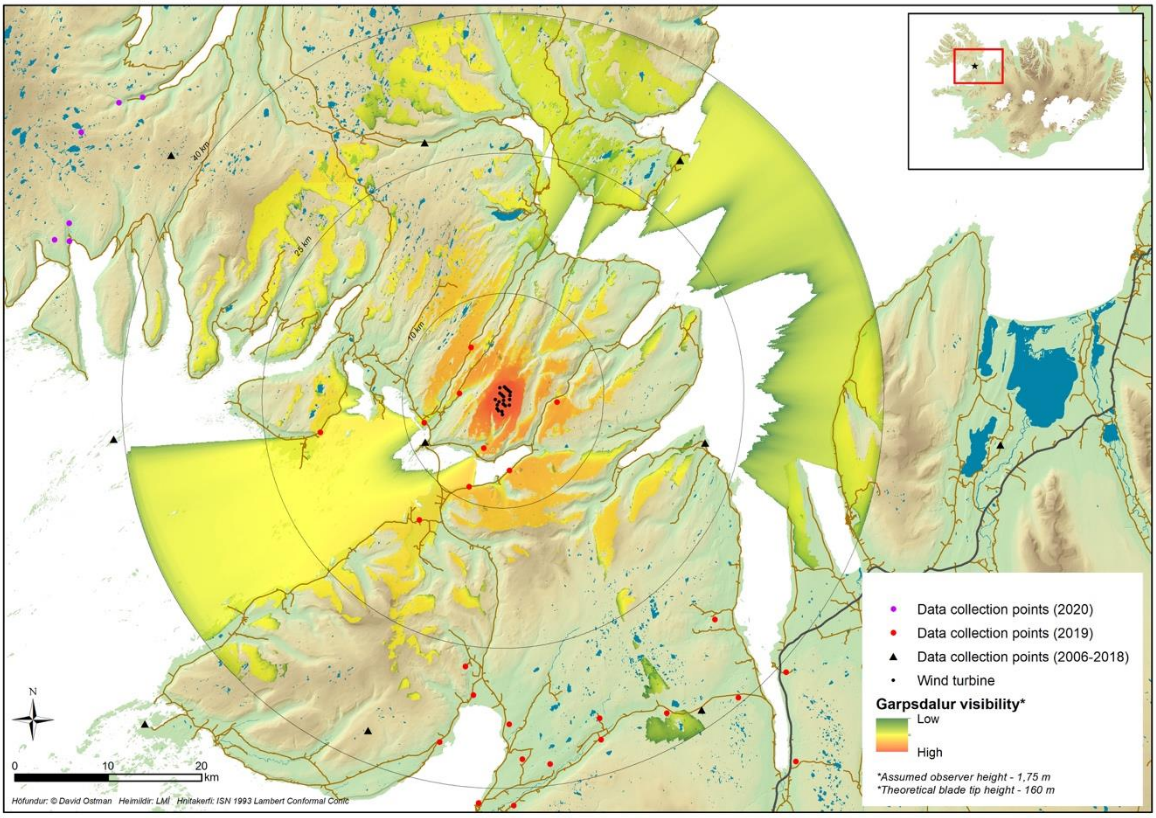



*Fig. 5. Data points for Vindorkugarður í Garpsdal windfarm with Viewshed Explorer visibility*

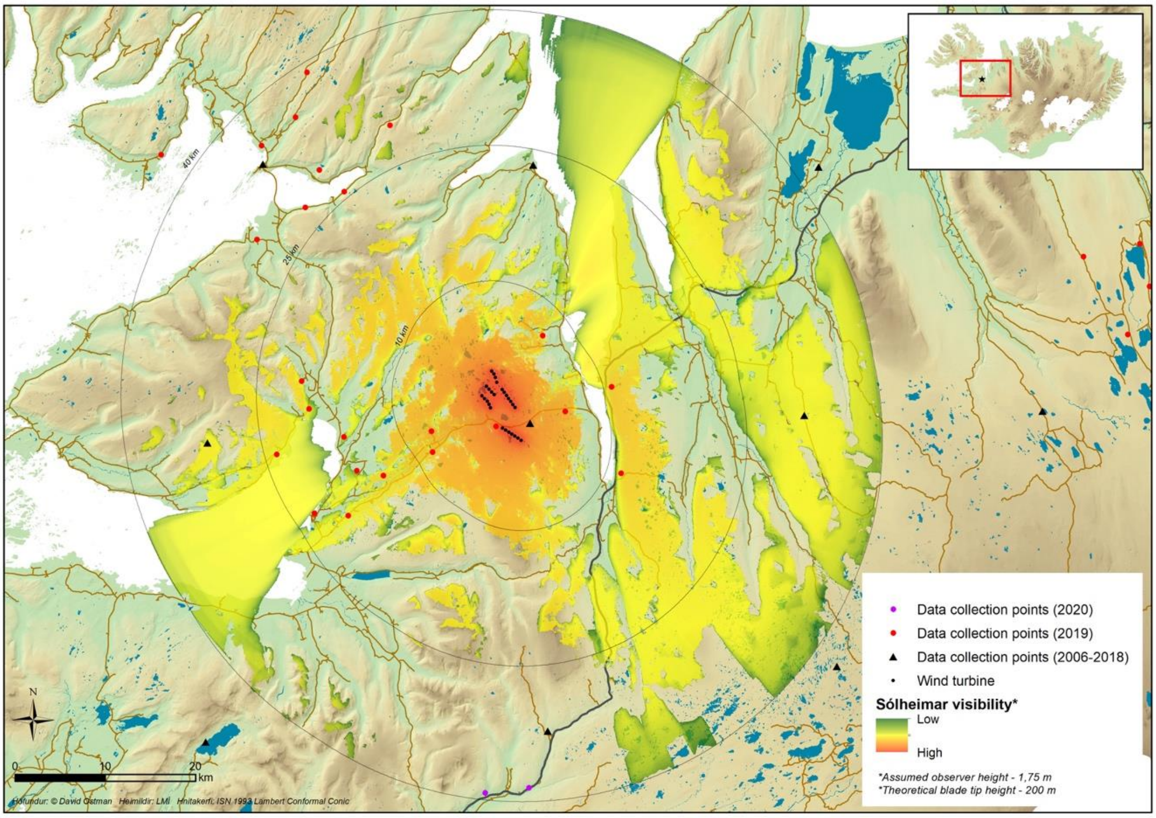



*Fig. 6. Data points for Sólheimar windfarm with Viewshed Explorer visibility*

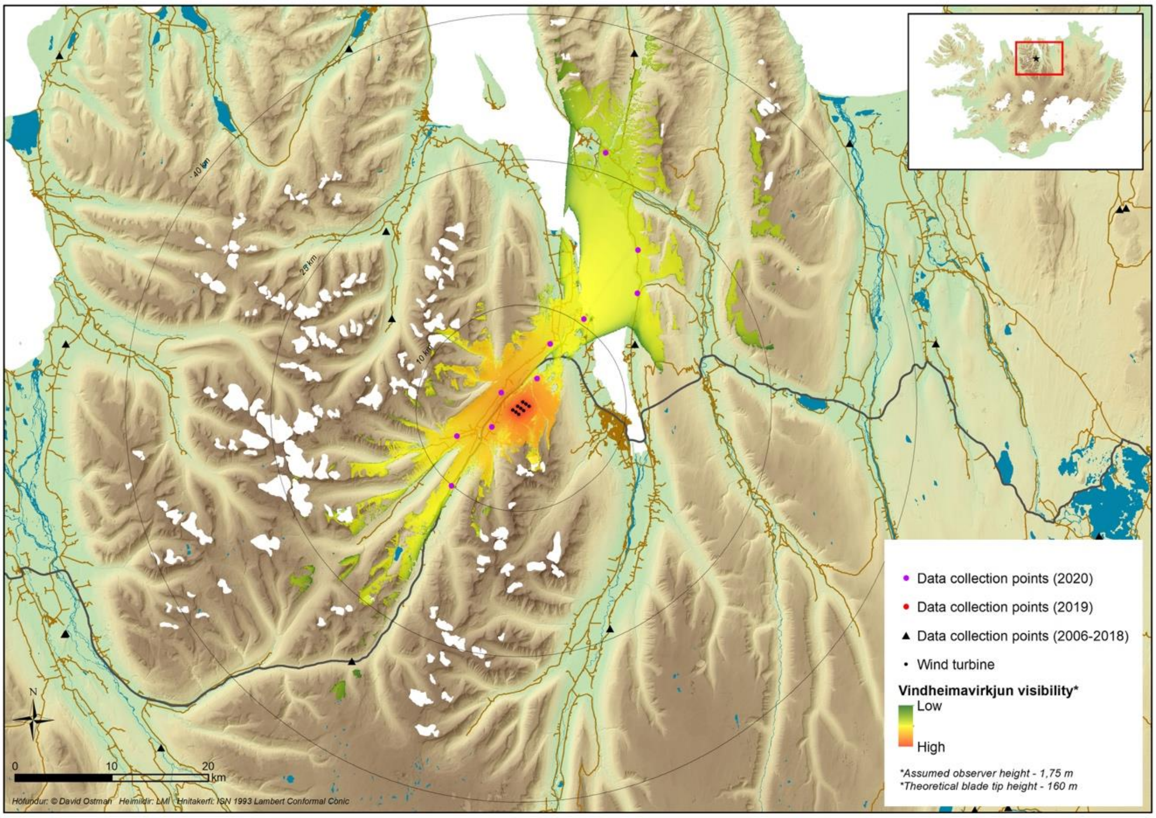



*Fig. 7. Data points for Vindheimavirkjun windfarm with Viewshed Explorer visibility*

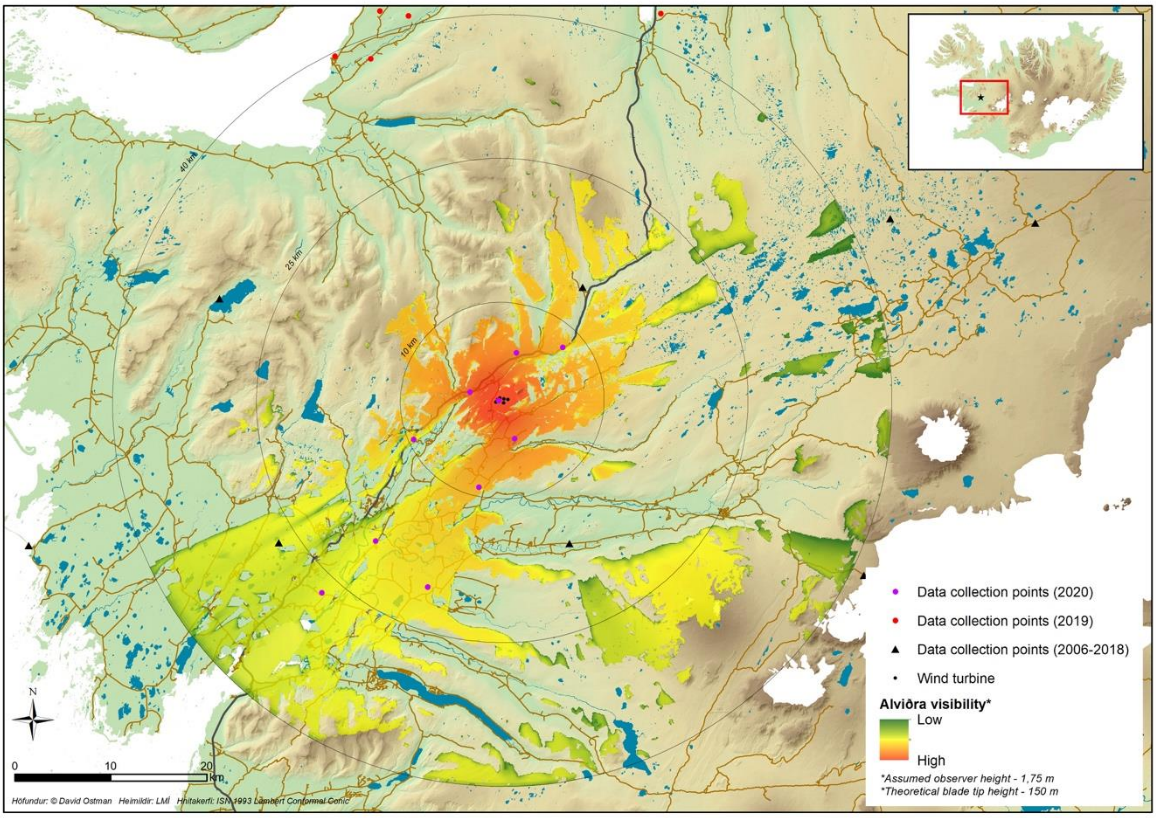



*Fig. 8. Data points for Alviðra windfarm with Viewshed Explorer visibility*

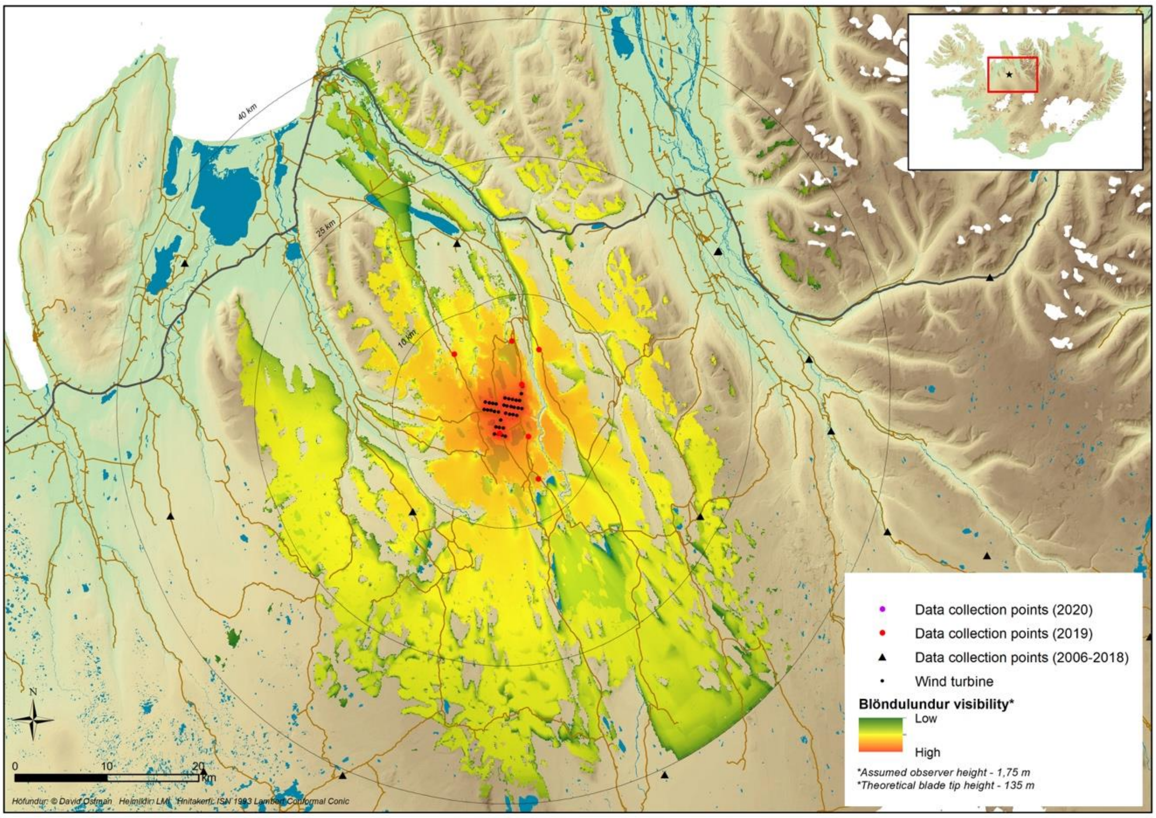



*Fig. 9. Data points for Blöndulundur windfarm with Viewshed Explorer visibility*

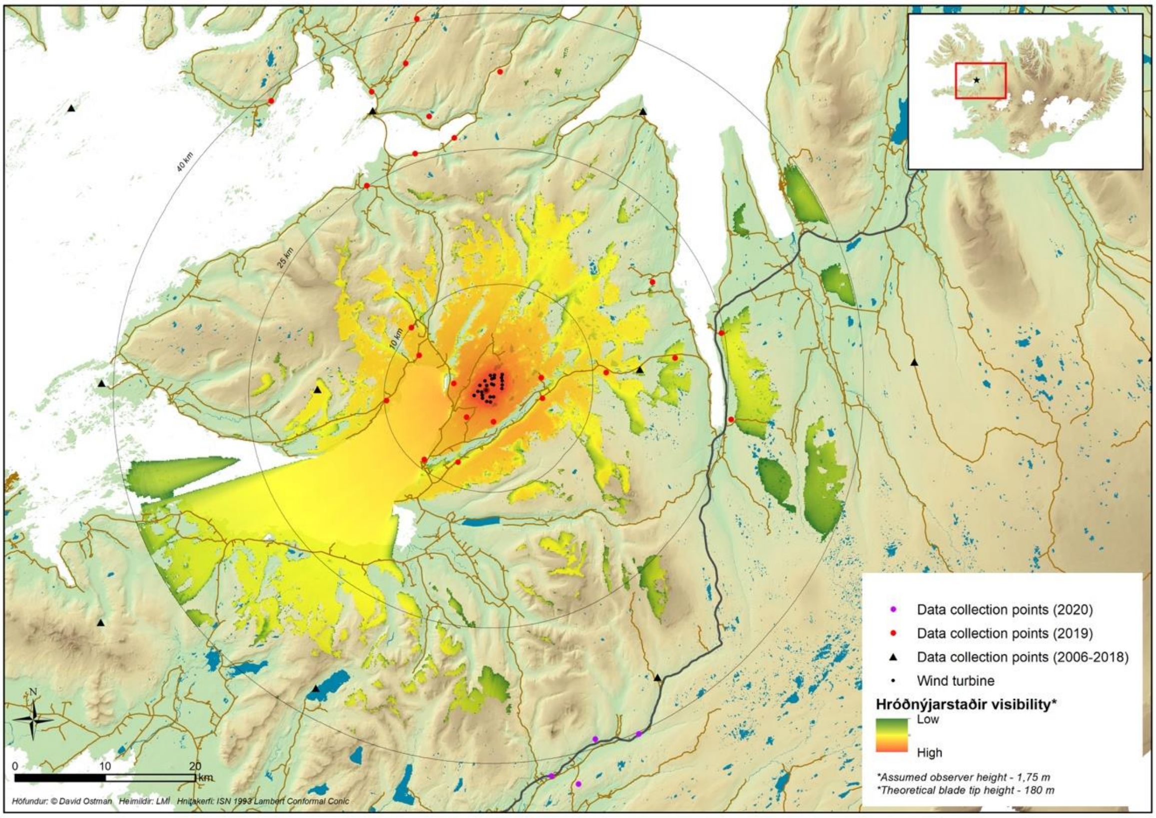



*Fig. 10. Data points for Hróðnýjarstaðir windfarm with Viewshed Explorer visibility*

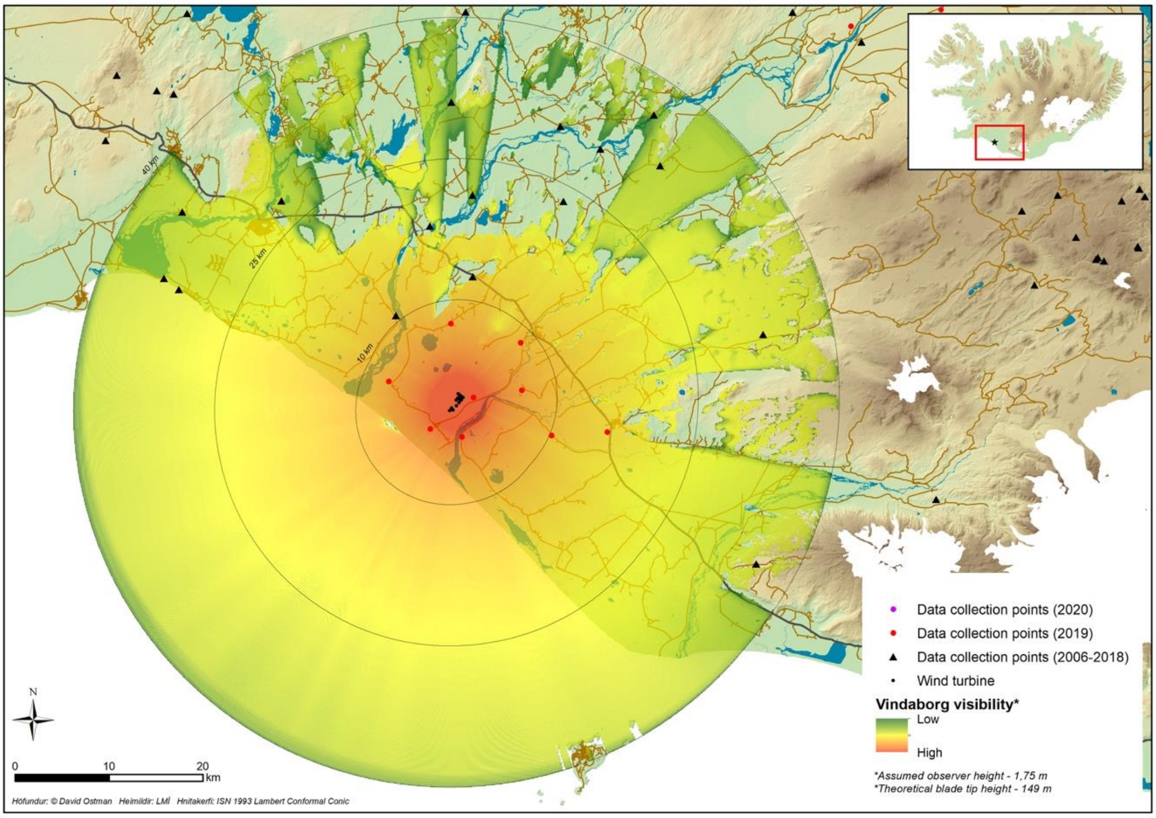



*Fig. 11. Data points for Vindaborg windfarmwith Viewshed Explorer visibility*

# 2. Cluster analysis and updated landscape categories

## 2.1 Overview and past cluster analyses

The addition of these newly-collected data points for RÁ4 contributes to a broader, ongoing research project of expanding the ILP classification system into a more robust landscape database and refined set of landscape categories (Ostman, 2020). The classification of each data point into a particular landscape category is determined by how well it groups together with other data points based on shared visual landscape features. These features include 22 visual characteristics of landscape (Table 1) that are assessed and recorded in the field, using a checklist worksheet during the data collection process.

*Table 1. Fieldwork checklist of landscape attributes used in cluster analysis*

| **Landscape attributes** | |
|---|---|
| Landscape contour | Diversity of patterns |
| Landscape depth | Texture (smooth, rough) |
| Elevation range | Texture diversity |
| Lines (straight, rounded, sharp, sinuous) | Water cover |
| Line diversity | Running water presence |
| Vegetation cover | Water diversity |
| Vegetation diversity | Sea presence |
| Color | Glacier & ice presence |
| Patch size of patterns | Overall diversity |

A hierarchical cluster analysis was used to establish the landscape categories. The first round of analysis was conducted in 2010 in R, which resulted in 11 landscape categories based on 108 data points, collected between 2006-2008 for use in RÁ2. Figure 12 shows the final dendrogram groupings along with the corresponding landscape category descriptions. Further information on each category can be found on p. 87 in Þórhallsdóttir, Árnason, Bárðarson & Pálsdóttir (2010).

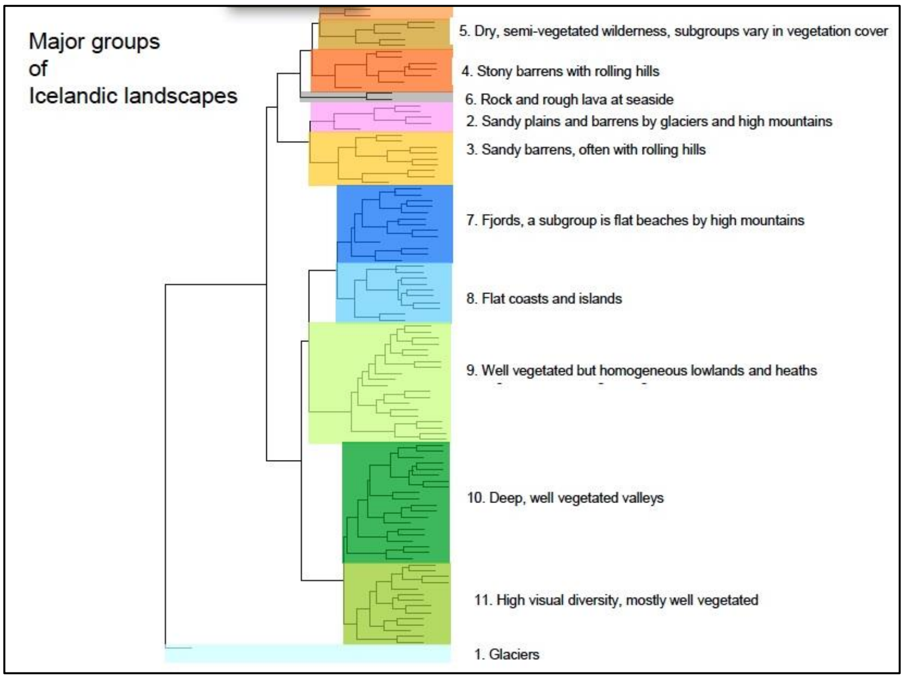



*Fig. 12. Original 2010 dendrogram results and 11 landscape categories based on the initial 108 data points collected between 2006-2008 (Þórhallsdóttir et al., 2010)*

The second round of analysis in 2016 also used R for the point clustering and incorporated the additional 67 new data points that had been collected in the summer of 2015 for RÁ3 (Hoffritz, Ostman & Árnason, 2016). The main difference in this second round of analysis was that 4 of the 22 landscape variables – basic shape (*grunnlögun*), vegetation cover (*gróðurþekja*), sea presence (*sjór*), and glacier presence (*jökull*) – were determined to be more defining and dominant visual characteristics of the landscape and were therefore given a weight (0.5) in the dataset. The resulting dendrogram showed the grouping of these 175 points based on their shared landscape features, and 11 new landscape categories were established (Figure 13), most of which were very similar to the original 11 categories formulated in 2010.

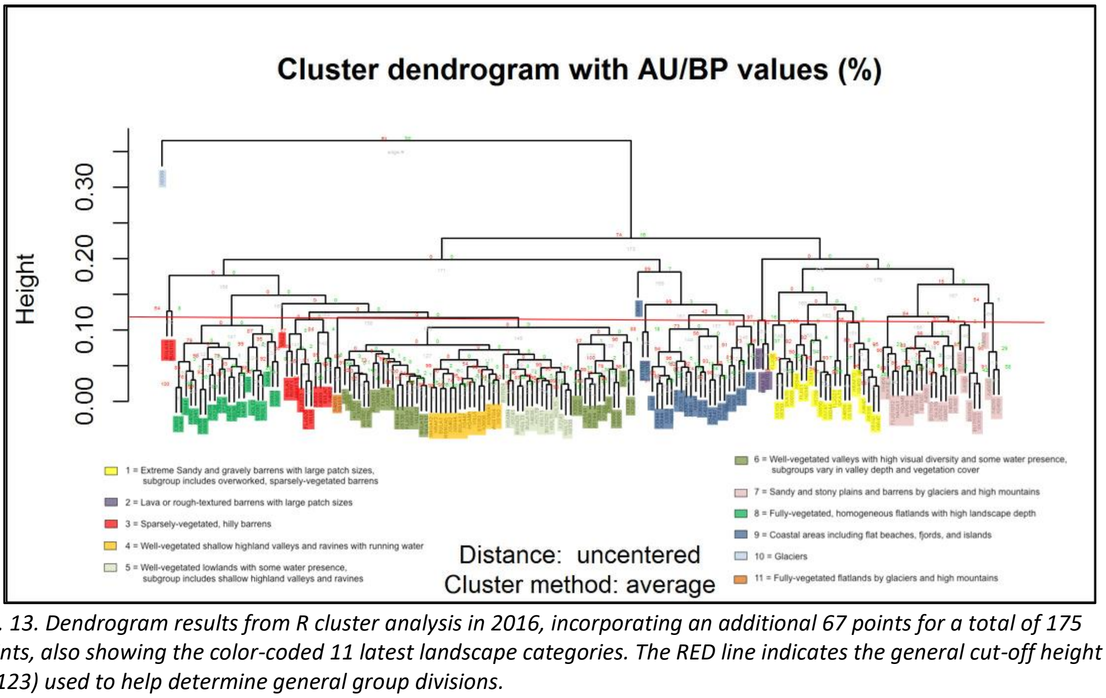



*Fig. 13. Dendrogram results from R cluster analysis in 2016, incorporating an additional 67 points for a total of 175 points, also showing the color-coded 11 latest landscape categories. The RED line indicates the general cut-off height (0.123) used to help determine general group divisions.*

This second round of analysis showed that a few of the original landscape categories based on the 2010 dendrogram were 'broken apart'. One of the reasons to explain this grouping alteration may be the inherent nature of how the cluster analysis deals with new data. That is, when adding in the newer points that contain potentially new variations of landscape feature information, which may not have existed in the original data set, the original dendrogram groupings may expand or contract with some points getting 'pushed out' into other groupings that share a more similar data set. What may have been considered 'similar' in a smaller data set may not be so 'similar' in a larger one. New data may result in nuanced versions of existing landscape categories and even the potential of new categories.

The third round of cluster analysis was conducted in early 2020 based on the addition of 45 new data points collected in the summer of 2019 for RÁ4, 6 points collected in the summer of 2016 for RÁ3 but previously not analysed, and a series of older, targeted landscape points based on their status as a 'geothermal' (Þórhallsdóttir et al., 2010) or 'nature pearl' site (Pálsdóttir, 2009); 39 and 45 points, respectively. Altogether, 310 points were processed, with all data which had by then been collected in the ILP and related projects. SPSS was used in this round of clustering instead of R, as SPSS was able to produce similar results as R but with more ease and efficiency. After finding some logical divisions in the resulting dendrogram branches, and using a general 'cut-off' height of about '10', 12 categories were demarcated. The resulting dendrogram and identified landscape groups are shown in Figure 14.

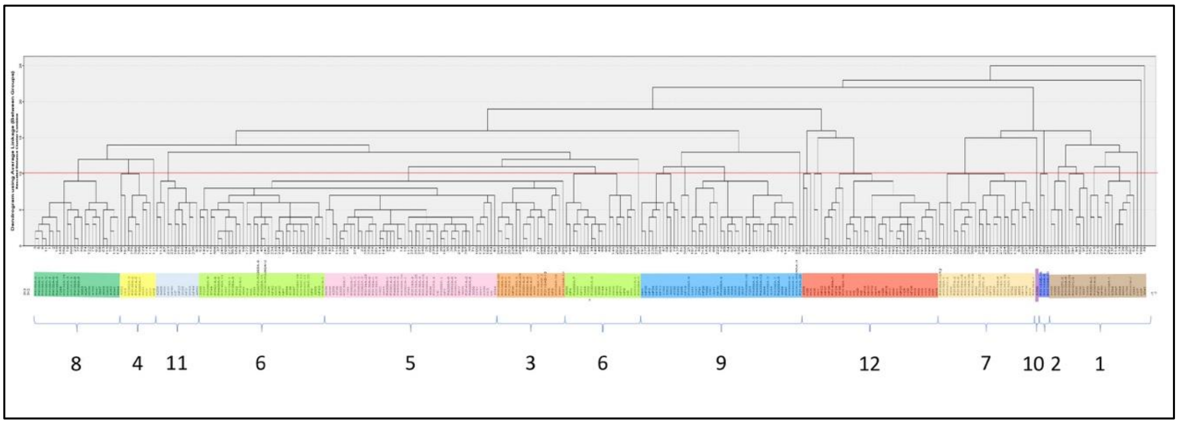



*Fig. 14. Dendrogram and new landscape category grouping results from SPSS cluster analysis in early 2020, based on all ILP data collection points to-date (310 points total). A general 'cut-off' height of about '10' (indicated by the RED line) was used to help determine logical divisions in the groupings*

## 2.2 Latest cluster analysis and final landscape categories

The fourth, and most recent, round of cluster analysis (SPSS) took place in September 2020 based on the addition of 33 new data points collected in the summer of 2020 (Ostman, 2020). Similar to the 2 previous rounds of analysis, 4 of the 22 landscape variables – basic shape (*grunnlögun*), vegetation cover (*gróðurþekja*), sea presence (*sjór*), and glacier presence (*jökull*) – were given a weight (0.5) in the dataset in order to highlight the more defining and dominant visual characteristics of the landscape. In SPSS the 'between-groups linkage' cluster method using the 'cosine' interval were applied as this combination had best recreated the original 2010 dendrogram results that were initially run in R.

Altogether, 343 points were processed in this latest analysis. The resulting dendrogram was then color-coded based on the most recent ILP classification categories to see how well the groupings stayed together. The newest 33 points added in this analysis would, of course, not have a category already assigned to them, but once all other points were color-coded, then it was possible to see if these remaining, newest points 'fit in' amongst the older points. If the old and new points grouped together well in the dendrogram based on the existing, color-coded categories (e.g. there were not too many outliers, and the color-coded categories grouped together well), then the new points could be tentatively assigned their appropriate landscape category. The appropriateness of the landscape category for each new point could be verified by checking if the fieldwork photos and video of those points align with the visual characteristics of their newly-assigned category description. They could also be compared to the photos and video of older points from the same category.

Once these preliminary categories (old and new points) in the dendrogram were distinguished, the data from all 343 points were then put into an excel spreadsheet and grouped based on these preliminary categories. The averages of all 22 landscape variable ratings for each grouping were calculated. The rating scale for each variable was 0-5 (0 = lowest, 5 = highest). A heat map was then created (Table 2) for these averages to help highlight extreme high and low variable ratings and ultimately help reveal distinct landscape features within a particular category.

The heat map results, along with any necessary visual references to the photos and videos for the data points, also determined distinguishing features and justification for the latest categories and their respective written descriptions.

*Table 2. Heat map of the 22 landscape variable rating averages (scale 0-5) for each of the 12 landscape categories. Dark RED indicates a lower rating, and dark GREEN indicates a higher rating*

| Fall 2020 Cat | Grunnlogun | vidsyni | breytileiki I head | beinar | avalar | hvassar | svigthur | fjolform | grodurthekja | grodurfjol | litbrigthi | blettastærd | mynstfjol | aferdfjol | aferdhrjuf | aferdslett | vatnthekja | straumur | Vatnfjol | Sjor | Jokull is | Fjolbreytni |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1.4 | 1.7 | 3.8 | 2.7 | 2.7 | 1.7 | 3.0 | 3.0 | 4.3 | 2.8 | 2.8 | 3.0 | 2.9 | 3.2 | 2.9 | 3.4 | 1.9 | 2.6 | 1.6 | 0.3 | 0.1 | 2.8 |
| 5 | 3.1 | 2.5 | 3.1 | 1.9 | 3.0 | 0.8 | 2.4 | 2.4 | 4.5 | 3.1 | 2.6 | 3.4 | 2.6 | 2.5 | 2.1 | 3.8 | 1.9 | 1.6 | 1.4 | 0.1 | 0.0 | 2.5 |
| 4 | 2.9 | 2.1 | 3.0 | 1.1 | 3.0 | 1.3 | 1.3 | 2.3 | 4.1 | 2.6 | 2.8 | 2.7 | 2.9 | 3.1 | 3.1 | 3.2 | 0.0 | 0.0 | 0.2 | 0.2 | 0.1 | 2.5 |
| 3 | 3.1 | 2.1 | 3.5 | 1.4 | 3.1 | 1.6 | 2.9 | 2.9 | 2.5 | 2.0 | 2.5 | 2.9 | 2.7 | 3.0 | 3.3 | 3.0 | 1.8 | 2.4 | 1.5 | 0.1 | 0.0 | 2.6 |
| 8 | 2.9 | 3.7 | 2.3 | 1.6 | 1.8 | 0.2 | 0.6 | 1.3 | 4.8 | 2.6 | 2.2 | 3.6 | 1.9 | 2.0 | 1.5 | 4.2 | 1.0 | 0.9 | 0.8 | 0.2 | 0.0 | 1.8 |
| 9 | 2.5 | 2.9 | 3.6 | 2.2 | 2.1 | 1.5 | 2.0 | 2.6 | 3.7 | 2.3 | 2.8 | 3.3 | 2.7 | 3.0 | 2.5 | 3.7 | 0.9 | 1.0 | 0.8 | 3.6 | 0.3 | 2.5 |
| 12 | 1.9 | 1.7 | 2.5 | 1.0 | 3.1 | 1.9 | 2.8 | 3.4 | 2.0 | 1.4 | 3.8 | 2.5 | 3.8 | 3.7 | 2.5 | 3.3 | 2.4 | 1.9 | 2.1 | 0.0 | 0.1 | 2.9 |
| 2 | 2.8 | 2.5 | 3.5 | 3.0 | 2.5 | 2.0 | 1.3 | 2.3 | 0.3 | 0.3 | 1.5 | 4.3 | 1.5 | 1.3 | 4.8 | 2.8 | 0.3 | 0.5 | 0.3 | 0.5 | 0.5 | 1.5 |
| 1 | 3.2 | 3.1 | 2.7 | 0.8 | 3.4 | 0.5 | 1.7 | 1.8 | 0.5 | 0.6 | 1.7 | 4.3 | 1.5 | 1.8 | 2.4 | 3.5 | 1.3 | 1.3 | 0.9 | 0.0 | 0.2 | 1.5 |
| 7 | 2.9 | 2.6 | 3.9 | 1.4 | 3.3 | 1.5 | 2.5 | 2.9 | 0.9 | 0.9 | 2.6 | 3.8 | 2.8 | 2.7 | 2.5 | 3.6 | 2.0 | 1.9 | 1.7 | 0.1 | 3.3 | 2.5 |
| 11 | 3.0 | 2.8 | 3.5 | 0.8 | 3.4 | 1.7 | 2.5 | 3.0 | 3.5 | 2.0 | 2.7 | 3.1 | 3.3 | 3.2 | 2.5 | 3.3 | 1.8 | 1.2 | 1.2 | 0.1 | 2.8 | 2.7 |
| 10 | 3.0 | 5.0 | 2.0 | 0.0 | 4.0 | 3.0 | 0.0 | 2.0 | 0.0 | 0.0 | 1.0 | 5.0 | 2.0 | 1.0 | 2.0 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 1.0 |

Logical divisions were also found in the resulting dendrogram branches, and a general 'cut-off' height of about '9' was used. Based on these above assessments (i.e. color-coding of the existing landscape category groupings, reference to certain point photos and video, heat map results, and logical branch divisions), 12 categories were demarcated. The final dendrogram and distinguished landscape groups are shown in Figure 15.

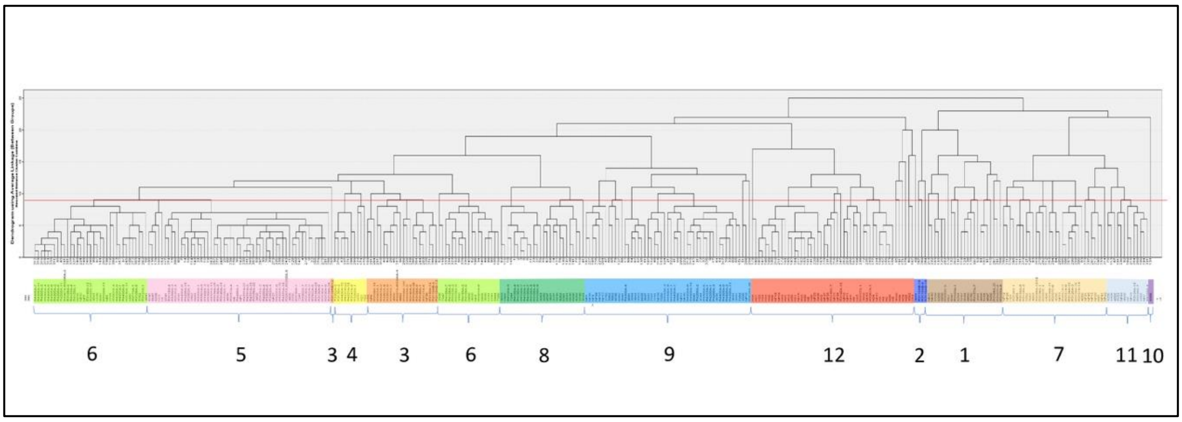



*Fig. 15. Dendrogram and new landscape category grouping results from the most recent cluster analysis (SPSS) in September, 2020 based on all data collection points to-date (343 points total). A general 'cut-off' height of about '9' (indicated by the RED line) was used to help determine logical divisions in the groupings*

The 12 category groupings from the previous analysis (early 2020) remained intact, with a handful of points being 'bumped' out of one category and into another, most likely due to the enhanced and more nuanced data set with the additional 33 new points. The number and type of categories also remained the same, besides a couple of small wording tweaks made to the category descriptions to provide a more accurate representation of each group. The written descriptions of each category are shown in Table 3.

*Table 3. Descriptions of 12 landscape categories based on the latest round of cluster analysis in September, 2020*

| Category Number | Category Description |
|---|---|
| 1 | Sandy and stony barrens with large patch sizes |
| 2 | Lava or rough-textured barrens with large patch sizes |
| 3 | Sparsely to semi-vegetated hilly barrens with some rough texture, water and stream presence |
| 4 | Semi to well-vegetated, dry, shallow valleys and barrens with some rough texture |
| 5 | Well-vegetated, shallow valleys and flatlands with some water presence |
| 6 | Well-vegetated, deep valleys, intermixed smooth and rough texture, with some water and stream presence |
| 7 | Sandy and stony plains and barrens by glaciers and high mountains |
| 8 | Fully-vegetated, homogeneous flatlands with high landscape depth |
| 9 | Coastal areas including flat beaches, fjords, and islands |
| 10 | Glaciers |
| 11 | Semi to well-vegetated areas by glaciers and high mountains |
| 12 | Valleys of high visual diversity. Subgroup includes geothermal areas with little to no vegetation. |

Figure 16 provides a spatial distribution of all 343 data point locations, color-coded by the latest landscape categories. This visual display not only exhibits a good overview of where the varying landscape types fall geographically in relation to each other, but it can be a useful tool to help identify potential outliers, establish the emergence of patterns, and verify that the assigned category in a particular location seems logical. For instance, the majority of category 8 points (*fully-vegetated,* *homogeneous flatlands*) are clustered together in the southwest lowland plains of the country, as one would expect. Also, the majority of points in categories 1 (*sandy and stony barrens with large patch sizes*) and 7 (*sandy and stony plains and barrens by glaciers and high mountains*) are found within the high plateau 'barrens' of the Central Highland.

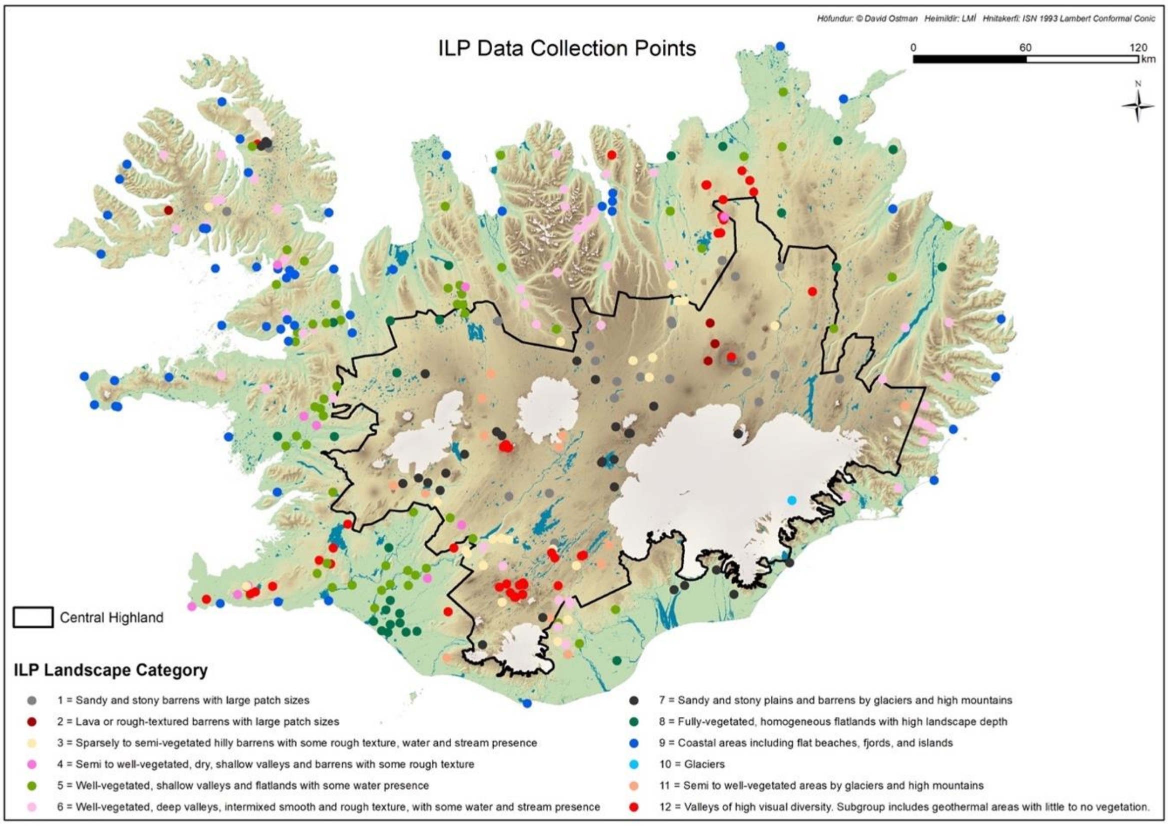



*Fig. 16. Map showing all 343 data collection point locations color-coded by the 12 latest landscape categories*

To test the resiliency of how well these categories remain grouped together, the newly-collected 33 points were processed in a cluster analysis on their own and then color-coded based on the 12 categories to see if they would group together similarly (Figure 17). A similar experiment was conducted with just the original 108 points (Figure 18). With a few outliers to be expected in both cases, it is visually clear that the groupings remain relatively intact.

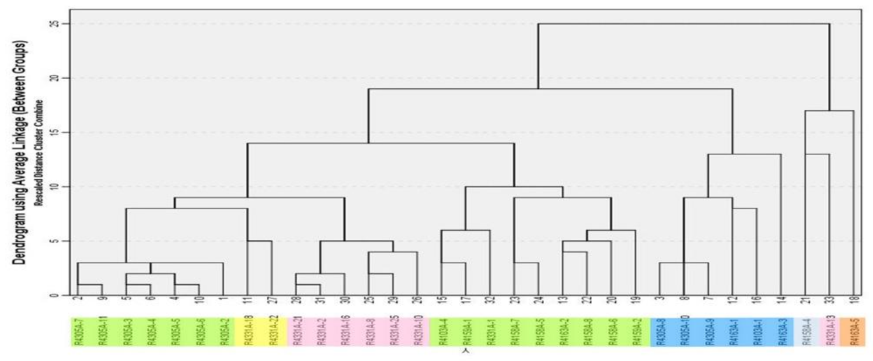



*Fig. 17. Dendrogram results of the 33 data points collected in the summer of 2020, color-coded by the 12 latest landscape categories*

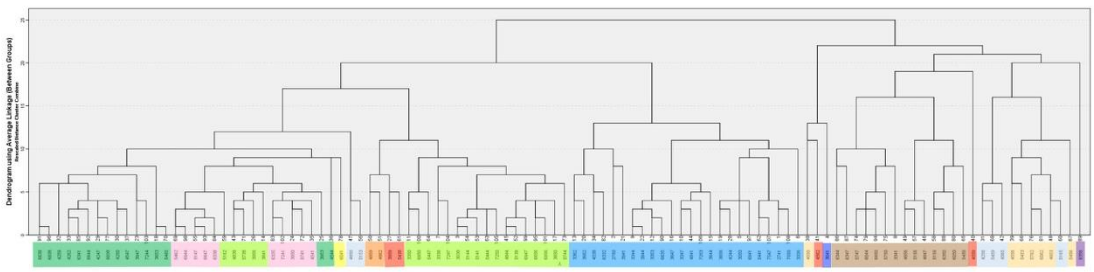
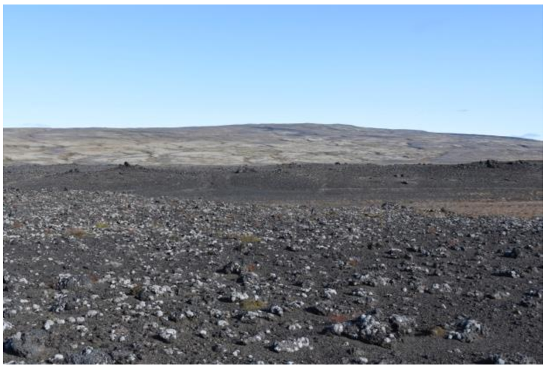



*Fig. 18. Dendrogram results of the original 108 data points collected between 2006-2008, color-coded by the 12 latest landscape categories*

Amongst the 2019 and 2020 data points targeted and collected for RÁ4, 7 of the 12 landscape categories are represented. Those 7 category descriptions and a sample photo for each category are presented below.

***Category 3****:* Sparsely to semi-vegetated hilly barrens with some rough texture, water and stream presence



***Category 4***: Semi to well-vegetated, dry, shallow valleys and barrens with some rough texture

***Category 5***: Well-vegetated, shallow valleys and flatlands with some water presence

***Category 6***:  Well-vegetated, deep valleys, intermixed smooth and rough texture, with some water and stream presence

***Category 8***:  Fully-vegetated, homogeneous flatlands with high landscape depth

***Category 9***:  Coastal areas including flat beaches, fjords, and islands

***Category 11***:  Semi to well-vegetated areas by glaciers and high mountains

Due to the exploratory nature of how cluster analysis is used in this context of constantly changing data sets (i.e. always adding in new rounds of collected data points), it is important to keep in mind that this process is partially a manual one. For instance, decisions may need to be made on the potential creation of new categories, the dissolving of existing categories into others, or adjusting category descriptions based on their most dominating and representative characteristics. There will, of course, be outliers and some points that may be appropriate in more than one category.

This raises the question of re-evaluating the overall divisional structure of the category groupings and the potential of including sub-categories. One may e.g. use a higher 'cut-off' height in the dendrogram, which would yield a smaller number of less descriptive categories that would be applicable to a larger number of points (e.g. *fully-vegetated valleys* instead of *semi to well-vegetated deep valleys with water and stream presence*). The concept of using sub-categories might be useful here, for example, if there are point groupings within this more general category that share similar features. It is possible that under this *fully-vegetated valleys* category, there are a cluster of points with and without water presence, or the valley deepness varies considerably, so grouping these points into sub-categories based on further distinguishing features should be considered.

Conversely, one may use a lower 'cut-off' height resulting in a larger number of more descriptive categories, each containing a smaller number of points. In this case, sub-categories would be obsolete. These questions acknowledge the partially-subjective nature of this process, and ultimately, the actual use of these categories (for local vs. nationwide land use planning, etc…) should dictate their resolution and scope.

This method of point-based landscape classification in Iceland is still in its developing stages. Also, a good deal of ground remains to be covered in terms of data collection points around the country, which means that as more data points are collected and added to the ILP classification database, new variations of landscape types are likely to be revealed, and this may yield a growing number of more refined landscape categories and sub-categories. This may result in some data points switching amongst categories and changing their dendrogram position in order to align more accurately with new data. So the potential of adding new classifications or making fine-tunings to older categories speaks less about the robustness of the ILP methodology and the resulting dendrogram and more about having to adapt to additional, more nuanced data.

## 3. New visibility analysis program overview (Viewshed Explorer)

Part of the post-fieldwork landscape analysis, specifically as it applies to the assessment of energy project proposals in Rammaáætlun, is understanding the potential impacts these proposals will have on the surrounding landscape(s), a dominating factor being the visual impact. This is especially relevant in the case of windfarm proposals where turbine visibility is much more influential than visibility from other forms of energy production (geothermal and hydroelectric in Iceland's case). Given the recent growing interest in wind production in Iceland, reflected in the numerous windfarm projects to be evaluated in RÁ4, there is a need for a more accurate and nuanced visibility approach.

In response to this need, new visibility software, *Viewshed Explorer* (VE), was licensed in the fall of 2019. Originally developed as a tool for helping to create a wild land mapping methodology in Scotland, VE has expanded its usability to a variety of projects and organizations. The most notable advantage of this software over other visibility programs (ArcGIS, etc...) is that it takes into account relative visibility and distance decay. Instead of typical visibility results displayed as a simple *binary* output (on/off, seen/not seen) or representing the number of objects seen (e.g. number of turbines), VE displays a *spectrum* of relative visibility, analyzing the proportion of the object (wind turbine in this case) compared to the background terrain. Figure 19 shows this difference between binary and relative visibility output. For example, observer 1 located 0.5 km away from the turbine may be able to see the entire turbine (bottom to blade tip) without any screening object that could partially or fully obscure its view (tree, hillside). Being this close to the turbine, it will also take up a sizeable portion of the observer's total view. In contrast, observer 2 located 5 km away from the turbine may not be able to see the entire turbine due to a small hill or other screening object partially hiding it. Being further away, the turbine will also appear smaller, and thus cover a much smaller portion of the observer's total view. This distinction between the location scenarios of observer 1 and observer 2 is precisely what VE takes into consideration when determining the amount of visual impact for each affected location. This approach will also be more useful when it comes to 3D simulations and analysis.

VE also contains a tiling tool option, which allows separate regions (or 'tiles') of the DEM input to be processed simultaneously, reducing overall processing times. Other adjustable settings include the observer height, minimum and maximum search radii, and the distance decay function – either linear (1/d) or square ($1/d^2$) – where d = distance from observer. A normalization option is also available for the output, which uses a logarithmic scale to help display the range of values in a more compact manner. VE then calculates the relative proportion of the viewshed for all grid cells from the DEM input and assigns a specific value to each cell based on this relative proportion of visibility. The value is a relative numerical assignment designated as a means to compare to the other cell values within the same output and so contains no unit. The resulting output can then be uploaded as a floating point file into a GIS software, where the values can be displayed as either continuous (the raw output) or grouped based on various statistical classification methods.

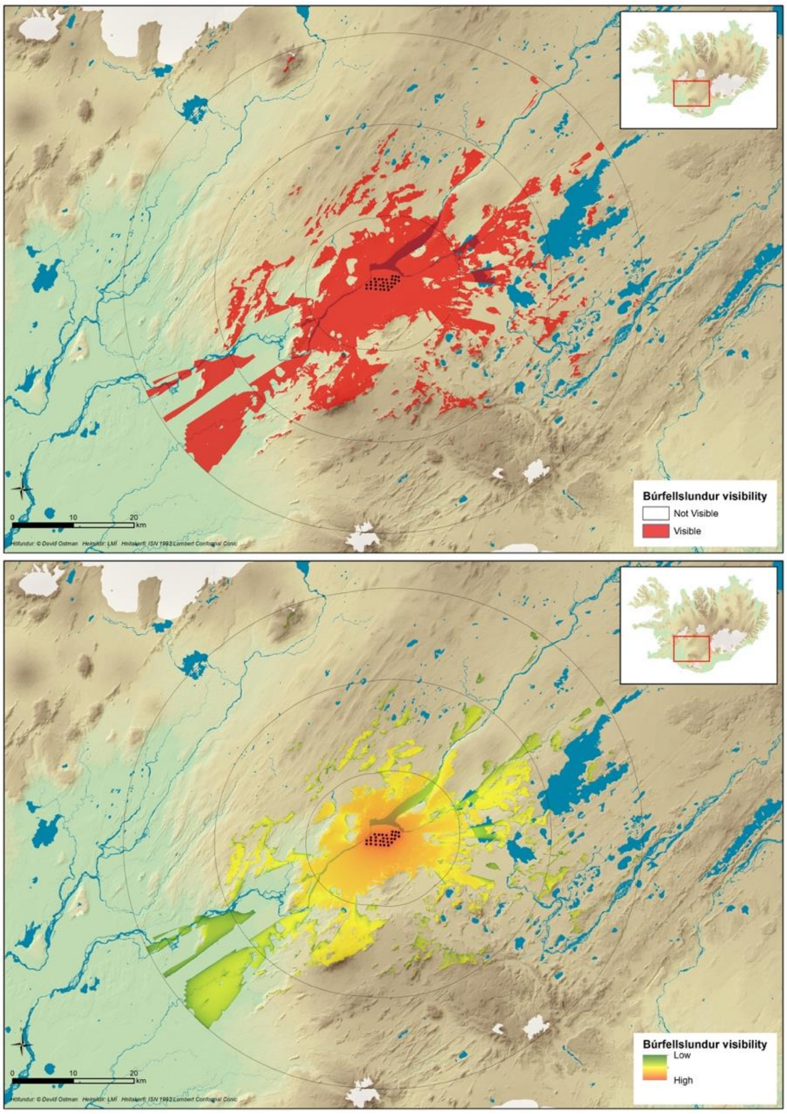



*Fig. 19. Comparison of visibility results between ArcGIS (top) and Viewshed Explorer (bottom), which accounts for distance decay and proportional visibility*

As noted in section 1, VE was used to create a ZTV layer for the 8 windfarm projects for which fieldwork was conducted (Figures 20 through 27). The study area was the same in all cases, that is a circular area extending to a distance of 40km from the outermost turbine locations. The decision to use a 40km radius was based on recommendations from the National Planning Agency, as the 25km radius used to demarcate impact areas of windfarms in RÁ3 for evaluation purposes was considered to be potentially too small, at least in certain cases. This choice of size for the study areas was, however, only intended for purposes of initial analysis, that is the development of a methodology to identify and assess the comparative scenic impacts of different windfarm proposals in a systematic, transparent manner. Should it be decided to use a smaller area for the formal evaluation of such impacts at a later stage, then the visibility analysis can simply be repeated, based on the new, smaller buffer size. Starting with a larger buffer size than might eventually be used for evaluation, furthermore, gives a rough idea of the degree of impact at various smaller scales, nested within the 40km maximum buffer. It should also be noted that 3 of the 8 studied windfarms were not subsequently evaluated in RÁ4.

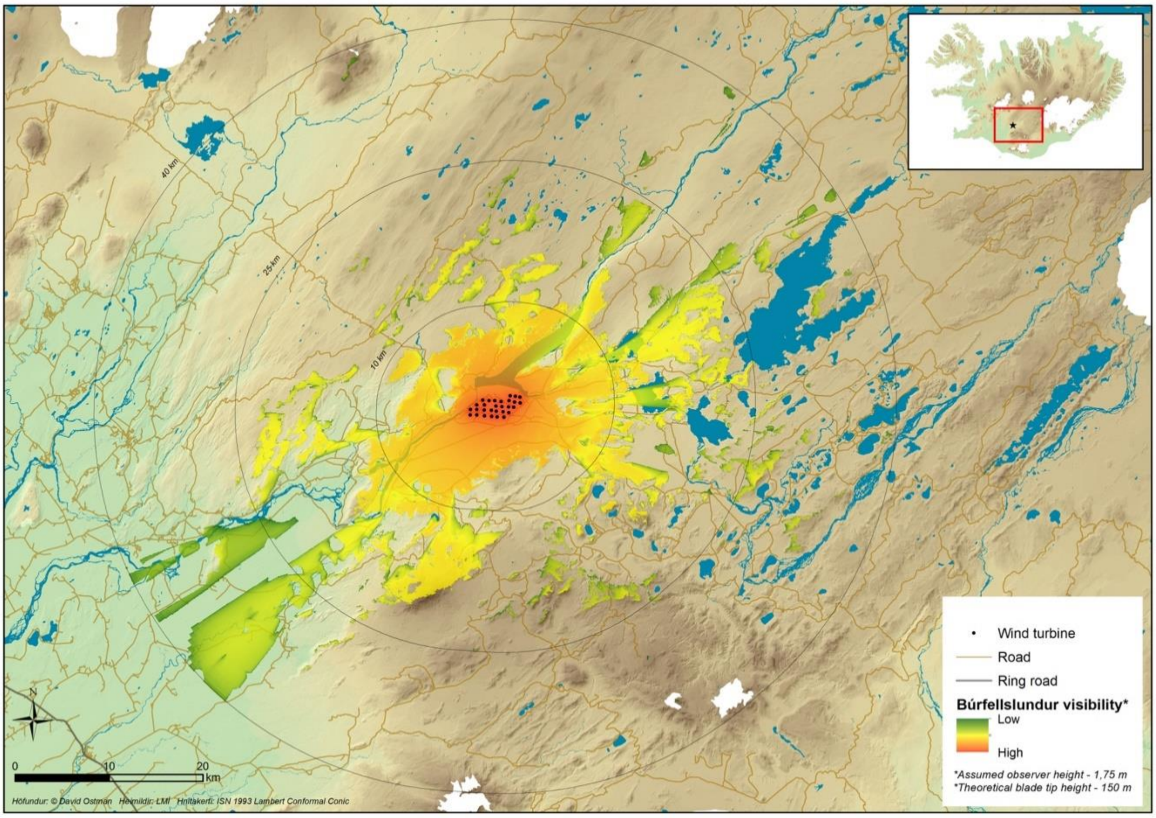



*Fig. 20. Búrfellslundur windfarm with Viewshed Explorer visibility*

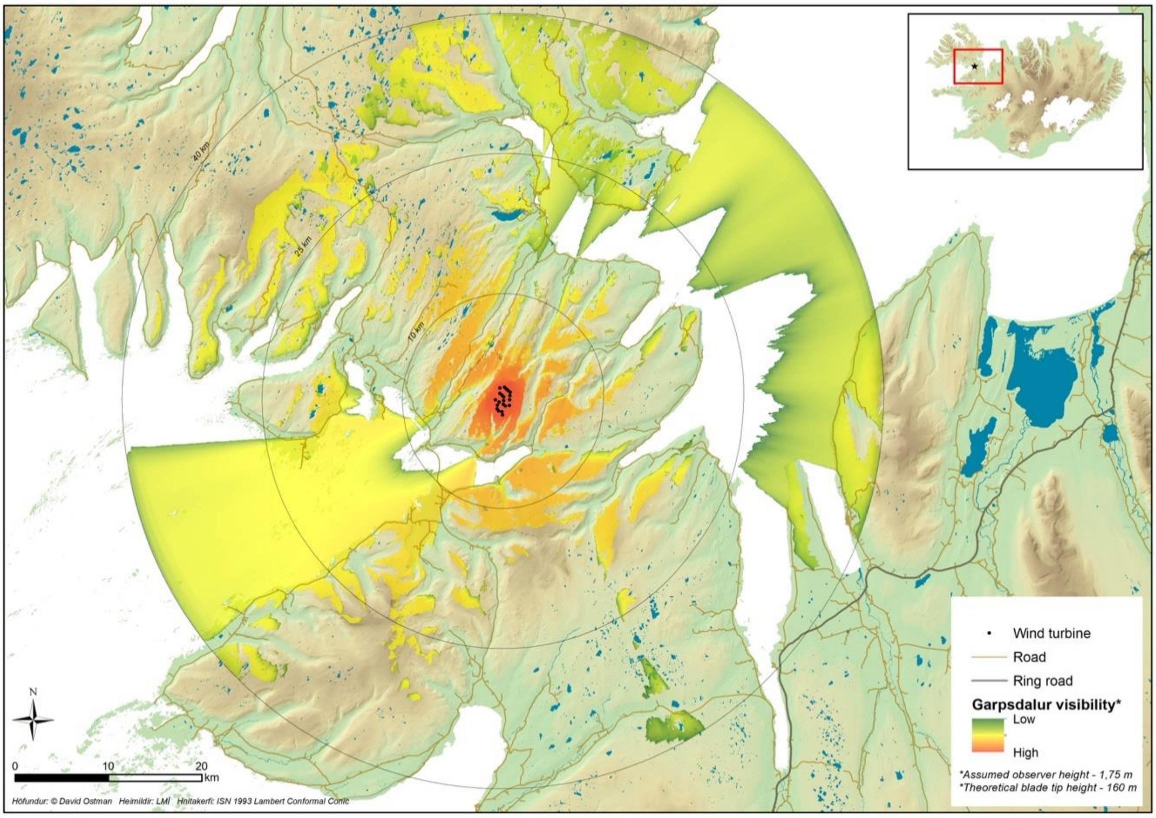



*Fig. 21. Vindorkugarður í Garpsdal windfarm with Viewshed Explorer visibility*

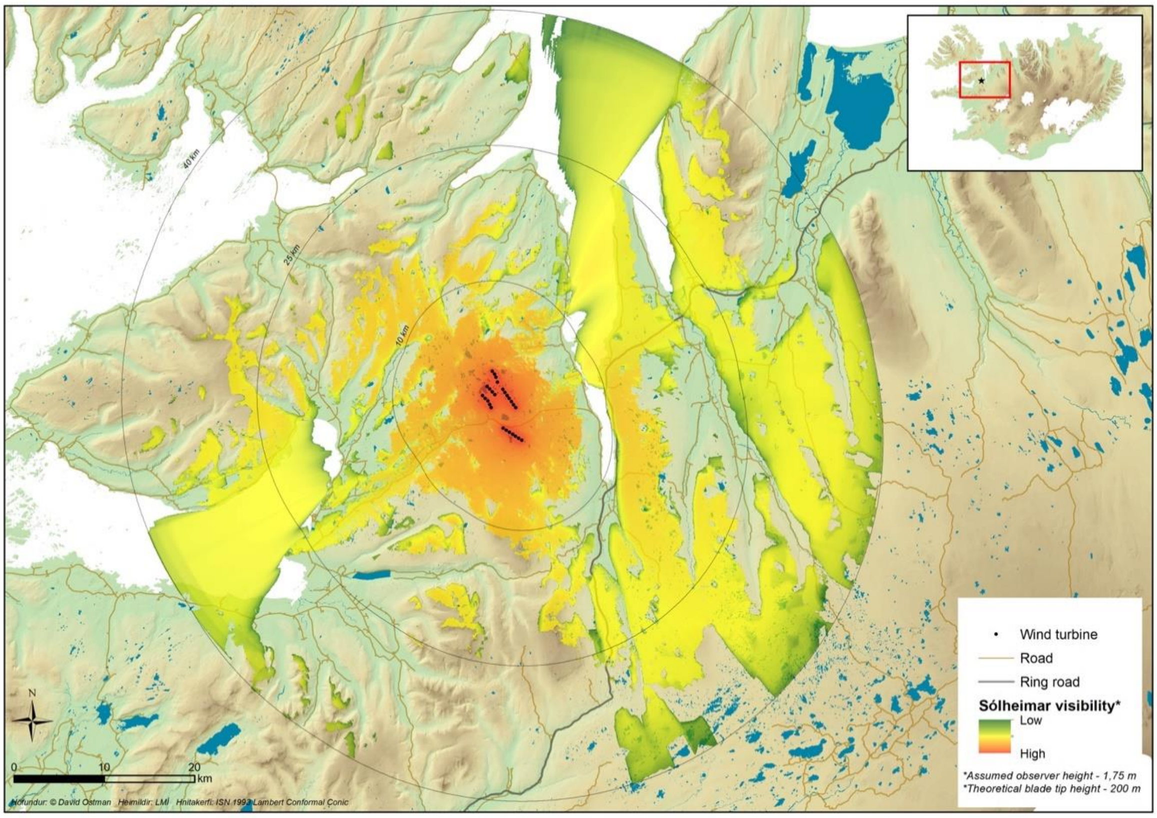



*Fig. 22. Sólheimar windfarm with Viewshed Explorer visibility*

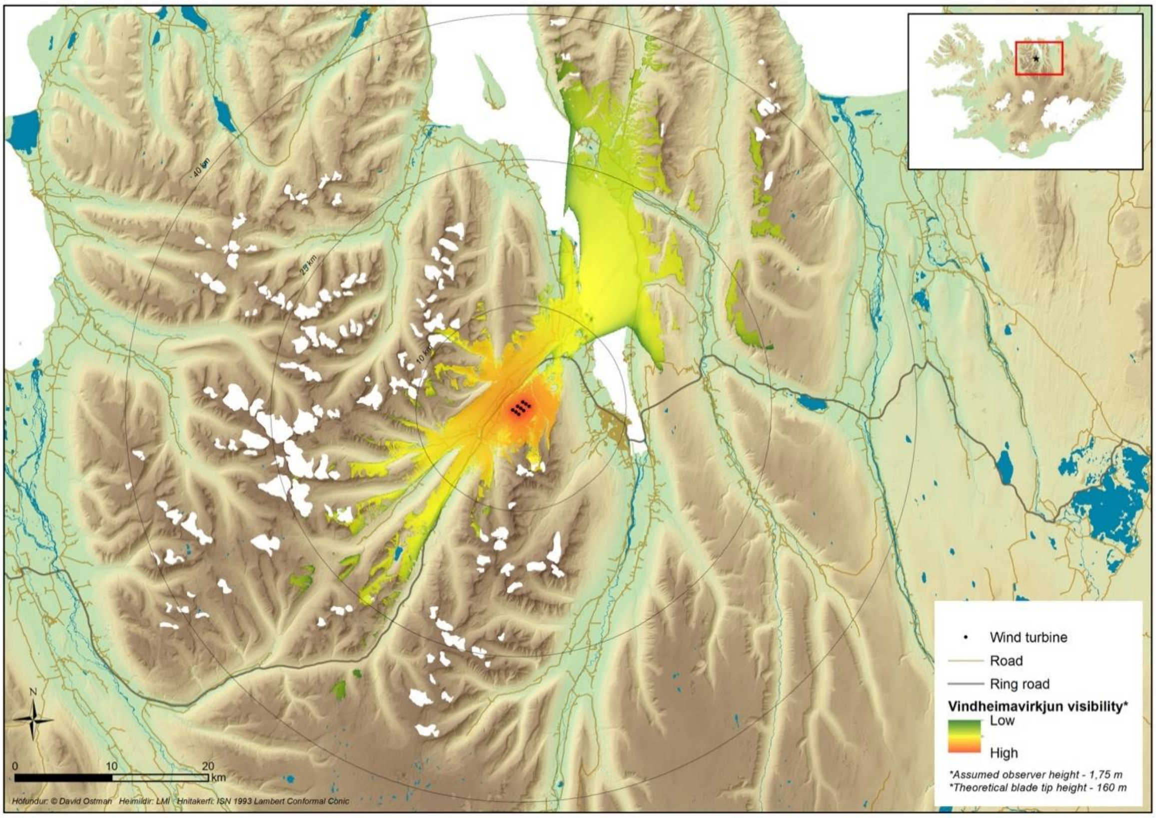



*Fig. 23. Vindheimavirkjun windfarm with Viewshed Explorer visibility*

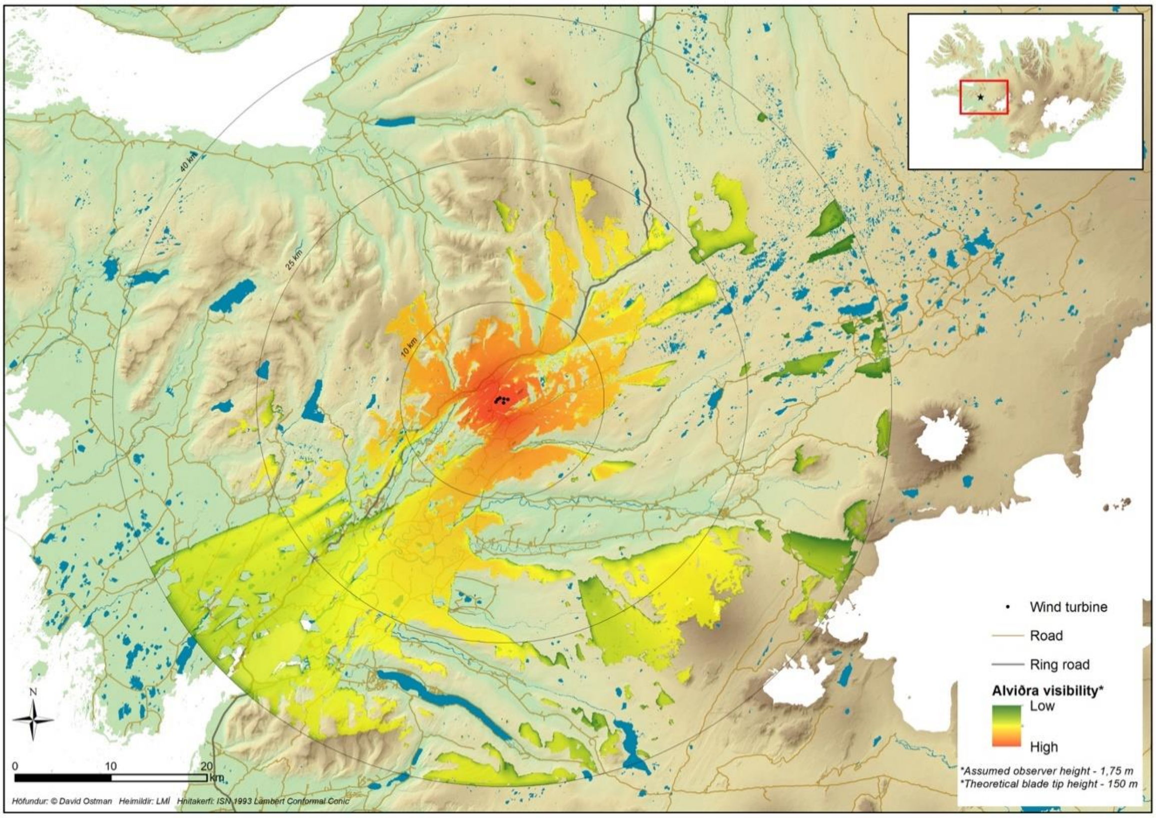



*Fig. 24. Alviðra windfarm with Viewshed Explorer visibility*

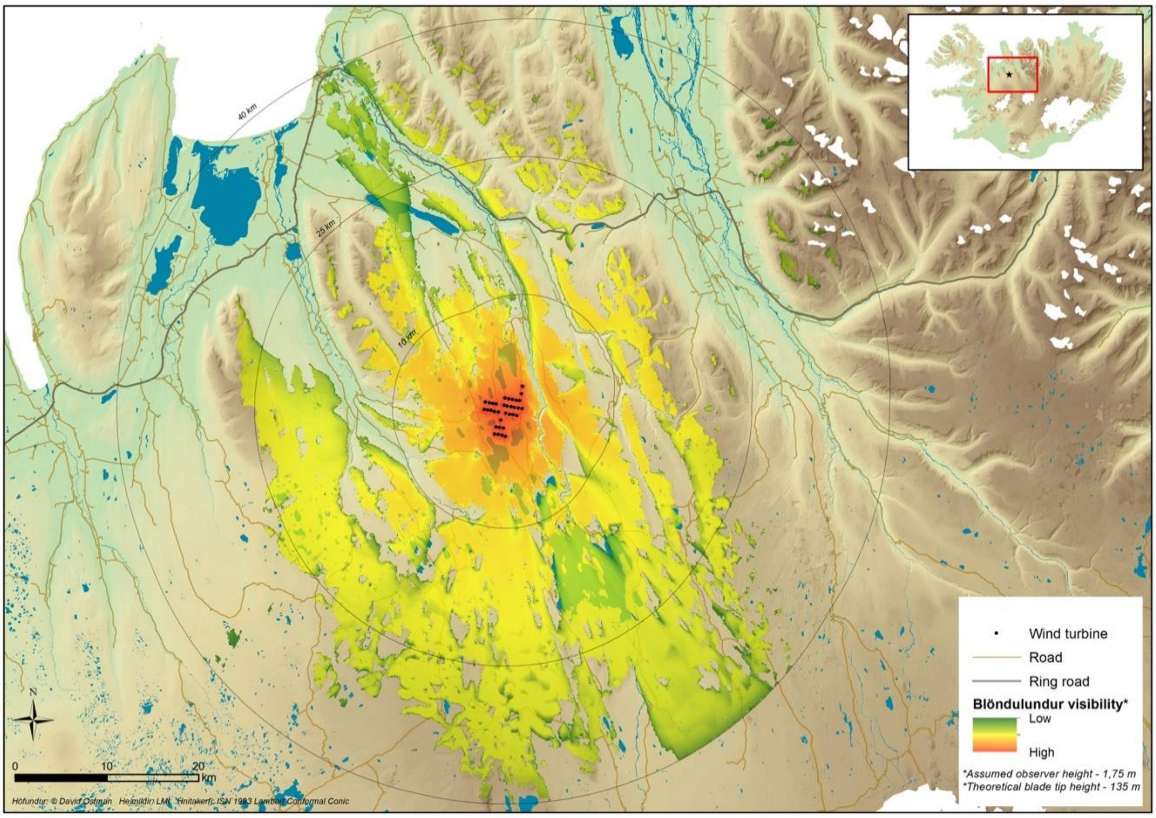



*Fig. 25. Blöndulundur windfarm with Viewshed Explorer visibility*

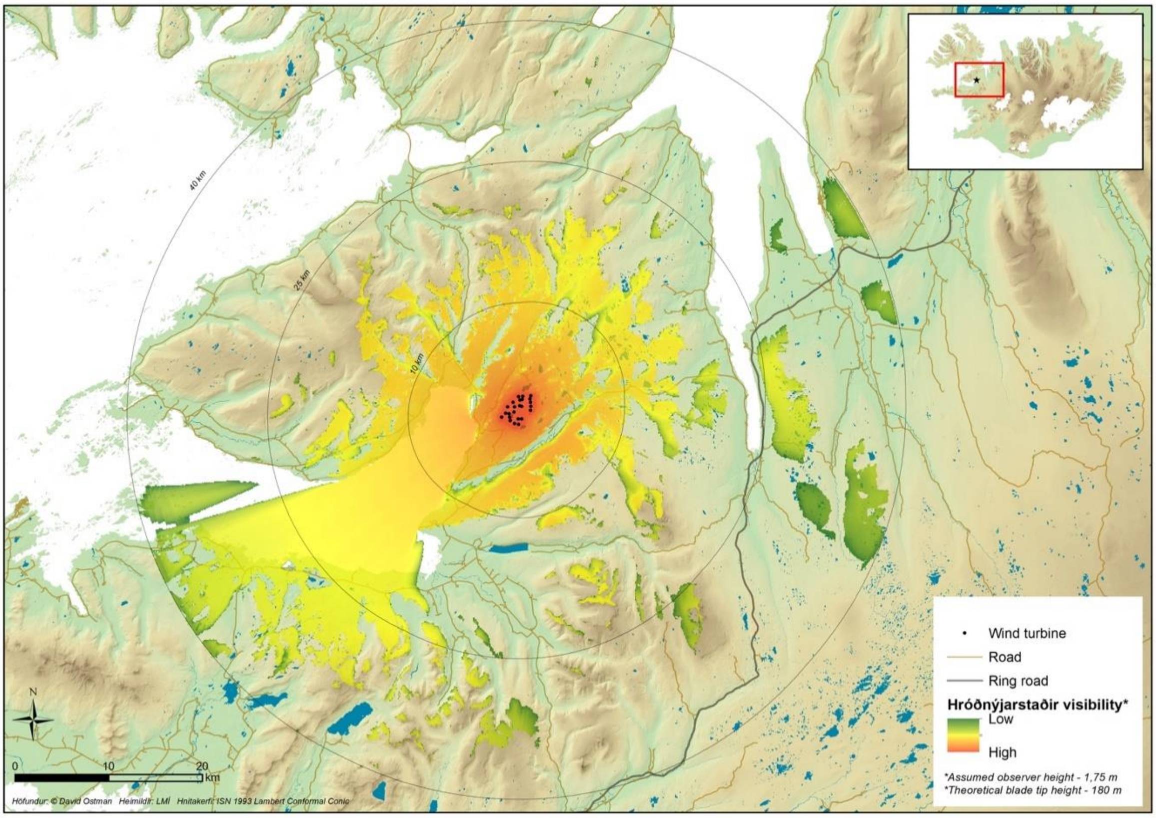



*Fig. 26. Hróðnýjarstaðir windfarm with Viewshed Explorer visibility*

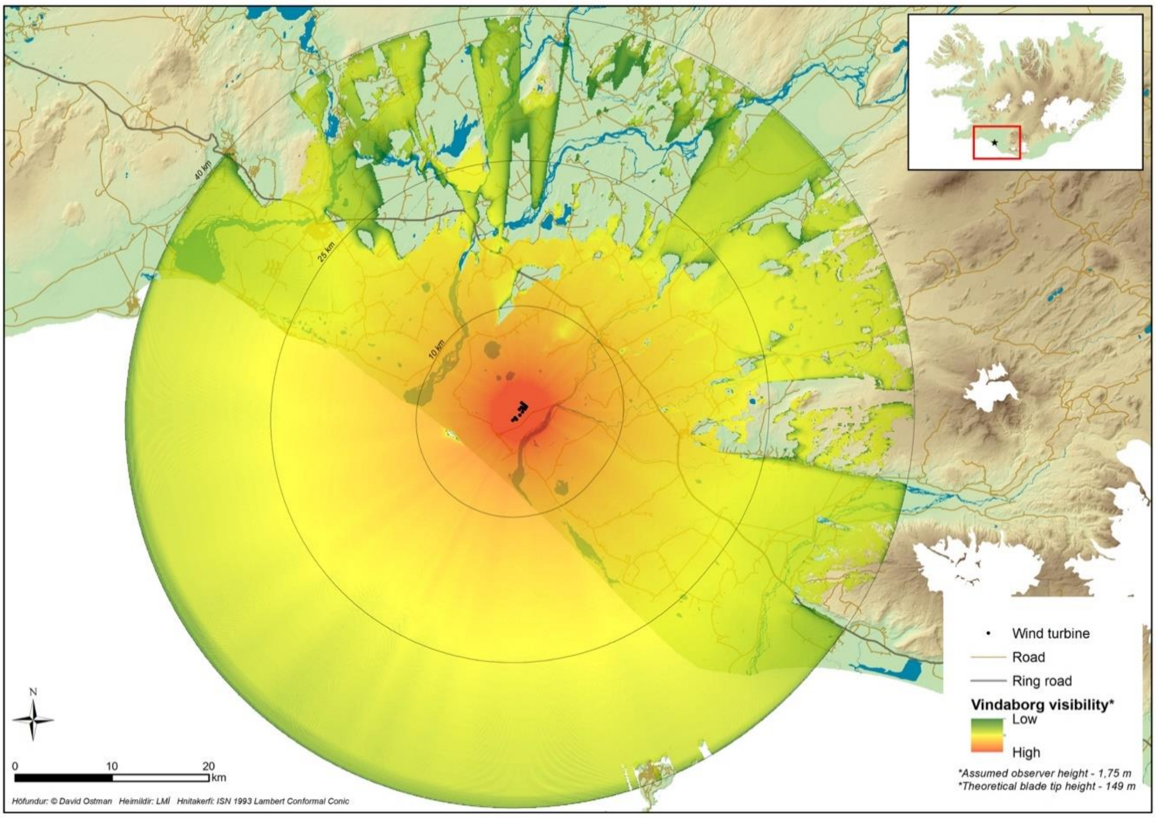



*Fig. 27. Vindaborg windfarm with Viewshed Explorer visibility*

This spectrum of visibility using VE provides a gradation of different cell data values representing the varying visibility, which opens up the opportunity to design a more nuanced classification scheme of visibility impact. In other words, instead of using mere *distance* to determine impact (e.g. the further away from the turbine, the lower the impact), the *proportion* of visibility can be used to classify the resulting values into statistical groups (i.e. impact classes).

As a means of validating VE‘s output, at least in terms of coverage, its visibility results were compared to the results of another visibility tool (ArcGIS in this case) using the same study area and input settings. The visibility of wind turbines from 2 proposed wind projects - Alviðra and Búrfellslundur- were analyzed in both VE and ArcGIS and then overlaid on top of each other to identify differences (if any) in the coverage. Figures 28 and 29 display the results of the comparisons, for Alviðra and Búrfellslundur respectively. In both examples, the VE outputs demonstrated consistent coverage with ArcGIS, with about a 98% overlap. In other words, the area that is considered visible is very similar in both visibility programs.

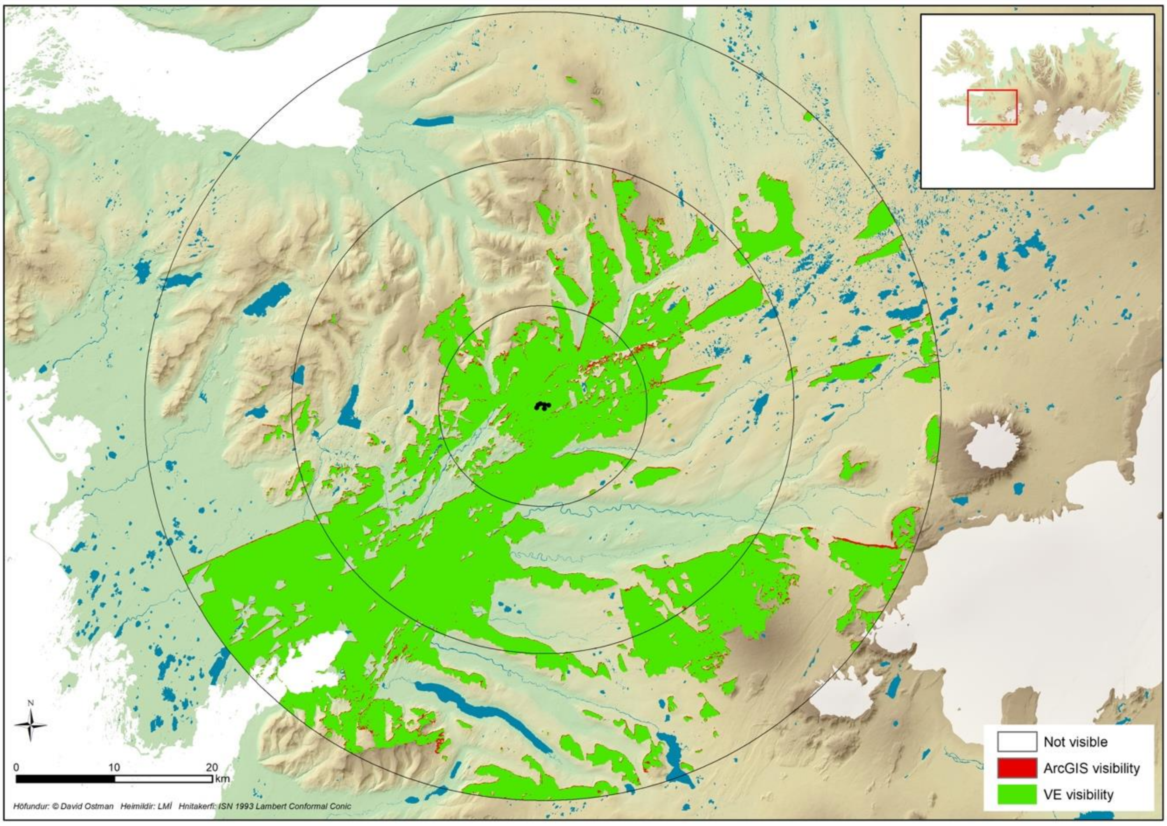



*Fig. 28. Visibility comparison conducted in ArcGIS (RED) and Viewshed Explorer (GREEN) for Alviðra windfarm*

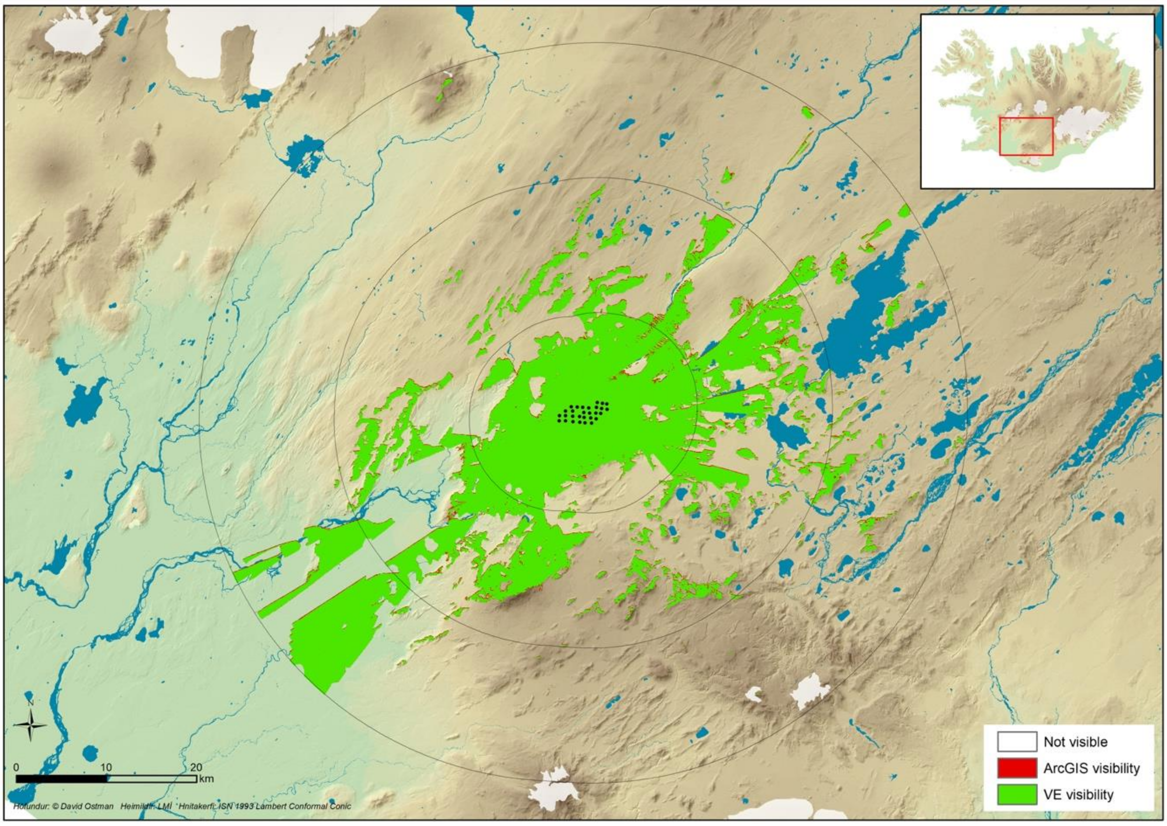



*Fig. 29. Visibility comparison conducted in ArcGIS (RED) and Viewshed Explorer (GREEN) for Búrfellslundur windfarm*

# 4. Improved DEM for visibility analysis (ÍslandsDEM)

In February 2020, The National Land Survey of Iceland (Landmælingar Íslands) released a new, high-resolution Digital Elevation Model (DEM), called ÍslandsDEM, for the whole of Iceland with a 2 x 2m cell size, replacing the previous 20 x 20m DEM. Figure 30 shows the substantial difference in resolution between the old and new DEMs. This years-long ÍslandsDEM project was part of a larger public-private initiative, spearheaded by the Polar Geospatial Center at the University of Minnesota, to produce highly-accurate, comprehensive elevation data in the Arctic, particularly in remote locations. Though still considered a work-in-progress with future versions to be rolled out, access to this high-resolution model will strengthen the capabilities of our own general landscape work and specifically help assess more accurate visibility impacts.

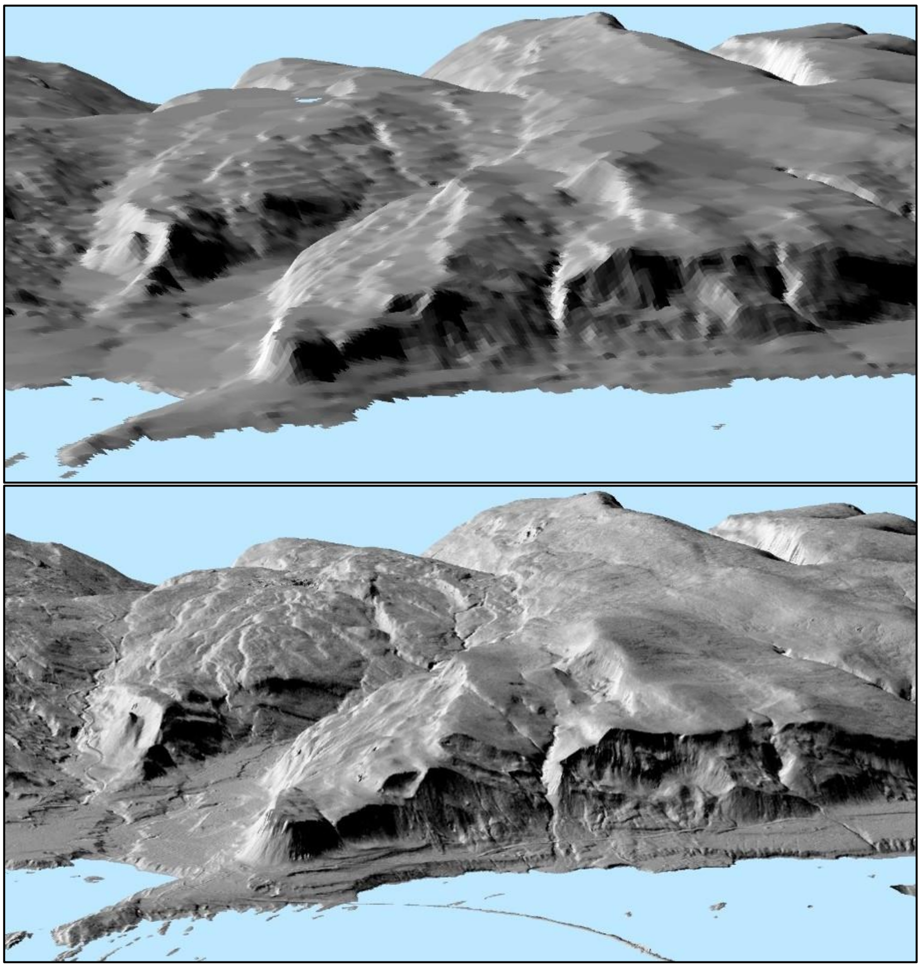


*Fig. 30. Resolution comparison between the existing 20 x 20m DEM (above) and new 2 x 2m ÍslandsDEM (below)*

Beyond the aesthetic sharpness of the ÍslandsDEM's high-resolution (e.g. the ability for it to identify individual anthropogenic structures - roads, buildings, etc…), one of its big advantages will be to overlay the VE viewshed results on top of it and show precisely where the visibility values fall onto the structures; that is, displaying with more certainty the exact visual impact on them. Figure 31 shows a sample of the VE viewshed analysis for the Búrfellslundur windfarm proposal (old turbine layout) draped over both the old and new DEM. Unlike in the old DEM, the new DEM allows for the possibility to identify the exact road locations surrounding the turbines, for instance, and where the visibility falls over them, without the dependency of additional GIS-based structure layers.

*Fig. 31. Resolution comparison between the existing 20 x 20m DEM (above) and new 2 x 2m ÍslandsDEM (below) overlaid with Viewshed Explorer (VE) visibility results*

At the present time, VE is not able to process this large, high-resolution ÍslandsDEM for the desired, full 40km radius impact area, although it can still be used in VE for smaller radii, say, within the immediate vicinity of the turbines, or it could be 'resampled' to a slightly larger cell size (5 x 5m, 10 x 10m, etc…), finding a balance between functionality and resolution. The existing visibility results in VE have been created using resampled versions of the 20 x 20m DEM, specifically 50 x 50m[6], for the full 40km impact areas with processing times that are manageable and still provide an accurate output of

[6] The 3 non-priority projects were processed in VE using 100 x 100m cell sizes: Blöndulundur, Vindaborg í Þykkvabæ, and Hróðnýjarstaðir í Dalabyggð.

the visibility coverage considering the large size of the area. It is also possible to use the ÍslandsDEM with ArcGIS, and the results are similar when compared to both the 50 x 50m DEM used in ArcGIS (Figure 32) and VE (Figure 33).

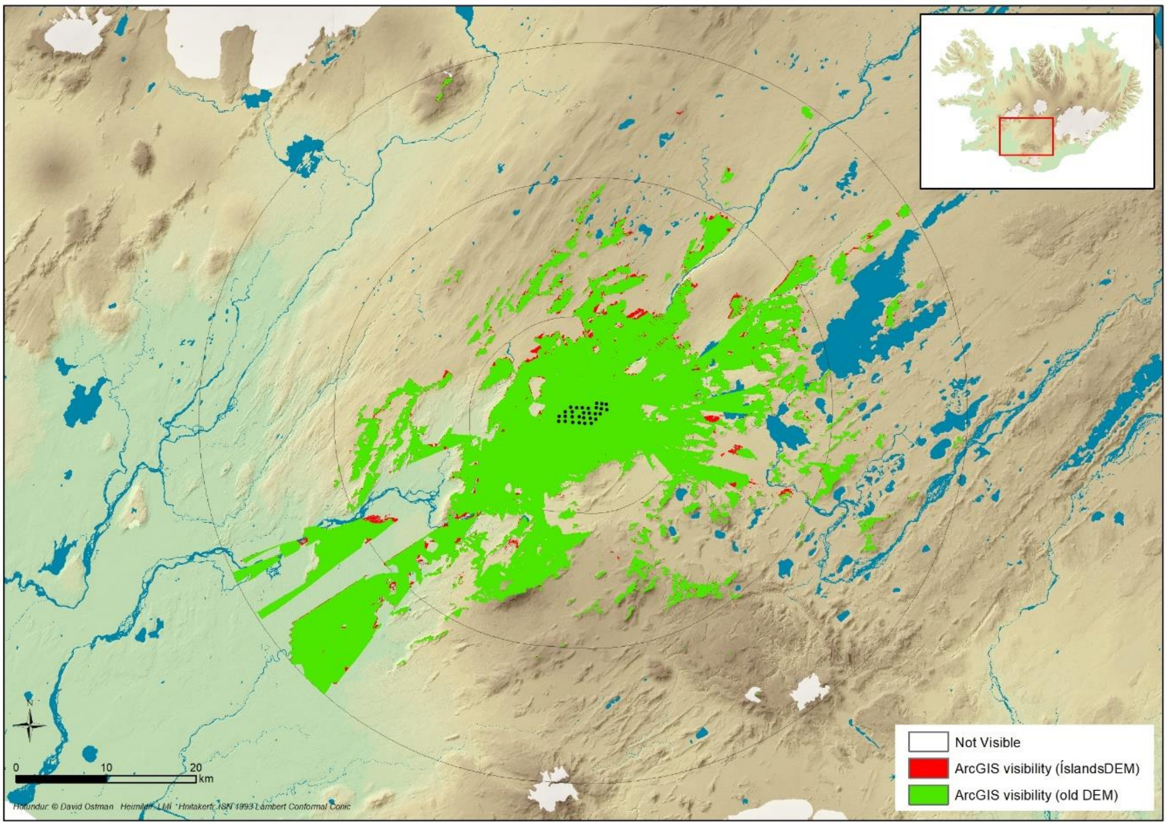



*Fig. 32. Visibility comparison of ArcGIS visibility using 2 x 2m ÍslandsDEM (RED) and ArcGIS using 50 x 50m DEM (GREEN) for Búrfellslundur windfarm*

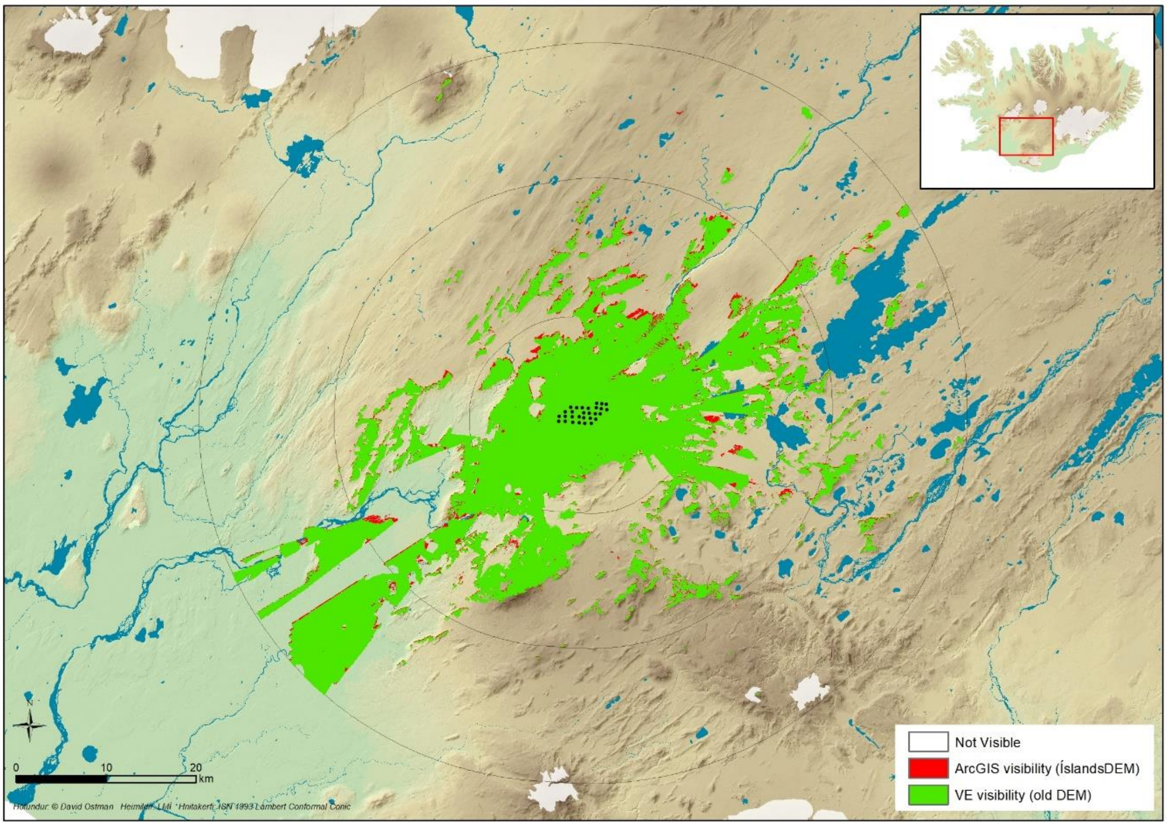



*Fig. 33. Visibility comparison of ArcGIS visibility using 2 x 2m ÍslandsDEM (RED) and Viewshed Explorer using 50 x 50m DEM (GREEN) for Búrfellslundur windfarm*

# 5. Photomontages

In the context of proposed development assessments, a photomontage is a 2D combination of a photograph and a computer-rendered insert of a proposed structure, in this case, wind turbines, to simulate its likely view in the landscape (Scottish Natural Heritage, 2017). This combination can be of great value as it provides relatable, eye-level perspectives of the theoretical turbines, typically from common or popular viewpoints. It should be noted that photomontages are of greatest value when used for turbines within 20km, as viewpoints beyond that distance can be difficult to represent accurately (Scottish Natural Heritage, 2017).

As mentioned in section 1, part of the data collection process involved taking a separate series of photographs specifically for the proposed wind projects pointed in the direction of the theoretical turbines (single images at varying focal lengths as well as ‘panning’ shots for potential panoramas). As part of a recent collaboration with the 3D Visualization Research Lab (3DVisLab) at the University of Dundee in Scotland, these images were rendered with turbine models to produce several preliminary photomontages (Figures 34 and 35). Though still in its early stages, work is ongoing to be able to produce these rendered images ‘in-house’. The extent of using photomontages in the current round of RÁ4 impact assessments is uncertain, but once a formal methodology for their implementation has been outlined (e.g. stakeholder photo surveys, etc.), there is no doubt that they will play a key role in the future of windfarm visual impact assessment in Iceland.

*Fig. 34. Photomontage of Búrfellslundur windfarm (old design), looking southwest and 2.7km from the nearest turbine*

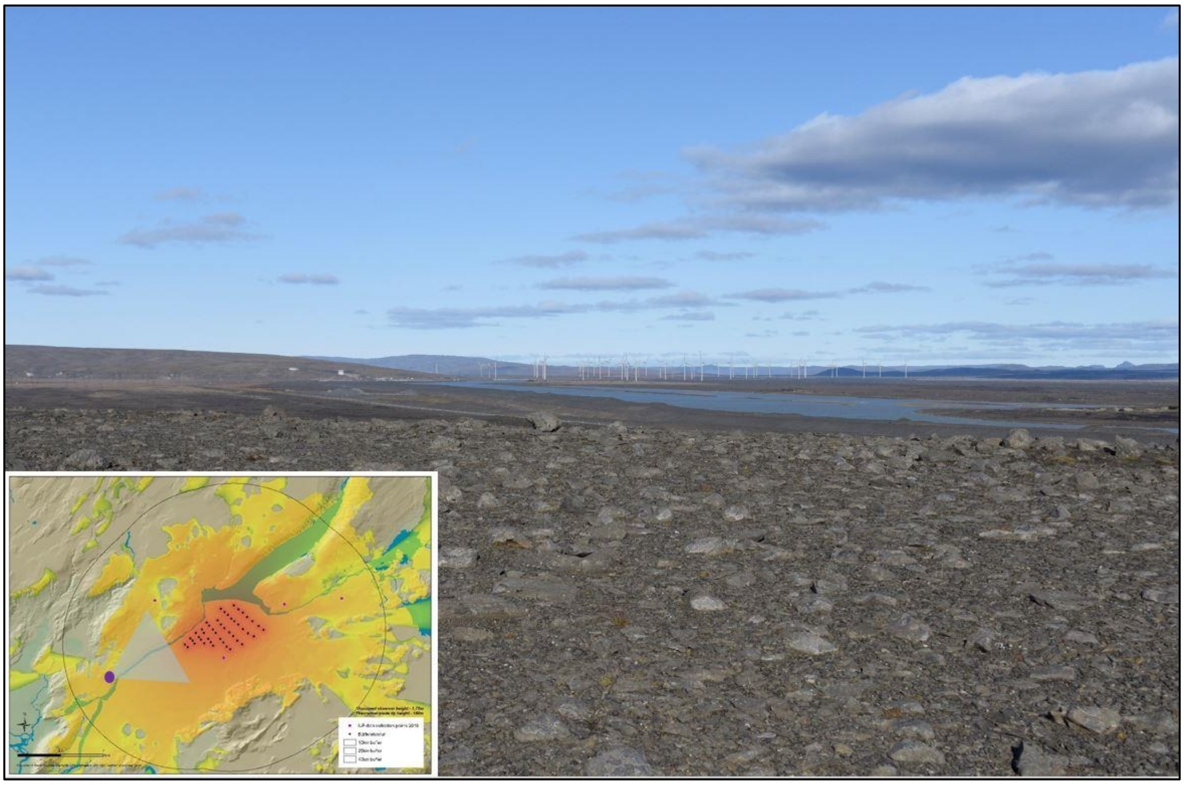


*Fig. 35. Photomontage of Búrfellslundur windfarm (old design), looking northeast and 7km from the nearest turbine*

# 6. 3D modeling and simulations

Another innovative and more interactive form of turbine visualization is the application of 3D simulations. Creating a 3D model and then inserting computer-rendered turbines within that environment allows for full-axis rotation and viewing. One of the future applications with this kind of 3D modeling would be within a Virtual Reality (VR) environment.

Work has already begun to build these models with the intention for them to be used in tandem with other visual impact assessment tools (photomontages, etc.). At the moment, the exploratory process consists of combining 3 programs (ArcGIS, QGIS, and Github) to render and share these models. First, ArcGIS is used to capture high-resolution satellite/aerial imagery from basemap layers. Then, these images are mosaicked together and imported into QGIS, along with the 2 x 2m ÍslandsDEM, and the point shapefile layer representing the turbine locations. The QGIS 3D plugin (Qgis2threejs) is then used, which drapes the satellite/aerial imagery over the extruded DEM. As a plugin option, the turbine points can be replaced by a CAD-designed collada 3D turbine model (e.g. Sketchfab). Turbine dimension settings can be adjusted to resemble varying turbine heights. The completed 3D model in the plugin is then exported to a Github repository, where a unique .html hyperlink is created and can then be made public and sharable with others.

It may be of particular use to match up one or more of the previously-collected ILP data collection viewpoints with the same viewpoint in the 3D model as a way to compare the perspective with and without the turbines and also compliment any photomontages created from that same viewpoint (Figures 36 and 37).

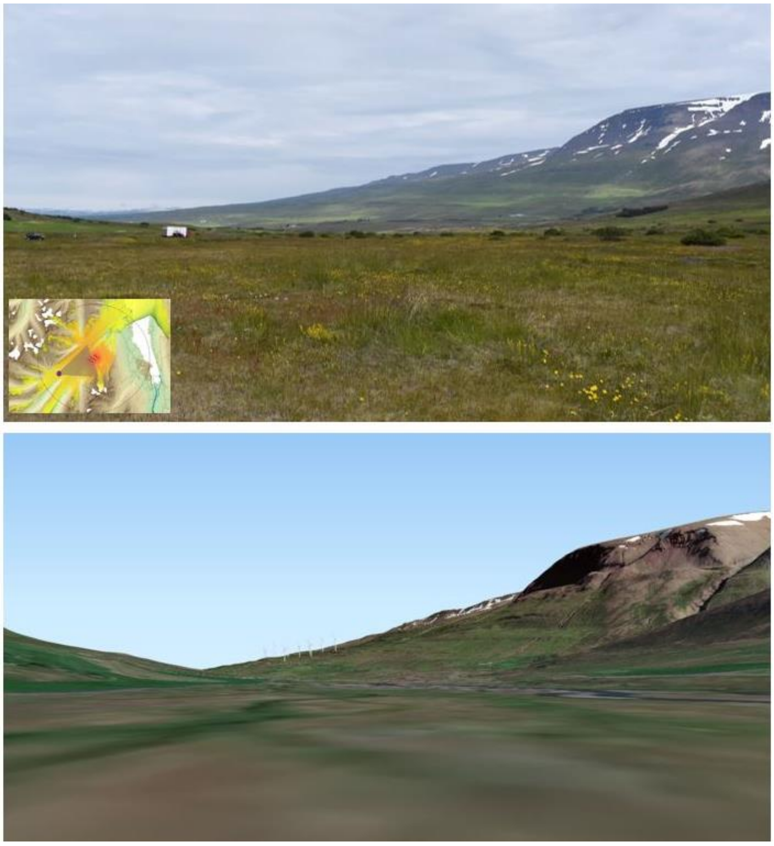


*Fig. 36. Example 1 of matching an ILP photograph (top) with the same viewpoint in the 3D model including rendered turbines (bottom)*

*Fig. 37. Example 2 of matching an ILP photograph (top) with the same viewpoint in the 3D model including rendered turbines (bottom)*

It is important to keep in mind that even though these visualization methods described above (visibility analysis, photomontages, 3D simulations) are meant to represent theoretical visual impacts, they are indeed simulations and will of course never completely match what is experienced on site in reality. Using these or other methods in isolation will, furthermore, represent only one aspect of theoretical visual influence. It is therefore recommended, if possible, to use multiple visualization tools together in order to create a more holistic picture of the visual landscape impacts and to best inform the evaluation process.

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