Fall 2018

Three Land Use Proposals for Geldinganes Framed by the City of Reykjavik's Municipal Plan and Climate Neutrality Goals

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Geldinganes Island

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Abstract

With global CO_2 levels rising every year, climate change is becoming a larger, looming threat. Cities around the world have an important role in reducing the negative impacts of climate change through strategic and sustainable urban planning. The purpose of this study is to conduct an introductory analysis of Geldinganes island and its potential and capacity for land development that will support and expand upon the city of Reykjavik's 2010-2030 municipal plan and 2040 climate neutrality goals. Within this study three proposals for Geldinganes are considered, the current proposal and two new proposals. The lowest development impact proposal for Geldinganes is leaving it as it currently exists, preserving it as a green space with the potential for adding minimal infrastructure to increase public accessibility to the island. This is the plan for Geldinganes within the current municipal plan. The second proposal of medium development impact is to forest the island with native birch trees. This plan simultaneously preserves the area as a green space and provides a carbon sink for the city. Lastly, the highest impact plan considered is to develop a wind turbine farm on Geldinganes, creating an additional renewable energy source for the city to help it meet its increasing energy demands with the potential to support a growing electric transportation industry.

Keywords: Urban & Regional Planning, Sustainability, Recreation, Oil, Gas, and Energy, Sustainable Technologies, Operations Research, Forestry and Wildlife, Natural Resources and Conservation, Natural Resource Economics, Public & Social Welfare

Introduction

Global and Regional Importance of Urban Planning

As of 2018, the world population has reached more than 7.5 billion people. More than half of these people live in urban areas and the shift from rural to urban is only expected to continue increasing. Now more than ever strategic, sustainable urban development plans are required in order to maintain and support bulging urban populations. In addition, as rising CO_2 emissions continue to raise global average temperatures, the effects of climate change pose a serious threat worldwide, proving the necessity of sustainable infrastructure that can support a growing population without destroying the planet in the process. In response to growing climate concerns, the Paris Climate Agreement was signed by 175 states in 2016 and as of 2018, 183 parties have ratified the agreement. The Paris Agreement specifically recognized cities, regions, and local authorities as having an important role in fighting climate change. Iceland was one of several European countries that committed, under the Paris Agreement, to reduce greenhouse gas emissions (GHG) to 40% of 1990 levels and increase renewable energy to 27% of total energy consumption by 2030 (European Commission 2018). In addition, in September of 2018 Iceland announced a new climate strategy, a plan to achieve climate neutrality by the year 2040. Reykjavik, being the capital and the largest city in Iceland, must use strategic urban planning to meet growing population demands with sustainable solutions that support its inhabitants while curbing its emissions.

Brief History of the Development of Reykjavik

Reykjavik, the capital of Iceland, is home to approximately 123,000 people - over a third of the entire population of Iceland ($\approx$348,000) (Statistic Iceland). Reykjavik was first established as a farmstead in 874 by Iceland's first settler, Ingolfur Arnarsson. It remained a farmstead until 1752 when the Danish king began an industrial experiment in Reykjavik for woolen manufacturing, establishing Reykjavik as a town. While this experiment ultimately failed, in 1786 the town was granted a charter and its trade monopoly was abolished, stirring development. The first town planning and building mandate was established in 1839 despite the city's mere 1000 inhabitants (Reynarsson 1999). Reykjavik continued on a path of slow and steady development until WWII which opened up Iceland to the rest of the world and sparked the city's first significant growth in population.

Along with a wave of other Western European metropolitan areas following the war, the city council proposed to develop a comprehensive development plan for the city in 1960. This land-use and transportation plan resembled "a typical post-war American city" with low densities through the development of suburban areas and a transportation system requiring the use of a personal automobile (Driscoll 2012). Seated on a peninsula, Reykjavik's growth was limited by the ocean to the North and West and the US army-built airport in the South so most development was directed Eastward (Valsson 2003). Development in Reykjavik continued outward, rather than upward, with "sustained investment in road capacity expansion" until the city's most recent 2010-2030 municipal plan which marks a significant shift in development ideology guided by new frameworks of sustainability and densification (Driscoll 2012).

City of Reykjavik Municipal Plan and Climate Policy

In 2009, the city of Reykjavik formally introduced a new municipal plan for 2010-2030. Finally approved in 2013, this plan replaced the previous municipal plan from 2001-2024. The new plan sought primarily to respond the question of where to house the additional 25,000 Reykjavik residents expected by the year 2030. In addressing this question, the plan made a major shift from the urban sprawl strategies in previous plans towards densification and a shift away from reliance on a private car. The new municipal plan is also greatly influenced by and in line with both the city and country's goal to become climate neutral by the year 2040. As a result, its two major focuses are on increasing densification (90% of new residential units are to be developed in current urban areas, an increase of 40% from the previous plan) and a shift towards more sustainable methods of transportation such as walking, biking, public transportation, and electric cars (City of Reykjavik Department of Planning and Environment 2014).

As mentioned, both Iceland and the city of Reykjavik have set plans in place to become carbon neutral by 2040. Because of Iceland's wealth of renewable energy resources (primarily geothermal and hydropower) that provide clean electricity and heating, the country's main source of GHG emissions come from the transportation sector and industry. As such, the new national plan aims to phase out fossil fuels in transport by banning the registration of new fossil fuel cars by the year 2030. Additionally, both country and city plans emphasize increased carbon sequestration through the "afforestation, revegetation, and restoration of wetlands" (Government Offices of Iceland 2018). For Reykjavik, a shift in the transportation sector is key in countering the city's previous reliance on the private vehicle. The city has many goals in place to move away from private vehicular use and reduce its GHG emissions from the transport sector by altering the traffic ratio to 58% automobile, 12% public transport, and 30% walking and biking by 2030 in addition to its goal to completely eliminate GHG emissions from automotive traffic and public transport by 2040 (Hrafnsdóttir 2018).

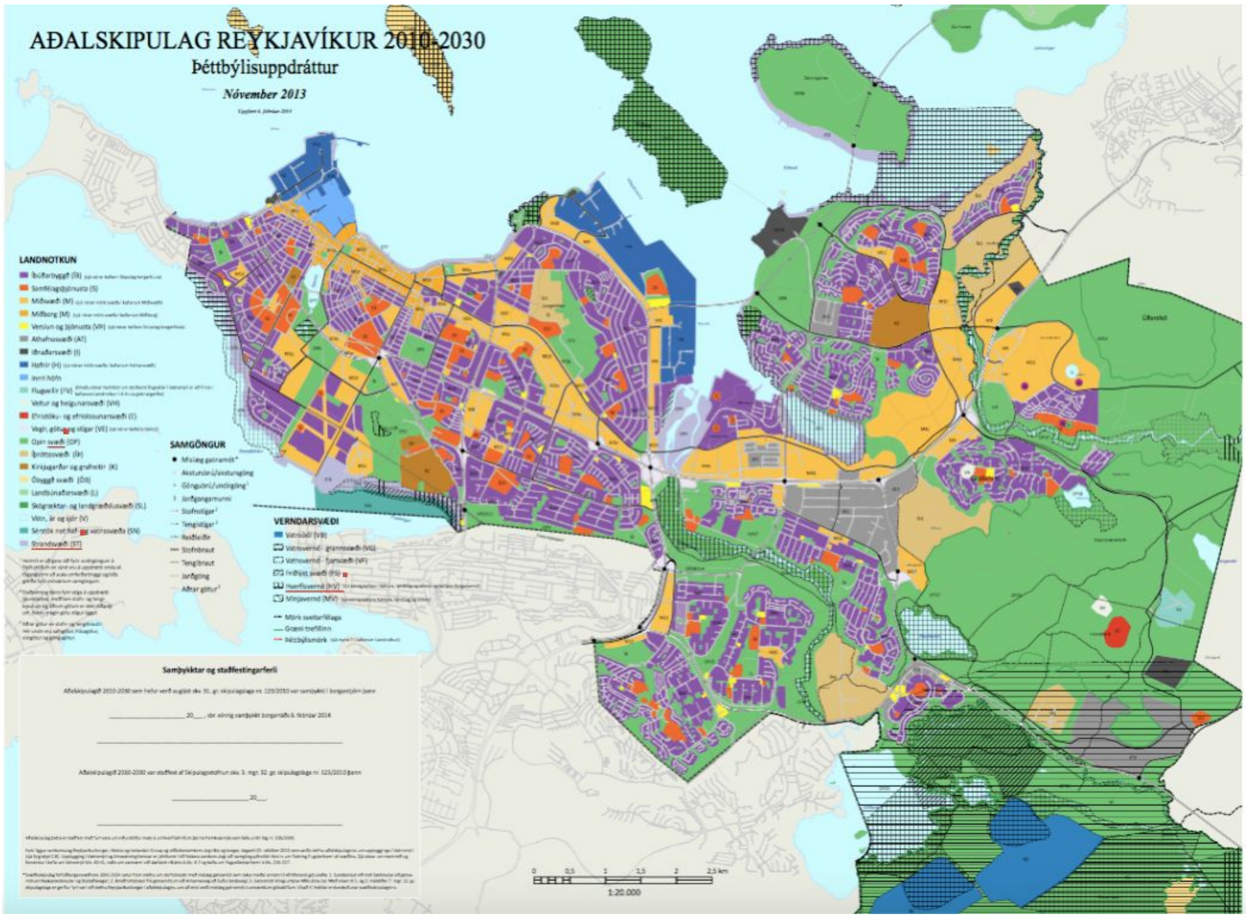

Fig 1. City of Reykjavik Municipal Plan Map for 2013. Updated Feb 9th, 2014 (Map in Icelandic)

Proposal for Geldinganes

In this paper I discuss the current proposal for Geldinganes island and develop two additional proposals for the land. The proposals for Geldinganes are not suggested to be implemented immediately, but rather, provide options for what to do with the island in the future. This study was conducted at the request of Hrönn Hrafnsdóttir, the city of Reykjavik's strategy and development manager for the Department of Planning and Environment in order to explore possibilities for Geldinganes that could contribute to the city's urban planning and climate goals. The three proposals discussed in this paper are

1. Leaving the island as a green space for recreational use (continuing the land use plan for the island that exists in the current municipal plan)
2. Reforesting the island, planting birch trees to create a carbon sink for the city
3. Developing a wind turbine farm on the island to meet growing energy demands and fuel the sustainable transportation industry as Reykjavik's population increases

Both reforestation and the development of wind energy on Geldinganes would require an alteration to the existing municipal plan. This could be done one of two ways. Period reviews of the municipal plan typically occur every four years and land use changes can be made during these revisions. Alternatively, there is a process that can be taken to make changes to the municipal plan at any time. First, the requested changes are determined to be either minimal, or significant. A significant change is one that has "significant land use changes" or "is likely to have a major impact on individual parties or affect a large area" (Skipulags stofnun 2011). Reforestation and developing wind energy on Geldinganes would qualify as significant changes. For further information on this process please visit skipulag.is for more information (Skipulags stofnun 2011).

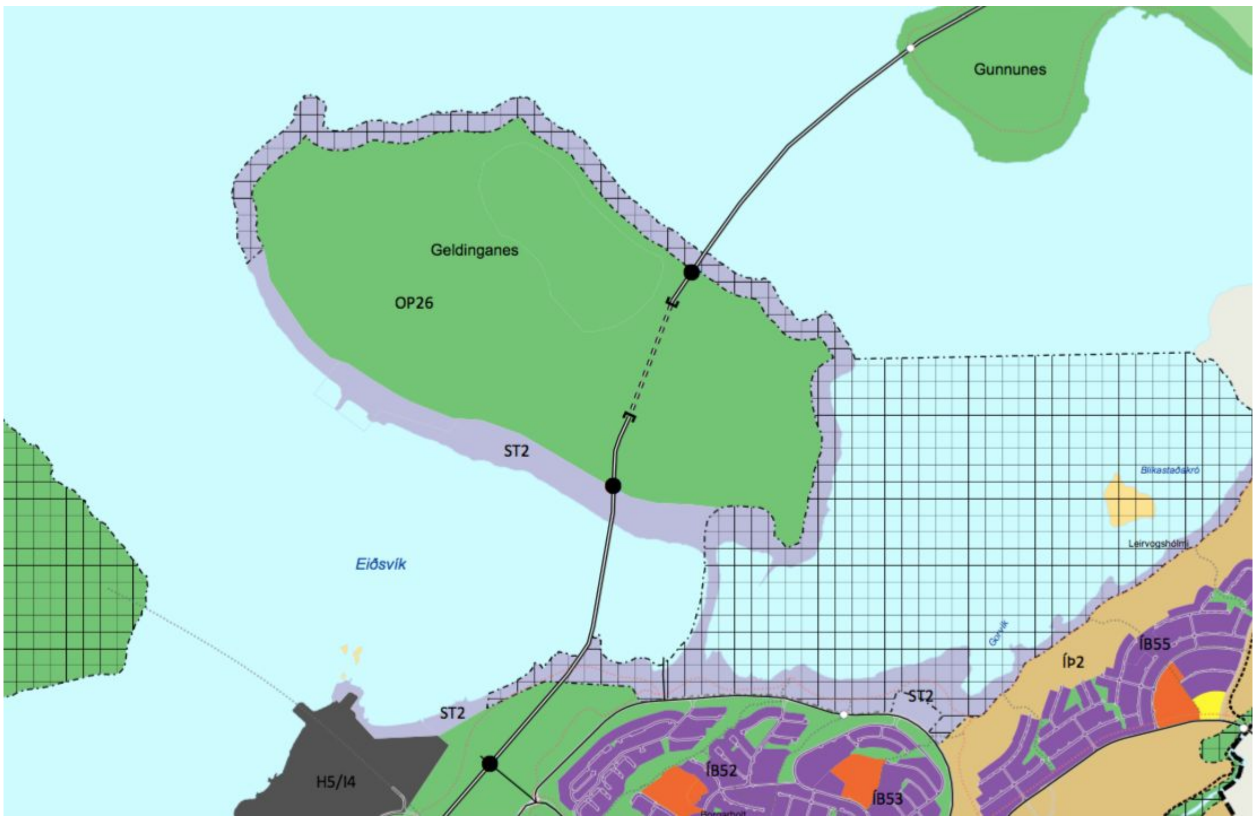

Fig 2. Current land use proposal for Geldinganes island. Green is open area, purple is open coastal area/beach, and the grid is environmentally protected areas. Additionally, there are currently long term plans for a road to be built connecting Reykjavik, Geldinganes, and Gunnunes.

Geldinganes

History

Geldinganes is an island of around 238 hectares connected to the mainland by a narrow isthmus that historically flooded during high tide. Located within the municipality of Reykjavik in the harbor behind Viðey island, Geldinganes was once apart of the Gulfunes estate and was used to keep livestock to feed the royal Danish falcons. Icelanders were obligated to catch and feed these falcons for the Danish king until 1840 when Geldinganes was sold by the Danish Royal Court and ultimately abandoned (NAT.is 2017). After 1840 Geldinganes was mainly used for pastures and an airstrip was built by the allied forces on the island during WWII. At the end of the 20th century the isthmus was elevated and a road was built across it, making it permanently connected and accessible to the mainland, for a harbor project that was later abandoned in 2004 (NAT.is 2017).

In 2017 a proposal to plan a settlement in Geldinganes was voted against 9-6. Supporters of the settlement hoped it would lower housing costs for the city by increasing the supply of affordable construction sites in the city and positively impacting the housing and rental market. The opposing majority however pointed to the city municipal plan which prohibits residential development in Geldinganes due to environmental impact, increased traffic, and transportation costs (mbl.is 2017). Additionally, development in the area contradicted one of the municipal plan's core proposals for 90% of all new residential units to be built within current urban areas (City of Reykjavik Department of Planning and Environment 2014).

Fig 3. View of Geldinganes from the path down to the beach

Fig 4. Path/beach connecting Geldinganes to the mainland

Fig 5. Abandoned mine on Geldinganes

Fig 6. View of mainland Reykjavik from Geldinganes

Fig 7. Rocky walking path and general terrain of Geldinganes

Current Use

I visited Geldinganes island on Tuesday, November 13th at sunset. It took around an hour to bus there from the city center near Harpa concert hall. The closest bus stop is about a ten minute walk from the isthmus connecting Reykjavik to Geldinganes. There is a row of houses across from Geldinganes on the mainland that overlook the island. A small parking area and shed sit at the beginning of the approximately 400m rocky pathway and beach that link Geldinganes to the mainland (Borgarvefsjá). The pathway is somewhat paved but the rocks are so large it would not be feasible to drive across. While I was exploring the island there were around eight or ten other visitors to the spot, mainly individuals and families walking their dogs along the beach. Unlike most of the others, I walked all the way to the end of the path at the NW corner of the island, stopping at the abandoned mine. Most of the island is covered in tall grasses, mosses, and bushes. The ground off the path is quite hilly and the vast plant species covered moist, clay-like dirt and rocks. There were also several small streams running across the island. I also noticed many sea birds flying and swimming near the shore. Other than the path, abandoned mine, and MET weather station, there was no other noticeable infrastructure on the island above ground.

Reforestation in Iceland

Ample evidence from written reports and place names to pollen analysis and isothermal curves suggest that prior to viking settlement, approximately 25-30% of Iceland was forested (Blöndal 1993). When settlers arrived to Iceland, they burned scrubland and cut down forests to make room for fields and grazing land for sheep, an Icelandic livelihood staple (Eysteinsson 2013). Sheep grazing in turn, prevented the regeneration of forests and by the mid 20th century, 95% of the original forest cover had been destroyed (Eysteinsson 2013). According to Skógræktin, the Icelandic Forest Service, between 1950 and 1980 net deforestation shifted to net afforestation thanks to the intentional efforts of many forestry groups (Skógræktin).

Downy birch *(Betula pubescens)* is the only native forest forming tree species in Iceland (Skógræktin). Birch trees in Iceland typically grow to shrub size, reaching a maximum height of around 15m (Skógræktin). Today, birch afforestation provides many benefits from creating additional recreational areas, restoring ecological tradition, creating more abundant ecosystems for plants, animals, and fungi to flourish, and sequestering carbon dioxide from the atmosphere.

Wind Energy in Iceland

In 2014, the first (and only) holistic study of the wind energy potential of Iceland was conducted using the Weather Research and Forecasting (WRF) model (Nawri 2014). While this model has since become somewhat outdated, the findings of this study were a fundamental starting point for wind energy research and production in Iceland. The 2014 study analyzed wind speeds from 1995-2008 and similarly to this study, chose a specific turbine model to project wind speed data to and determine a weibull distribution and potential energy output from. Overall, the study found Iceland to have favorable conditions for wind energy development, fitting well within the highest wind power class of western Europe (Nwari 2014). This study further asserted that the development of wind energy in Iceland would be strategic for a country with "high wind energy potential and a low population density" (Nwari 2014).

Additionally, the study highlighted the potential for wind power to add to and balance out existing renewable energy sources in Iceland, as more than 80% of the country's energy comes from geothermal and hydropower (Nawri 2014). As mentioned in that study, wind speeds tend to be faster in the winter time and lower during the summer while stream flow's large annual variation reaches its lowest point during the winter and highest point during the summer (due to fluctuations in glacial melt). In this way, wind power provides a nice power compliment to hydropower, producing more energy when hydropower produces less and vice versa. Additionally, wind power is projected to be more stable than hydropower in the coming decades. As a result of climate change, glacial melt is expected to reach its peak increase during the latter half of the century, and then taper off while wind speeds are projected to remain steady (Sveinsson 2010, Björnsson 2011). Furthermore, the study found that "wintertime increases in the actual energy production are typically between 50 and 150% of the summer average" which is convenient for the increased light demands during the winter (Nwari 2014).

In February of 2013, Landsvirkjun (the National Power Company of Iceland) began operating the first wind turbines in Iceland at the Hafið site in the south of Iceland. Landsvirkjun erected two wind turbines, E-44 models from the German company Enercon, at the Búrfell wind farm for a total of 2 MW of installed power. Together they have the capacity to generate 5.4 GWh per year. These turbines are IEC 1A class meaning that they operate at full capacity when wind speeds reach 15-28 m/s making them the highest wind class (Landsvirkjun). Furthermore, the Búrfell turbines are located inland as an experiment to determine "operational experience with wind turbines far inland and the Icelandic climate" while the turbines proposed at Geldinganes would be located at the shoreline and therefore, unlike the Búrfell turbines, would benefit from steadier winds and no risk of icing (Landsvirkjun). Because of the success of the Búrfell experiment, Landsvirkjun has proposed the development of the first commercial wind farm in Iceland in the Búrfell region.

Methods

Birch Farm Proposal

In order to evaluate the sequestration potentials of Geldinganes it is necessary first to determine the species of tree to afforest the island with. For the purposes of this study, I calculated the sequestration potential of a birch *(Betula pubescens)* forest. I chose birch because in my meetings with Hrönn Hrafnsdóttir she recommended birch for its traditional native value.

Geldinganes is approximately 238 hectares but most of the coast from the northwest tip, along the northeast side, to the southeast tip is a protected coastal area as of the current municipal plan. Additionally, there are currently two roads running along the island as well as a proposed road that will cut across the center of island connecting Geldinganes to the mainland in the south and northeast. Furthermore, the abandoned mine sits on the southwest side of the island. In order to determine where trees could feasibly be planted, these land restrictions must be taken into account. A more detailed land assessment would be necessary to actually determine the best locations for tree planting with more specific restrictions not taken into account in this broad analysis. However, for the purposes of this study I created a map showcasing the areas which tree planting would be most generally feasible and calculated the sequestration potentials and costs of these areas combined.

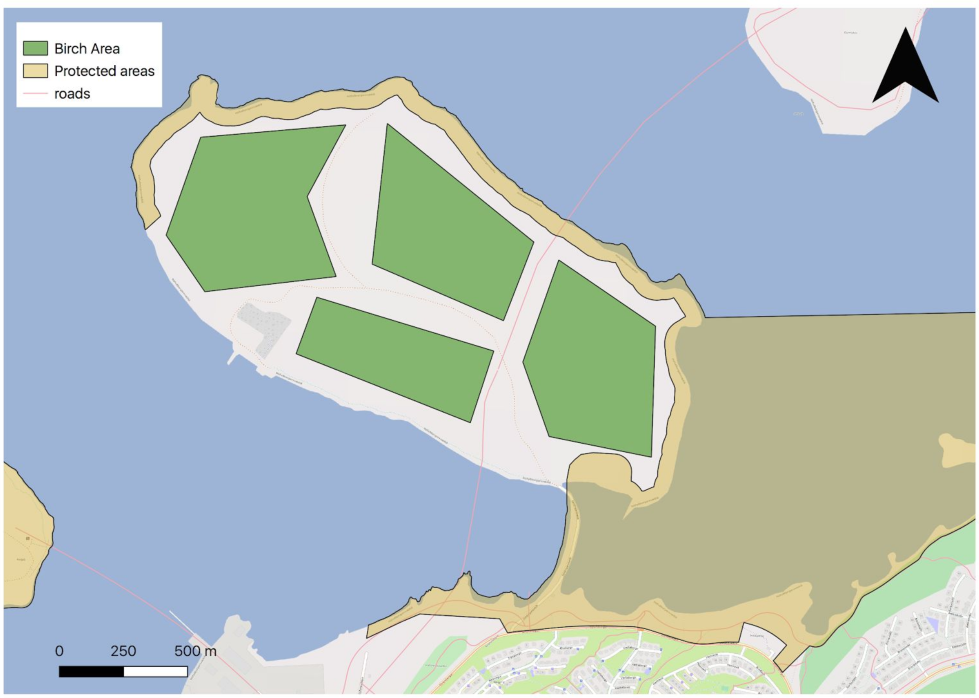

Fig 8. Proposed birch reforestation areas for Geldinganes. Layers from thorarinnjj3709 2018.

As you can see in the map above, I have proposed four areas for reforestation. I used QGIS to create four green polygons that demonstrate potential birch forest development. The other layers on the map include roads (two existing and one projected road) and protected areas (beige) as shown in the municipal plan. Area one (farthest west) is 32.687 hectares, area two (north and middle) is 25.406 hectares, area three (south and middle) is 18.544 hectares, and area four (farthest east) is 28.446 hectares. In total, I have proposed approximately 105 hectares for birch forest development. On average, including seedling mortality, approximately 3,500 trees fit on one hectare of forest (Eysteinsson 2018). This means there is potential for 367,500 birch trees to forest Geldinganes within the areas I have proposed. These areas take into account the existing road and mine infrastructure already on the island as well as the proposed road to cross the island and stays out of the proposed protected areas as well. In a more in-depth analysis, the city would need to determine whether their goal is to plant the most amount of trees possible on Geldinganes for maximum carbon sequestration or if they want to consider other options for cost or land purposes.

Downy birch sequesters 3.1 tons of CO_2 a year per hectare, while soil and plant litter sequester 1.34 tons of CO_2 and 0.52 tons of CO_2 respectively (Snorrason 2018). In total, birch sequesters 4.96 tons $CO_2\ tree^{-1}\ year^{-1}$. If 105 hectares of birch trees were planted, as proposed, they would be the capable of sequestering 520.8 tons of CO_2 every year.

In order to determine the costs of reforesting Geldinganes, I spoke on the phone with a woman from the Sólskógar nursery located in Akureyri to inquire about their pricing for native birch. I was informed that a container of 67 birch trees costs approximately 67,000 ISK (around 1000 ISK per tree). Planting 367,500 trees would require 5,486 birch containers (because you cannot purchase only part of a container). This would cost $367,562,000 ISK. This cost only covers the purchase of the birch containers and does not include the cost of shipping or planting the trees. To determine these additional costs, further detailed cost analysis is required.

Wind Farm Proposal

In order to evaluate Geldinganes potential for wind energy, I first obtained data from the City of Reykjavik and the Iceland Meteorological (MET) Office on the size and weather conditions of the island. I also used the open source GIS tool Borgarvefsjá for additional measurement estimations of the land. In the summer of 2004, the Icelandic Met Office installed a weather station on Geldinganes that collects weather data at 10m above ground level in the middle of the island (64°10.067', -21°48.228'). From August 1st 2004 - July 31st 2018 the average yearly temperature on Geldinganes was 5.3℃. During this period average daily wind speeds were 5.88m/s at 10m.

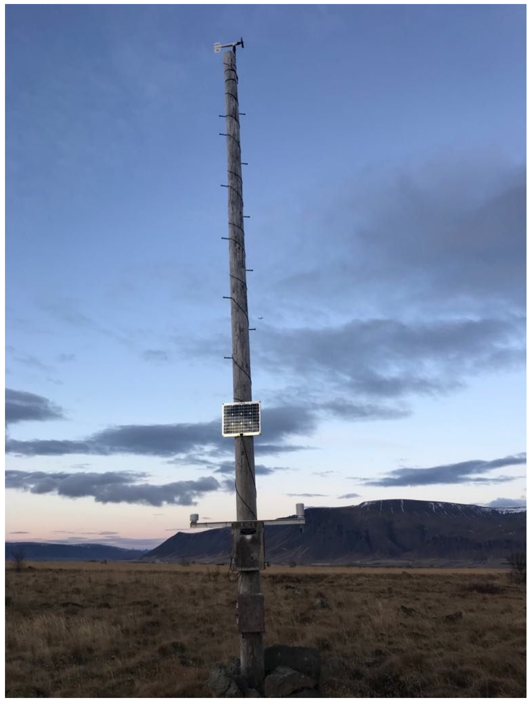

Fig 9. MET weather station on Geldinganes

Month	Average monthly wind speed at 10m (m/s)	Average monthly wind speed projected to 91.5m (m/s)
January	7.00	9.67
February	6.96	9.61
March	6.71	9.27
April	6.23	8.60
May	5.40	7.46
June	4.62	6.38
July	4.17	5.76
August	4.36	6.02
September	5.58	7.70
October	5.89	8.13

November	6.84	9.45
December	6.85	9.46

Fig 10. This table shows the average monthly wind speeds on Geldinganes island from 2005-2017 taken from the Icelandic MET office weather station (column 2) and projected to 91.5m (column 3). Wind data are missing from December 2012 and January 2013.

Once obtaining and averaging the weather conditions for Geldinganes, I analyzed the Vestas wind turbine models currently on the market and chose one to project my wind speed calculations to. I chose a Vestas model because they are the world's leading wind turbine design, manufacturing, installation, and service company. While a more detailed study would require comparing multiple models from a variety of wind energy companies, the purpose of this study is simply to determine general feasibility and wind energy potential for Geldinganes, and therefore working with a single model is sufficient. Additionally, the five week time constraint of this project limited the ability to consider multiple models.

The model I chose is the V117-3.45MW turbine. More detailed information on this turbine can be found on the Vestas website and at wind-turbine-models.com. This turbine has three hub height options, 80m, 91.5m, and 116.5m (Vestas). Both the 80m and 91.5m turbines are wind class IEC IB, meaning they operate best under conditions at medium average wind speeds, 7.5-8.5 m/s (Vestas Wind System). My average daily wind speed at 20m AGL was 5.88 m/s and I chose to project it to the taller turbine (91.5m) because wind speeds increase with increase in height.

In order to determine the average wind speeds at this hub height, I projected the average wind speed measurements taken from the weather station at 10 mAGL using

$$S(h_2) = S(h_1)\frac{ln(h_1/z_0)}{ln(h_2/z_0)}$$

Where $h_1 = 10m$, $h_2 = 91.5m$, $S(h_1) = 5.88 m/s$, and $z_0 = .03m$ (Nwari 2012).The average surface roughness for Iceland is approximately 3cm (Troen and Petersen 1989). Using this formula I calculated the average wind speed at 91.5m for each day from August 1st 2004 to July 31st 2018. The average daily wind speed over this period was 8.12 m/s.

In order to determine the average production (per time unit), annual energy production, and capacity factor of the turbine it is first necessary to determine the weibull distribution of the average daily wind speeds. The weibull distribution shows how frequently each daily average wind speed occurs over the entire period of data.

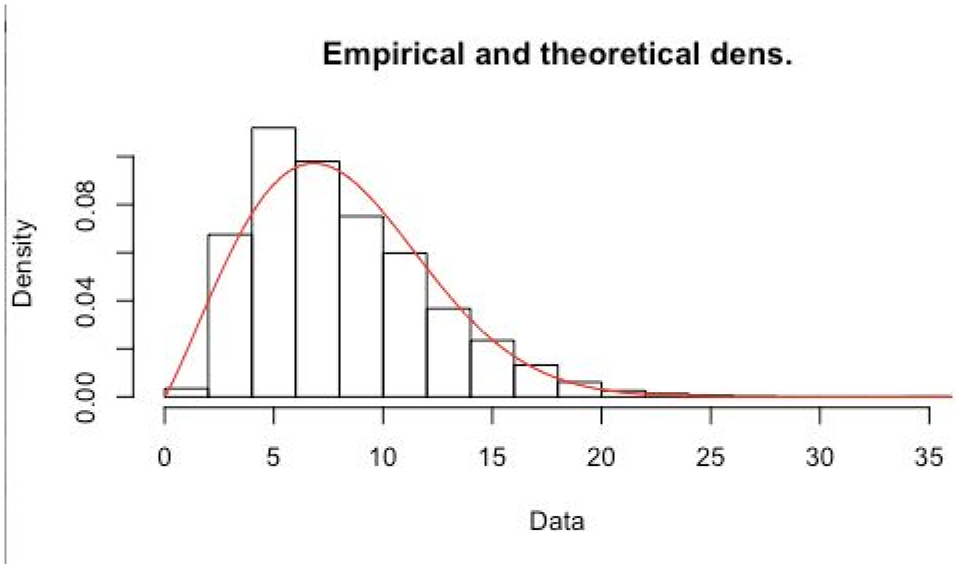

Figure 11. Weibull distribution graph. X axis shows wind speeds (m/s) while X axis shows frequency (%)

From the weibull distribution we obtain two key parameters, the shape parameter (β) and the scale parameter (α). The shape parameter is also known as the weibull slope because it is equal to the slope of the line in a probability plot. The shape parameter is typically between 1-3. A small β value signifies variable winds while a larger value signifies steadier winds (Swiss Federal Office of Energy). The scale parameter in m/s is a measure for the characteristic wind speed of the distribution and is proportional to the mean wind speed. In order to calculate the weibull distribution I used the programming language R (R Core Team 2017). I installed the "fitdistrplus" package in R and ran the weibull distribution function fit.w (Delignette-Muller & Dutang 2015). Then I summarized and plotted the results in order to get my shape and scale parameter values and histogram with the weibull distribution fit line.

Once I found the shape and scale parameters from the weibull distribution using R, I calculated the probability of the distribution at each wind speed from 1-27 m/s to find f(U) using

$$f(u) = \frac{\beta}{\alpha} \times \left(\frac{u}{\alpha}\right)^{\beta-1} \times e^{-\left(\frac{u}{\alpha}\right)^{\beta}}$$

In order to determine the average production (per time unit) of the V117-3.45MW model I needed to find $P\,(u)$, the power the V117-3.45MW turbine produces at a given wind speed in kW. These values corresponding with wind speeds 1-25 m/s were taken from the power curve of the V117-3.45 MW turbine.

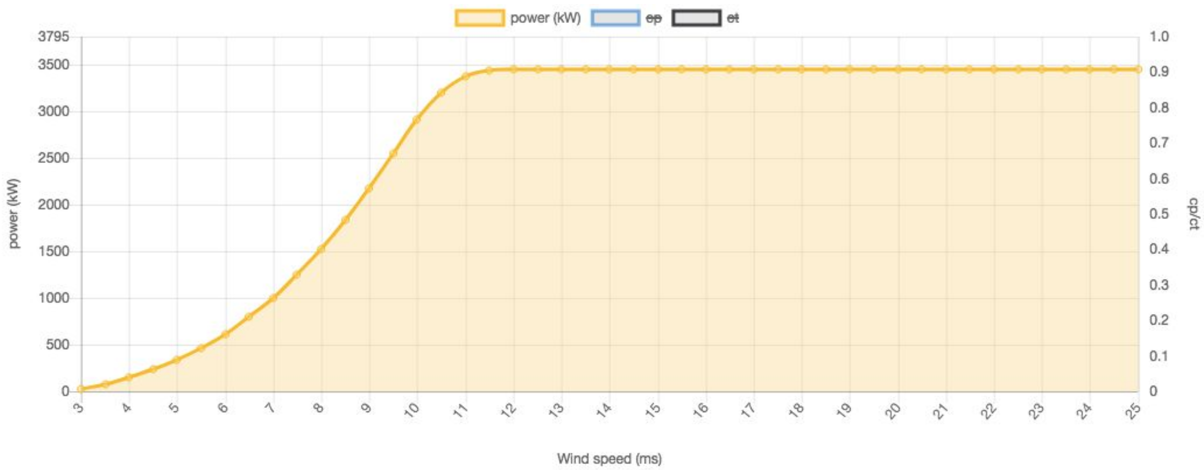

Figure 12. V117-3.45MW turbine power curve from wind-turbine-models.com. The V117-3.45 MW model cut-in wind speed is 3 m/s and cut-out speed is 25 m/s.

Wind Speed u (m/s)	Power output $P(u)$ (kW)
1	0
2	0
3	22
4	150
5	340
6	617
7	1006
8	1522
9	2178
10	2905
11	3374
12	3448
13	3450
24	3450

15	3450
16	3450
17	3450
18	3450
19	3450
20	3450
21	3450
22	3450
23	3450
24	3450
25	3450
26	0

Fig 13. Table showing the power curve values for power output at each wind speed.

After finding $P(u)$, in order to find the average production (per time unit) calculate the sum of $f(u)$ and $P(u)$ using:

$$\sum P(u) \times f(u)$$

The average production per time unit found was 1663.69 kW. To obtain the annual energy production multiple the average production per time unit by 8760 (the number of hours in a year) you get 14,573,951.2 kWh/year or 14.6 GWh/year.

$$\left(\sum P(u) \times f(u)\right) \times 8760$$

Finally, to find the capacity factor for the turbine I used the following formula and found the capacity factor of the V117-3.45MW turbine to be 0.48.

$$\frac{\sum P(u) \times f(u)}{\max\left(P(u)\right)}$$

The capacity factor expresses how much energy the turbine actually produces as opposed to how much it could potentially produce if it was operating at full capacity all the time (capacity factor = 1). I found the capacity factor of the V117-3.45MW turbine model to be 0.48 or 48%. This is a high capacity factor, as the annual capacity factor for wind generators in the US 2017 was 34.6% (U.S. EIA 2018). However, this number does not take into account power losses that would occur when considering additional condition specific variables such as shadowing and wake effects. Shadowing is the phenomenon that wind farms often "compromise optimal distance between turbines" in order to save costs on land or to squeeze as many turbines as possible onto land with high quality wind conditions (Boccard 2009). Wake effects are the result of down-windstream turbine having a lower energy content than up-windstream. This occurs because the wind downstream of a turbine has "reduced speed and is turbulent" as a result of passing through the first turbine (González-Longatt 2012). As a result, both shadowing and wake effects can lower turbine capacity factor.

Once the capacity factor and annual energy production of a single turbine have been determined, the next step is to estimate how many turbines could comfortably fit on Geldinganes. The average daily wind direction on Geldinganes from August 2004 - July 2018 was 148°. This means that the primary wind direction is coming from the SSE. In my personal communications with Stefán Kári Sveinbjörnsson, he informed me that typical spacing for wind turbines should be 5D (5 x the rotor diameter) in the main wind direction and 3D in the direction perpendicular to the wind.

Fig. 14. Wind rose directions in Reykjavik. Retrieved from Veðurstofa Íslands with edits by Stefán Kári Sveinbjörnsson

For the purposes of this general analysis, I took a single measurement for the SSE and perpendicular directions of Geldinganes. Of course, Geldinganes is not a perfect rectangle and more specific and accurate land measurements would be required to actually determine the spacing availability of the island. In the SSE wind direction, Geldinganes is approximately 2287m long. The rotor diameter of a V117- 3.45 MW turbine is 117m. Multiplying this rotor diameter by 5, turbines must be spaced 585m apart in the SSE direction. Within the spacing limitations of Geldinganes, 3.9 turbines could fit along the island. The 2287m measurement of Geldinganes taken was an estimation using QGIS and measuring from the edges of the protected coastal areas on each side of the island. As a result, a more accurate measurement of the island must be taken to determine whether 3 or 4 wind turbines would be feasible. In the perpendicular direction, Geldinganes is approximately 1117m wide. With 3D spacing in this direction (351m), 3 turbines could fit across the island. Therefore, in total, a general spacial estimate reveals that between 9 and 12 wind turbines of the V117-2.45 MW model can be built on Geldinganes. This would provide a renewable energy resource between 131.4 GWh/year and 175.2 GWh/year. This number is difficult to make comparisons with because there are no other existing wind turbine farms on Iceland. Additionally, due to spatial limitations, a wind turbine farm on Geldinganes could never be of substantial, commercial size, such as the proposed wind turbine farm at Búrfel. At Búrfell, the current proposal estimates that 67 turbines 150m in height will produce 705 GWh/year (Landsvirkjun).

Ethics

As an urban planning research project, ethical considerations for this project were somewhat limited as I did not deal with human subjects. I did however conduct several in-person meetings and email communications with professionals throughout my research process. During these interactions I made sure to be respectful, considerate, and gracious to these individuals for their help. Additionally, I received data from many of these interactions and made sure to credit the individuals and organizations for the data I received from them. I have acknowledged all those who helped me with this project in this paper and correctly cited all of my sources from the literature I read, to the data I received, and maps and images I used.

In addition, with any urban planning project, it is important to consider the effects that land use changes will have on the environment and greater community. For the purposes of this study I did not conduct in-depth research of the consequences of each proposal but I did make sure to mention briefly what these consequences might be. As a result, if any of these proposals are taken further into action planning, reviewing and researching these potential consequences is of utmost importance and ethical implications must be taken into consideration.

Discussion

Geldinganes as a Green Space

In order to strengthen its role as a green city, one of the Reykjavik's major goals is to preserve existing green spaces throughout the city in order to provide "favorable access to diverse recreational and green areas" as well as sustain "the natural diversity of Reykjavik's land and biota" (City of Reykjavik Department of Planning and Environment 2014). Geldinganes has always been an open space, largely untouched, which a rare thing in such an urban city. Preserving Geldinganes as the open space it currently is would contribute to the city's goals and have the lowest impact on the area, causing the least amount of disturbance to the environment and ecosystem. Additionally, for the residents who live in close proximity to Geldinganes, their access to and use of the island would not be compromised. Furthermore, with no major land use changes, the visual impacts would be minimal, leaving the coastal views in tact for the many houses that overlook the island from the mainland.

Preserving Geldinganes as an open green space does not necessarily mean leaving the island as is. As mentioned, part of Reykjavik's goal is to create "favorable access" to green spaces. Green spaces provide an inherent ecological and environmental benefit in their existence alone but they can also provide an important recreational and social/well-being benefit if made accessible. In the current municipal plan, the city hopes that recreational areas and green spaces will form "a continuous web or a green net" over the city, connecting "residential areas to diverse nature and recreational areas" (City of Reykjavik Department of Planning and Environment 2014).

When I visited Geldinganes, I would not have described it as particularly accessible. There is road that leads down to the water across from the island and it ends in a small parking area looked as if it could fit 8-10 cars. There is also a walking/biking path that leads down to the water. From the parking area, a beach parallel to a rocky path/road connect the mainland to Geldinganes. I found this path very difficult to walk on. There were huge, misshapen rocks along it and if you did not have good hiking boots or were elderly, it would be almost impossible to cross without injury. The path connecting the island to the mainland continues across the island but its rugged condition does not change. Once on the island there are expansive open grasses and shrubs. This provides space for dogs to run freely, but the ground is very uneven and when I ventured off the path I again, found it difficult to walk. In order to fulfill the city's goals of preserving the area as a green space and making it accessible for public use, I recommend building more infrastructure on the island. First and foremost the road connecting and along the island should be paved. Additionally, I think Geldinganes would benefit from creating more spaces for designated for recreation. It could be beneficial to build a dog park on the island for the many dog owners that currently utilize the island. Additionally, as there is plenty of space on the island there is room for multiple possible recreation spaces such as children's playgrounds, fields, gardens, and multiple hiking/walking trails.

Birch Forest on Geldinganes

Developing a birch forest on Geldinganes, while altering the natural ecology of the island, would allow the island to remain as a green space, in line with the current municipal plan. Additionally, it would contribute to the city's goal to "strengthen urban forestry in the peripheral area" and to "increase the green appearance of the city with trees and other vegetation" (City of Reykjavik Department of Planning and Environment 2014). While the exact number of birch trees that could viably be planted is unknown (as the analysis in this study is only an estimation), the island has a significant amount of open space with only limited protected coastal areas around the periphery. Therefore it is likely that birch forest potentials would be significant.

In 2015 Reykjavik emitted 350,000 tons of CO_2; 201,000 tons from transportation, 133,000 tons from industry, and 16 tons from aviation, fishing, and sailing (Hrafnsdóttir 2018). The proposed birch forest at Geldinganes would sequester 520.8 tons of CO_2 every year. This forest has the potential offset all of the cities 2015 carbon emissions from aviation and some of the emissions from industry or transportation as well. While the upfront costs are significant (up to $367,562,000 ISK not including shipping and planting costs) maintenance costs for forestry are relatively low as once trees are properly planted they do not require much upkeep. Additionally, the scale of the forest could be easily altered according to the desires/budget of the city as any number of trees would result in a positive sequestration impact.

Afforestation of Geldinganes would keep the area preserved as a green space and help Reykjavik achieve its carbon neutrality goals. Additionally, as birch is native to Iceland and has been used successfully in multiple other afforestation projects, there are few expected barriers to afforesting Geldinganes with birch trees. Furthermore, a birch forest on Geldinganes would have several additional benefits to carbon sequestration such as contributing to soil and water conservation and enhancing biodiversity of the island (Skógræktin).

Wind Farm on Geldinganes

As demonstrated, a wind turbine farm on Geldinganes islands is not only feasible, but advantageous as it would provide a valuable renewable energy source for the city of Reykjavik of potentially up to 175.2GWh/year. The wind turbines at Geldinganes would be connected to an underground cable, supporting the existing energy grid. This could be beneficial to meet the city's increasing energy demands as there is an expected population increase of 25,000 people by 2030 (City of Reykjavik Department of Planning and Environment 2014). Furthermore, this additional energy supply has the potential to support Reykjavik's growing sustainable transportation sector. While wind itself cannot be stored, wind power could be stored in batteries, such as the latest, fast-charging Enercon E-Charger 600, that in turn can be used to power electric vehicle charging stations throughout the city (Enercon 2018). Additionally, wind energy has the potential to fuel the city's plans for a light rail system with a high voltage power line. One item in the current municipal plan is a proposed transportation corridor that will have a special emphasis on public transportation featuring an "express route and priority lane for busses (and) future route for light rail" (City of Reykjavik Department of Planning and Environment 2014). Building a wind turbine farm on Geldinganes would support these transportation developments and fulfill Reykjavik's goal for all busses and cars run by the city and the majority of private cars to be run entirely on renewable energy sources by 2030 (City of Reykjavik Department of Planning and Environment 2014). In addition, the turbines have the potential to charge ships as well, another of Reykjavik's sustainability goals in the future.

Geldinganes' location makes another strong case for wind turbine development there. It is near the sea and therefore is likely to have steadier winds than in other inland areas. It is within city limits and therefore would not require significant effort and materials to connect the farm to the city's existing energy grid. Furthermore, the wind farm would be somewhat isolated and removed from the rest of the city by being on an island, lessening its visual and noise impacts as well as shadow flicker effects. Shadow flicker is the effect of the rotating wind turbine blades casting a shadow behind them that can often be a visual annoyance and distraction when poorly located too close to residential areas.

Wind turbines inherently have more fluctuating production levels than hydro or geothermal power due to the unpredictable and variable nature of wind, and therefore wind "does not always blow when electricity is needed" (United States Department of the Interior, BLM). Additionally, being an isolated power market, Iceland will have to rely on other domestic power sources when wind energy does not suffice energy demands (Askja Energy). Therefore, wind turbines require more backup power than geothermal or hydropower. However, they have a much greater energy potential than hydro and geothermal and in the case of Geldinganes, would be increasing the energy capacity of the grid and would not be relied upon as the sole energy source for the city. Additionally, wind power is stronger during the winter season while hydropower is stronger in the summer, providing a nice compliment.

Wind turbines can be a significant cost upfront with 80% of the cost in the machinery in addition to site preparation and installation costs (United States Department of the Interior, BLM). Additionally, in order to be the most cost efficient, it would be beneficial for Reykjavik to install as many turbines as space permits on Geldinganes because smaller scale wind farm projects are much costlier than commercial scale projects (personal communication, Stefán Kári Sveinbjörnsson). The costs of the Vestas 117-3.45 MW turbines were not determined in this study as their pricing is not publicly available. Further analysis would require a more in depth cost-benefit analysis to confirm the feasibility of developing a wind turbine farm at Geldinganes. However, over the life cycle of all energy generators, wind turbines tend to be the most cost effective because, unlike with hydro and geothermal power, there is no cost of fuel to power them and wind turbines have minimal operating expenses (United States Department of the Interior, BLM). Additionally, a wind turbine repays its energy footprint after five months, that is, it only takes five months for it to produce the amount of energy it consumes in its lifetime (Landsvirkjun). Furthermore, a recent study by IIT Comillas in Madrid and MIT in Boston show that wind farms in Iceland have the potential to generate electricity at a localized cost of energy as low as 35 USD/MWh which is less expensive than all of the current planned geothermal and most of the planned hydropower projects in Iceland (Duenas 2018). As wind energy technology costs continue to decline, the feasibility of wind farm development to harness Iceland's natural wind resources will increase significantly.

Environmental Impacts

Wind turbines can be easily dismantled leaving the land they stand on undamaged. This means that while the turbines themselves are a significant development on Geldinganes, and do impose an undeniable visual impact, they will not leave a great impact on the land itself and if, in the future, the turbines are no longer wanted on the island, there will not be significant challenges to removing them. Additionally, the environmental impacts of wind power are less serious than geothermal and especially hydropower which requires the serious alteration of rivers and waterfalls (Askja Energy).

In addition to land impacts, ecosystem impacts must be considered as well. A bird impact assessment was conducted from May to September 2006 for the estimation of Sundabraut, the proposed road that will, in part, run across Geldinganes. According to the study, there are a significant amount of breeding birds in Geldinganes. On June 8th, 2006 the East side of the peninsula was estimated to have 222 pairs of birds per square kilometer. The study also found that increasing numbers of owls, a species determined to be "in imminent danger", have nested in the Geldinganes area but that overall bird populations have been decreasing with increasing traffic in the area (Hilmarsson 2006). The birdlife around Geldinganes must be carefully considered as wind turbines can pose a serious threat to bird life, increasing mortality rates from collisions into the turbine blades. Therefore, a detailed and thorough environmental impact assessment of the Geldinganes region is necessary to determine if the site is safe for bird life.

Noise and Visual Impacts

Turbine technology developments in recent years have resulted in significant noise reductions. However, as Geldinganes is relatively close to a residential area, a noise impact study must be conducted in the future. A visual impact study should also be conducted. The Grafarvogur residential district would suffer greatest visual and noise impact. Many of the houses in Grafarvogur overlook the water and Geldinganes as well as the island of Þerney and the Gunnunes peninsula which are both behind Geldinganes. Building a wind turbine farm on

Geldinganes would significantly alter the current view and obstruct the sightline to Þerney and Gunnunes.

Conclusion

This project was designed to provide the city of Reykjavik with multiple land use options for Geldinganes. The current municipal plan leaves the island as it presently is. While this is the lowest impact plan it is not necessarily the worst, as it preserves the island as a green space, promoting Reykjavik's "green city" image. In order to make Geldinganes an accessible green space however, additional infrastructure is suggested not only to increase the usability of Geldinganes, but also to create more recreational versatility on the island. The proposal to afforest Geldinganes with native birch is a medium impact development project. Afforesting Geldinganes would have significant carbon sequestration benefits that could not only contribute to the city's municipal plan, but assist in lowering its carbon footprint as well by offsetting some of its emissions. Lastly, developing a wind turbine farm on Geldinganes would have perhaps the most significant benefits and also the largest impacts of all three plans. Developing a coastal wind turbine farm to support the existing renewably-fueled energy grid in hopes of eventually creating a completely electric transportation sector would propel Reykjavik to an elite sustainable and innovative urban development status. The wind farm would add to and diversify Iceland's renewable energy sector by utilizing the wind, another natural energy source Iceland is endowed with. While the wind farm would likely have limited visual and noise impacts, the environmental impacts are largely unknown and would need to be further studied. Additionally, a detailed cost-benefit analysis would determine if wind energy at Geldinganes would be realistically affordable in the current market. While each of these plans are distinct with varying degrees of impact to Geldinganes, all contribute to the city of Reykjavik's development goals, climate neutrality goals, and fight against climate change, making them all effective and productive proposals.

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