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Transitioning towards renewable energy and sustainable storage solutions at remote communities in the Arctic, Case study of Flatey, Iceland

M R A Hjallar[1,*], E D Víðisdóttir[2], O T Gudmestad[1,3,*]

[1] UiT, The Arctic University of Norway
[2] Orkubú Vestfjarða, Ísafjörður, Iceland
[3] University of Stavanger, Stavanger, Norway

*Corresponding authors: mhj015@post.uit.no and otgudmestad@gmail.com

Abstract: The need for transitioning towards renwable energy and sustainable storage solutions is particularly challenging for remote communities in the Arctic, located far away from the electricity grid. This paper explores the potential for use of renewable energy on the remote island of Flatey, Iceland, which currently relies on two diesel aggregates for power. The primary goal is to assess the feasibility of transitioning from fossil fuels to renewable energy sources, such as solar or wind power, to meet the island´s variable energy demand while reducing its environmental impact. With a year-around population of 5 and with a considerably increased energy consumption during vacation times, due to more population, Flatey´s annual energy consumption is ~ 209.000 kWh, peaking in July at ~ 25.000 kWh. This fluctuation requires an adaptable and resilient energy infrastructure. The paper examines the viability of Flatey as a self-sufficient renewable energy provider. The study considers the island´s energy requirements, consumption patterns, and geographical constraints, while also evaluating technical, economic, and social factors that may influence renewable energy adaption. This paper, thereafter, investigates the feasibility of achieving energy self-sufficiency on the small island of Flatey. Different energy storage options is considered, focusing on battery storage, underground solar power/energy storage, and hydrogen storage.

1. Introduction

The availability of energy at smaller remote societies is challenging. The remoteness restricts the possibility to ensure connection to the national electric grid and the costs prohibits the society to build separate electricity generating systems based on renewable energy. Therefore, coal or diesel is normally used to support the electricity plants at these locations. It shall be noted that use of diesel gives rise to emittance of less greenhouse gases than coal. The emission of CO_2 per million Btu is according to [1] 74 kg for diesel while it is 96 kg for coal. Switching to natural gas, the emission is 53 kg per million Btu. In some remote societies the use of compressed gas (normally methane) is encouraged, [2]; larger societies are using LNG (Liquefied Natural Gas); however, the use of LNG requires building of very costly regasification facilities. For any of the different fuel sources, emissions associated with production and transportation must be added.

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A shift to renewable energy sources with very limited emission of greenhouse gases is much encouraged. In this paper, the transition to use of renewable energy at a remote location is discussed by considering a case study. The motivation for presenting the paper is to investigate the feasibility of the transition from being a society basing the energy on fossil fuel to a society where the emissions are reduced compared with present situation. It should be noted that the sources of energy used at remote locations is of considerable discussion worldwide. The International Renewable Energy Agency (IRENA) and the Natural Resources Canada (NRCan) initiated the "Global Initiative for Transitioning Remote Communities to Renewable Energy" [3], in 2021. Reference is also made to [4], where Renewable Energy Alternatives for Remote Communities in Northern Ontario, Canada, are considered. In reference [5], a cost analysis is carried out for remote communities when hydro, solar and wave energy are available. To identify renewable energy alternatives where hydropower or wood is not available (like on Flatøy) or where the construction costs of wave energy plants will be too onerous, is a large challenge, therefore, the case of providing the barren Flatøy with renewable energy represents the ultimate challenge.

The location considered is Flatey, a remote island with a very famous history, one of the main cultural centres on Iceland, the location where one of the most important old Icelandic sagas, the Flateyjarbók [6], was written during the period 1387 to 1394. The book tells the history of the Norwegian kings and is a very important document for Norway and Iceland.

Flatey is a small island located in the centre of Breiðarfjörður in the north-western part of Iceland (Figures 1 and 2). The island is around two kilometres long and one kilometre wide and the landscape is, as the name indicates, almost completely flat, Figure 3. Until the latter part of last century the population on the island was growing and the island was in relation to its size heavily populated. Due to social change, change in the labour market and settlement condensation, the population has dwindled down and as of today there are only around 6 to 10 persons with permanent year-round residence on the island. The habitation on the island is seasonal, in the summertime considerably more persons live or spend time on the island. Some permanently move to vacations homes, some spend a few days at the island’s hotel and others spend the day exploring the island. The main industry on the island today is tourism and the main attraction on the island is the cultural history and old village that mostly is in its original shape along with the unspoiled nature and wild bird life.

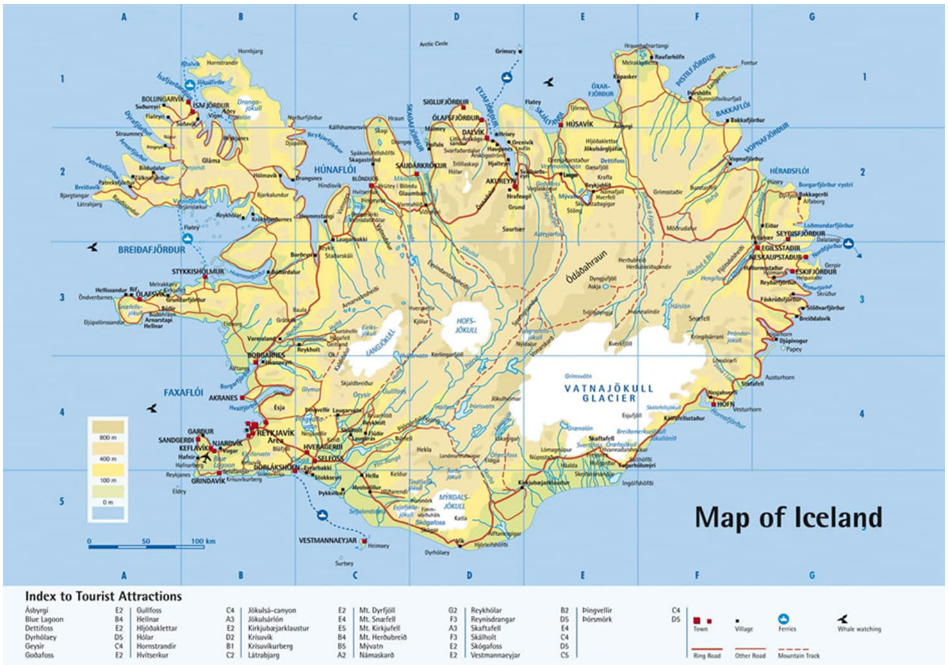

Figure 1. Map of Iceland. Note the location of Flatey in Breiðarfjörður to the North West.

The climate on Flatey is like Arctic climate in general. Flatey experiences a distinct climate characterized by relatively cool temperatures and moderate precipitation. The yearly average temperature in the district is 2,13 ºC, which is approximately -1,04 ºC lower than the average temperatures recorded across Iceland. In terms of precipitation, Flatey receives an average of approximately 59,75 mm of rainfall throughout the year. The precipitation in form of rain, is spread over a total of 144,3 rainy days, which amounts to approximately 39.71% of the year. This indicates that rain is a common occurrence on Flatey, with a considerable portion of the year experiencing wet weather. In contrast, the total snowfall precipitation in January 2020, which had the highest snowfall of that year, amounted to only 114 mm. This suggests a comparatively low occurrence of snowfall on Flatey [7].

Figure 2. Clearly marked old map of Flatey (Platey) [8].

Figure 3. Map of Flatey [9].

Flatey is not connected to the national grid in Iceland and grid connections to the island are not viable due to technical, economic, geographical, and climatic limitations. Due to this fact all the island needs to be self-sufficient when it comes to power production. All power production on the island today is done using two diesel aggregates. With increased awareness of the polluting effects of burning fossil fuels along with rising oil price and rapid price reduction of renewable energy, all further development on Flatley's power system is set towards a greener system. In Iceland 98% of electricity production comes from renewable energy sources, where hydro power and geothermal power are the building pillars. That leaves around 2% of the electricity generation to the burn of fossil fuels [10]. The goal is to further reduce this ratio as well as the Icelandic government has set a goal to increase the diversity of energy production where the focus has been on integrating both solar and wind power on larger scales than existing in the power system to this day [11].

The burning of fossil fuels for power production has many disadvantages other than the emission of CO_2 and other greenhouse gases, the maintenance cost is relatively high and the continuous diesel transportation to the island is both expensive and time-consuming. For the power system on Flatey where connection to the national grid is not an option, solutions of local sustainable energy production are set in focus. The potential local renewable energy sources are wind, solar, tidal, and green hydrogen. The option of tidal power has been researched in the area around the island, but the results were disappointing as the current measured is too slow for power production, or around 1 m/s. The use of hydrogen as fuel instead of the diesel has been researched but the results show that this would not be cost efficient. Leaving the first two options, wind, and solar power. Those options are the most feasible and despite high upfront cost for those renewable energy sources, the maintenance costs are low. These two power sources will be discussed further in this paper. For longer perspective, also the question of energy storage must be discussed as relying on wind and solar power results in using the existing diesel aggregates during high stable weather pressures wintertime, when there is no wind and limited daylight or when the wind velocities are high (at around 25 m/s) such that the wind turbine must close. The Flatey power generation project could be seen as a case study for the introduction of renewable power at an isolated location and its findings could be useful for other similar communities around Iceland or at other cold climate locations.

2. Present energy production and energy demand on Flatey

The annual energy production on Flatey has been around 210.000 kWh for the last years, that corresponds to burning over 60 thousand litres of diesel. Of those, around 50 thousand litres are used directly for heating of houses on the island, [12]. The electricity is produced by two 30kW diesel aggregates on automatic control and depending on the energy demand, either one or both machines are in operation. Due to the variating population on Flatey, the energy consumption varies drastically between seasons and, as in other bigger power systems, there are as well large variations in power demand within each day.

During low season in the winter the energy consumption during this period is quite stable at around 15.000 kWh per month. This changes with the increased population on the island and the number of visitations to the island during the summertime causing a large increase in the power demand. The power demand reaches over 24.000 kWh per month in this season, which lasts from June to August and in this period the maximum power demand per one day does reach up to 765 kWh. During these high peak energy consumption months, the variations within each day get larger and the maximum power demand reaches around 60kW, that happens at and around dinner time. Meaning that the power system on the island must be able to produce up to around 60 kW to cover the demand when it peaks, although the power demand is much lower at most times.

The required power generation supplied by the diesel aggregates is highly controllable, and the production can easily and rapidly be either increased or decreased in accordance with the power demand in the system at any time. When it comes to the generation of the renewable solar and wind power they are not as controllable or reliable since they do not generate energy when the sun is not shining, or the wind is not blowing, even not during the situations where the wind is excessively strong. Because of this, the introduction of these power sources into the power generation system will increase fluctuation in the system. With increased fluctuation in a power system, a rather large and easily accessible reserve capacity is needed to act as backup, balancing out the fluctuations caused by the renewable source [10]. In this case it would therefore be necessary to keep the diesel aggregates in the system as reserve capacity at first and later, they could possibly be replaced by a greener option, batteries or potentially hydrogen.

Before the integration of the variating renewable power sources to the system takes place, a comparison of the power demand on the island and the power production from the power sources needs to be done. If the curves of power demand and production are in line with each other, on both a longer time scale like seasons and on a shorter time scale like when during the day when the demand and production tends to peak, that shows that the power source is suitable for the selected power system. Of concern is also situations when the energy production is low. The potential for energy storage and full self-sufficiency based on energy storage is in this respect, of importance.

3. Solar power availability

3.1 Power demand vs. power production

As Flatey is located at latitude 65.3° North the winters are long, and the summers are relatively short. In these conditions, close to the Arctic Circle the power production of solar panels cannot be expected to be even throughout the year. During the winter, when the sun rises low above the horizon the production from the solar panels is low, but during the summer when the sun is high above the horizon and barely sets during the night, the production is high.

In the case of Flatey these large seasonal variations in the solar power production are not necessarily negative since the most important factor is how the power output from the solar panels and the power demand in the system correspond. In Flatey these two curves are correspondent, as both power demand and production peak during the summer.

The power demand is high when the sun rises high, and the days are the longest during the summer months at that time the solar panels have large power output. The power output from the panels diminishes as the days gets shorter but simultaneously the power demand on the island gets much lower as the number of persons staying and visiting the island decreases drastically.

Figure 4 shows the power demand in Flatey in the years 2018 and 2019 which can represent a typical year in Flatey with regards to the number of persons living on and visiting the island. From the graph the power demand is quite stable during September to May and that the curve rises significantly during June to August with a peak in July. This is completely in line with the tourist season on the island.

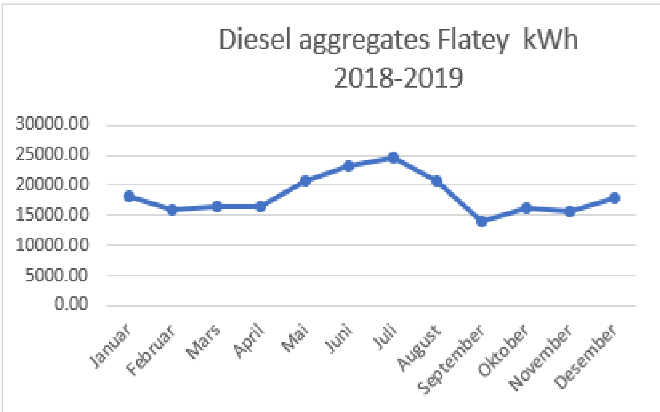

Figure 4. Power demand in Flatey (kWh), analysis of actual data

When researching the power demand in a power system, it is important to look at the variation of power demand on several different time scales. The daily power demand variations in the power system in Flatey are different during the different seasons as well. During winter the power demand is rather stable around the clock, varying with around 3kW per hour. In summer the power demand is not only larger in general, but the daily fluctuations are much larger as well. The average days during high season in June, July, and August the power demand peak occurs at or around dinner time and the hourly variations between night and day reach up to 17 kW. These variations need to be considered when it

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comes to estimating the available power in the system at each instant and the overall feasibility integrating solar power to the system.

3.2 Solar power in Iceland

Solar power has not, yet, been utilized on a large scale in Iceland. The utilization is mostly limited to regions that are not connected to the grid such as vacation homes and measurement stations that do not have a large power demand. There is although one solar power project on a larger scale installed in Iceland as 17 kW of solar power has been installed on one of IKEA's buildings in Reykjavík. The project is a research project for solar power in Iceland and there the panels are installed in two different angles, 50 panels are placed on a flat roof at a 20° angle from the horizontal and 13 panels are at a 90° angle on the wall of the building. Regarding the production per solar panel on the roof and wall of IKEA for the first two years of operation, the vertical panels on the wall produce more power when the sun rises low above the horizon during winter, from September to February and when the sun rises higher the production increases and the panels at 20° position on the roof exceed the ones on the wall by quite a bit [13].

When comparing the solar radiation data from Reykjavík (IKEA's location) to the solar radiation data from the nearest weather measurement station to Flatey, located at Gufuskálar on Snæfellsnes peninsula, the results are quite similar. The annual solar radiation at Gufuskálar is shown on Figure 5. The annual radiation is measured to 750 kW/m^2 while at IKEA´s location it is measured to 777 kW/m^2, but since Reykjavík is south of Gufuskálar the solar radiation is slightly more evenly spread out there. Indicating that at Gufuskálar the production of panels in a vertical position would be higher for a longer time period compared to in Reykjavík [14].

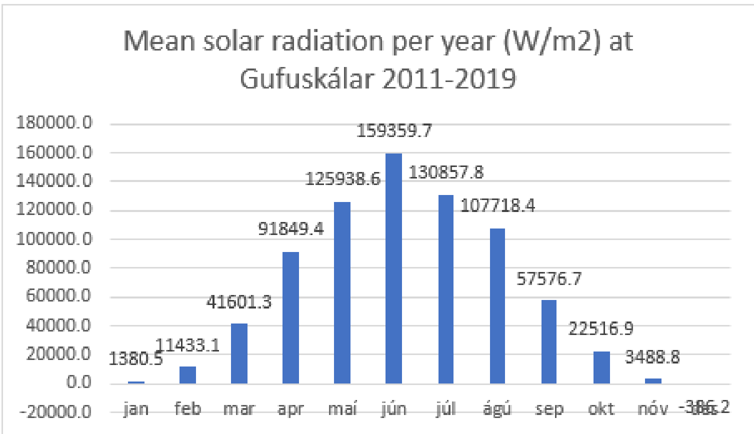

Figure 5. Mean solar radiation at Gufuskálar in W/m^2 from 2011-2019 [12]

The solar radiation data shown on Figure 5 is from a station located 70 km away from Flatey and the data has been accumulated from the year 2011. It must be noted that solar radiation devices from the meteorological office are from the horizontal placed panels and that the solar panels are most likely not going to have the same angle as well as more snow accumulates on a horizontal surface than on an angled one. The data does include some errors since it shows negative radiation for December but that cannot happen [15].

It can be seen from the solar radiation data at Gufuskálar that the monthly and seasonal radiation variations are drastic. Very little radiation is measured during the darkest months from October to March but as the sun rises higher and higher, the radiation increases with a significant peak in June.

Previously, it was believed that solar panels would perform better in warmer climates. However, more recent studies have shown that they perform better in colder climate. According to a study conducted by [16], the efficiency of solar panels decreases by 0,.5 %/°C increase in temperature.

Therefore, a temperature increase of 20 °C would reduce the efficiency of solar panels by up to 10%. They exhibit optimal efficiency at -5 °C, making them particularly suitable for Arctic climates.

3.3 Installation of solar power in Flatey
The accumulation of snow on the solar panels does affect the production a lot, especially in cold climate where the temperature can be expected to be below zero a large part of the year like in this case. This needs to be considered when the optimal angle for solar panels is decided on every specific location.

In Flatey the first step toward a greener power system is to be installation of solar panels on an old building once operating as a fish factory. There are several different options when it comes to the placement of the panels on the building, the two most feasible ones are either on a part of the roof or a large south-south-east (SSE) facing wall. The building, on the other hand, is old and closer inspection of the roof would need to be done in order to decide if it can support the panels without too expensive renovations. To get a better idea of the different scenarios regarding the placement and the angle the solar panels are installed at, calculations are done using an online calculator established by the European Commission [17].

The panels installed 2023 have an efficiency of 19,8% and each module has the maximum power of 335 W at standard test conditions. In the calculations the before mentioned wall of the old fish factory is taken as an example, it is 80 m^2 and is estimated to fit 40 Jinko solar panels. The calculated annual energy output from these 80 m^2 is just below 9000 kWh. This calculation refers to panels in a 90° position on a wall facing SSE in Flatey. When changing the angle that the panels are installed in is performed and the results shows that an optimal angle at this location is according to these calculations to be 47° from the horizontal. The energy output curve has the shape of the normal distribution. The annual energy output is calculated to be quite a lot higher compared to the 90° installation, or around 12.700 kWh. That is close to 40% higher. The output during the darkest months is similar in both cases but the curve is much steeper in the latter case and the output during summer is much larger. In both cases the energy output peaks in May with just above 1250 kWh for the 90° system and just above 2000 kWh in the 47°system.

Since the power demand in Flatey is much higher during summer and the main challenge for the system is to be able to meet that peaking demand, it would be wise to install the solar panels at an angle that provides the most during summer. As stated earlier the energy production from the diesel aggregates is around 210.000 kWh per year and this first installation of solar panels on the island will only account for a small amount of the total production. But it is a step in the direction to a greener power system in Flatey and will act as a research project for the actual potential of solar power production on the island.

3..4 Economics
The electricity cost from solar photovoltaics (PV) has reduced significantly in the last decade. As the cost reduces, PV becomes a more viable and competitive option. An economic analysis will be necessary, considering the Net Present Value of the economical return compared to the investments and the operating costs. The discount rate selected will be important driver for the result of the economic analysis. When considering the costs of PV it is also important to know the estimated lifetime of the panels.

Maintenance cost is very low compared to the start-up costs of installing the solar panels. As of today, it does only account for about 1% of the start-up cost but with continuing cost reduction of the panels, that share will increase [13]. Solar panels require very low maintenance and that especially in PV systems that have no moving parts as expected in this case, the only predictable maintenance is washing and visual inspection of all parts once or twice a year.

4. Wind power availability
The wind power potential in Flatey looks promising although further research would need to be performed by setting up a measuring mast, measuring both wind speed and direction so that the

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feasibility of the installation of a wind turbine can be determined more accurately. The online available wind data from the Icelandic meteorological office shows two drastically different results.

The older data from a small weather station in Flatey shows that the mean wind speed in the years between 1953 and 1978, is only 4.8 m/s which is rather low for wind power production [11].

The data available from a newly prepared wind atlas from the Icelandic Meteorological office from a location just outside of Flatey shows that the mean wind speed is just over 10 m/s with the prevailing wind direction from east-north-east [19]. The power production of wind turbines is controlled directly by the wind speed at any given moment. Typically wind turbines start producing power at a so-called cut-in wind speed around 4m/s, the power output does then increase with increasing wind speed up to around 13 m/s where it reaches the maximum output. A typical cut-off frequency of the turbines is than often around 25 m/s [20]. With a mean windspeed of just over 10 m/s along with the power production characteristics of a wind turbine, installing wind power to the power system looks promising.

4.1 Installation of wind turbine on Flatey

The power demand in Flatey, shown on Figure 4 above, is rather stable during winter at just over 16 kW per month. Installation of around 25 kW of wind power to act as a base power in a green power system in Flatey could therefore be an exciting option.

4.2 Other factors that affect the feasibility of a wind power project

When researching the feasibility of a wind power project on a specific site, the data from the wind atlas along with detailed data on the topography, surface roughness and obstacles around the turbine siting to calculate the estimated power production. On Flatey, which is a small and flat island, as the name indicates, a wind turbine would likely be located close to the shoreline, where roughness is low and no, or few obstacles are in its way. A study to find the optimal location would be required and as large areas both on Flatey and the smaller islands close to it are protected areas due to archaeological and cultural remains as well as the unique wild bird life the available locations are limited. The potential wind turbine must be installed on a location where it does not disturb the persons permanently living on the island, the wild bird life and where it does not shun away the tourists, which will be challenging. When calculating the feasibility of a wind power project the mean values for the specific wind parameters do not, as well as with solar power projects, require more detailed information on the wind characteristics, for example in which seasons and what time of the day the wind speeds tend to be the strongest.

The curve of the estimated power production from the wind turbine and the power demand on the island need to be compared, as well as comparison to the power production curves from other power sources in the system need to be considered. As the different power sources in the system need to be coordinated in the most efficient manner.

In the case of the power system in Flatey the production curve for wind power opposes the production curve for solar power. The production from the wind turbines is estimated to be largest during the winter months when the wind speed tends to be higher, and the production of solar power is largest during summer. This shows that the combination of these two power sources in the same power system potentially should be efficient.

4.3 Other factors at this site

The small community in Flatey relies on the tourism as the main industry and income, where the main attractions are the unspoiled nature and wild bird life. These facts need to be considered when it comes to choosing the size and the location for a wind turbine on the island. Infrastructure on the island is very limited as well, with only one road leading from the harbour to the old village. Large constructures like the building of new roads on the island are not likely to be accepted or well-liked by the islanders or people that have strong relation to the island and its community.

Therefore, the choice of a turbine needs to be smart and with these special circumstances in mind. The turbine would need to be easily installed without the use of large cranes or heavy machinery. Smaller turbines as predicted to suite well in Flatey must be identified.

5. Energy storage options

5.1 Storing solar power in battery banks

The use of battery storage in Photovoltaic systems (PV-systems) has its drawbacks [18]. Research has been limited when it comes to stationary batteries for larger facilities, but more prevalent in the realm of portable batteries – primarily electric car batteries. Additionally, energy can only be stored for a short duration and cannot be stored seasonally, for instance from spring to winter. In comparison to other storage methods, battery storage for PV-systems experiences greater energy loss, including heat loss and reduced efficiency from an inability to extract enough energy from the Suns radiation. Moreover, a considerable number of batteries must be connected in series to meet the necessary energy demand for a larger demand.

On the other hand, there are numerous advantages to using battery storage for PV-systems. Old, non-stationary batteries, such as used electric-car batteries, can be repurposed, which is both cost-effective and sustainable. Car batteries have greater size and weight requirements than stationary batteries, which are more flexible in terms of form factor. This makes it possible for larger stationary facilities with higher energy-demand, to connect old car batteries in series. Furthermore, battery storage for PV-systems requires less space than hydrogen storage.

5.2 Underground solar power storage

Borehole thermal energy storage (BTES) is a viable method of storing solar power, utilizing the ground as a storage medium for supplied heat. This system is particularly suitable for seasonal storage of solar energy. Ground source heat exchangers (BHE) are an essential component of BTES and are available in two main types: U-tube and coaxial wells.

U-tubes typically comprise either a single or double pipe circuit (double U-tubes), and wells with U-tubes require fill-material to enhance the heat transfer between the pipe/tube and the surrounding bedrock. Coaxial wells, on the other hand, feature two coaxial pipes, with downward or upward flow interacting with the bedrock. Subsequently, the flow direction is reversed to charge and extract heat. Effective contact between the outer pipe and the surrounding rock can enable a coaxial heat exchanger to facilitate efficient power transmission between the working fluid and the surrounding rock. The suitability of Flatey for BTES is contingent on the geology and physical properties of the bedrock, such as thermal heat capacity and heat conductivity, which are crucial factors in determining its compatibility with the system. Without detailed knowledge of Flatley's geology, it is challenging to ascertain whether it is a suitable candidate for BTES implementation [21, p. 37].

5.3 Storing power by using hydrogen

There are two main methods of hydrogen production: grey hydrogen and green hydrogen. In this context, the focus will be on green hydrogen, which is typically produced through electrolysis - the process of splitting water molecules into hydrogen and oxygen gas. The resulting hydrogen can then be used in fuel cells, where it reacts with oxygen to produce heat and electricity.

However, storing hydrogen presents a significant challenge due to its high volumetric density. To reduce its volume, hydrogen is typically stored under high pressure, with typical storage pressures ranging from 350.000 to 700.000 hPa. Such high-pressure storage requires additional safety measures to prevent leaks or explosions, necessitating more secure storage tanks. Additionally, storing hydrogen in liquid form requires extremely low temperatures or high pressures, as hydrogen evaporates at -253 °C.

When hydrogen and oxygen gas react in a fuel cell, they release heat or electricity. The efficiency of a fuel cell delivering electricity is typically 40-60%, significantly higher than that of solar power (η = 20%) or wind power with similar average efficiency. By utilizing both the electricity and heat generated by the fuel cell, an efficiency of 85-90% can be achieved [22]. So, in order to produce green hydrogen,

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the only required regular input is water. The economics of using hydrogen for power storage, must, however, be further evaluated.

6. Review of the various options for providing renewable energy and energy storage at Flatey

Based on the information given in Sections 3, related to solar power, Section 4, related to wind power and to Section 5, related to energy storage, a summary of the options is presented in Table 1. The table assesses availability, installation difficulty, operational complexity, and maintenance requirements.

Table 1 Comparison of different methods to produce and store renewable energy.

Energy resource/ Storage option	Availability	Installation difficulty	Operational complexity	Maintenance requirements
Solar power	Available in abundance during the summer period when the demand of energy is highest. Limited availability during winter months, location is 65,3°N.	Low difficulty. A gradual investment in solar panels is possible according to available budget. The initial costs of the first panels and the required electric system are relatively high	The operation of solar panels is considered to have low complexity. However, there are frequent reports of fires associated with solar panels and panels should be separated by distance to ensure redundancy.	Maintenance requirements are medium. It is necessary to clean the panels from dirt and from snow. Furthermore, regular checks of the safety of the electrical connections are needed.
Wind power	Available most of the year, noticeably better during fall and winter months than during the summer period	Relatively high difficulty. Installation of wind turbines is a complex task that requires careful planning to ensure that the bird population is protected. Also, it is a challenge to bring heavy construction equipment to the location. Smaller wind turbines rather than one big will ensure redundancy.	The operation of wind turbines is highly complex and requires knowledge of mechanical systems as well as monitoring of weather to ensure that the turbines shall not be overloaded in strong winds. During periods with atmospheric icing, the turbines should also be stopped to avoid that ice is thrown onto buildings or other infrastructure	Maintenance requirements are large and complex. The access to the nacelle involves climbing stairs that could be taken care of by the local population, while the checking of blades will normally involve specialists. Maintenance costs might run very high and cause considerable downtime.
Use of fuel	Available all year, however, diesel is not a renewable option, although ammonia might be considered as renewable if produced by renewable sources	Diesel generators are installed and should be kept available as backup. To retrofit the diesel aggregate for use of ammonia is considered and the costs of refurbishing the generator to run on ammonia might be affordable	As ammonia is extremely toxic, extreme care must be taken to handle ammonia.	Engines running on ammonia might be susceptible to unfamiliar wear and tear compared with diesel fuel. Maintenance assistance might have to be called to large costs and possible delays where the aggregate is down.
Battery storage	Us of older car batteries can be considered. The storage time and capacity will be limited though.	Installation of used batteries is quite easy. Beware not to put “all eggs in one basket”	Operations of the system is somewhat complex as many batteries are required. Note that the batteries will have different level of wear and tear. The potential for battery fires must not be underestimated.	Maintenance requirements are medium, damaged batteries must be taken out and the power bank must be checked daily.
Underground energy storage using boreholes	The drilling of borehole for energy storage requires knowledge about the geology. On Iceland, the temperature in the ground might be favourable for this solution.	The energy provided during times of abundant solar power or wind power could be transferred to hot water that can be stored in a borehole. This will require drilling of borehole. Heavy equipment for	The operation of such system should be feasible by the persons living on Flatey.	The maintenance requirements would be relatively low and well known for a technically interested person.

		drilling of the borehole is required		
Production of hydrogen for storage	A production system for hydrogen might be outside the financial resources of the Flatey community	A suitable hydrogen production system will have to be assembled locally. The need for careful workmanship to ensure no leaks makes the operation complex.	Operation of hydrogen facilities require extreme careful handling of all equipment. Any leak can cause a huge explosion	Maintenance of hydrogen facilities is outside the capability of the residents. Maintenance personnel must be hire in at large costs.

7. Conclusions and recommendations

The paper reviews feasibility of achieving energy self-sufficiency on the small island of Flatey using a combination of solar and wind power in combination with necessary energy storage; the storage being a most crucial part of the system. Different energy storage options are considered, focusing on battery storage, underground solar power/energy storage, and hydrogen storage. While battery storage has its drawbacks, such as limited storage duration and energy loss, repurposing old electric car batteries can provide a cost-effective and sustainable solution. The paper also discusses the potential of underground solar power storage using Borehole Thermal Energy Storage (BTES) and the challenges of implementing this system without detailed knowledge of Flatley's geology. Additionally, the use of hydrogen production through electrolysis is discussed, also pointing to the challenges of storing hydrogen due to its potential for explosions is discussed.

The discussion presented shows that utilization of both solar and wind power on Flatley's power system is promising, with relatively high mean wind speeds, according to the wind atlas data, and long days during summer when the sun rises high above the horizon. The combination of these two power sources at this location fits well, since the power curves of the two sources are quite different, with high wind power production during winter and high solar power production during summer. The power demand in this system has quite large seasonal variations with a lower stable demand from September to May and a higher demand during summer, from June throughout August. This fact plays a role when it comes to determining what amount of renewable power will be viable to install into the power system.

In a system without any batteries to store excess power production it may not be viable to install renewables with a maximal production higher than the demand at each season or time period. As the power system in the case of Flatey varies so much between seasons it can be questioned whether it would be viable to aim for a system completely driven by renewable sources as the peak power demand is high and only last for short periods of time. That is given that the diesel aggregates already operating in the system will remain there so that no further investment will be needed. Use of ammonia produced from renewable energy, rather than on diesel fuel, is considered in Table 1.

The possibility of energy storage to ensure full energy self-sufficiency based on renewable sources has been discussed in the paper and should be further evaluated.

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