IS IT POSSIBLE FOR WESTERN SOCIETY TO RUN ONLY ON RENEWABLE ENERGY? – THE CASE OF ICELAND

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Abstract: *Iceland is rich of energy sources, mainly hydropower, geothermal energy and wind. The energy production in 2016 was 13,472 GWh in hydropower and 41,400 GWh in geothermal energy. The wind energy is barely used but that could change in next decades. Realistic maximum potential of electricity production is 30,000 GWh from hydropower and 20,000 GWh from geothermal energy but the potential in wind is not known. Lot of oil is used in Iceland and it is important to decrease consumption of oil and try to revert to renewable energy as much as possible. When analysed in categories it comes out that airplanes are the biggest users of oil, 10,000 kWh/capita per year. In second place are ships using 6,000 kWh/capita of oil and in third place is the family car using 5,700 kWh/capita. Other users of oil are heavy cars, heavy machines and agricultural machinery. The possibilities of reverting to renewables in these categories is very different. It is easy in the case of family cars and that change is ongoing in Iceland. It is difficult in the cases of ships, heavy cars, heavy machines and agricultural machinery. In these categories the change to renewable energy is heavily dependent on production of electric equipment of this kind or production of fat for biodiesel, mainly with oil plants like rapeseed. Regarding airplanes use of renewable energy is difficult and totally impossible these years. So the answer is no, it is not possible for western society like Iceland to run only on renewable energy. Not at this point in time but there are technical solutions so in the future it should be possible. Because of the long distance between Iceland and the rest of Europe it has not been possible to use the resources of the country for export of electricity. It is now technically possible using submarine power cable. The longest cable in the world of this kind is the 580 km long NorNed cable. Such cable between Iceland and Scotland would have to be over 1,000 km. The energy through cable from Iceland could be sufficient for about 600,000 people in Britain. Because of the unused wind source in Iceland it is likely that more cables would be set up if the fists would be of success.*

Keywords: *Iceland; renewable energy; electricity; biodiesel; energy production; energy consumption per capita; submarine power cable.*

JEL classification: *Q2; Q4.*

1. Energy production in Iceland

Iceland is 103,000 km2 island in North Atlantic Ocean. The island is slightly bigger than Hungary but the inhabitants are only 340.000. Big part of the island is uninhabited highlands. In the highland are several glaciers, one of them the biggest glacier in Europe.

Iceland has several energy sources which all are renewable. Because of the extensive highland there is plenty of hydro energy. As well there is lot of geothermal

energy in Iceland. The third source is the wind. But it has not been used for energy production jet as it has not been competitive to the other two sources. That will probably change in next decades. No oil or gas has been found in or around Iceland. The energy production in Iceland can been seen on Figure 1.

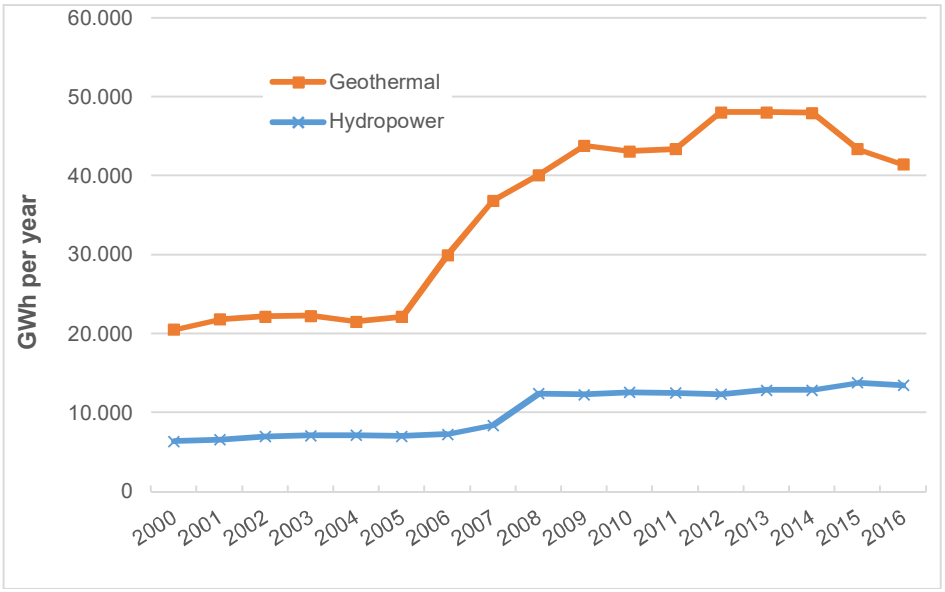

Figure 1: The energy production in Iceland.
Source: Author with data from Orkustofnun

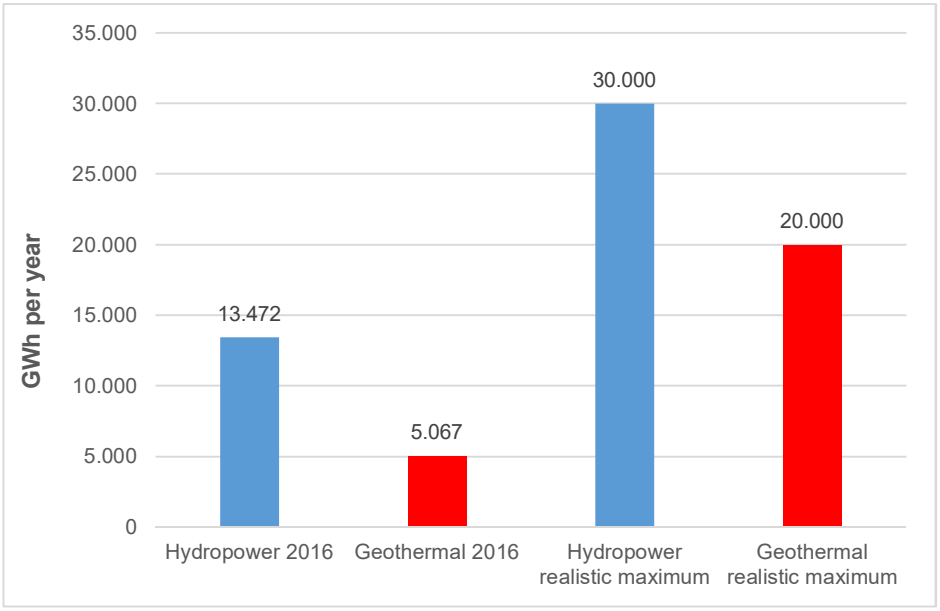

Figure 2: Electricity production in Iceland and the potential of production.
Source: Author with data from Orkustofnun

About 41,400 GWh geothermal energy was produced in Iceland in year 2016 (Orkustofnun, 2017a). There of 8,200 GWh is used for various kinds of heating (Orkustofnun, 2017b) and to produce 5,100 GWh of electricity (Orkustofnun, 2017c). The rest is not used (wasted), mostly in the production of electricity.
The electricity production in Iceland in 2016 in shown in next figure (figure 2). The potential of electricity production in the country is also shown. The National Energy Authority has estimated that the realistic maximum in electricity production is about 30,000 GWh in hydropower and 20,000 GWh in geothermal energy (Orkustofnun; 2004).
The potential in wind for electricity production has not been investigated as much as the hydropower and geothermal power. What is known is that conditions for windmills are good, the island is windy. Two windmills have been running for some years as development project by Landsvirkjun (National Power Company of Iceland) and running time seems to be higher percentage than in Europe. The potential for the whole country in wind energy is likely to be counted in TWh (TWh = 1,000 GWh) or dozens of TWh.

2. Energy consumption in Iceland

For what is energy used in Iceland? It is used for:

- Energy intensive industry, electricity
- Heating of houses
- Common electricity use, households and industry
- Family cars
- Heavy cars, for transportation of goods and people
- Heavy machines
- Agriculture machinery, (tractors)
- Ships
- Airplanes
- Various oil and geothermal use

2.1. Energy intensive industry

Iceland is very special regarding energy intensive industry. In Iceland there are few inhabitants in big country with plenty of energy to produce electricity. Because of how far away Iceland is from other European countries it has not been possible to export electricity. ,,Export" of electricity has only been possible by building factories in Iceland. Three aluminium smelters and one silicon metal factory are now operated in the country plus other smaller factories. The energy intensive industry used 76,4% of produced electricity in 2015 (Orkustofnun, 2016). That percentage is 14.200 GWh of the total 18,539 GWh produced electricity in 2016. That is about 42,000 kWh/capita per year. This energy, electricity produced by hydropower and geothermal, is 100% renewable. The energy intensive industry uses also little bit of coals in its production process, the only coals used in Iceland.

2.2. Heating Houses

In Iceland about 6,500 GWh where used in year 2015 to heat houses, residential and industry (Orkustofnun, 2016). More in needed in cold years, less in hot years.

Included is all other household use of hot water (shower and etc.). This is about 19,000 kWh/capita per year. About 90% of this energy use is geothermal heat and about 10% is electricity. Almost no oil or coal are used for heating houses in the country. Energy used to heat houses is 100% renewable energy.

2.3. Common electricity use

In Iceland about 3,400 GWh where used in year 2014 for common electricity use. That is use by households and industry except energy intensive industry. In short this is all electricity production minus energy intensive industry and minus loss in the electrical grid (the loss is about 5%). Common electricity use is about 10,400 kWh/capita per year. About 73% of electricity is produced with hydropower and about 27% produced from geothermal steam. This energy is 100% renewable.

2.4. Cars and machines

In Iceland about 285,000 tons of oil were used in year 2014 for cars and machines (Statistics Iceland, 2017). That is about 870 kg of oil/capita per year and equivalent to 10,100 KWh/capita per year (1 kg of oil giving 41,868 MJ=11.63 kWh). This number divides in 245,000 tons used on cars and 40,000 tons on machines. Information are not available how these 245,000 tons split between family cars and bigger cars. Neither are information available how 40,000 tons on machines split between heavy machines (bulldozers, diggers, wheel loaders etc.) and agricultural machinery (mainly tractors) but here educated guess is put forward. The estimation is as follows:

2.5. Family cars

It is estimated that 65% of 245,000 tonnes of oil, that is 159,000 tons, were used on family cars in 2014. Additional to that about 7,000 tons of renewable fuel were used on family cars. Altogether plus electricity on electric cars this energy use on family cars is probably about 2,000 GWh. That means that this use is about 6,100 kWh/capita per year.

Only 1%-2% of family cars do run on other energy than oil. About 1,200 electricity cars and 1,000 natural gas cars of 240.000 (Iceland Transport Authority, 2017). But this is changing. Energy used on family cars is about 6% renewable energy and 94% non-renewable.

2.6. Heavy cars

It is estimated that 35% of 245,000 tons of oil, which gives 86,000 tons, were used on heavy cars in 2014. That is equivalent to 1000 GWh or 3,000 kWh/capita per year. This energy used on bigger cars is 0% renewable and 100% non-renewable.

2.7. Heavy machines

It is estimated that 25,000 tons of oil, equivalent to 290 GWh, were used on heavy machines in 2014. That is 900 kWh/capita per year. This energy use on heavy machines is 0% renewable and 100% non-renewable.

2.8. Agriculture machinery

The estimation is that 15,000 tons of oil, equivalent to 170 GWh, were used on agriculture machinery in 2014. That is 500 kWh/capita per year. This energy use is 0% renewable and 100% non-renewable.

2.9. Ships
In 2014 169,000 tons of oil were used in Iceland on ships. 140,000 tons on fishing vessels and 29,000 tons on other ships (Statistics Iceland, 2017). This energy use is equivalent to 2,000 GWh. That means that energy use on ships is about 6,000 kWh/capita per year. This energy use is (almost) 0% renewable and 100% non-renewable.

2.10. Airplanes
190.000 tons of oil were used on airplanes in Iceland 2014 (Statistics Iceland, 2017). As number of tourists in Iceland rose by 29% from 2014 to 2015 and by 39% from 2015 to 2016 (Icelandic Tourist Board, 2017) the 2014 number is not giving right picture of present situation. It is likely that somewhere around 300,000 tons were used on airplanes in 2016. That number would mean 3,500 GWh per year and 10,000 kWh/capita per year. This energy use is surely 0% renewable and 100% non-renewable.

2.11. Other geothermal use
This use is more or less because in Iceland is plenty of geothermal heat. This use is not essential for the society to run normally (Orkustofnun, 2016).
Green houses (agriculture) 230 GWh, 700 kWh/capita.
Swimming pools and baths 550 GWh, 1,700 kWh/capita.
Fish farming 700 GWh, 2,100 kWh/capita
Snow melting 550 GWh, 1,700 kWh/capita
Industry 230 GWh, 700 kWh/capita
All this other geothermal use, altogether 2,260 GWh is of course 100% renewable energy and is equivalent to 6,900 kWh/capita.

2.12. Other oil use
About 10,000 tons of oil were used in industry in Iceland in 2014. Furthermore other use of oil was about 5,000 tons (Statistics Iceland, 2017). This together was about 530 kWh/capita. This is of course is 100% non-renewable energy.

2.13. Summing up
When all this energy consumption in Iceland is summed up the outcome is as next figure shows, figure 3. When renewable and non-renewable consumption are added up the outcome is that 58% of the energy consumption in Iceland is renewable energy and 42% is non-renewable. This is the result besides the energy intensive industry.
Attention must be made that the numbers reflect the latest year of available information. It is various whether these years are 2014, 2015 or 2016. In the cases numbers from the year 2014 are used it is assumed it has not changed a lot until 2016. In case of rapid change like in the flight the 2014 number is not used but estimation made how much it has changed till 2016. The sum up is therefore thought to be rather good estimation on energy consumption in Iceland in year 2016.

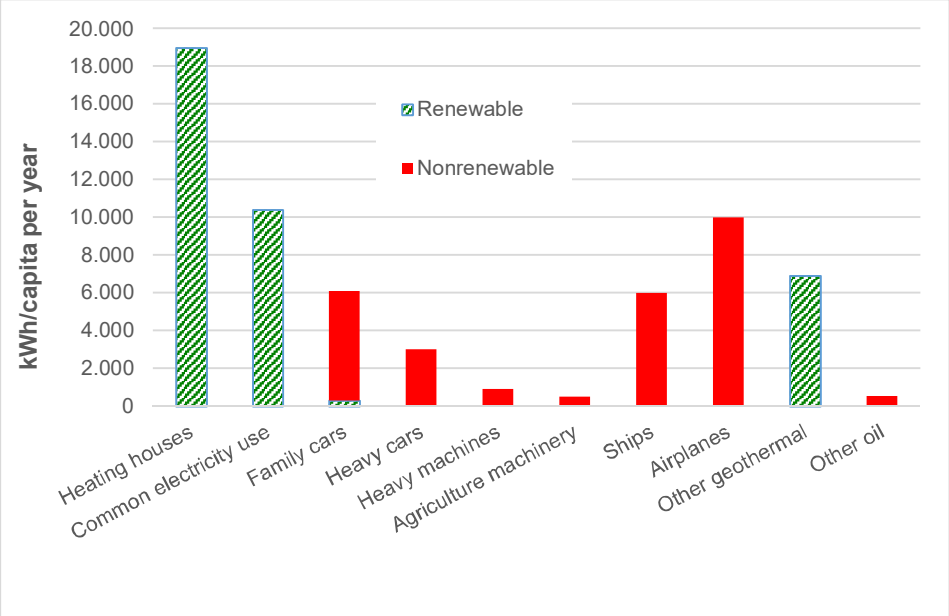

Figure 3: Energy use in Iceland, renewable or non-renewable in different categories.
Source: See text before figure.

3. Energy consumption in the European Union

In the EU some key numbers regarding energy consumption are as follows on next figure, figure 4. (Eurostat, 2017)

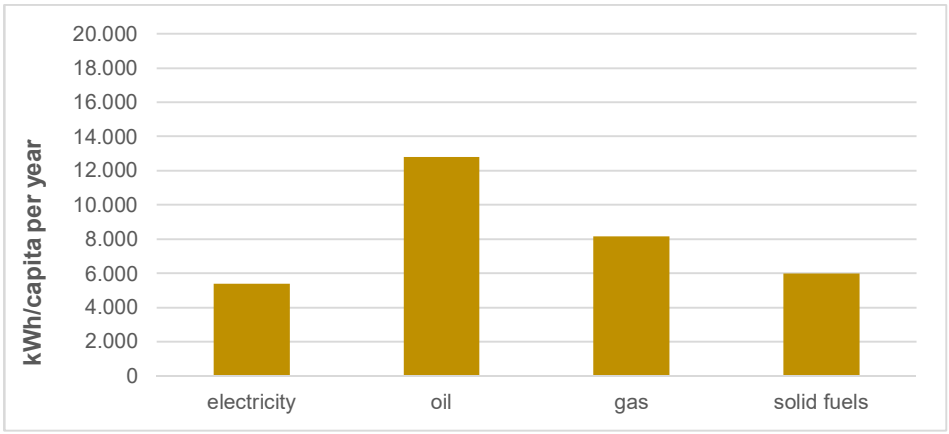

Figure 4: Energy consumption in EU (28) in 2015.
Source: Author with data from Eurostat

The electricity is produced in many ways in Europe. Partly it is produced from gas and solid fuels so part of the gas and solid fuel columns in figure 4 are transformed into the electricity column. It is easy to see that electricity consumption is Iceland is much higher than in Europe. It is also easy to see that the oil consumption is also

much higher in Iceland. The total consumption in oil in Iceland is more than 2 tons/capita per year (about 2,3) but in the EU it is just slightly over 1 ton/capita (1,1).

4. Possibilities of reverting to renewable energy

From figure 3 it can be seen in what sectors the non-renewable energy is used in Iceland. If western society like Iceland should change from non-renewables to renewables the read columns should be looked at. That is: family cars, heavy cars, heavy machines, agricultural machinery, ships and airplanes.

4.1. Renewable energy on Family cars

In this case the reverting to renewable energy is ongoing. The choices for the family car instead of oil is biogas (from bio waste) and electricity. Biogas has been available in Reykjavik for more than 10 years and is now available also in Akureyri. Family cars using biogas are few thousands and electricity cars are about 1.100. Total number of family cars in Iceland is 240,000 in end of 2016 but about 140,000 are in common use (Iceland Transport Authority, 2017b). In the year 2016 about 6% of all new family cars were electricity or natural gas cars. It is expected that the electricity car will be more and more popular as its range increases and price goes down. It is therefore likely that bigger and bigger part of the nation will be driving on renewable energy in next years. So this is probably not the field to be worried about, the evolution is on full speed.

4.2. Renewable energy on Heavy cars

In this type of cars there is not as much going on in reverting to renewable energy as in the case of family cars. The choices of reverting seem to be: Natural gas, biodiesel and electricity. Natural gas is real choice for heavy cars but it is only possible to produce limited volume from bio waste. Something else is needed. Biodiesel has been produced in Akureyri for several years. But more fat is needed. More collection from homes and industry is in action but never the less limited volume is accessible. Is it possible to produce more fat in Iceland? Is it possible to grow oil plants, for example rapeseed or is it too cold? Growing of rapeseed has been tried in Iceland. It seems to be possible but more experience needed (Bernódusson, 2010). If it is something that Iceland can offer then it is LAND. Few people but plenty of land.

It is also question about the electricity, will the next step be electric heavy cars after the step of electric family cars? Hopefully producers will take this step but that is uncertain.

Hopefully some evolution will take place next years but there is no optimism of fast reverting to renewable energy.

4.3. Renewable energy on Heavy machines

The choices of reverting seem to be: biodiesel and electricity. Electricity should be good choice, these machines have to be heavy! Can't they be heavy with batteries instead of iron? We know one machine which runs on electricity, the forklift. But unfortunately producers of heavy machines do not seem to have high interest to produce machines which run on electricity. Fast reverting to renewable energy is unlikely.

4.4. Renewable energy on Agricultural machinery, tractors
More or less the same situation as regarding heavy machines. Electric tractor could be choice but no one is producing such tractor except the smallest kind. Something seems though be going on.

4.5. Renewable energy on Airplanes
The highest of the read column in figure 3 is the Airplanes-column. What possibilities are there to switch from fossil fuel to renewable energy on airplanes? The answer is that such change is difficult. Some research has been done on alternative renewable jet fuel (Hileman and Stratton, 2014). Other possibility is to use hydrogen instead of common jet fuel. That seems technically possible (Verstraete, 2013, 2015) but no producer of airplanes has announced that development of such airplane is underway.

4.6. Renewable energy on ships
There are not many choices of substitute for the oil used on ships. It is barely realistic that ships can entirely be driven by electricity though they could be partly driven with that form of energy. More use of wind like in the old days has been mentioned but the most realistic substitute is probably biodiesel.

4.7. Reverting to renewable energy, summing up
Reverting to renewable energy on family cars is easy, electric cars and gas cars (natural or bio) are already in production and plenty of electricity in Iceland and some of biogas.
Regarding heavy cars, heavy machines, agriculture machinery and ships it is not easy. The reversal is heavily dependent on production of electric equipment of this kind or production of fat for biodiesel, mainly with oil plants like rapeseed.
Regarding airplanes it is difficult and totally impossible these years. Hydrogen airplanes are not produced and are not likely to be produced next decades. But hydrogen can easily be produced in Iceland as there is plenty of electricity.

4.8. The question
Is it possible for western society like Iceland to run only on renewable energy? At this stage the answer is no. It is technically possible and in Iceland the energy is available. But new equipment is necessary which is not yet in production. But it is possible to take steps towards this goal and go as far as possible in the direction of renewable energy.

5. Submarine power cable, European integration?
Is it possible to sell “green” electricity from Iceland to Europe through submarine power cable? The short answer is yes but it is huge project. NorNed is the world longest submarine power cable and it is between Norway and Nederland. It is 580 km long, 450 kV, carries 700 MW, did cost 600 M€ and has been in operation since 2008. This cable, NorNed, has been success story.
Cable between Iceland and Scotland would be over 1,000 km about twice as long as NorNed, the longest in the world. There are though dreams of much longer cables (Chatzivasileiadis et al., 2013). Cost would be much higher than double cost of NorNed.

But what would such cable mean? The National Power Company of Iceland (2017) anticipates that about 5,700 GWh would flow through the cable to Scotland each year. Does it make any difference in Scotland? In United Kingdom the consumption of electricity was 4,670 kWh/capita in 2015. This means that 5,700 GWh is sufficient for 1.2 million people. It means that the cable does matter. If this cable would be of success, like NorNed, other cables would probably be set up from Iceland some years or decades later. As the wind in Iceland is unused source for electricity production the potential is probably for more than one cable from Iceland to Scotland or other European countries. Submarine power cable would also make the electricity price in Scotland (Britain) more even.

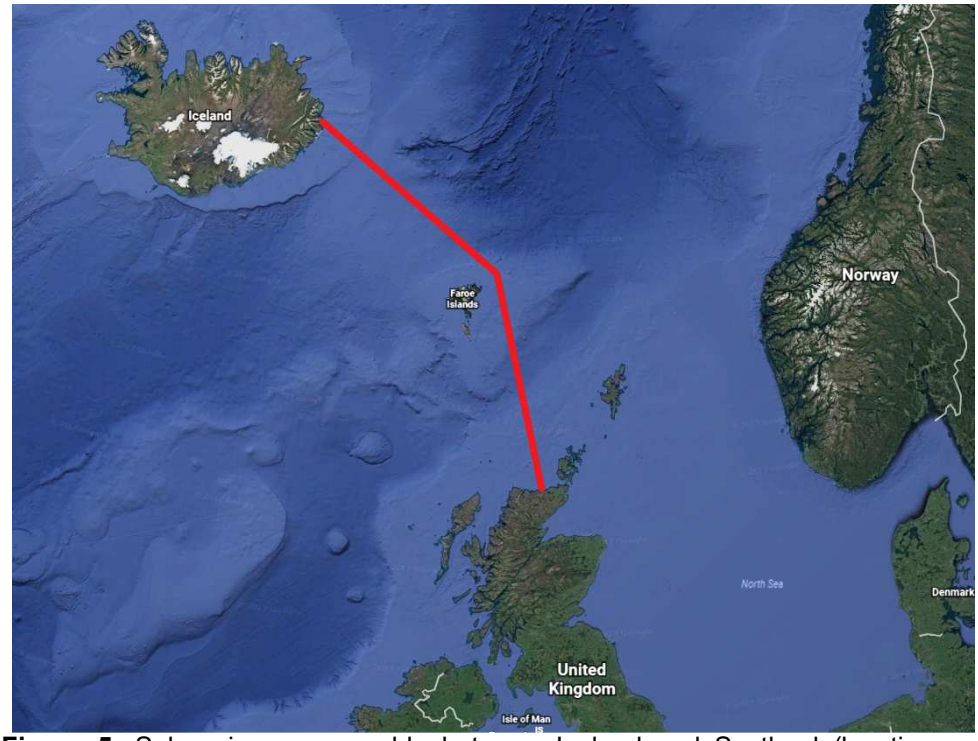

Figure 5: Submarine power cable between Iceland and Scotland (location not decided)
Source: Authors drawing on Google Earth picture.

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