MECH433 Energy and the Environment Assessment Part 1 - Population 5m

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Location Info

The Republic of Ireland is the site for all the energy sources. The population of 300,000 people is currently situated in the City of Dublin. Mean daily winter temperatures vary from 4.0 °C to 7.6 °C. Mean daily summer temperatures vary from 12.3 °C to 15.7 °C. Most of the eastern half of the country gets between 750 and 1000 (mm) of rainfall in the year. Rainfall in the west generally averages between 1000 and 1400 mm. Average annual wind speeds range from 5m/s in parts of south Leinster to over 8 m/s in the extreme north.[2]

For Nuclear Reactor: Must be placed away from the population. Sites near the seashore are preferred. For instance, *County Wexford* extreme costal area can be good option.

Fig: Suggested locations of nuclear plants.

For Onshore wind turbines: West Costs have excellent wind speeds and can support wind farms. Centre of *Munster* and east side terrain of *Connaught* can be considered. (in red)

For Offshore wind turbines: These farms can take advantage of Irish sea wind currents and shallow banks on South-east side of Ireland. (in blue)[1]

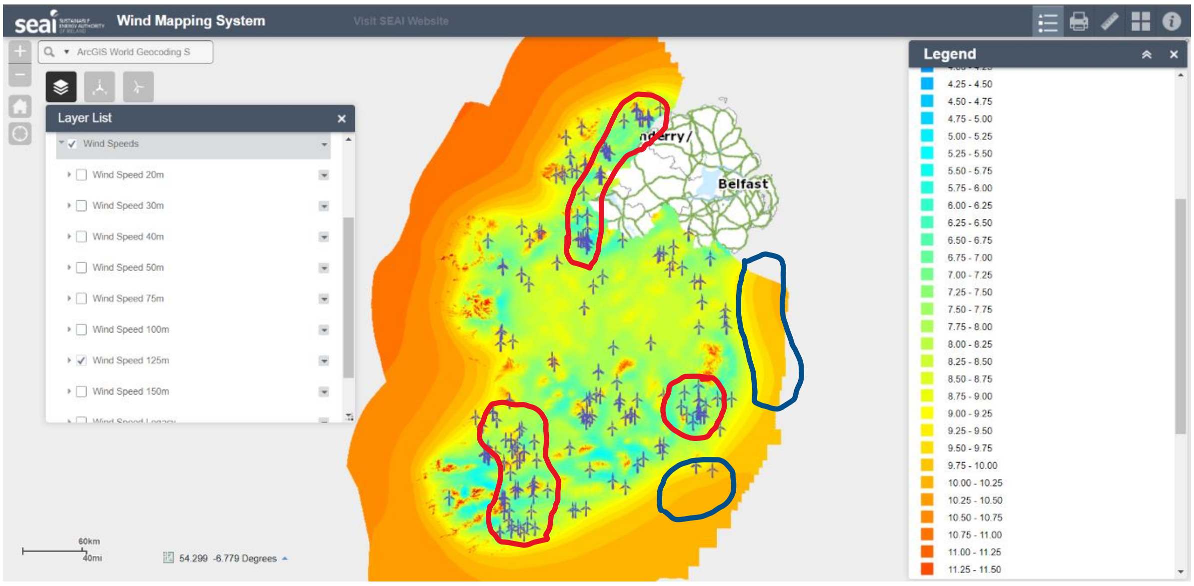

Fig: Wind Speed Mapping and Locations Suggested

For Tidal: The nice locations for building Tidal Barrage with good tidal energy are *Shannon Estuary* and *South East coast.*[12]

For Solar Farm: Solar farms can be accommodated around *Dublin* as the location has considerable sun hours in summer and energy transmissions would be easy.

For Hydro: Hydro flow energy takes advantage of natural water currents. Primarily being, *Ardnacrusha* (in County Clare), Falls on River Erne at *Ballyshannon* and *Cliff* (County Donegal) and more.

For Natural Gas and CCS: The advantage of already existing natural gas sources can be taken to build natural gas plants near them. For example, *Aghada* (County Cork), *Poolbeg* (Ringsend, Dublin), *Tarbert* (County Kerry) and more. The nearest working CCS is located at *Sleipner* in North Sea, offshore Norway[20].

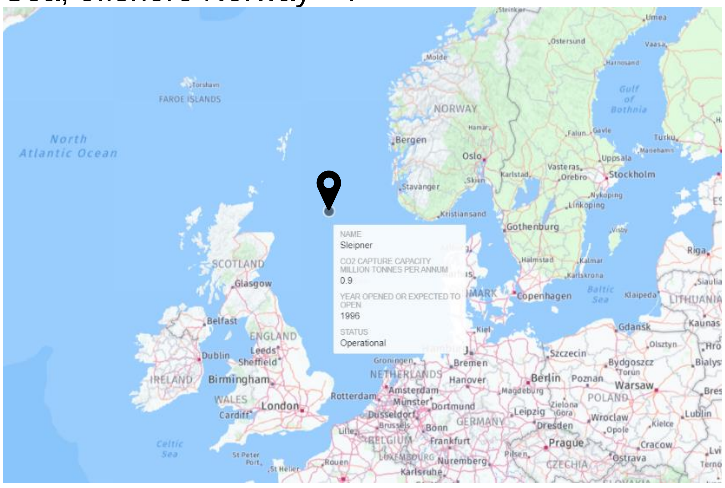

Fig: Carbon Capture Storage at Sleipner

Assumptions Made

1. There are no energy losses due to energy/thermal conduction.
2. The energy calculations are done using Annual Energy Method.
3. Solar energy is available from April to September only.
4. Wind speeds are considered at the height of 150m from sea level.

5. Lighting usage is varying throughout the year and extremes are in December and June.
6. The population is divided into households for simple calculations.
   Single- 2000000
   Couple- 750000
   Family- 375000
7. Heating is varying throughout the year and daytime.
8. Only Kettle, Hob, Oven and Microwave are considered for cooking purpose.
9. Equipment usage for cooking 3 meals daily is considered differently.
10. When judging demand, and give the number of households it is assumed that there is a semi-flat rate of energy usage across the day, based on the 15/9 hour split, however the maximum demand is based on them all being on at 10A draw.
11. Only 1 type of electric vehicle is considered, and details are assumed as, Tesla Model X P100D[4] –
    Chosen charging rate- 30 kW
    Usage per km- 0.226 kWh
12. Weather differences and its effect on heating, lighting and services is not included.
13. In summer hot water is still needed equivalent to 1 hour per day per household, sink stuff mainly.
14. Daily peak in December is 33.08GW at 7pm, while daily peak in July is 39.29GW and it is also at 5pm.

Energy Mix

Generation	Energy 1	Energy 2	Energy 3	Energy 3	Energy 3	Energy 3	Energy 3
Type	Nuclear	Onshore Wind	Offshore Wind	Tidal	Solar	Hydro-Flow	Natural Gas
Total Output Capacity	7434.25 MW	3910.75 MW	2690.00 MW	3636.36 MW	850.25 MW	335.92 MW	2312 MW
% of Total Output Capacity	30	20	13	20	5	2	10
Normal Output Rate	4999.75 MW	3333.20 MW	2166.66 MW	3333.20 MW	833.30 MW	333.35 MW	1666.60 MW
Standard cost (MWh^{-1})	92.5	63	75	90	76	80	120
Weighted cost (MWh^{-1})	27.75	12.6	9.75	18	3.8	1.6	12

Average Cost per MWh : £ 85.5

The current mix consists of 30% nuclear, 33% wind, 20% tidal, 5% solar, 2% hydro and 10% of natural gas energy. The mix is calculated based on total annual energy consumption of 5 million people while satisfying the daily demand across the year. The energy sources were divided into percentage and generation is calculated based on selected parameters to meet the requirement. In this current mix, hydro and natural gas energy is calculated based on existing hydro plants in Ireland.

Specific Information Required for Different Technologies

1. Nuclear-

Small Reactor- 10

Reactor Type: Advanced Gas-cooled Reactor[6]
Manufacturer: EDF energy
Output Capacity: 480 MW electric (36% efficient)
Refueling: 3-4 weeks, every 6 months

Bigger Reactor- 3

Reactor Type: Boiling Water Reactor[7]
Manufacturer: Hitachi Nuclear Energy
Output Capacity: 1100 MW electric (36% efficient)
Refueling: 3-4 weeks, every 6 months

2. Wind-

OnShore- 4000 Turbines

Size of the Turbine: Hub Height 125m[10]
Diameter (m): 155
Mode Wind Speed: 6-8 m/s
Power Efficiency: 977682.96 W

OffShore- 1000 Turbines

Size of the Turbine: Hub Height 150m
Diameter (m): 167
Mode Wind Speed: 8-10 m/s
Power Efficiency: 2690195.251 W

3. Tidal-

No of Turbines- 130
Min Tidal Range: 2 m
Max Tidal Range: 4.1 m
Basin Area: 12 km^2

4. Solar-

Type of Solar: PV Panel Farm
Manufacturer: REC Alpha
Area of Farm: 46.21515113 km^2
No of Panels Used: 27000000
Panel Size: 67.8x40 inch
Panel Area: 1.746577 m^2
Output: 360 W[13]
Derate Factor: 0.79
It is paired with a Li-Battery Unit to meet energy demand. (Discussed below)

Month	April	May	June	July	Aug	Sept	Total
Sun Hours in Summer[14]	150	190	180	170	150	130	970

5. Hydro-Flow-

Generator	MW	Fall (m)	Flow m^3/s	Turbines	Annual output GWh	New Output GWh
Ardnacrusha	86	44	390	3	432	672.0116832
Erne - Cathleen's Falls	45	45	270		306	475.812468
Liffey - Pollaphuca	34.18	32	190	4	147	238.1020416
Erne - Cliff	20	41	310		265	497.7429192
Lee - Inniscara	19	39	310		156	473.4627768
Lee - Carrigadrohid	8	40	375		421	587.4228
	212.18				**1727**	**2944.554689**

6. Natural Gas-

Name	Capacity (MW)	Cycle	Boiler Type
Aghada	258	Condensing Steam Turbine	Once Through
Dublin Bay	402	Single Shaft Combined Cycle	Waste Heat Recovery
Tynagh	386	Combined Cycle	Air
Poolbeg	463	Combined Cycle	Waste Heat Recovery
Huntstown	339	Combined Cycle	Waste Heat Recovery
Great Island	464	Combined Cycle	HRSG

Carbon Capture and Storage-

Location: Sleipner, North Sea, offshore Norway.

Size: Up to 0.9 million ton per annum

Capture Method: from gas stream by scrubbing with a physical solvent, CO_2 is stripped out and transported further.

Transportation: Pipe or Ship

Storage: Deep Saline Formations

Storage

Storage	Storage 1	Storage 2	Storage 3	Storage 4	Storage 5
Type	Pumped Storage	Li-Ion Battery Unit 1	Li-Ion Battery Unit 2	CAES Unit 1	CAES Unit 2
Energy Storage Capacity	35500 MWh	70000 MWh	30000 MWh	3600 MWh	3600 MWh
Output / Discharge Rate	7100 MW	8750 MW	2500 MW	300 MW	300 MW
Lifetime during discharge	5 hours	8 hours	12 hours	12 hours	12 hours
% of Total	24.8	49	21	2.6	2.6
Standard cost (MWh^{-1})	148	100	100	108	108
Weighted cost (MWh^{-1})	36.7	49	21	2.8	2.8

Average Cost per MWh : £ 112.3

Combination of 3 types of storage is used to provide the required energy in different scenario. The total storage capacity 142700 MWh. The maximum shortage is coming out to be for scenario (b), where energy requirement over 5 hours is 112.69 GWh. While remaining energy storage is used to meet the daily fluctuations in wind and solar energy. From the calculation, maximum energy to be stored is 17857 MWh, during the day. The storage system is built considering all these.

1. Pumped Storage:

Here, Silvermines is used as pumped storage with few modifications in volume [19].
Storage Capacity- up to 35.5 GWh
Max Output- 7.1 GW

2. Li-ion Battery:

2 different units with different discharge rates are used for different purposes. Unit 1 is used to help with daily energy fluctuations and store excess energy to meet daily peak demand, while unit 2 is used to store energy from solar only.

Storage Capacity- 7 and 3 GWh
Charging Time- 2 to 4 hr
To get 2500 MW Output, minimum $\frac{2500\ MW}{1\ MW}$ = 2500 battery containers in series are required.
For 30000 MWh storage, $\frac{30000\ MWh}{5\ MWh}$ = 6000 battery containers are required.

3. Compressed Air Energy System (CAES):

2 different plats are used to store the compressed air. This allows to provide even more energy quicker in peak hours and takes less time to charge.

Charging Time- 8 hours[21]

Reasons for Choosing Energy Generation Types

The energy generation types are mainly selected for their compatibility with location and renewable source. Uranium is abundant in some Ireland mines. In addition, Ireland has water bodies available to aid the nuclear plant. It provides constant and quite high output. It has no carbon emission for running the plant. Wind is readily available over the area of Ireland. The average wind speed of 8m/s throughout the year makes it good place for wind farms. Although many offshore wind farms cannot be built, few available ones will provide high power. Geographical location of Ireland is excellent for tidal energy, as it is surrounded by sea. As it available for whole year, it is reliable renewable energy source when compared with storage system to provide constant output. Solar is also favorable in summer, as there are many sun hours available with pretty much clear weather. So, solar can be used efficiently to meet the demands. Hydroelectric is beneficial to generate power whenever required to meet the demands. Ireland has plenty of flowing water resources and sites to build hydroelectric stations. Hence, hydro power turns out to be viable option. Natural gas is least favorable choice among selected, but it can provide energy whenever needed. There is ample amount of natural gas source in Ireland. Also, with the help of CCS, the carbon emission is almost zero.

Response to Failure Scenario 1

The sporting event at 6pm is causing increase in the total energy demand by 40% for 5 hours in December. The Calculations are provided in excel, which gives daily distribution of the demand considering the increase. The peak demand is 46.313 GW at 7pm. The total energy consumption in the event hours is 139.601 GWh. If available energy sources (nuclear, low tide, hydro, and natural gas) are run at maximum capacity, 98.287 GWh of energy is obtained over the 5 hours. So, remaining 41.3 GWh energy is obtained from storage. As, daily peak is not occurred before event, the storage can store and provide the required energy over the time.

Response to Failure Scenario 2

The system is unable to generate energy for 6 hours from 5pm in month of July. The daily demand peak in July is 39.6 GW, which occurs at 5pm. So, the maximum energy is to be provided at the start when hack occurred. From the calculation, the energy demand is 112.69 GWh from 5 to 11pm. So, this amount of energy is to be provided using the storage, as they are working. Pumped storage and battery storage is used to provide the constant output and CAES is used to provide energy quickly during peak hours. After 11pm, all systems, except nuclear, solar and hydro, can generate energy back again. Nuclear and hydro will take 24 hours to start generating energy again, while solar will be available after 9 hours. The demand for next 24 hours is 178.42 GWh. The separate solar storage system can provide its share during this time and other energy sources (wind, tidal and natural gas) can be operated at full capacity to meet the requirement.

Response to Failure Scenario 3

Due the lockdown, there is increased demand in electric and heating energy by 25 and 30% respectively for 7 days in month of February. The calculations are presented in excel file. It is assumed that no private transportation is used, hence no need to charge the car. Also, there is less load on services as malls, schools and public transports etc. are not in use. Other demand is changed accordingly. The new requirement of energy for a day in lockdown is 415.42 GWh. This demand is managed by running nuclear, wind, tidal and natural gas at maximum capacity. For peak, the storage system can be used to provide excess energy required. The peak of 35.89 GW is coming at 7pm, with all energy systems working more than normal output can provide this demand.

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