MECH433 Energy and the Environment Assessment Part 1 - Population 300k

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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.

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.

For Offshore wind turbines: These farms can take advantage of Irish sea wind currents and shallow banks on South-east side of Ireland.

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

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[17].

Assumptions Made

The calculated energy demand is presented in table below,
These calculations were based on following assumptions,

Requiremnt	Voltage (V)	Current (A)	Wattage (W)	Time (hr) per	Wh/day	People No.	Quantity	Total per day	Total per year (GWh)
Fridge	230	5	1150	15	17250	Household	187500	3.234375	1180.546875
	230	10	2300	9	20700	Household	187500	3.88125	1416.65625
Washing Machine	230	10	2300	2	4600	Household	187500	0.8625	314.8125
Dryer	230	10	2300	3	6900	Household	187500	1.29375	472.21875
Dishwasher	230	10	2300	1.25	2875	Household	187500	0.5390625	196.7578125
Lighting	230	1	230	varies	5750	Individual	300000	1.38	100.878
Broadband			5	24	120	Household	187500	0.0225	8.2125
TV			100	5	500	Individual	300000	0.15	54.75
Laptop			67	5	335	Individual	300000	0.1005	36.6825
Charging			15	3	45	Individual	300000	0.0135	4.9275
Heating			varies	varies		Household	187500	6.6780822	2437.5
Cooking			varies	varies	0	Household	187500	4.449375	1624.021875
Transport			varies	varies		Household	67500	2.81475	1027.38375
Services					6000000	Individual	300000	4.9315068	1800
									10675.34831

1. Lighting usage is varying throughout the year and extremes are in December and June.
2. The population is divided into households for simple calculations[6].
   Single- 120000
   Couple- 45000
   Family- 22500
3. Heating is varying throughout the year and daytime.
4. Only Kettle, Hob, Oven and Microwave are considered for cooking purpose.
5. Equipment usage for cooking 3 meals daily is considered differently.
6. Different combination of induction hob is considered for different households.
   Smaller Stove (5 3/4")- 1.2kW
   Bigger Stove (8")- 1.8kW
7. Individual transportation method is electric car and it is owed by couples and family households, charging time is considered on daily basis.
8. Only 2 types of electric vehicles are considered, Tesla Model 3 and Volkswagen e-Up. Details assumed as,
   Tesla Model 3 –
      Electric Range- 265km[3]
      Charge Power- 11kW AC
      Charge Time- 12.5 hrs
   Volkswagen e-Up –
      Electric Range- 200km[4]
      Charge Power- 7.2kW AC
      Charge Time- 10.5 hrs
9. Weather differences and its effect on heating, lighting and services is not included.
10. Daily peak in December is 3GW at 7pm, while daily peak in June is 2.3GW and it is also at 7pm.

Energy Mix

Generation	**Energy 1**	**Energy 2**	**Energy 3**	**Energy 4**	**Energy 5**	**Energy 5**
Type	Nuclear	Onshore Wind	Offshore Wind	Tidal	Solar	Hydro-flow
Total Output Capacity	1600 MW	678.947 MW	226.985 MW	327.272 MW	125.968 MW	139.395 MW
Normal Output Rate	398.34 MW	347.625 MW	131.358 MW	304.661 MW	121.864 MW	60.932 MW
% of Total	30	21	9	25	10	5
Standard cost (MWh^{-1})	92.50	63	75	90	76	80
Weighted cost (MWh^{-1})	27.75	13.23	6.75	22.5	7.6	4

Average Cost per MWh : £ 81.83

The current mix consists of 30% nuclear, 30% wind, 25% tidal, 10% solar and 5% of hydro flow energy. The mix is calculated based on total annual energy consumption of 300,000 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, only hydro energy is calculated based on existing hydro plants in Ireland.

Specific Information Required for Different Technologies

1. **Nuclear:**

30% of the total energy required is 10675.348 × 0.3 = 3202.6044 GWh.
To generate that energy,

Reactor Type- EPR advanced pressurized water reactor[7]
Manufacturer- Framatome
Output Capacity- 1.6GW electric, 36% efficient
Refueling time- 3 to 4 weeks, in 18 months[8]
(This time be planned to be occurred in Winter, when Wind speeds are faster to generate max energy from wind farms and hydro power is also used.)

Output Capacity of 1 reactor is,
= 1.6GW*24hr*335days ….(considering 4 week downtime)
= 12864 GWh.

So, Normal Output to meet the demand would be,
= (3202.6044/12864)*1.6
= 0.398333881 GW
= 398.34 MW.

2. **Wind:**

Expected wind speeds are taken as avg min and max value which varies throughout the year. Min in summer (Jun) and Max in Winter (Dec)[9]. Density of air is 1.2 kg/m^3. Coefficient of performance is 0.4.

<u>OnShore</u>

21% of the total energy required is 10675.348 × 0.21 = 2241.823 GWh.

Size of the Turbine- Hub Height- 125m
Diameter- 155m[11]
Expected Wind Speed: 8-10 m/s (avg wind speed onshore where the current wind farms are located)
No of Turbines- 150
Power Efficiency- 2.3175 MW

Power output of one wind turbine is calculated as,

$$= \frac{1}{2}\rho \times \pi r^2 \times U$$

$$= \frac{1}{2} 1.2 \times \pi (\frac{155}{2})^2 \times 8$$

$$P = 5.794 \text{ MW}$$

Power Efficiency = P × Cp = 5.794 × 0.4
= 2.31747 MW
Power Produced in year by one wind turbine = Power Efficiency × 8760

= 20.30104351 GWh

So, minimum number of turbines required is,

n = $\frac{required\ power}{power\ produced} = \frac{2241.82308}{20.30104351}$ = 110.428

But, No of Turbines implied = 150

So, Output Capacity at Max speed is,

= 4.5 × 150

= 678.9465 MW.

<u>OffShore</u>

9% of the total energy required is 10675.348 × 0.09 = 960.78132 GWh.

Size of the Turbine-	Hub Height-	150m
	Dia-	167m
Expected Wind Speed	10-12 m/s (avg wind speed onshore where the current wind farms are located) [10]	

No of Turbines-	25
Power Efficiency-	5.2543 MW

Power output of one wind turbine is calculated as,

$$= \frac{1}{2}\rho \times \pi r^2 \times U$$

$$= \frac{1}{2}1.2 \times \pi(\frac{167}{2})^2 \times 10$$

$$\underline{P = 13.136 \text{ MW}}$$

Power Efficiency = P × Cp = 13.136 × 0.4

= 5.254 MW

Power Produced in year by one wind turbine = Power Efficiency × 8760

= 46.02755938 GWh

So, minimum number of turbines required is,

n = $\frac{required\ power}{power\ produced} = \frac{960.78132}{46.02755938}$ = 20.874

But, No. of Turbines implied = 25

So, Output Capacity at Max speed is,

= 9.079 × 150

= 226.985224 MW.

3. Tidal Barrage:

25% of the total energy required is 10675.348 × 0.25 = 2668.837 GWh.

Min Tidal Range-	2 m
Max Tidal Range-	4.1 m[13]
Basin Area-	9 km^2
Desnsity of sea Water-	1026 kg/m^3
No of Turbines-	15

For higher tide,

$$Energy\ per\ Cycle = \frac{1}{2}\rho g A h^2$$

$$Energy\ per\ Cycle = \frac{1}{2}1026 \times 9.81 \times 9 \times 10^6 \times 4.1^2$$
$$Energy\ per\ Cycle = 422.984\ \text{MWh}$$

Energy per Day = 422.984 × 2 = 845.968293 MWh

For 15 turbines,

= 845.968293 × 15 = 12689.52 MWh

For lower tide,

$$Energy\ per\ Cycle = \frac{1}{2}\rho g A h^2$$
$$Energy\ per\ Cycle = \frac{1}{2}1026 \times 9.81 \times 9 \times 10^6 \times 2^2$$
$$Energy\ per\ Cycle = 100.6506\ \text{MWh}$$

Energy per Day = 422.984 ×2 = 201.3012 MWh

For 15 turbines,

= 201.3012 × 15 = 3019.518 MWh

Total Energy per Day = 12689.52 + 3019.518 = 15709.0424 MWh

Total Energy per Year = 15709.0424 × 365 = 2866.900237 GWh

4. **Solar:**

10% of the total energy required is 10675.348 × 0.1 = 1067.5348 GWh.

Type of Solar- PV Panel Farm

Area of Farm- 6.986 km^2

Panel Size- 67.8x40 inch

Panel Area- 1.746577 m^2

Manufacturer- REC Alpha[14]

Output- 360 W

Derate Factor- 0.79

Month	April	May	June	July	Aug	Sept	Total
Sun Hours in Summer [15]	150	190	180	170	150	130	970

Annual energy per panel = 360 × 0.79 × 970 = 0.275868 MWh

Now, number of panels required,

$$n = \frac{Required\ Energy}{Annual\ energy\ per\ panel} = \frac{1067534.8}{0.275868} = 3869730.451$$

But, No. of panels used = 4000000

So, Area needed for Solar farm = 1.746577 × 4000000 = 6.986308 km^2

5. **Hydro-Flow:**

5% of the total energy required is 10675.348 × 0.05 = 533.7674 GWh.

$P = \eta \times \rho \times g \times h \times Q$

Where, η= Efficiency of generator

ρ= Water density kg/m3

g= acceleration due to gravity

h= fall (m)

Q= Flow rate (m^3/s)

Generator[17]	MW	Fall (m)	Flow m^3/s	Turbines	Annual output GWh	New Output GWh
Ardnacrusha	86	33	330	3	332	498.772
Erne - Cathleen's Falls	45	33	230		206	412
Liffey - Pollaphuca	34.18	23	130	4	47	60.503
Erne - Cliff[18]	20	33	230		65	96.525
Lee - Inniscara	19	33	230		56	85.47
Lee - Carrigadrohid	8	20	330		21	67.83
	212.18				727	1221.1

Storage

Storage	Storage 1	Storage 2
Type	Pumped Storage	Li-Ion Battery
Energy Capacity	4410 MWh	1890 MWh
Output / Discharge Rate	260 MW	90 MW
Lifetime	17 hr	21 hr
% of Total	70	30
Standard cost (MWh^{-1})	148	100
Weighted cost (MWh^{-1})	103.6	30

Average Cost per MWh : £ 133.6

Combination of 2 storage is used to provide the required energy if one of the energy sources is failed to provide the normal output. The maximum shortage is when one of the energy supply fails is around 350MW, considering it is out of order for 18hrs, the storage system of 350 × 18 = 6300 MWh is provided to meet the daily peeks.

1. Pumped Storage:
   Here, Silvermines is used as pumped storage[20].
   Storage Capacity- Upto 1.8 GWh
   Max Output- 360 MW

2. Li-ion Battery
   Storage Capacity- 5 MWh
   Discharge Rate- 1 MW
   Charging Time- 2 to 4 hr

To get 90 MW Output, minimum $\frac{90\ MW}{1\ MW}$ = 90 battery containers in series are required.
For 1890 MWh storage, $\frac{1890\ MWh}{5\ MWh}$ = 378 battery containers are required.
So, 4 combinations of 90 battery containers in series can be used to provide the required energy with 90 × 2 = 180 hrs charging time.

Reasons for Choosing Energy Generation Types

First, the nuclear is selected because 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 can not 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. All of these energy generation types are renewable and carbon emission is zero.

Response to generation failure for 24 hours

The energy requirement for the given population comes out to be 10.675TW per year. All of the required energy generation is distributed proportionately, considering the generation capacity without giving too much load on one energy system. Most of the major contributors, like nuclear and wind, operate at lower outputs instead of full capacity. If nuclear reactor fails to generate the energy, then all other systems can operate at higher output to meet the requirement. Wind can contribute more in winter or solar with hydropower will help in summer to meet the need if nuclear fails. In case wind fails to generate the power, nuclear can provide the energy required when operated at more capacity than normal. Usually, tidal is reliable throughout the year but in case it fails, then nuclear and wind both together can generate the required energy. Even if solar has less share in energy mix, its contribution can be handled by nuclear and hydro. At last, energy contribution by hydro can be easily shared by any of the other energy source. So, demand will be satisfied by the current energy mix even though there is failure of one of the sources.

References

1. https://www.seai.ie/data-and-insights/seai-statistics/energy-data/
2. https://weatherspark.com/y/33845/Average-Weather-in-Dublin-Ireland-Year-Round
3. https://ev-database.uk/car/1060/Tesla-Model-3-Standard-Range
4. https://ev-database.uk/car/1650/Volkswagen-e-Up
5. https://www.electricalsafetyfirst.org.uk/guidance/safety-around-the-home/home-appliances-ratings/
6. https://kitchenni.com/induction-cooktops-electrical-requirements-voltage-power-and-temperature/
7. https://www.framatome.com/EN/businessnews-136/areva-np-large-projects--management-and-execution-of-nuclear-reactor-new-build-projects.html
8. https://www.framatome.com/EN/us_platform-791/framatome-u-s-fuel.html
9. https://www.met.ie/climate/what-we-measure/wind
10. https://globalwindatlas.info/area/Ireland
11. https://www.siemensgamesa.com/products-and-services/onshore/wind-turbine-sg-4-7-155
12. https://www.seai.ie/technologies/ocean-energy/ocean-energy-technologies/
13. https://dusac.org/divinginireland/tides/
14. https://www.solarelectricsupply.com/rec360aa-360w-rec-alpha-black-solar-panel
15. https://weather-and-climate.com/average-monthly-hours-Sunshine,Dublin,Ireland
16. https://www.seai.ie/technologies/seai-maps/hydro-power-map/
17. https://www.cru.ie/wp-content/uploads/2006/07/cer06242.pdf
18. https://www.power-technology.com/?s=Erne+-+Cliff+power+plant
19. https://www.esb.ie/docs/default-source/education-hub/erne-stations74dc5b2d46d164eb900aff0000c22e36
20. https://silvermineshydro.ie/about-silvermines/#:~:text=Ireland%27s%20only%20pumped%20hydroelectric%20storage,demand%20and%20is%20instantly%20dispatchable