Goal: compare high-level national potential capacities and costs for solar, wind, nuclear, OTEC, geothermal etc. against demand.

Recipe

1. Find annual demand in TWh/yr (or PWh/yr). Note the difference between primary demand (before efficiency losses) and final consumption. For example, Japan primary energy demand is around 5000 TWh/yr with 900 TWh/yr electricity demand [1].
2. For each technology, find the technical potential installable capacity p (MW) (solar, wind, OTEC, geothermal), or annual potential energy e_{annual} (MWh). The link between the two is (where κ is capacity factor: hours operating at rated capacity / 8760 annual hours):
$$e_{\text{annual}} = p \cdot 8760 \cdot \kappa \tag{1}$$
3. If installable capacity estimates are missing (or to sense-check them), use technology footprint (m^2/MW) and compare with available land/sea area (especially for solar and wind). For geothermal and OTEC, might need to get more creative than land-use and availability, e.g. use parallels with countries where technical potential has been estimated.
4. Find generation cost assumptions by technology: CapEx in EUR/MW, lifetime y, and capacity factor κ. Ignore storage for now. You can get capital costs in literature or data sheets (such as my personal faves from the Danish Energy Agency [2]): look at the cost per MW of technology capacity. E.g. Offshore wind AC 2 390 000 EUR/MW, with $y = 30$ years and $\kappa = 0.40$. Pick an interest rate ι (example: 10%).
5. To convert CapEx to an annuity (rent-like annual payment), we use the capital recovery factor (CRF, or a for annuitisation factor):
$$a = \frac{\iota(1+\iota)^y}{(1+\iota)^y - 1} \tag{2}$$
For offshore wind with $\iota = 10\%$ and $y = 30$, $a \approx 0.106$.
6. We can now compute, for installed capacity p, annuitised capital payment and annual energy:
$$C_{\text{annual}} = \text{CapEx} \cdot p \cdot a, \qquad e_{\text{annual}} = p \cdot 8760 \cdot \kappa \tag{3}$$
Build-out example for intuition: if offshore wind technical potential is 100 GW = 100 000 MW (fixed-bottom), then annual production at $\kappa = 0.40$ is
$$e_{\text{annual}} = 100{,}000 \cdot 8760 \cdot 0.40 = 350.4\,\text{TWh/yr} \tag{4}$$
Compare this to demand:
$$e_{\text{demand}} \approx 900\,\text{TWh/yr}, \qquad e_{\text{offwind,max}} \approx 350.4\,\text{TWh/yr} \tag{5}$$
So other energy sources (e.g. floating wind) would likely be needed in addition. Total upfront CapEx is $C_{\text{upfront}} = 2{,}390{,}000 \cdot 100{,}000 = 239\,\text{GEUR}$, with annuitised capital payment $C_{\text{annual}} = C_{\text{upfront}} \cdot a \approx 25.3\,\text{GEUR/yr}$.
7. And now compute the levelised cost of electricity (LCOE) (CapEx-only as we've ignored OpEx):
$$\text{LCOE}_{\text{capex}} = \frac{C_{\text{annual}}}{e_{\text{annual}}} = \frac{\text{CapEx} \cdot p \cdot a}{e_{\text{annual}}} = \frac{\text{CapEx} \cdot a}{8760 \cdot \kappa} \tag{6}$$
For this per-unit cost, p cancels out. E.g. for our offshore wind:
$$\text{LCOE}_{\text{capex}} \approx \frac{2{,}390{,}000 \times 0.106}{8760 \times 0.40} \approx 72\,\text{EURh/MW} \tag{7}$$
For slightly fuller accounting, add OpEx[1]:
$$\text{LCOE} = \frac{\text{CapEx} \cdot a}{8760 \cdot \kappa} + \text{OpEx} \tag{8}$$
8. Compare at the end to potential energy import costs from literature. For example, there is a plant-gate green ammonia estimate of 60.71 $\text{EUR/MWh}_{\text{HHV}}$ (converted from AUD/t to 2020 EUR)[3][2]. Assuming

[1] Here $\text{OpEx} = \frac{\text{OpEx}_{\text{fixed}}}{8760 \cdot \kappa} + \text{OpEx}_{\text{variable}}$, with $\text{OpEx}_{\text{fixed}}$ in (EUR/(MWyr)) and $\text{OpEx}_{\text{variable}}$ in (EURh/MW).

[2] A 2050 UK imported-green-ammonia value including shipping of 30 EURh/MW is also reported [4]; treat this as uncertain and scenario-dependent.

ammonia-to-power turbine efficiency $\eta_{\text{turb,HHV}} = 0.55$, the fuel-only imported electricity cost is $C_{\text{el,import}} = C_{\text{NH}_3\text{,HHV}}/\eta_{\text{turb,HHV}}$, giving (at minimum, since this excludes shipping and other logistics costs):

$$C_{\text{el,import}} \approx \frac{60.71}{0.55} = 110.4\,\text{EURh/MW}. \tag{9}$$

We can now compare offshore-wind electricity cost $C_{\text{el,offwind}}$, imported-ammonia electricity cost $C_{\text{el,import}}$, and current market electricity cost $C_{\text{el,market}}$ (e.g. currently reported Japan price).

$$C_{\text{el,offwind}} \approx 72\,\text{EURh/MW}, \qquad C_{\text{el,import}} \approx 110.4\,\text{EURh/MW}, \qquad C_{\text{el,market}} \approx 80\,\text{EURh/MW} \tag{10}$$

So, if storage and distribution constraints/costs are roughly comparable across options, $C_{\text{el,offwind}}$ appears market-competitive, while green-ammonia-based imports look more expensive but still in a similar order of magnitude.

9. Consider limitations. What fraction of costs might we have missed not accounting for storage and transmission? Would the added costs apply similarly to all the technologies we want to compare?

Warnings

- MW_{in} vs MW_{out}: you can think of power as MWh/h, and that can be input-energy flow or output-energy flow. Generators (like wind and solar) are usually costed per MW_{out}. Energy converters (which are often called "links"), such as electrolysers, are usually specified on MW_{in}. Gas turbines are technically energy converters (gas → electricity) but are usually costed as generators on MW_{out}. I prefer to report *all* technology costs on a MW_{out} basis, although e.g. PyPSA-Earth uses MW_{out} for generators and MW_{in} for links.
- Higher vs Lower heating value (HHV vs LHV) basis: efficiencies are basis-dependent, so values are not directly comparable unless the basis is stated. Methane example: HHV $\approx 15.4\,\text{MWh/t}_{\text{CH}_4}$, LHV $\approx 13.9\,\text{MWh/t}_{\text{CH}_4}$; the $\approx 1.5\,\text{MWh/t}_{\text{CH}_4}$ gap is latent heat of water condensation[3]. Many turbine efficiencies are reported on LHV basis (numerically higher for electricity production), while e.g. electrolysers are often reported on HHV basis (numerically higher for hydrogen production). For example, if a turbine delivers $7.7\,\text{MWh}_{\text{el}}/\text{t}_{\text{CH}_4}$, efficiency is $7.7/15.4 \approx 50\%$ on HHV or $7.7/13.9 \approx 55\%$ on LHV; if an electrolyser uses $50\,\text{MWh}_{\text{el}}/\text{t}_{\text{H}_2}$, efficiency is $39.4/50 \approx 79\%$ on HHV or $33.3/50 \approx 67\%$ on LHV. I prefer to report *all* technology costs on a HHV basis, although e.g. the European and PyPSA-Earth convention is LHV.
- Currency: normalise all costs to e.g. 2020 EUR like the DEA data sheets. All costs in this work are normalised to this currency.

References

[1] Hannah Ritchie, Pablo Rosado, and Max Roser. Energy Production and Consumption. *Our World in Data*, July 2020.

[2] Danish Energy Agency. Technology Catalogues | Energistyrelsen. https://ens.dk/en/analyses-and-statistics/technology-catalogues, December 2024.

[3] Andrew Fletcher, Huyen Nguyen, Nicholas Salmon, Nancy Spencer, Phillip Wild, and Rene Bañares-Alcántara. Queensland green ammonia value chain: Decarbonising hard-to-abate sectors and the NEM. Technical report, Centre for Applied Energy Economics & Policy Research, 2023.

[4] Carlo Palazzi, Richard Nayak-Luke, Jasper Verschuur, Nicholas Salmon, Jim W Hall, and René Bañares-Alcantara. Green ammonia imports could supplement long-duration energy storage in the UK. *Environmental Research: Energy*, 1(4):043001, December 2024. ISSN 2753-3751. doi: 10.1088/2753-3751/ad785d.

[3] This is the heat left in atmospheric water vapour by the combustion – which can only be recaptured by something like a condensing boiler