Energy Security and Natural Resources

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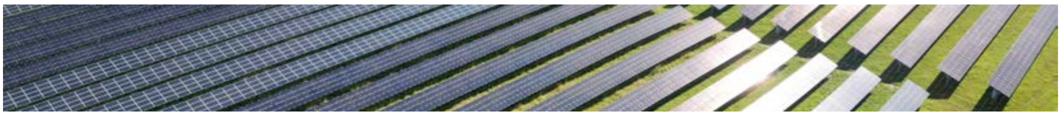
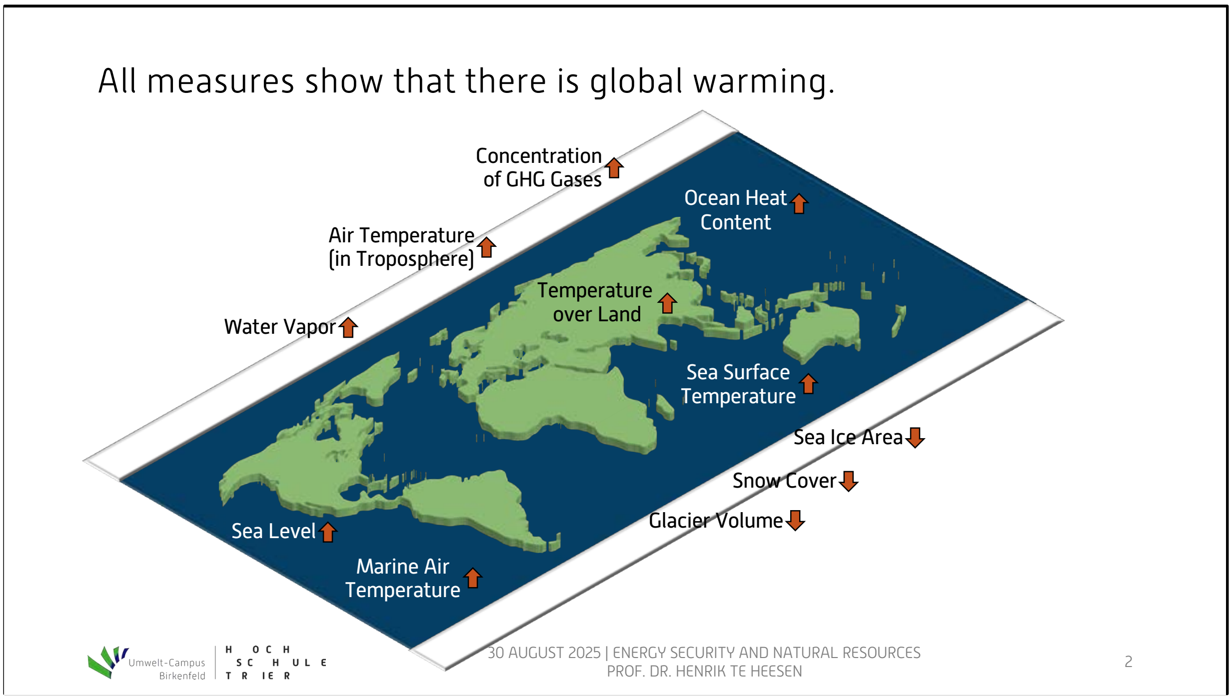
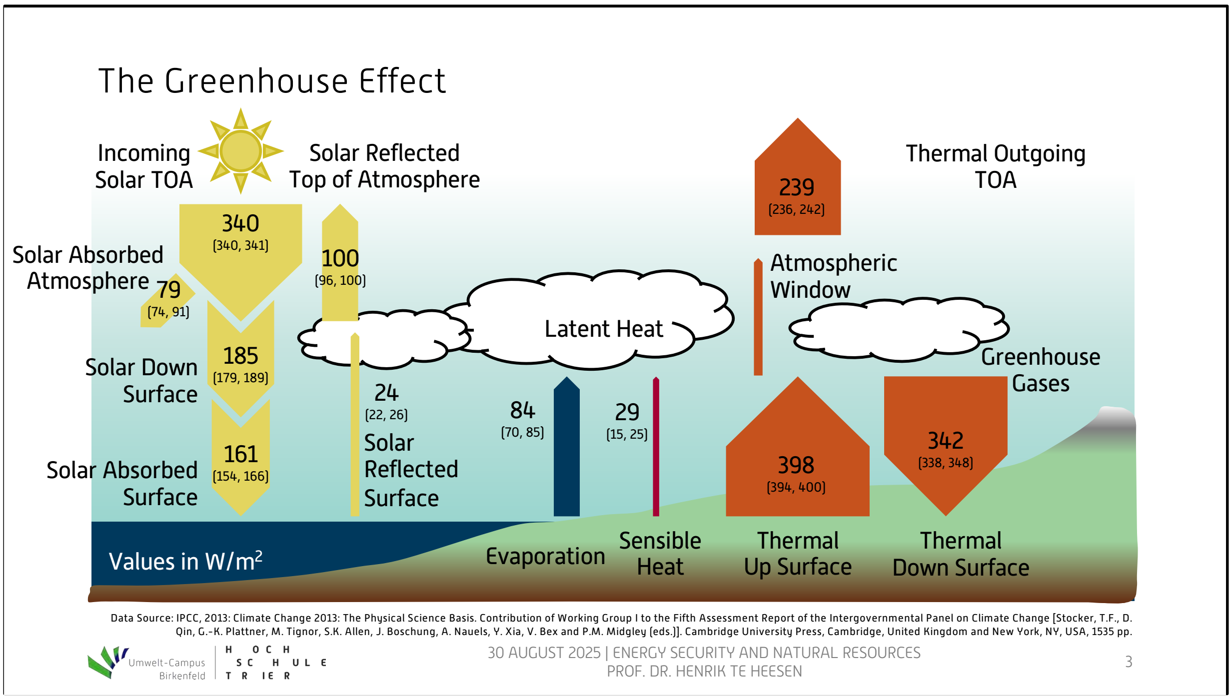
Outline for Today's Workshop

- Lecture on the basics of energy technology
  Determining the energy profile of your home country
- Short break
- Realize 100 percent renewable energy in your home country



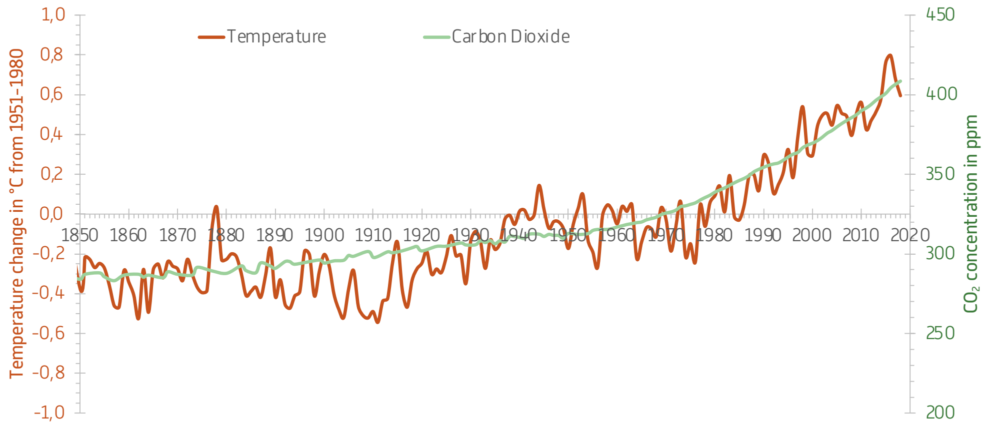


Multiple independent measurements show warming: rising air and ocean temperatures, shrinking glaciers and sea ice, and rising sea levels. When many different measurements agree, it's strong evidence of a real trend.
Weather is short-term and can be noisy; climate is the long-term average. A cold week doesn't contradict decades of warming.



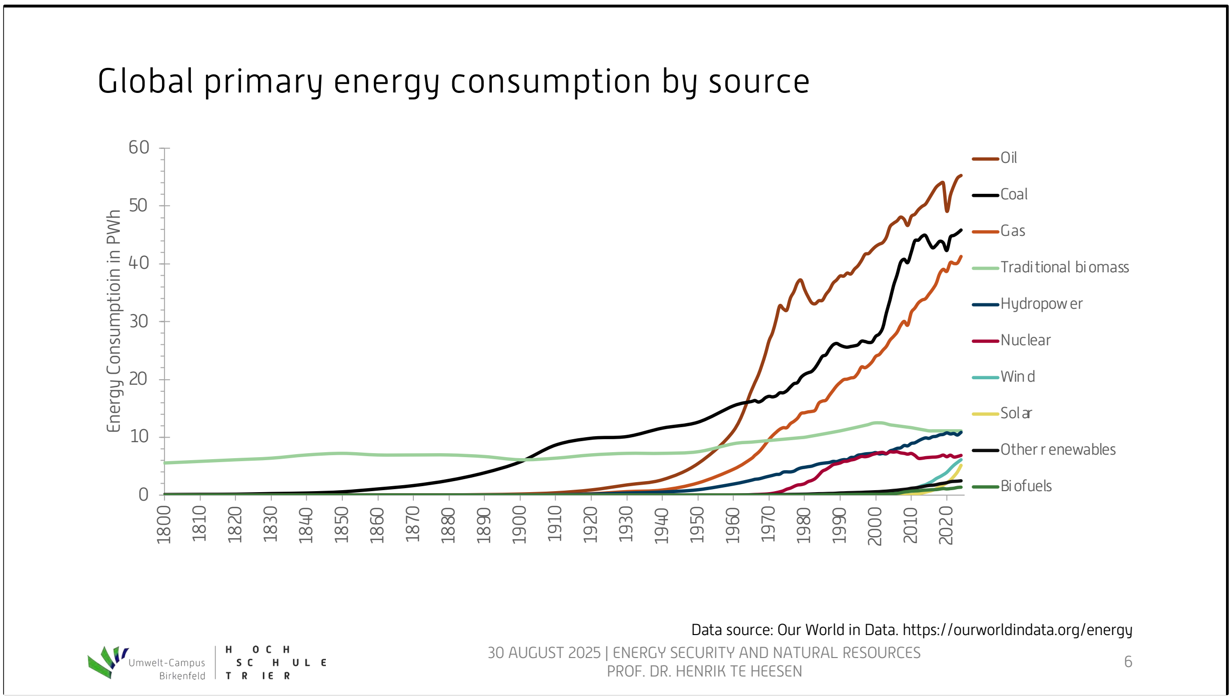
Sunlight (mostly visible light) enters the atmosphere easily and warms the surface; the Earth then emits heat back out as infrared radiation (IR).
Greenhouse gases (GHGs) absorb some of this outgoing IR and re-emit it, which keeps the lower atmosphere warmer—like a light blanket that slows heat loss rather than creating heat.
The energy-flow diagram on the slide (values in watts per square meter, W/m^2) shows how incoming solar and outgoing thermal energy must balance; GHGs change that balance by reducing the amount of heat that escapes directly to space.

There is a strong correlation between concentration of carbon dioxide and the global temperature.



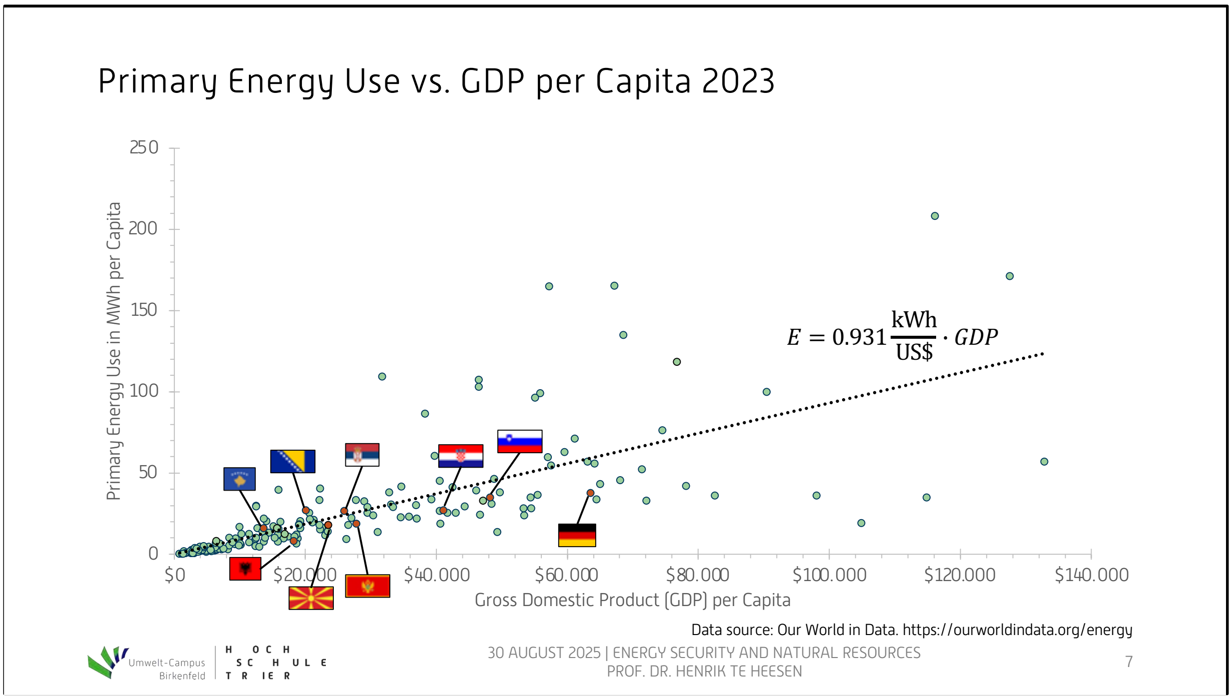
Lüthi, D., M. Le Floch, B. Bereiter, T. Blunier, J.-M. Barnola, U. Siegenthaler, D. Raynaud, J. Jouzel, H. Fischer, K. Kawamura, and T.F. Stocker. 2008. High-resolution carbon dioxide concentration record 650,000-800,000 years before present. Nature, Vol. 453, pp. 379-382, 15 May 2008. Jouzel, J., V. Masson-Delmotte, O. Cattani, G. Dreyfus, S. Falourd, G. Hoffmann, B. Minster, J. Nouet, J.M. Barnola, J. Chappellaz, H. Fischer, J.C. Gallet, S. Johnsen, M. Leuenberger, L. Loulergue, D. Luethi, H. Oerter, F. Parrenin, G. Raisbeck, D. Raynaud, A. Schilt, J. Schwander, E. Selmo, R. Souchez, R. Spahni, B. Stauffer, J.P. Steffensen, B. Stenni, T.F. Stocker, J.L. Tison, M. Werner, and E.W. Wolff. 2007. Orbital and Millennial Antarctic Climate Variability over the Past 800,000 Years. Science, Vol. 317, No. 5839, pp.793-797, 10 August 2007.
SILSO data/image, Royal Observatory of Belgium, Brussels. http://sidc.oma.be/

Ice-core records reveal a tight link between atmospheric CO_2 levels and global temperature over hundreds of thousands of years.
Today's CO_2 levels are far above recent natural ranges; physics (IR absorption by CO_2) and observations together explain the rapid warming we see now.

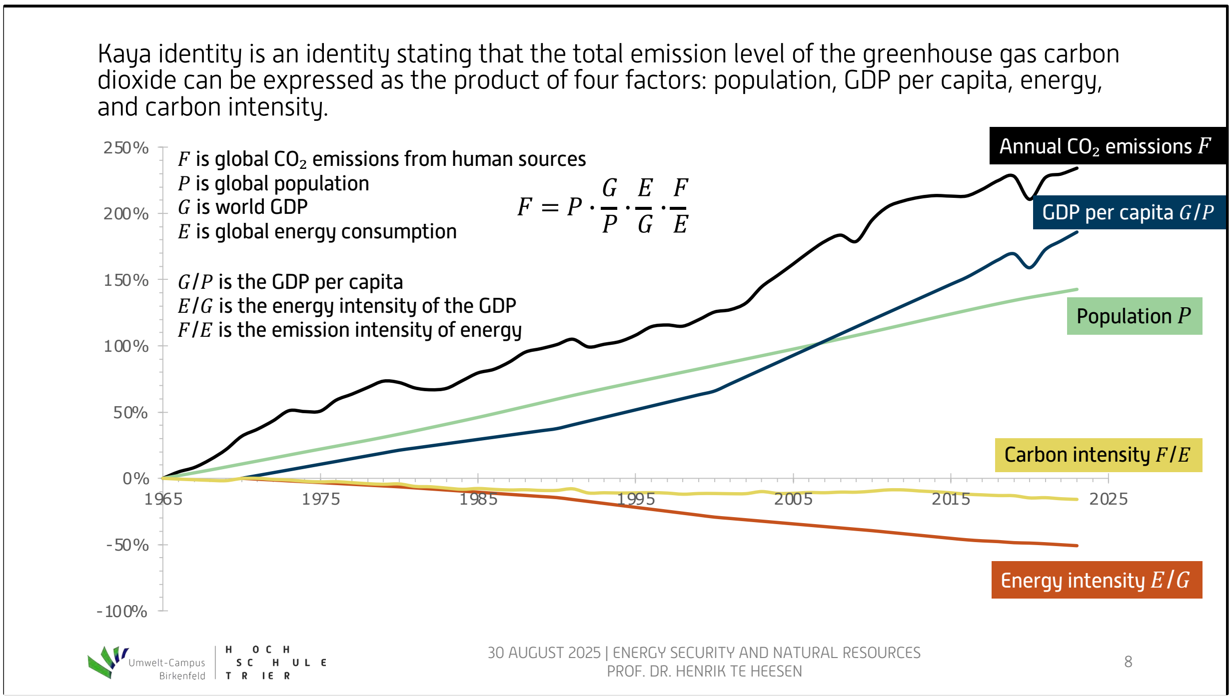


Primary energy means energy *before* conversion—coal, gas, oil, uranium, sunlight, wind, water, biomass.

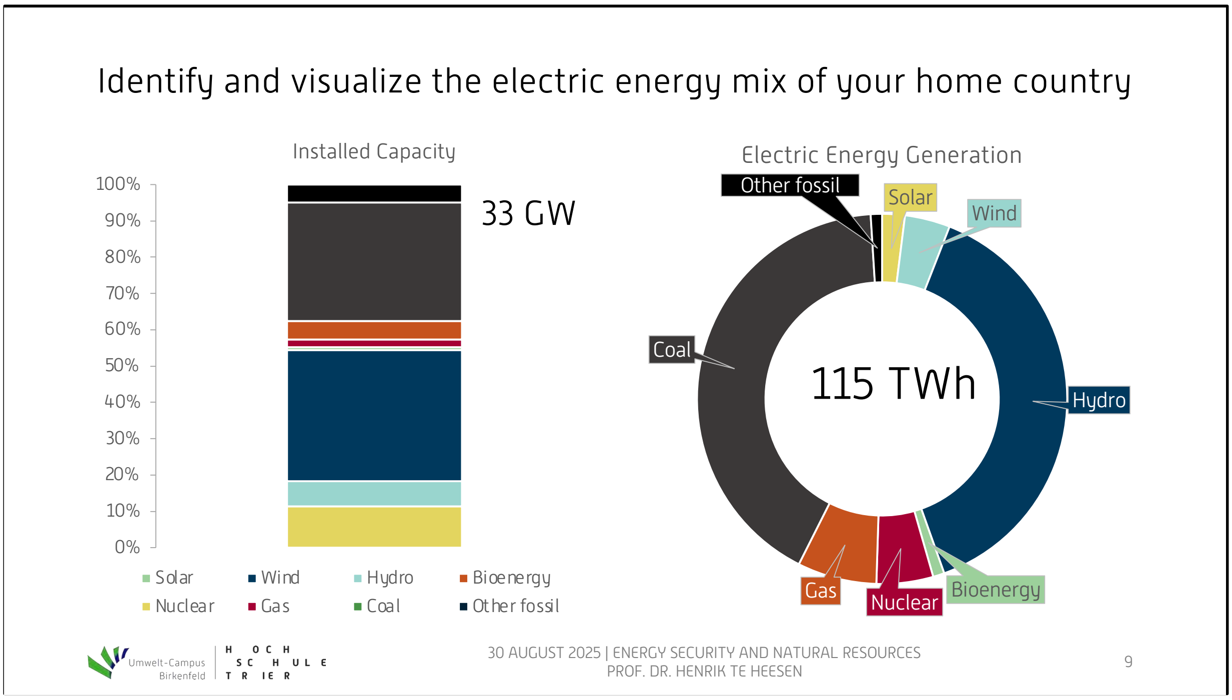
The chart shows the large global role of fossil fuels today and the growing share of renewables; understanding the “starting mix” helps explain why transitions differ by country.



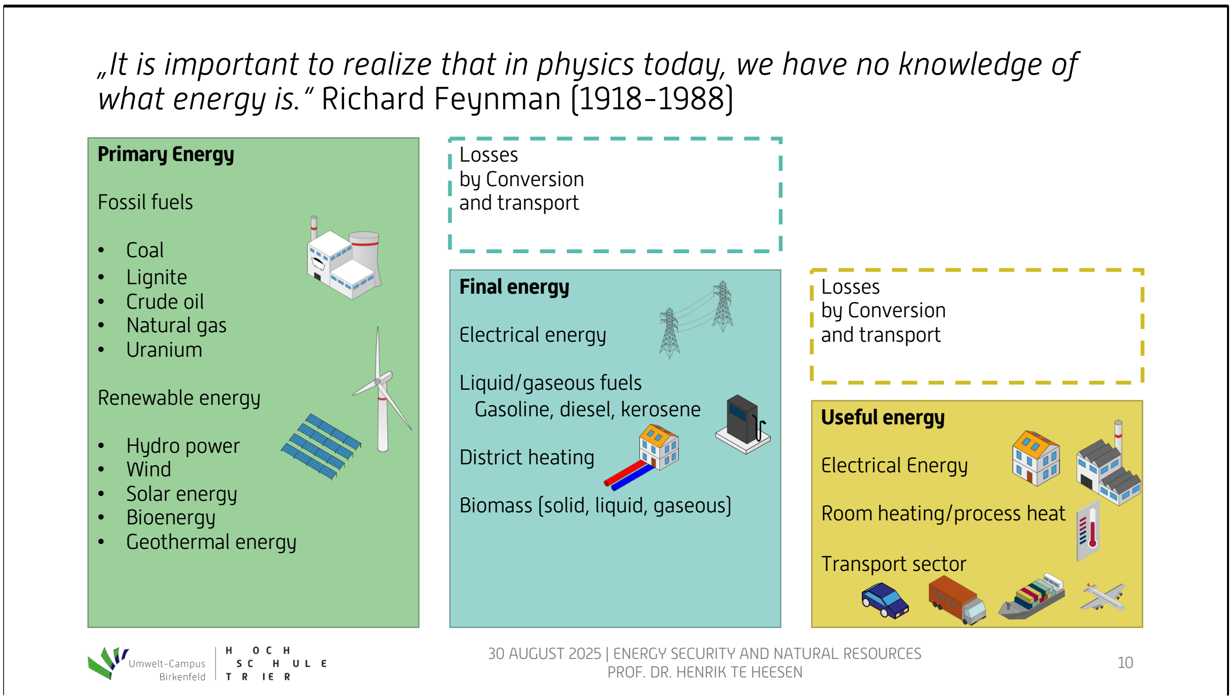
Energy use per person tends to rise with income at low income levels; after a point, efficiency and technology choices allow more economic output with slower growth in energy use.
This relationship highlights the need to expand **clean** energy and **efficiency** so prosperity can grow while emissions fall.



CO_2 emissions = Population × (GDP per person) × (Energy per GDP) × (CO_2 per unit energy).
We can act on efficiency (less energy per GDP) and “cleanliness” (less CO_2 per unit energy) without limiting prosperity; examples include LEDs, efficient motors, heat pumps, and switching to wind/solar.

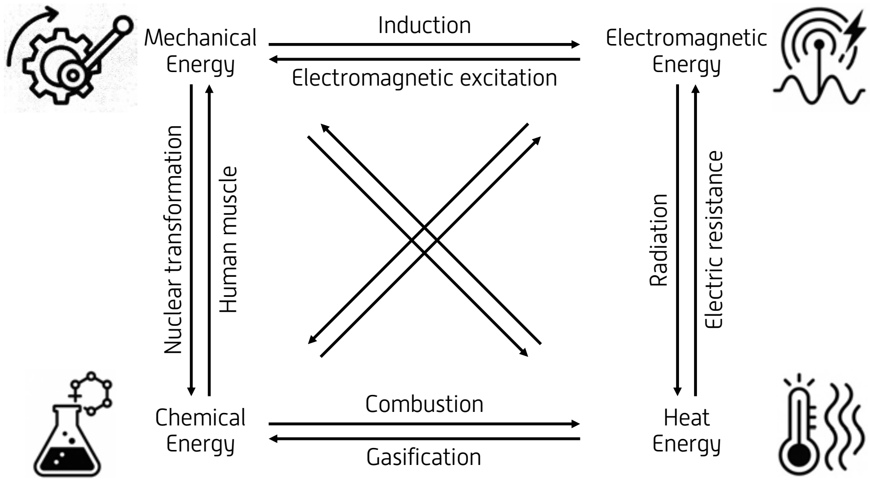


Estimate your country's current electricity sources: coal, gas, nuclear, hydro, wind, solar (rough percentages are fine).
This "baseline" shapes the path forward—countries rich in hydro face different challenges than coal-heavy systems.



Primary energy is the raw input (e.g., natural gas, wind). **Final energy** is what reaches users (e.g., electricity, district heat, gasoline). **Useful energy** is what we actually want (light, room heat, motion).
At each step, losses occur in conversion and transport, so smart system design aims to reduce losses and deliver more **useful** energy from the same inputs.

Types and Transformation of Energy



Energy Units and Conversion Factors

Metric Prefixes

Kilo (k) $= 10^3$

Mega (M)$= 10^6$

Giga (G) $= 10^9$

Tera (T) $= 10^{12}$

Peta (P) $= 10^{15}$

Exa (E) $= 10^{18}$

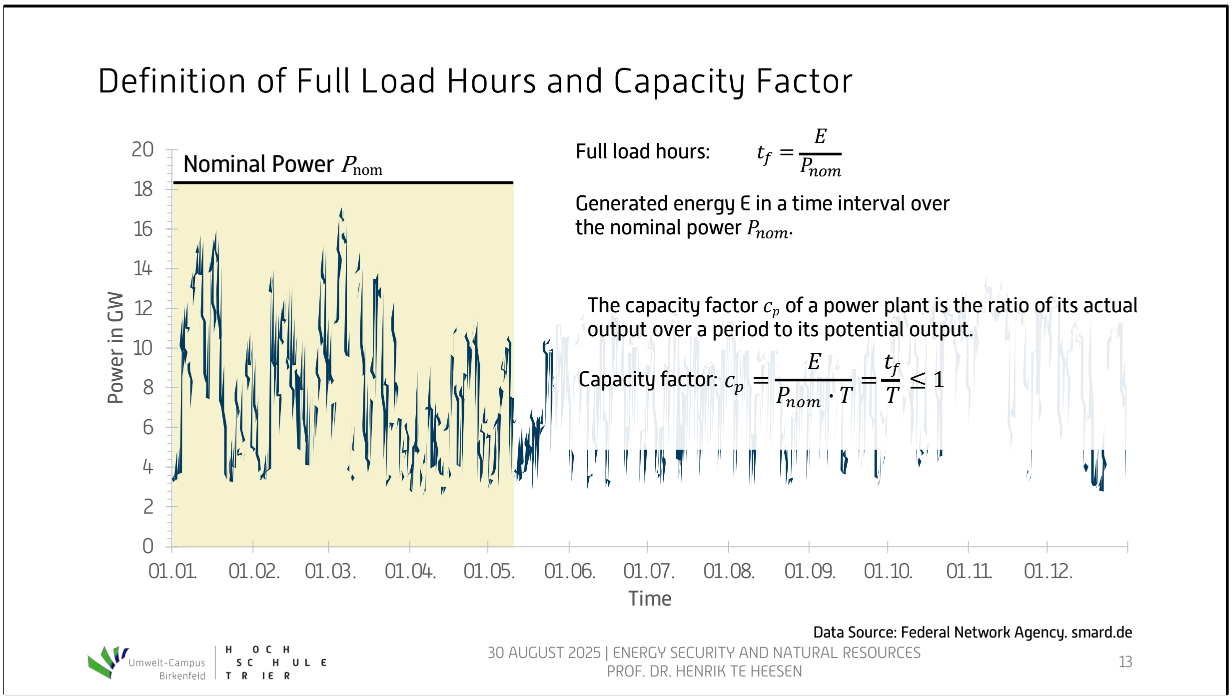
multiply by	GJ	Toe	MBtu	MWh
GJ	1	0.024	0.948	0.278
Toe	41.868	1	39.683	11.630
MBtu	1.055	0.025	1	0.293
MWh	3.600	0.086	3.412	1

Volume

1 m^3	= 1,000 litres (l)
1 US gallon	= 3.78 l
1 Imperial gallon	= 4.55 l

GJ: Giga Joule
Toe: Tonne of Oil Equivalent
MBtu: Mega British Thermal Unit
MWh: Mega Watts Hours

Power (kW, MW, GW) is the *rate* of doing work—like speed. **Energy** (kWh, MWh, TWh) is the *amount over time*—like distance.
Handy memory: a 1-kW kettle running for 1 hour uses 1 kWh of energy.
Metric prefixes: kilo (k, 10^3), mega (M, 10^6), giga (G, 10^9), tera (T, 10^{12}), peta (P, 10^{15}), exa (E, 10^{18}).



FLH = yearly energy produced ÷ nominal (nameplate) power. It answers: “How many hours at full power would give this year’s energy?”
Capacity factor = FLH ÷ 8,760 (hours in a year). Higher values mean a plant ran closer to its full potential, on average.
Example from the slide: Onshore wind ~1,800 FLH (~20%); Offshore ~4,450 FLH (~50%). These reflect wind quality and technology, not “good” vs “bad.”

Calculation of full load hours

The time in hours in which production is carried out at the nominal output indicates the capacity utilization of the system. In a year with 365 days, a wind turbine can achieve a maximum of 8,760 full load hours.

$$\text{Full Load Hours} = \frac{E_{electric} \text{ (Electrical energy in kWh)}}{P_{electric} \text{ (Nominal electrical power in kW)}}$$

Utilization rate: Ratio of full-load hours to total hours in a year (8760 h)

Example

Onshore: W_{el} = 18 GWh, P_{el} = 10 MW => 1800 Full Load Hours (Utilization Rate: 20 %)

Offshore: W_{el} = 267 GWh, P_{el} = 60 MW => 4450 Full Load Hours (Utilization Rate: 50 %)

Availability: fraction of time a plant is ready to run.
Capacity factor: how fully a plant is used over a year.
LCOE (levelized cost of electricity): average cost per kWh across the plant's lifetime.
Emissions per kWh: climate impact of generation.
Resource use: land/water/materials needed to build and operate.

Typical Key Performance Indicators

System	Full Load Hours	Capacity Factor	System	Full Load Hours	Capacity Factor
Nuclear Power Plant	7000 h	0.8	Hydropower	4000 h	0.45
Lignite Power Plant	5000 h	0.57	Wind Energy (Onshore)	2000 h	0.23
Coal Power Plant	3500 h	0.4	Photovoltaics	1000 h	0.11
Gas Power Plant	2000 h	0.23	Biomass	6000 h	0.68

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Availability: fraction of time a plant is ready to run.
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What is better and why?

1 Gigawatt of Photovoltaic

1 Gigawatt of Nuclear Power

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"1 GW" is power, not yearly energy. A 1-GW nuclear plant with ~90% capacity factor might produce ~7.9 TWh/year and is dispatchable (steady, controllable output).
A 1-GW solar PV fleet with ~12–20% capacity factor might produce ~1–1.8 TWh/year and is variable (day-night and weather dependent).
A fair comparison considers role in the system, cost, build time, flexibility, waste, emissions, and land use—not just the nameplate number.

Definition of Power Plant Types

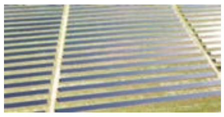
Baseload power plants
- Nuclear, lignite, and run-of-river power plants
- Utilization time from 6000 to 7000 hours per year
- 50 % of the maximum annual load and 70 % of energy consumption

Medium-load power plants
- Hard coal-fired power plants and individual oil/gas-fired power plants
- Utilization time: 3000 to 5000 hours per year
- Technical suitability for frequent load changes

Peak-load power plants
- Gas turbine, storage, and pumped storage power plants
- Utilization time is about 1000 hours per year
- Start-up and shut down several times a day with short start-up times and high-power changes

Volatile energy systems
- Wind energy, photovoltaics
- Strongly limited controllability (only switch-off)



Baseload (e.g., nuclear, lignite, large run-of-river hydro) runs many hours with steady output.
Mid-merit (e.g., hard-coal, some gas) ramps up and down to follow daily demand.
Peakers (e.g., gas turbines, storage/pumped-hydro) start quickly for short peaks.
Variable renewables (wind, solar) are clean but weather-driven; they need flexible demand, storage, and strong grids to integrate.

Coal burned in the boiler heats water to produce steam. The steam spins the turbine, which drives the generator.

Fuel heats water in a **boiler** to make high-pressure steam; steam spins a **turbine** connected to a **generator** to produce electricity.
Steam then cools back to water in a **condenser** (often using river water or cooling towers) and is recycled to the boiler—this is the steam loop.
Each step has efficiency limits; the condenser's cooling needs are part of why these plants have significant thermal losses.

Gas-fired Power Plant

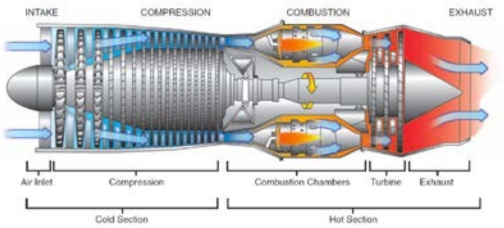
- The gas turbine produces extremely high combustion temperatures, ranging from 900 to 1,250 °C, at a pressure of 15 to 20 bar. For this reason, extremely high-quality materials must be used to withstand these process conditions.
- The rotational energy of the turbine drives the generator and the compressor.
- The compressor sucks in the combustion air, compresses it, and consumes about 2/3 of the energy of the gas burned in the gas turbine.
- Advantages of gas-fired power plants: No cooling equipment is necessary, and exhaust gas cleaning is not required.

Differences between gas and steam power plants

No steam is generated in a gas turbine power plant.

The exhaust gases generated by the combustion process are fed directly to the turbine blades.

Gas turbines can produce full power within a few seconds, making them suitable for a minute reserve.



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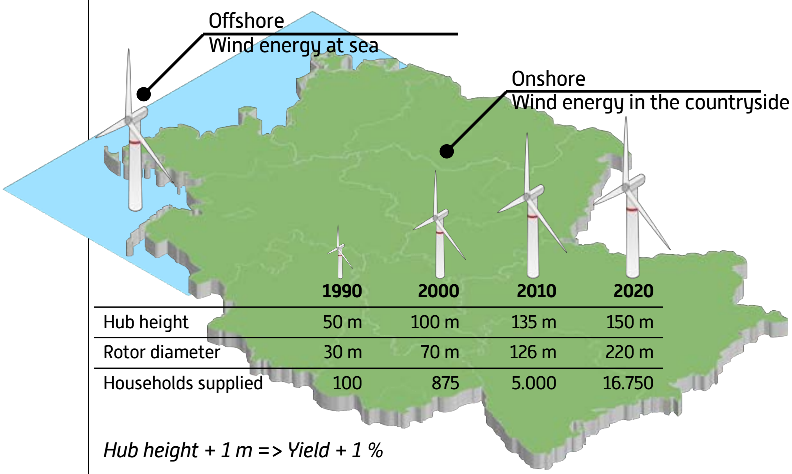
Air is compressed, fuel is burned to create very hot, high-pressure gases, and those gases spin the turbine directly—no steam loop.
The compressor itself uses a large share of the turbine’s output (about two-thirds), which is why materials and aerodynamics matter.
Gas turbines ramp up to full power very quickly (seconds to minutes), which makes them valuable for balancing short-term fluctuations.

Wind power
Generating electrical energy from wind

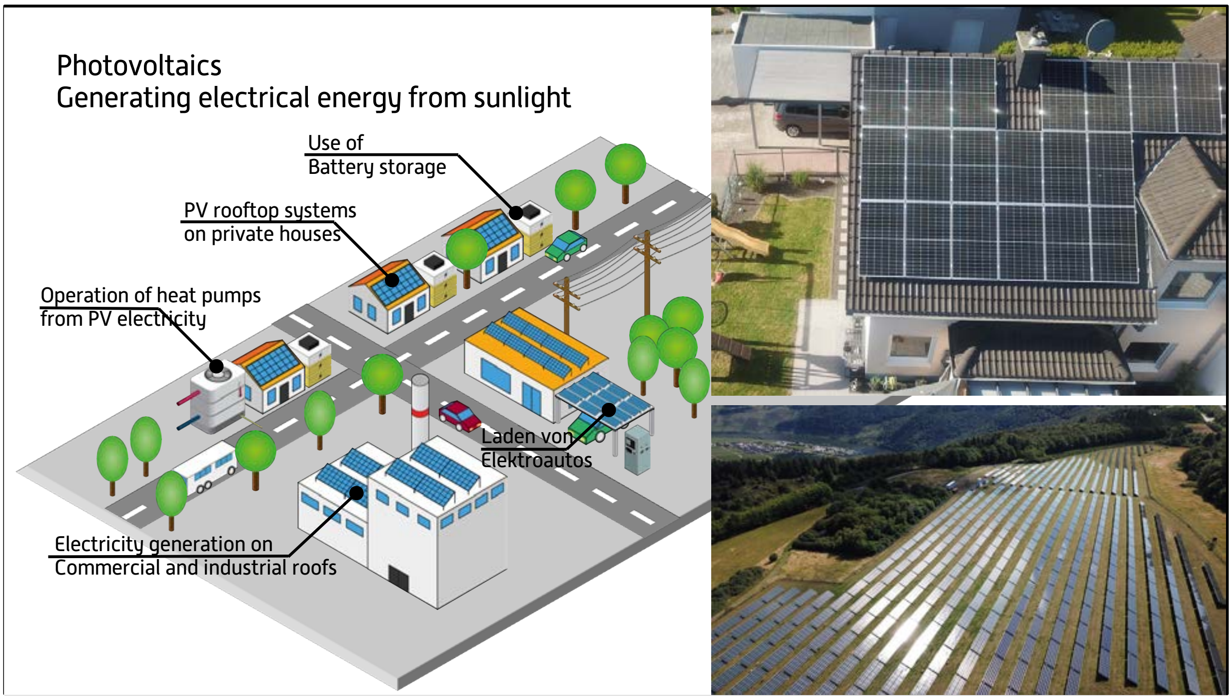


	1990	2000	2010	2020
Hub height	50 m	100 m	135 m	150 m
Rotor diameter	30 m	70 m	126 m	220 m
Households supplied	100	875	5.000	16.750

Hub height + 1 m => Yield + 1 %

Doubling of the rotor diameter=> Quadrupling of yield

Higher hub height → higher wind speeds → higher energy; a rough rule on the slide is ~+1% yield per extra meter of hub height.
Rotor diameter matters a lot: doubling diameter increases swept area by ~4×, so potential energy capture rises strongly. Site quality still dominates.

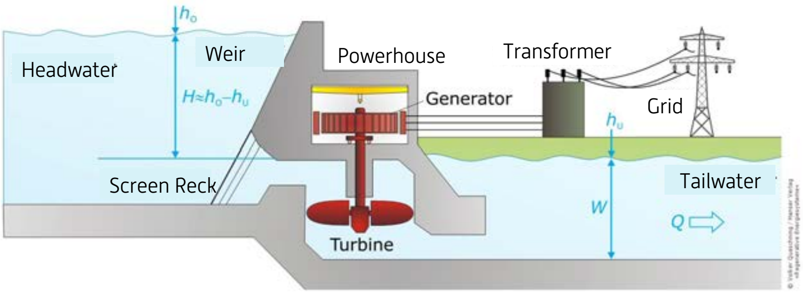


PV modules convert sunlight into direct current (DC); **inverters** turn DC into alternating current (AC) that matches the grid.

Output depends on sunlight, orientation, temperature, and shading; PV is strongest in the daytime and varies with weather.

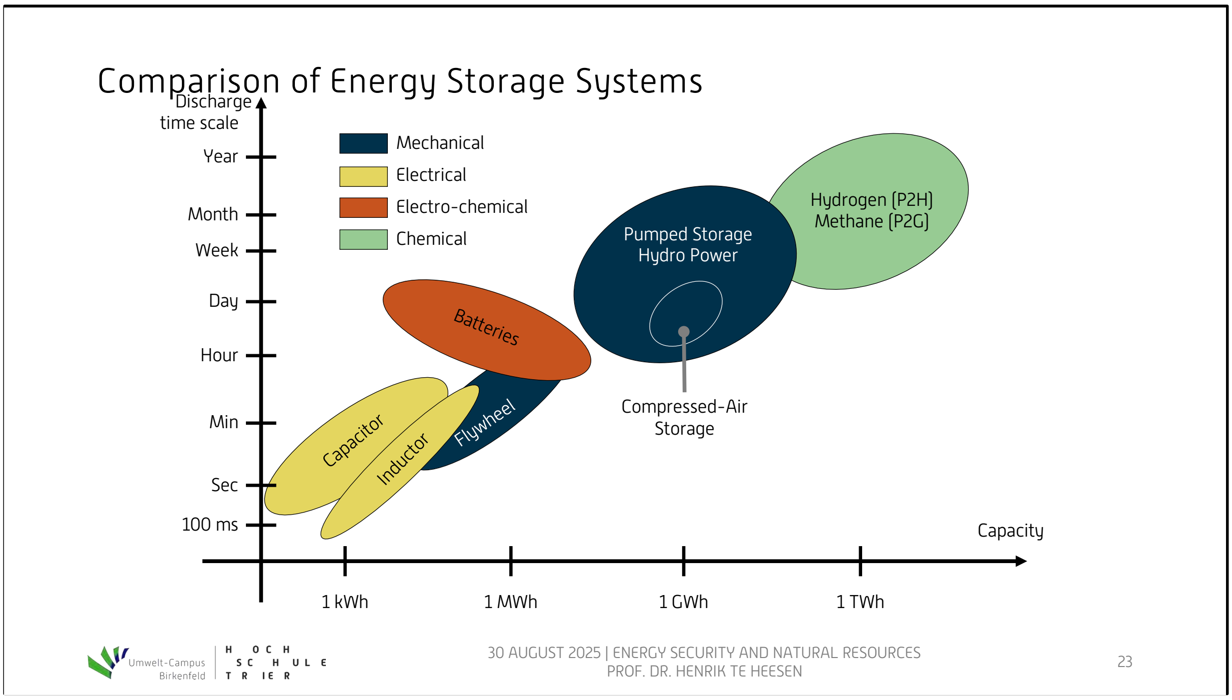
Storage and flexible demand help align PV output with when people need electricity.

River Power Plant

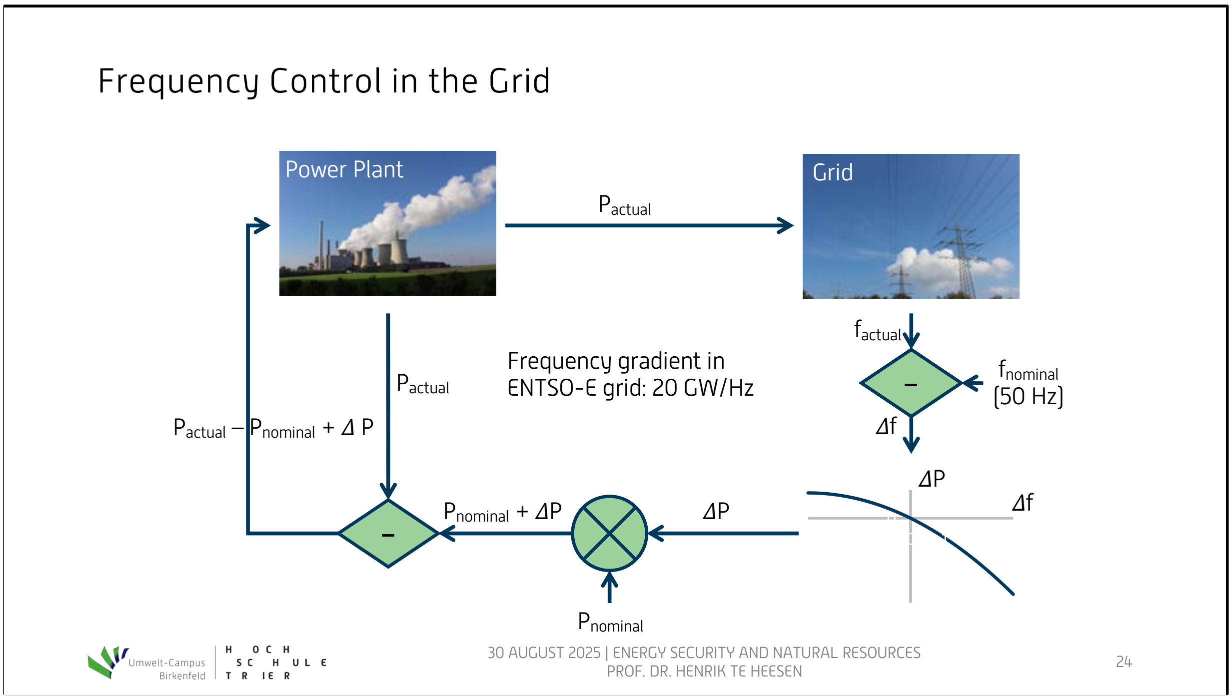


Source: Quaschning. Regenerative Energiesysteme. S. 299

Flowing water turns a turbine to generate electricity; output tracks river flow, with limited storage in the river channel itself.
Because it can’t store much water, run-of-river is less flexible than large reservoir hydro, but it provides steady clean energy where rivers allow.

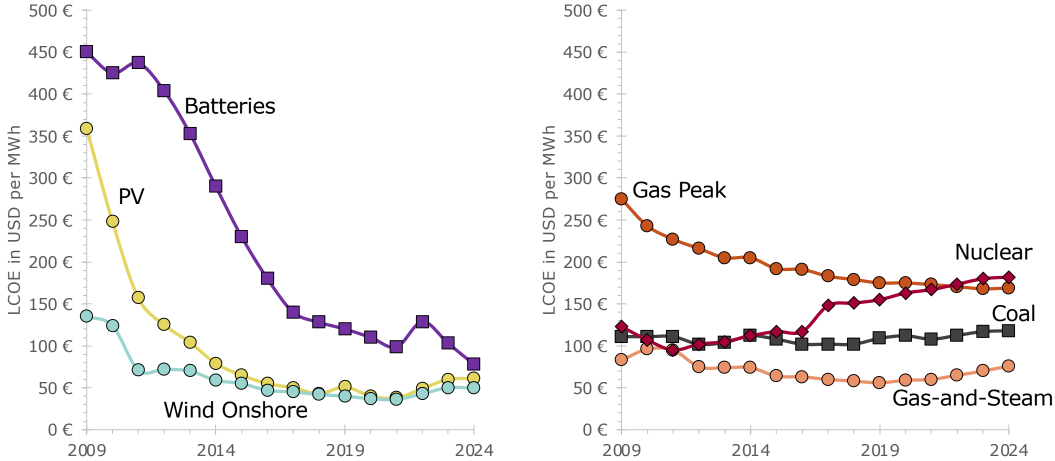


Different storage fits different jobs:
Seconds–minutes: capacitors, flywheels help stabilize frequency quickly.
Minutes–hours: batteries smooth daily solar/wind swings.
Hours–days: pumped-hydro and compressed-air cover multi-hour peaks.
Days–seasons: hydrogen/synthetic methane (power-to-X) can bridge longer gaps.
No single storage does everything best; systems combine several types.



Electricity systems must match supply to demand every second; otherwise grid frequency drifts from 50 Hz.
If generation is short, frequency falls; if there's surplus, it rises. Plants and batteries adjust output to keep frequency steady.
In the ENTSO-E area, frequency shifts roughly with a gradient of ~20 GW per Hz—a reminder of how large and coordinated the system is.

Renewable energy systems produce electricity more cheaply than newly built fossil fuel power plants.

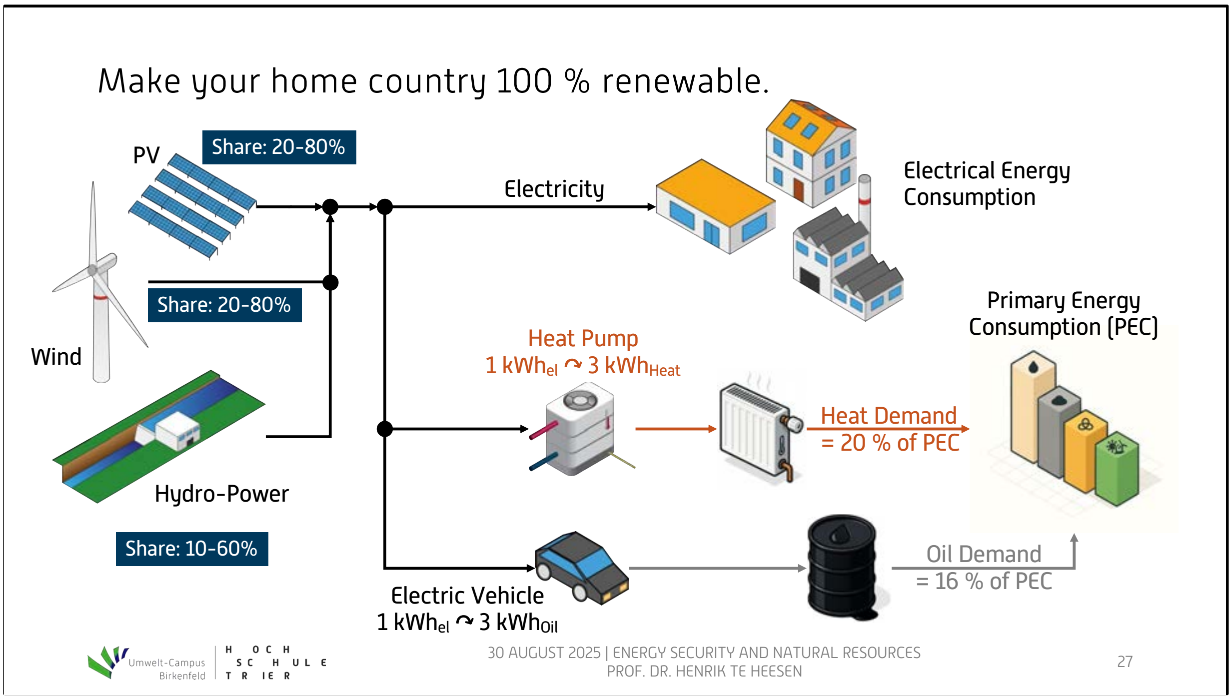


Data source: Max Roser (2020) - "Why did renewables become so cheap so fast?". Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/cheap-renewables-growth

Over the last decade, costs for **solar PV, wind, and batteries** have dropped dramatically due to learning-by-doing, scale, and technology improvements.
In many regions, new renewable power is now cheaper than building new fossil plants—this shifts investment toward clean options. Local details still matter, but the global cost trend is clear.

Make your home country 100 % renewable.

- Set up a mix of renewable energy systems (solar, wind, hydro-power) to feed the demand for electrical energy in your home country.
- Identify the electrical energy generation and the primary energy demand of your home country.
- Derive the increasing demand for electricity due to heat pumps for space heating and due to electric vehicles in the future.
- Calculate the total electrical energy demand.
- Combine solar, wind, and hydroelectric power to meet electricity demand. Use the capacity factor to calculate the installed capacity of each renewable energy system.
- Is this simplified energy model realistic? What are the limits of your model, and how could your model be improved?


Make your home country 100 % renewable.
PV
Share: 20-80%
Wind
Share: 20-80%
Hydro-Power
Share: 10-60%
Electricity
Electrical Energy
Consumption
Primary Energy
Consumption (PEC)
Heat Pump
1 kWhel ↷ 3 kWhHeat
Heat Demand
= 20 % of PEC
Electric Vehicle
1 kWhel ↷ 3 kWhOil
Oil Demand
= 16 % of PEC
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