IEooc_Methods1_Exercise1a: Energy measures and the energy supply chain

Goal: *Provide an overview of the salient energy and power measures and indicators. Calculate the different energy flows for the conversion from electricity to vehicle operation for different drive technologies, using efficiency measures for the processes involved.*

Overview and introduction: (scroll down to last page for the exercise!)

What is energy? Figure 1 shows the definition of this central socio-metabolic quantity.

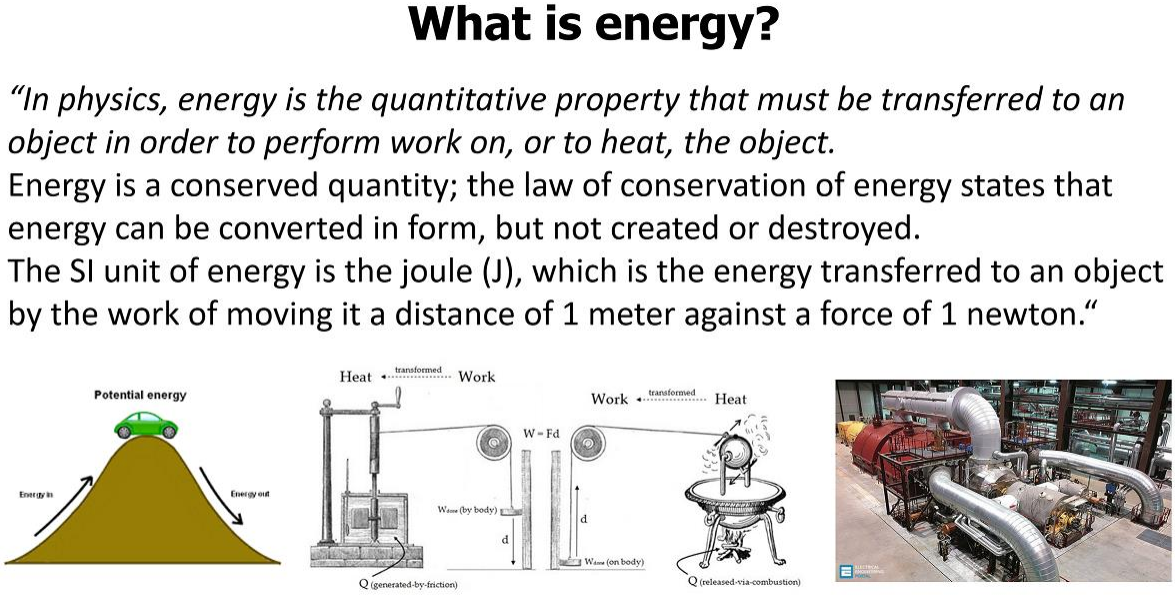

Figure 1: Energy, overview. Source: https://en.wikipedia.org/wiki/Energy

"Common forms of energy include the kinetic energy of a moving object, the potential energy stored by an object (for instance due to its position in a field), the elastic energy stored in a solid object, chemical energy associated with chemical reactions, the radiant energy carried by electromagnetic radiation, and the internal energy contained within a thermodynamic system. All living organisms constantly take in and release energy." https://en.wikipedia.org/wiki/Energy

Energy is a salient socio-metabolic indicator, as it determines the level of operation of buildings and vehicles for service provision and is a proxy for the environmental and resource implications of socioeconomic metabolism.

PUBLIC DOMAIN

Power indicates the rate at which energy is transformed (Fig. 2). Power is thus an indicator for the capacity and size of energy conversion devices, such as power stations, industrial boilers, or heat pumps.

Energy and power

"In physics, power is the rate of doing work, the amount of energy transferred per unit time. Having no direction, it is a scalar quantity.
In the International System of Units, the unit of power is the joule per second (J/s) […].
Another common and traditional measure is horsepower (comparing to the power of a horse).
Being the rate of work, the equation for power can be written:"

$$P = \Delta W / \Delta t$$

Figure 2: Power, overview. Source: https://en.wikipedia.org/wiki/Power_(physics)

Energy and power are used in different settings:

Applications of energy:

- Measures total work done and converted over time
- Use to determine total amount of material/goods/etc. produced over time.
- Determines total resource use and emissions over time.

Applications of power:

- Comparing energy conversion devices
- Designing machines, devices, and infrastructure
- Determines plant/engine/machine size and material demand
- Determines resource use and emissions per hour

Note: In the English language, ‚power' can mean many different things!

- First, power as electricity, i.e., a form of energy, measured in kWh etc., as in 'power station'. This use is common in engineering.
- Second, power as rate of energy transfer as defined here, measured in W etc., as in 'horse power'. This use is common in physics.

PUBLIC DOMAIN

Here, we use the concept 'power' in its second meaning, as common in physics.

The overview below in Fig. 3 shows typical units and orders of magnitude of energy flows and the power of living organisms and technical in-use stocks.

Energy and power: Units and Scales

The examples below represent typical values

Energy	
Daily energy consumption (body)	10 MJ
Car trip 1000 km	2.2 GJ
Intercontinental flight, per person	10 GJ
Global electricity consumption	22000 TWh

Power	
Human athlete	300 W
Midsize car	60 kW
Wind turbine	2 MW
Large coal-fired power station	2 GW

Figure 3: Overview of energy and power units and orders of magnitude.

Important unit conversions:

1 kWh = 3.6 MJ // 1 TWh = 3.6 PJ

1 toe (ton of oil equivalent) = 41.868 GJ // 1 Mtoe = 11.63 TWh // 1 Mtoe = 41.868 PJ

Recommended reading:

"A sense of units and scale for electrical energy production and consumption"

Available via: https://ourworldindata.org/scale-for-electricity

A number of energy and power measures/indicators are used to characterise socioeconomic metabolism and the energy system, in particular (Fig. 4).

Energy quantities can be reported as

- stocks (like the energy in kWh stored in a battery at a given point in time),
- cumulative flows (like the total electricity in MWh generated by a wind turbine during one year),
- average flows (like the average power, calculated as the total electricity in MWh generated by a wind turbine during one year, divided by one year, given in MWh/year or MW),
- instantaneous flows (like the current rate of energy conversion, energy converted per second, which is a measure of power!)

PUBLIC DOMAIN

Power quantities can be reported as

- conversion stocks (like the installed power in MW or the average metabolic turnover rate of a living organism)
- additions to conversion stocks (like the newly build capacity in MW/yr)

The different energy and power measures/indicators used to characterise socioeconomic metabolism and the energy system, in particular, are shown in Fig. 4 below.

Energy system quantities

New addition to power (new capacity)	Installed power (capacity)	Generated or stored electricity (Energy)
Nominal power (energy conversion per second) of newly installed plants per time during which installation happens	Nominal power (energy conversion per second) of installed plants, calculated as integral over newly installed assets minus integral over demolished assets (use phase balance for installed power)	Amount of energy generated, calculated as Nominal power * operation hours Energy stored in a battery, in a certain amount of biomass, or in a dam
Unit: MW/yr (It's a flow!)	Unit: MW (It's a stock!)	Unit: MWh/yr (for energy flows), kWh or GWh (for energy stocks (and flows))
Example: Constrution rate of new wind turbines over a year: 1000 MW/yr	Example: Total installed capacity at the end of a year: 30000 MW	Example: Total generated electricity with 3000 operating hours: 90000000 MWh

Figure 4: Salient energy system quantities.

PUBLIC DOMAIN

Energy carriers and energy quality

Next to their stock, flow, or rate aspects, energy flows are also distinguished by the different energy carriers and by their degree of conversion into useful energy carriers. The following energy indicators are commonly used (*).

Primary energy (PE) is the energy found in nature that has not been subjected to any human engineered conversion process. It encompasses energy contained in raw fuels and other forms of energy, including waste, received as input to a system. Primary energy can be non-renewable or renewable.

Total energy supply (TES) or total primary energy supply (TPES) is the sum of production and imports, plus or minus stock changes, minus exports and international bunker storage.

Final energy (FE) indicates the energy carrier and the energy flow into its final use for service provision in end-users sectors such as buildings, transport, and industry. Final energy is not further converted into other energy carriers but used to generate motion, heat (as a service, not as a further energy carrier), light, or feed chemical reactions. For households, all energy purchases are for final energy.

Total final consumption (TFC) is the worldwide consumption of energy by energy end-users sectors such as buildings, transport, and industry.

Useful energy is the energy that goes towards the desired output of the end-use application. For example, the total energy supplied in warm air in building heating.

(*) Sources:

https://en.wikipedia.org/wiki/Primary_energy

https://ourworldindata.org/energy-definitions

Eurostat and "International recommendations for energy statistics (IRES)" (PDF). UN Department of Economic and Social Affairs

PUBLIC DOMAIN

Application and exercise: Energy flows of different energy carriers and different stages of conversion in a systems context.

Energy can be supplied (converted, transported, and stored) to services via different pathways. The following scheme shows three different energy supply pathways from electricity at the point of generation to passenger vehicles (Fig. 5). For each of the three supply chains (battery electric storage, fuel cell vehicles, and synthetic fuels), the main conversion steps and their efficiencies (desired energy output divided by necessary energy input) are given.

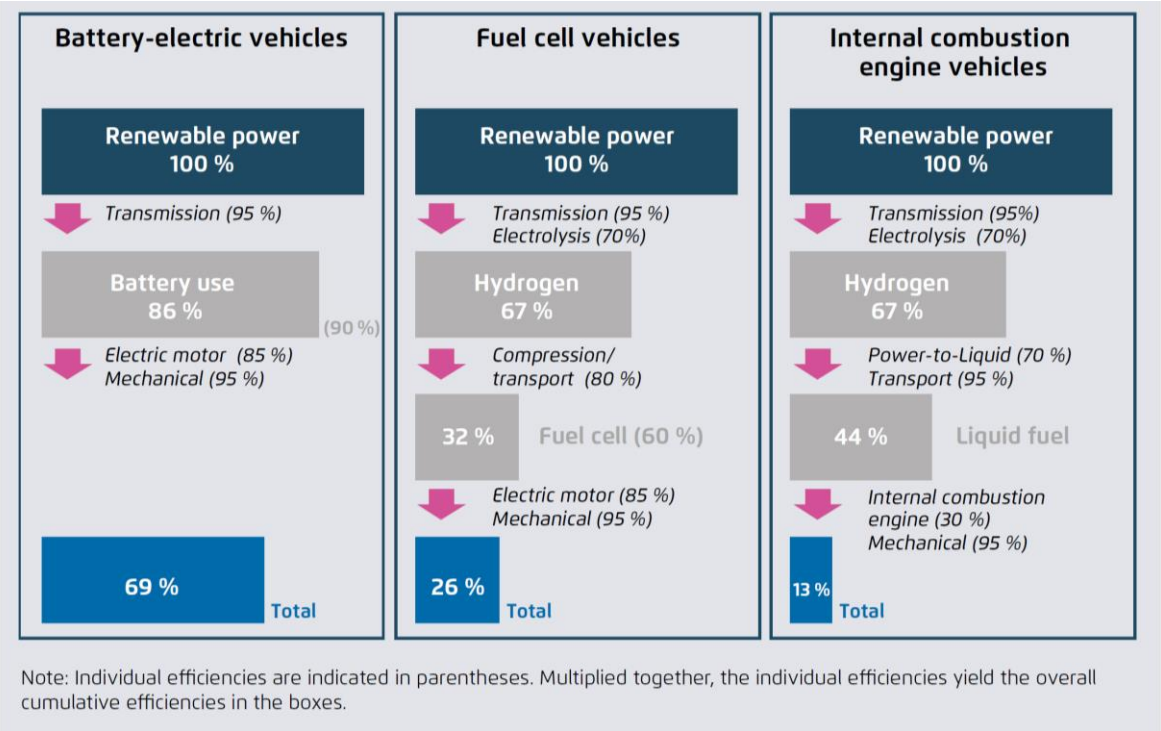

Figure 5: Efficiency in different energy conversion chains for passenger vehicles. Source: Agora Verkehrswende, Agora Energiewende and Frontier Economics (2018): The Future Cost of Electricity-Based Synthetic Fuels.

Task: For a trip length of 1 km (longer distances simply scale with the distance), develop a MEFA system definition for each case and calculate the following energy flows: (1) the primary energy, (2) the final energy, and (3) the useful energy! Re-calculate the system efficiency as useful energy per primary energy! (already shown in Fig. 5) Interpret your findings!

Assumptions and additional data: Figure 5 only contains %-values. One reference energy flow must be given to scale the %-values to values in MJ: Assume that the final energy demand for battery-electric vehicles is 0.7 MJ/km (purchased electricity!). Assume further that the useful energy to propel the vehicle is the same for all cases! A fourth case can be constructed for internal combustion vehicles operated with gasoline as final energy, where 1.25 MJ of crude oil are needed for 1 MJ of gasoline.

PUBLIC DOMAIN