Energy and Buildings

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This lecture is based on BATEM, but what is BATEM?

BATEM is a software framework dedicated to the teaching of many aspects of energy management related to buildings.

It is an open source interactive toolbox to design energy systems and especially building systems. You can use it for research and design or for learning and teaching purposes.

You. can get:

- the full sources at https://www.gricad-gitlab.univ-grenoble-alpes.fr/batem/batem_all
- just the tutorials sources: https://www.gricad-gitlab.univ-grenoble-alpes.fr/batem/tutorials
- the online access to tutorials: https://shorturl.at/sBWDy
- the baterm tool to solving building energy problems: `pip install batem` then baterm for the CLI

Install tutorials on your machine (overview)

Working locally avoids the latency of cloud notebooks (e.g. mybinder). You need: Python, VS Code, the tutorials folder, and a few minutes for first-time setup.

Step 1 — Python

- Windows: install from python.org/downloads/windows
  ⚠️ Tick “Add Python to PATH” during setup.
- macOS: Python 3 is often already present; if not, use python.org/downloads/macos.

Step 2 — Windows-only dependency

In PowerShell:

```
pip install --only-binary=:all: timezonefinder
```

(Avoids build issues for some wheels on Windows.)

Step 3 — Editor

Install Visual Studio Code: code.visualstudio.com

Steps 4–6 — Tutorials folder

1. Download tutorials as a ZIP from the GitLab link above.
2. Unzip into your working folder.
3. In VS Code: File → Open folder → select the `tutorials` folder. Accept recommended extensions when prompted.

Workshops: `workshopXX_*.ipynb`
Matching slides (PDF): `slidesXX_*.pdf`

`baterm` (optional CLI)

For course exercises and quick interaction with the framework, use `baterm` (command-line tool shipped with batem).

```
pip install batem    # Python ≥ 3.12 recommended
baterm
```

Whole course content (1/2)

0. Introduction — Earth context · `slides00_intro`
1. Sun–Earth system & solar radiation · `slides01_sun` + `workshop01_sun`
2. Climate change · `slides02_climate` + `workshop02_climate`
3. Inhabitants & comfort · `slides03_human` + `workshop03_human`
4. Building physics · `slides04_physics` + `workshop04_physics`
5. Dynamic / inertia · `slides05_dynamic` + `workshop05_dynamic`
6. Systems (heat pumps, emitters) · `slides06_systems` + `workshop06_systems`

Course programme (2/2)

7. Model fitting to measurements · `slides07_fitting` + `workshop07_fitting`
8. Control of occupied zones · `slides08_control` + `workshop08_control`
9. Photovoltaics · `slides09_photovoltaic` + `workshop09_photovoltaic`
10. Energy communities · `slides10_community` + `workshop10_community`
11. Ski resort case: graphs · `1/3`
12. Ski resort case: multi-agent · `2/3`
13. Ski resort case: design · `3/3`
14. PLEIADES tutorials (IZUBA)

Anthropocene

A (short) history of Earth

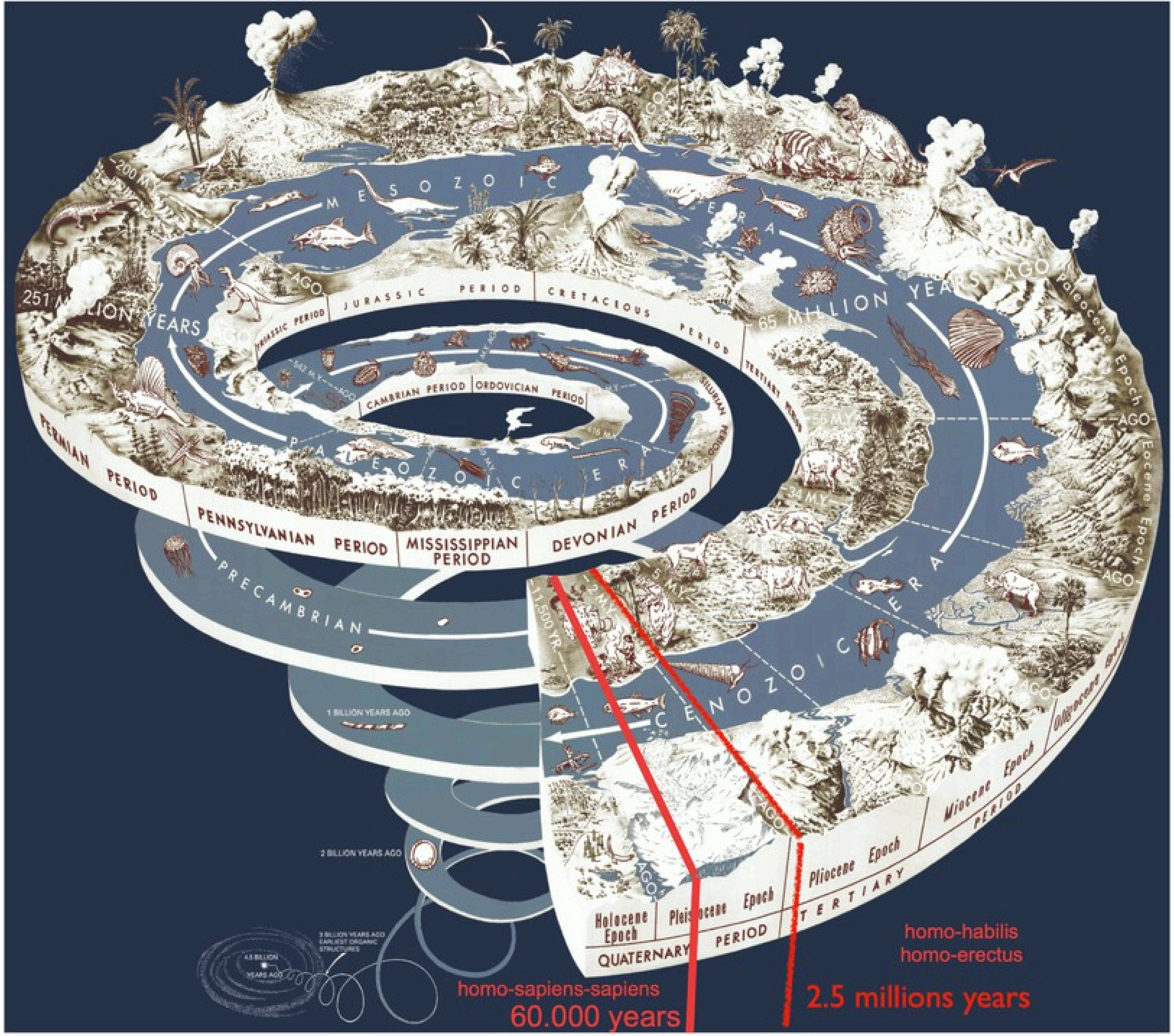
What this lecture connects

- Scale: muscle power → fossil fuels → TW-level global power (TW: Tera-Watt = 10^{12} W).
- Earth system: thin atmosphere, radiative balance, ocean vs land.
- Society: emissions by sector and country, final vs primary energy, electricity in the mix.

Two time scales

- Geological time: formation of fuels, climate, biodiversity — slow compared to a human life.
- Industrial time: extraction, combustion, land use — fast; cumulative stocks in atmosphere & ocean.

The next figures give a compressed visual history: useful as intuition, not as a substitute for detailed models.


MESOZOIC ERA
251 MILLION YEARS AGO
65 MILLION YEARS AGO
JURASSIC PERIOD
CRETACEOUS PERIOD
TRIASSIC PERIOD
CAMBRIAN PERIOD
ORDOVICIAN PERIOD
SILURIAN
PALEOZOIC ERA
PERMIAN PERIOD
PENNSYLVANIAN PERIOD
MISSISSIPPIAN PERIOD
DEVONIAN PERIOD
PRECAMBRIAN
1 BILLION YEARS AGO
2 BILLION YEARS AGO
3 BILLION YEARS AGO EARLIEST ORGANIC STRUCTURES
4.5 BILLION YEARS AGO
CENOZOIC ERA
Paleocene Epoch
Eocene Epoch
Oligocene Epoch
Miocene Epoch
Pliocene Epoch
Pleistocene Epoch
Holocene Epoch
QUATERNARY PERIOD
TERTIARY PERIOD
homo-habilis
homo-erectus
2.5 millions years
homo-sapiens-sapiens
60.000 years

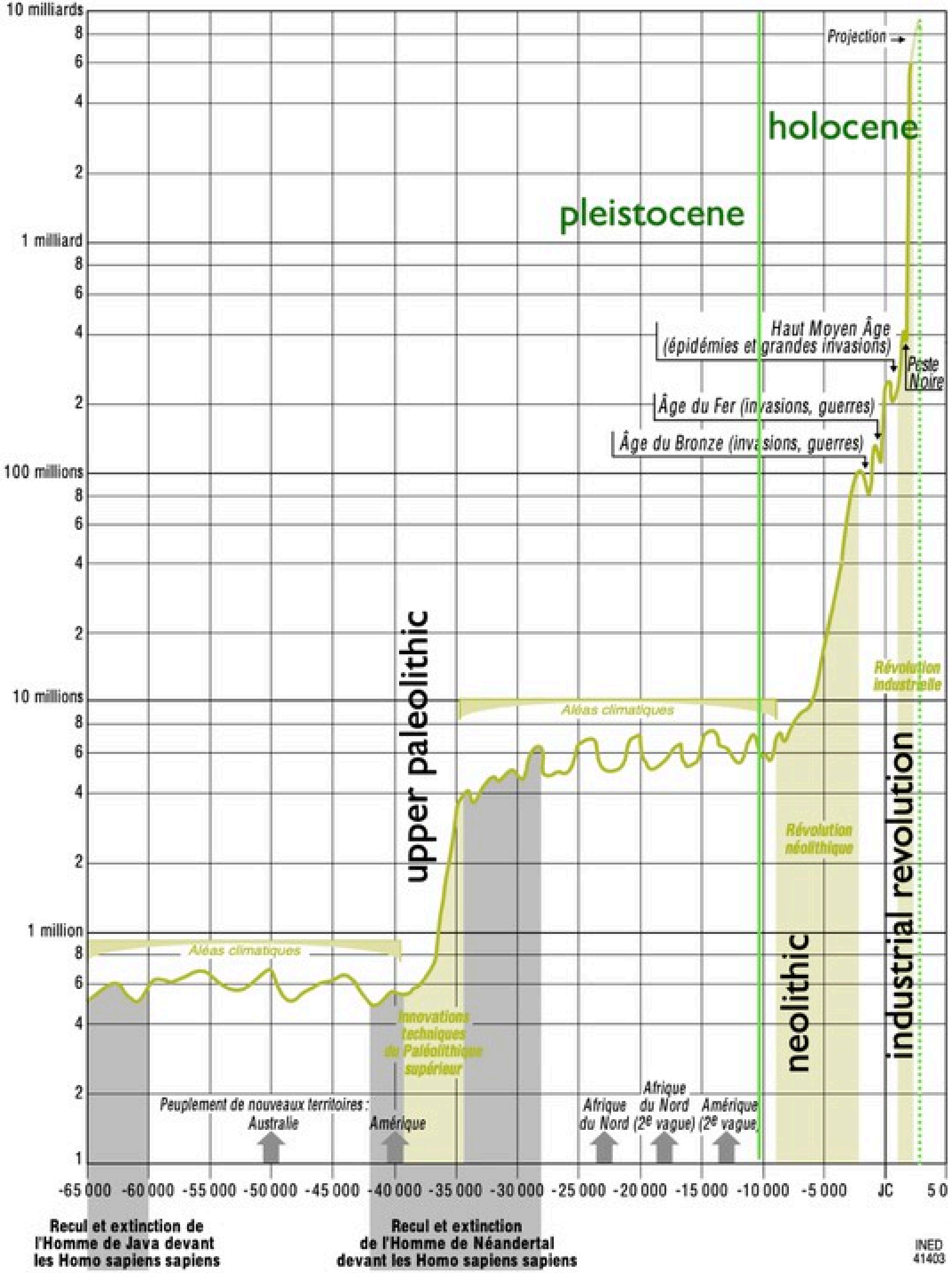
Exponential growth of humankind

The next figure shows the exponential growth (pay attention to the log-scale of the y-axis) of humankind: it looks like the development of an parasitic species consuming resources.

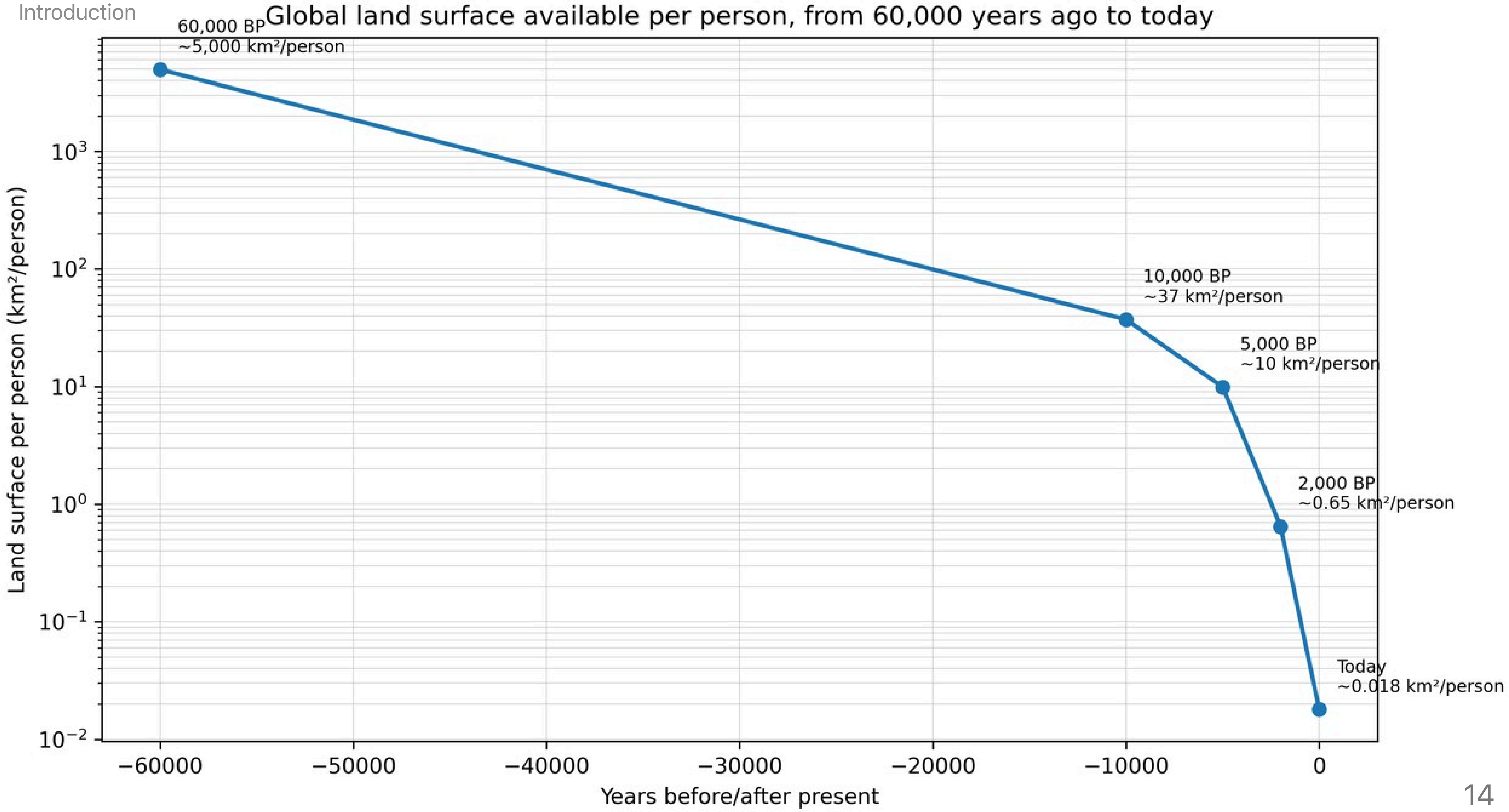
60,000 years ago, each homo-homo sapiens had a square area of land with an 70km edge (5000km^2) to live on and to produce food for himself whereas todays each human has about a square with an edge of 110m (~2 ha), of land.

If the environment was resilient enough to support a limited growth, it's no longer the case today.

We are now at the limit of the Earth's carrying capacity. We need to care about the environment where we live. This is a characteristic of the Anthropocene era.



10 milliards
1 milliard
100 millions
10 millions
1 million
Projection
holocene
pleistocene
Haut Moyen Âge (épidémies et grandes invasions)
Peste Noire
Âge du Fer (invasions, guerres)
Âge du Bronze (invasions, guerres)
Révolution industrielle
Aléas climatiques
upper paleolithic
Révolution néolithique
industrial revolution
neolithic
Innovations techniques du Paléolithique supérieur
Peuplement de nouveaux territoires : Australie
Amérique
Afrique du Nord
Afrique du Nord (2e vague)
Amérique (2e vague)
-65 000 -60 000 -55 000 -50 000 -45 000 -40 000 -35 000 -30 000 -25 000 -20 000 -15 000 -10 000 -5 000 JC 5 0
Recul et extinction de l'Homme de Java devant les Homo sapiens sapiens
Recul et extinction de l'Homme de Néandertal devant les Homo sapiens sapiens
INED 41403


Global land surface available per person, from 60,000 years ago to today
60,000 BP
~5,000 km²/person
10,000 BP
~37 km²/person
5,000 BP
~10 km²/person
2,000 BP
~0.65 km²/person
Today
~0.018 km²/person
Land surface per person (km²/person)
10⁻²
10⁻¹
10⁰
10¹
10²
10³
−60000
−50000
−40000
−30000
−20000
−10000
0
Years before/after present

Energy and services

Humankind has built more and more tools; energy converts into services (mobility, heat, light, computation, industrial throughput).

- Social history: from muscle and animal traction to industrial systems — including coercive labour and fossil extraction as enablers of scale.
- Orders of magnitude (illustrative): modern societies often sit around tens of MWh per person per year of commercial energy — to be compared carefully with Sun–Earth fluxes (next slides).

Sun–Earth: intercepted power (orders of magnitude)

At the top of the atmosphere, the solar flux is $S_0 \approx 1361\ \mathrm{W/m^2}$. The Earth intercepts a disk of radius R_E:

$$P = S_0\,\pi R_E^2, \qquad R_E \approx 6371\ \mathrm{km}.$$

Reflected vs absorbed — annual energy

- Intercepted power order of magnitude: $P \approx 1.74 \times 10^{17}\ \mathrm{W} \approx 174{,}000\ \mathrm{TW}$.
- About 30% is reflected (albedo): clouds, aerosols, atmosphere, bright surfaces.
- Absorbed fraction ≈ 0.7: $P_{\mathrm{abs}} \approx 1.22 \times 10^{17}\ \mathrm{W}$, i.e. $\sim 10^9\ \mathrm{TWh/year}$.

Human primary energy vs absorbed sunlight

Global primary energy demand is roughly $\sim 10^5\ \mathrm{TWh/year}$ (order of 10^5–10^6 depending on year and accounting rules).

$$\frac{1.1 \times 10^9}{1.7 \times 10^5} \approx 6\,500$$

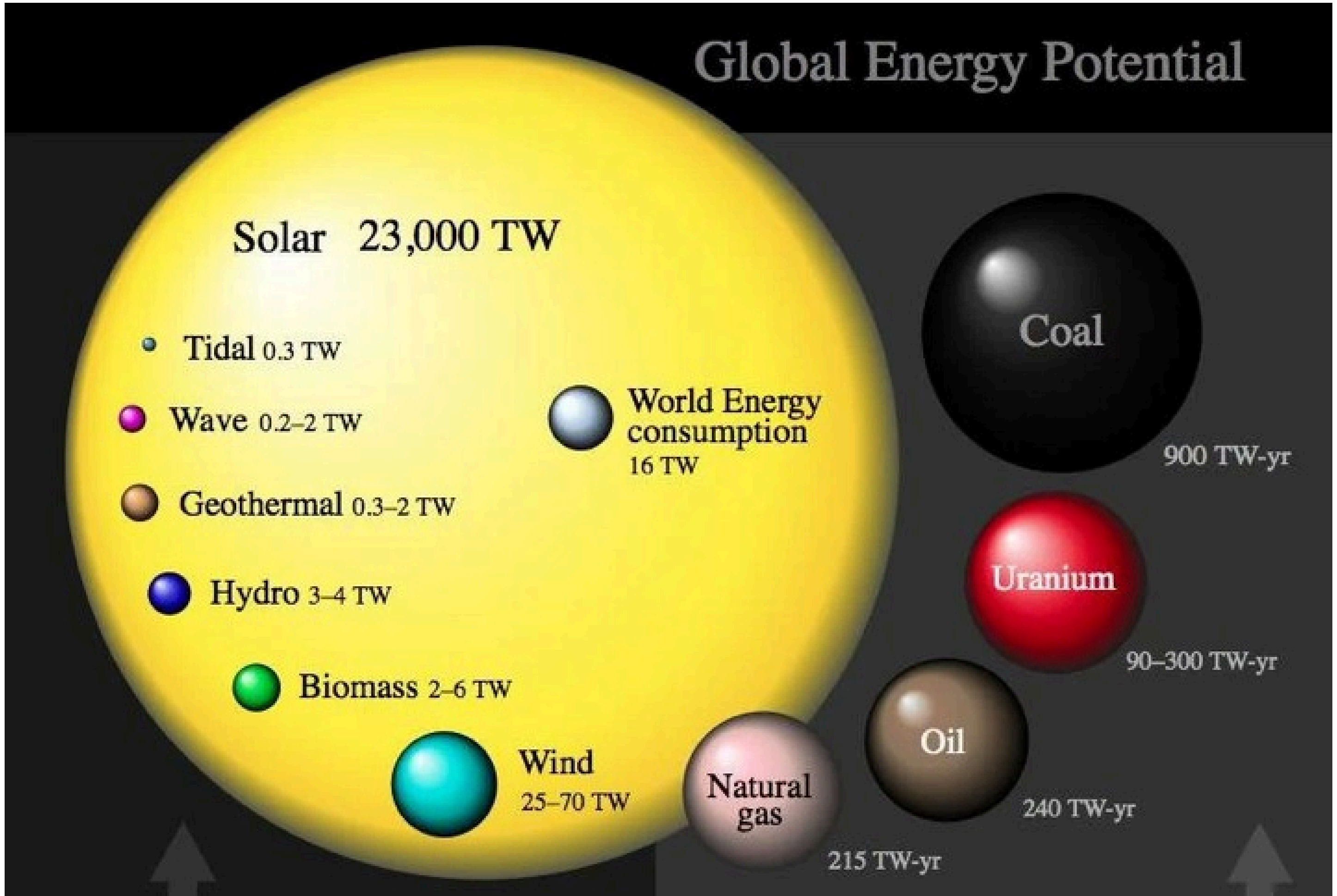
So absorbed solar throughput is thousands of times larger than human needs.

Note that most absorbed sunlight drives the climate engine (evaporation, circulation, chemistry), not a metered “energy service” for humans.

Societies rely heavily on fossil energy and concentrated vectors — not on capturing the whole planetary flux.

Supply-side view (orders of magnitude)

Perez & Perez (2009): *A Fundamental Look at Supply Side Energy Reserves for The Planet* — comparative resource scales (not annual rates, read legends carefully).



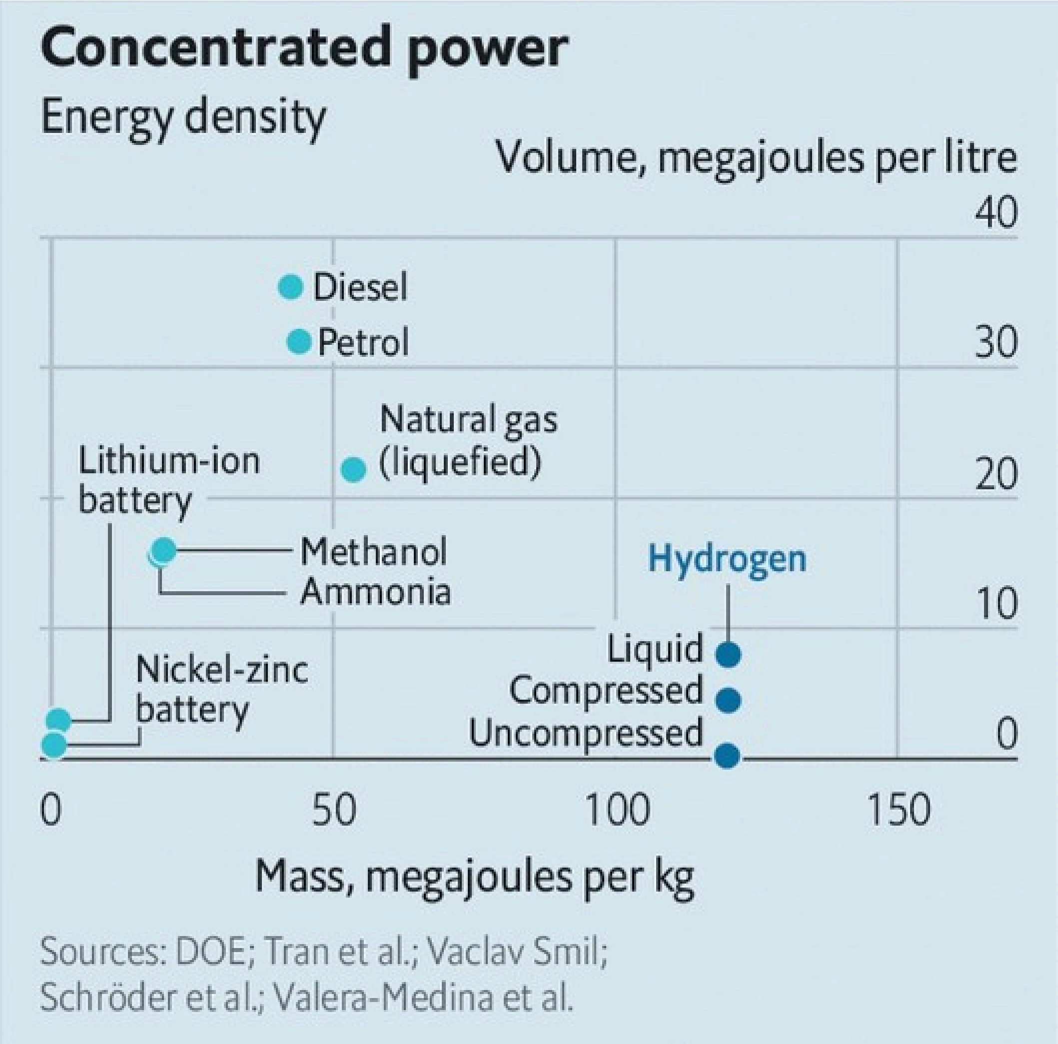
So why fossil fuels (historically)?

We do not “replace” the Sun with coal; we use concentrated, dispatchable stocks and infrastructures.

- Logistics: centralised conversion + grids and fuel chains simplify reliability at scale.
- Stocks vs flows: geological reserves decouple instant delivery from instant weather.
- Energy density: for transportation purpose,cfuels carry much more MJ per kg or per m^3 than any energy storage system..

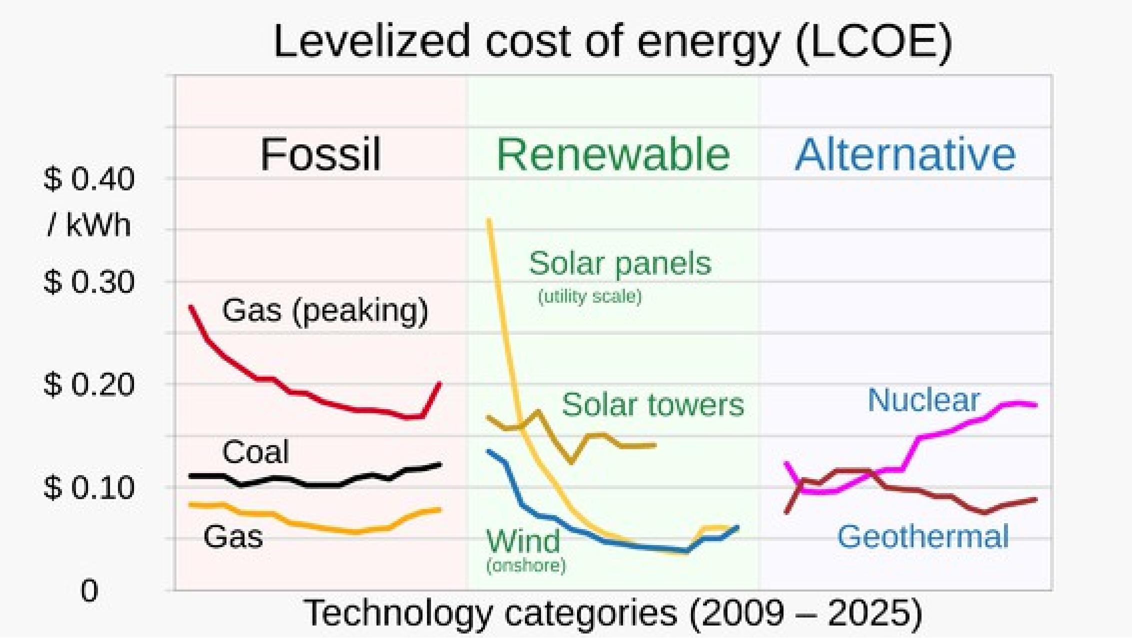
Volumetric / gravimetric power density

Power density (W/m², W/kg) matters for transport, urban form and infrastructure footprint.



Cost of energy (LCOE-style comparisons)

Economic competitiveness shapes deployment — but externalities (climate, air quality) are not always in the same price. Note the drop down of the cost of energy for solar and wind power in the last years.



Bottom line (for this course)

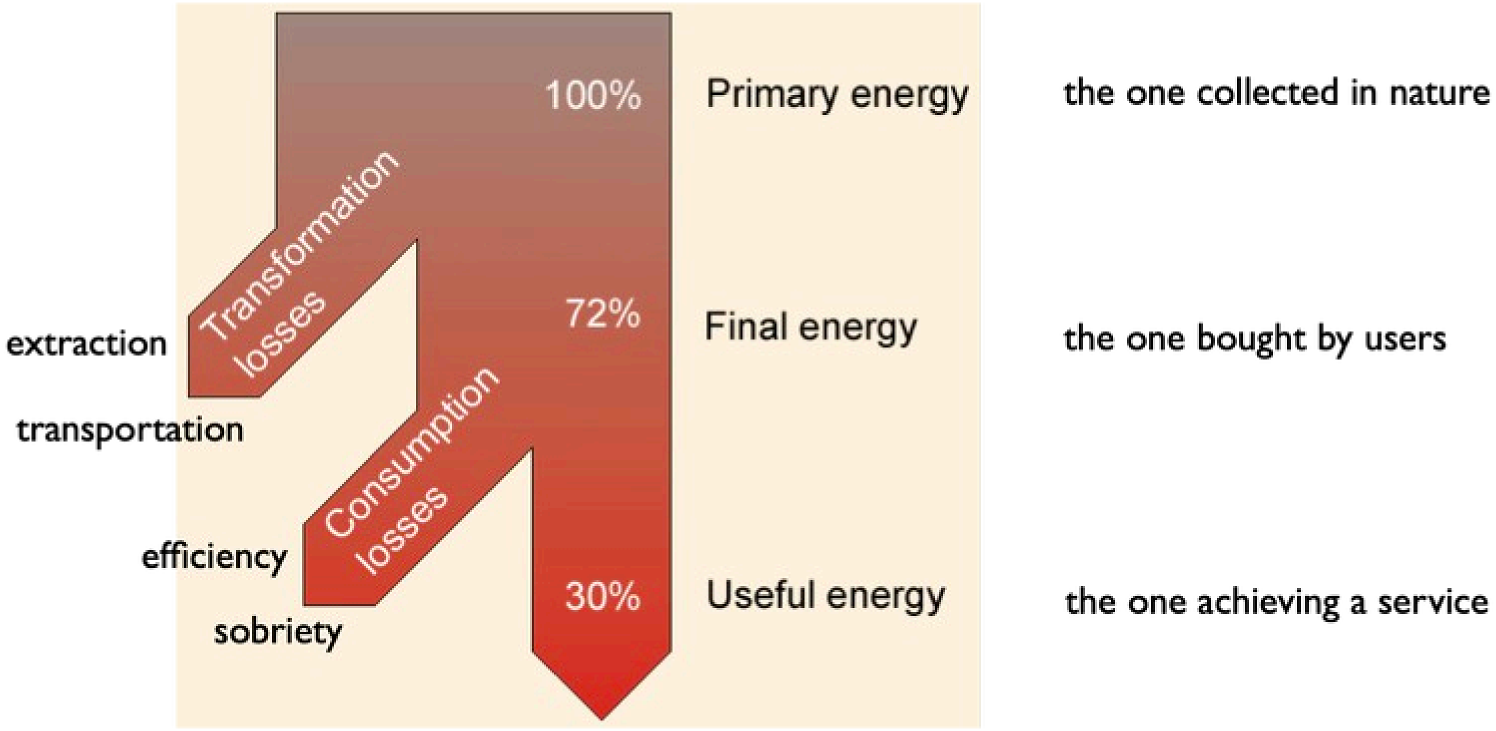
We could imagine a solar-based civilisation; historically we grew on dense, storable vectors.

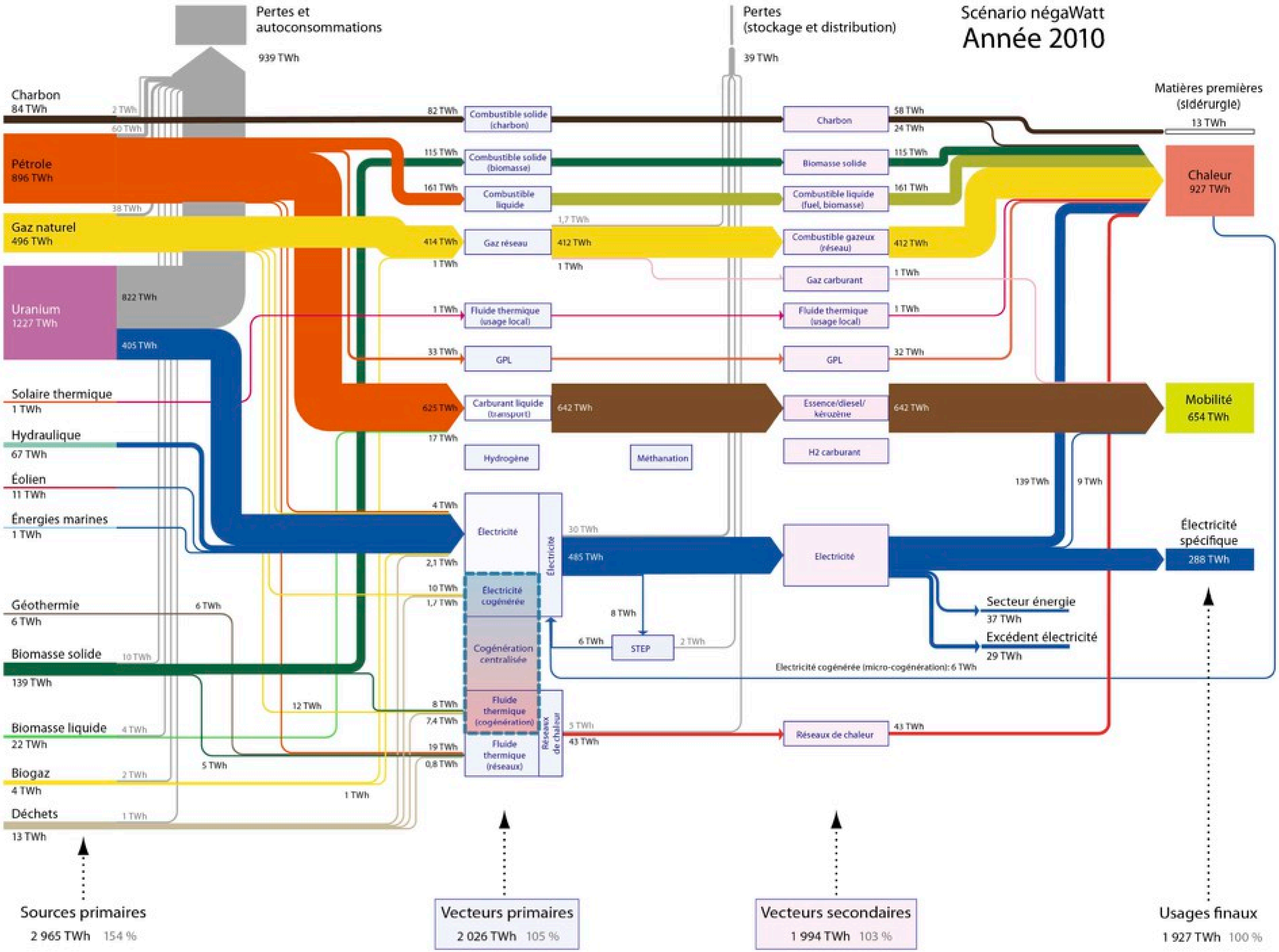
Buildings are central in this transition because they are spread all over the planet, are long-lived infrastructures, consume energy every day, and increasingly interact with several energy vectors: electricity, gas, heat networks, biomass, solar thermal, and photovoltaic systems.

Is the fossil fuel our property? Or is it our descendant's property too?

Different kinds of energies: from primary to final energy (Sankey logic)

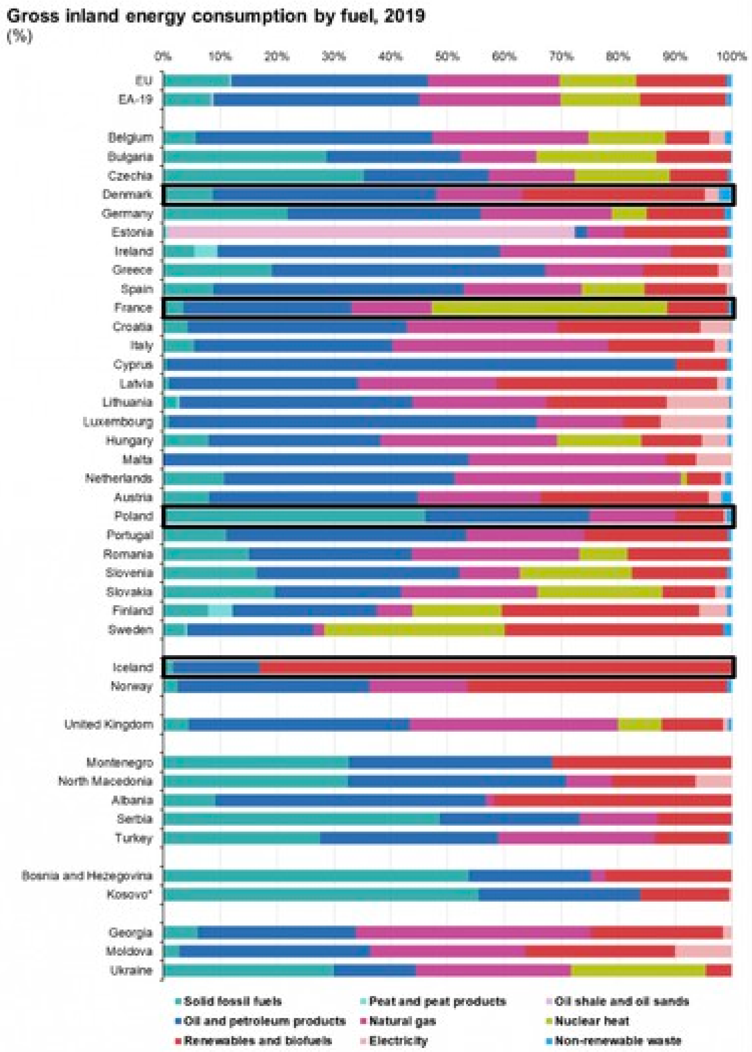
Primary → conversion / transport losses → final carriers used by end users. Electricity is secondary energy.



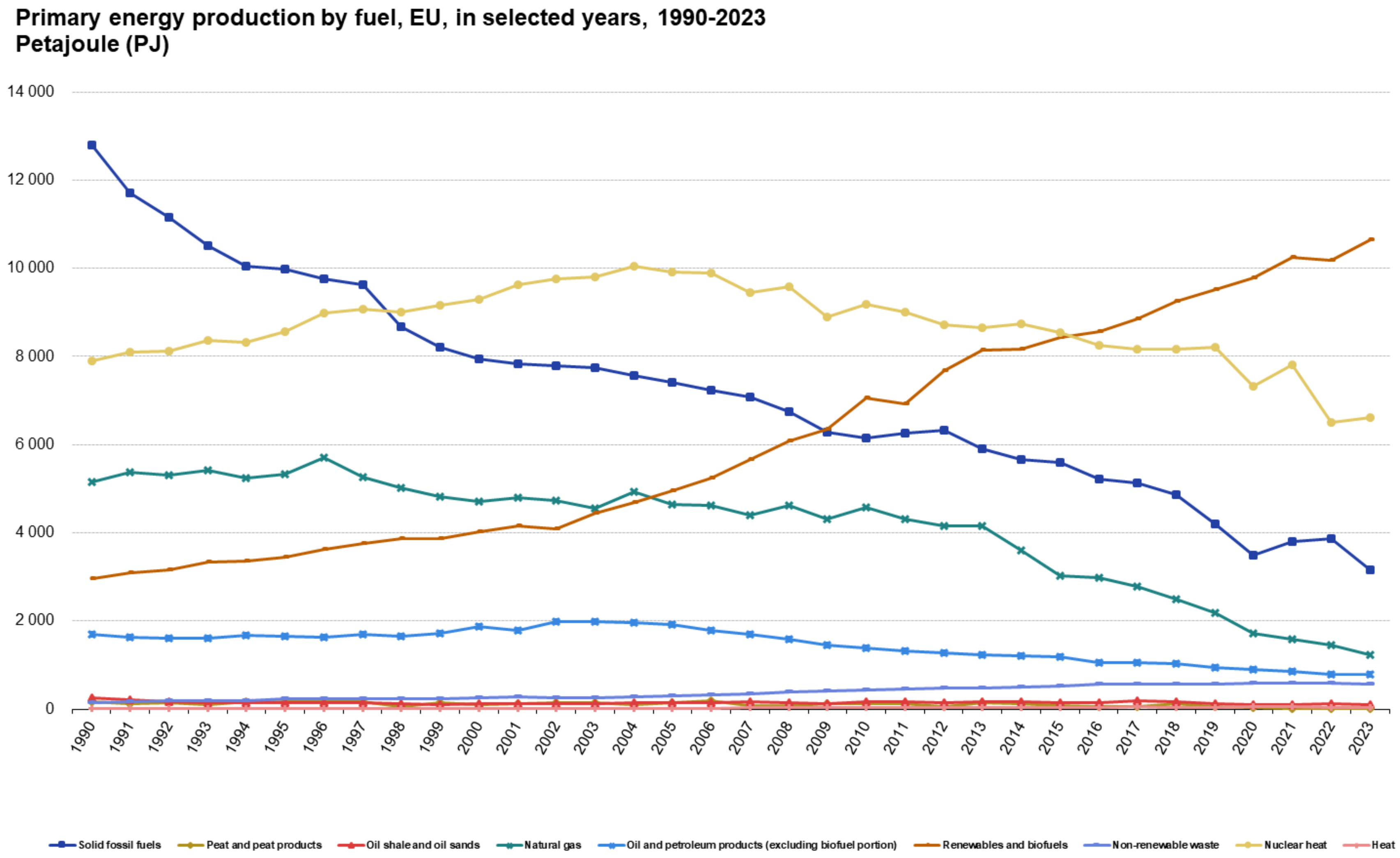

Scénario négaWatt
Année 2010
Pertes et autoconsommations
939 TWh
Pertes (stockage et distribution)
39 TWh
Charbon
84 TWh
Pétrole
896 TWh
Gaz naturel
496 TWh
Uranium
1227 TWh
822 TWh
405 TWh
Solaire thermique
1 TWh
Hydraulique
67 TWh
Éolien
11 TWh
Énergies marines
1 TWh
Géothermie
6 TWh
Biomasse solide
139 TWh
Biomasse liquide
22 TWh
Biogaz
4 TWh
Déchets
13 TWh
Combustible solide (charbon)
Combustible solide (biomasse)
Combustible liquide
Gaz réseau
Fluide thermique (usage local)
GPL
Carburant liquide (transport)
Hydrogène
Méthanation
Électricité
Électricité cogénérée
Cogénération centralisée
Fluide thermique (cogénération)
Fluide thermique (réseaux)
Réseaux de chaleur
STEP
Charbon
Biomasse solide
Combustible liquide (fuel, biomasse)
Combustible gazeux (réseau)
Gaz carburant
Fluide thermique (usage local)
GPL
Essence/diesel/kérosène
H2 carburant
Électricité
Matières premières (sidérurgie)
13 TWh
Chaleur
927 TWh
Mobilité
654 TWh
Électricité spécifique
288 TWh
Secteur énergie
37 TWh
Excédent électricité
29 TWh
Électricité cogénérée (micro-cogénération): 6 TWh
Sources primaires
2 965 TWh 154 %
Vecteurs primaires
2 026 TWh 105 %
Vecteurs secondaires
1 994 TWh 103 %
Usages finaux
1 927 TWh 100 %

Energy mix — Europe (map)

Gas, coal, hydro, wind… national security, price, and policy trajectories differ.

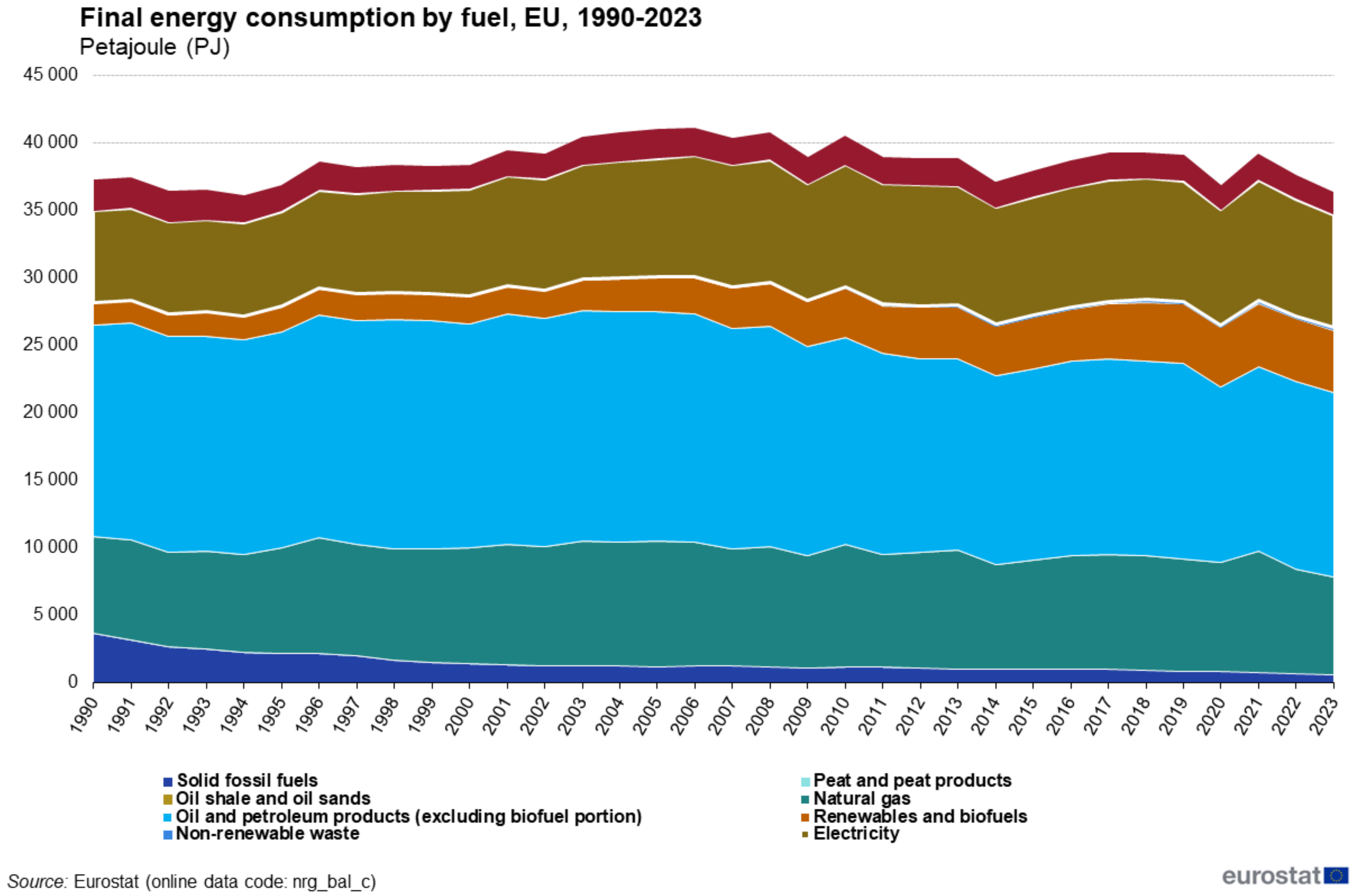


Primary energy production by fuel in EU (1990-2023)



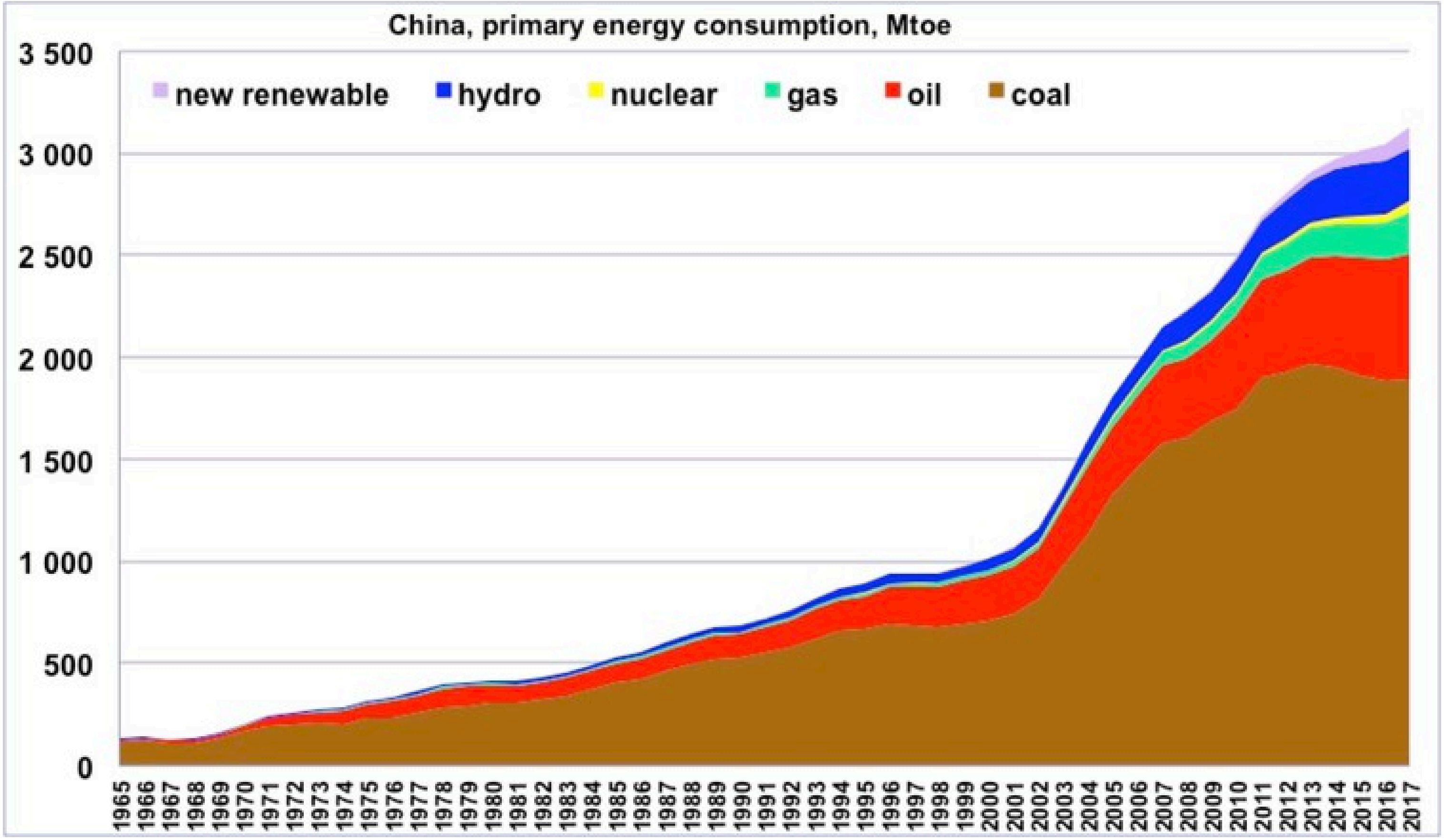
Source: Eurostat (online data code: nrg_bal_c)

Final energy consumption by fuel in EU (1990-2023)



China — consumption context

Scale effects: industry, power sector, urbanisation — compare per capita vs absolute totals when interpreting.



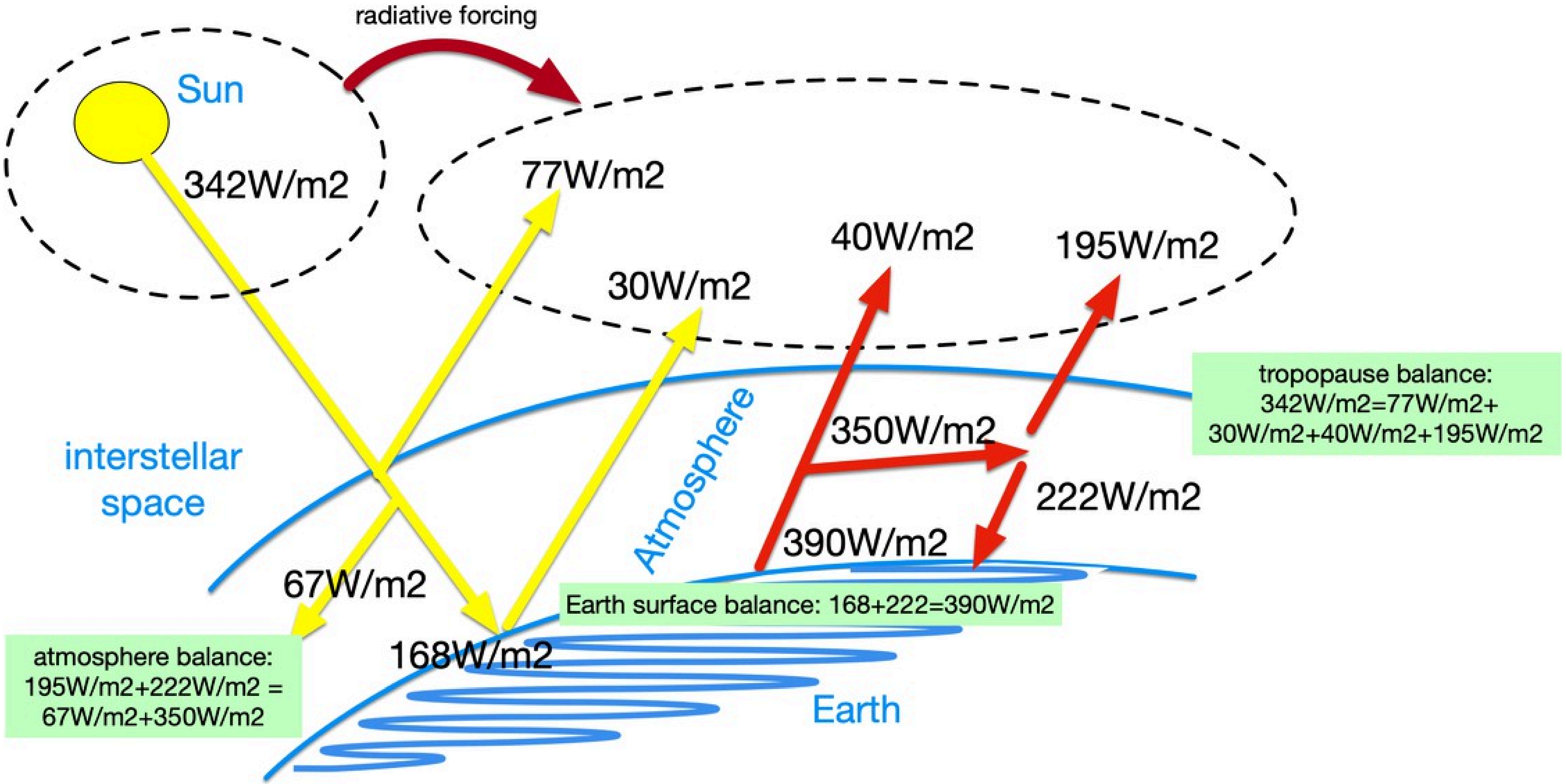
CO_2, Water Vapor, Radiative Forcing, and Global Warming

A scientifically consistent causal chain for explaining the greenhouse effect, the energy imbalance, and GWP

$$\mathrm{CO_2} \rightarrow \text{direct radiative forcing} \rightarrow \text{warming} \rightarrow \text{increased water vapor} \rightarrow \text{amplification}$$

CO_2 is a direct forcing agent; water vapor is mainly an amplifying feedback.

Radiative forcing is the change in net radiative flux at the tropopause (or top-of-atmosphere in some conventions) after stratospheric adjustment — a key bridge between composition and warming.


radiative forcing
Sun
342W/m2
77W/m2
40W/m2
195W/m2
30W/m2
tropopause balance:
342W/m2=77W/m2+
30W/m2+40W/m2+195W/m2
interstellar
space
Atmosphere
350W/m2
222W/m2
390W/m2
67W/m2
Earth surface balance: 168+222=390W/m2
atmosphere balance:
195W/m2+222W/m2 =
67W/m2+350W/m2
168W/m2
Earth

The Greenhouse Effect: Minimal Physical Picture

Earth mainly receives shortwave solar radiation and emits infrared radiation back to space.

````
Sun → shortwaves directed and reflected by the ground
→ GHG transform shortwaves into longwaves at all directions
→ atmosphere opaque for some longwaves (15 µm band)
→ shortwaves are absorbed by the atmosphere instead of being refleted
→ more GHG, more heat

<small>

Some gases absorb and re-emit infrared long-wave radiations:
| water vapor: $\mathrm{H_2O}$ | fluorinated gases |
|------------------------------|-------------------|
| **carbon dioxide: $\mathrm{CO_2}$** | **methane: $\mathrm{CH_4}$** |
| **nitrous oxide: $\mathrm{N_2O}$** | |
</small>

---

## CO₂: A Direct Greenhouse Gas

CO₂ directly absorbs infrared radiation, notably around the $15\,\mu\mathrm{m}$ band.

Two characteristics make it climatically decisive:

- it is well mixed in the atmosphere;
- it is long-lived: part of emitted CO₂ persists for a very long time in the climate system.

An increase in CO₂ reduces the net outgoing infrared flux to space, for an unchanged temperature. This is a positive radiative forcing.

But C_O$2$ is not our enemy because it feeds vegetation: with 120ppm of CO2, during the middle-age was less fertile than todays.

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## Water Vapor: A Dominant Gas, but Mainly a Feedback

Water vapor is a powerful greenhouse gas, but its atmospheric concentration is strongly constrained by temperature and condensation.

When air warms, its capacity to contain water vapor increases approximately according to the Clausius–Clapeyron relationship:

$$
\frac{d e_s}{e_s} \approx 7\% \ \mathrm{K}^{-1}
$$

where $e_s$ is the saturation vapor pressure.

Therefore:

$$
\text{initial warming}
\rightarrow \text{more water vapor}
\rightarrow \text{increased IR opacity}
\rightarrow \text{amplified warming}
$$

---

## Forcing vs Feedback

| Concept      | Example                                   | Climate role                                             |
| ------------ | ----------------------------------------- | -------------------------------------------------------- |
| Forcing  | CO₂ added by fossil fuel combustion         | Persistent external perturbation of the radiative balance |
| Feedback | Water vapor increasing with temperature     | Amplification or damping of the response                  |
| Response | Increase in global mean surface temperature | Adjustment of the climate system                          |

CO₂ is often the control knob; water vapor is a rapid amplification driven by temperature.

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## Radiative Forcing: Formalization

Effective radiative forcing $F$ measures the perturbation of the energy balance at the top of the atmosphere, in $\mathrm{W\,m^{-2}}$.

<div class="formula">


$F>0$: the Earth gains energy
$F<0$: the Earth loses energy

</div>

Examples of positive forcings: CO₂, CH₄, N₂O, some fluorinated gases.

Examples of negative or partially compensating forcings: some reflective aerosols, albedo changes.

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## Useful Approximation for CO₂

A classical approximation of CO₂ radiative forcing is:

$$
\Delta F_{CO_2}\approx 5.35 \ln\left(\frac{C}{C_0}\right)
$$

where:

- $C_0$: reference concentration;
- $C$: current or future concentration;
- $\Delta F$: forcing in $\mathrm{W\,m^{-2}}$.

A doubling of CO₂ gives approximately:

$$
\Delta F_{2\times\mathrm{CO_2}} \approx 3.7\ \mathrm{W\,m^{-2}}
$$

---

## Energy Imbalance and Temperature

The global balance can be summarized as:

$$
N = F - \lambda \Delta T
$$

where:

- $N$: net Earth energy imbalance;
- $F$: radiative forcing;
- $\lambda$: climate feedback parameter;
- $\Delta T$: global mean temperature increase.

If $N>0$, the system accumulates energy, mostly in the ocean.

Temperature rises until increased infrared emission approximately restores equilibrium: $N \rightarrow 0$.
<!-- rightarrow 0$. -->

---

## Complete Causal Chain

```text
Anthropogenic emissions
        ↓
Atmospheric GHG concentrations
````
````

GWP: What It Measures

Global Warming Potential compares the cumulative climate effect of a gas with that of CO_2 over a given time horizon.

$$\mathrm{GWP}_H(i) = \frac{\int_0^H RF_i(t)\,dt}{\int_0^H RF_{\mathrm{CO_2}}(t)\,dt}$$

By convention, RF=Radiative Forcing and:

$$\mathrm{GWP}_H(\mathrm{CO_2}) = 1$$

The choice of the horizon H is crucial: 20 years, 100 years, or 500 years do not tell the same story.

Examples of GWP Values from AR6

Gas	Symbol	GWP20	GWP100	Interpretation
Carbon dioxide	CO_2	1	1	Reference
Fossil methane	CH_4	82.5	29.8	Very strong in the short term
Non-fossil methane	CH_4	80.8	27.2	Very strong in the short term
Nitrous oxide	N_2O	273	273	Long atmospheric lifetime

Example:

$$1 \text{ kg fossil CH}_4 \approx 29.8 \text{ kg CO}_2\text{e} \quad \text{over 100 years}$$

Source: IPCC AR6 values summarized by Greenhouse Gas Protocol (2024).

Important Distinction: GWP of Gases ≠ Impact of Energy Sources

GWP is a relative property of gases.

The climate impact of an energy source depends on an emissions inventory:

$$\mathrm{CO_2e} = \sum_i m_i \times \mathrm{GWP}_{100,i}$$

For electricity, the result is often expressed as:

$$\mathrm{gCO_2e\,kWh^{-1}}$$

Therefore, one must distinguish:

- the gas: CO_2, CH_4, N_2O;
- the energy carrier: electricity, heat, fuel;
- the technology: coal, natural gas, nuclear, hydropower, solar, wind, biomass.

Orders of Magnitude: Electricity by Technology

Median life-cycle values, in $\mathrm{gCO_2e\,kWh^{-1}}$.

Technology	Indicative median
Coal	820
Natural gas, combined cycle	490
Dedicated biomass	230
Utility-scale solar PV	48
Geothermal	38
Hydropower	24
Concentrated solar power	27
Offshore wind	12

How to Calculate the Climate Impact of an Energy Source

Simplified life-cycle assessment method:

$$I = \frac{\sum_s \sum_i m_{s,i}\, \mathrm{GWP}_{100,i}}{E_{\text{useful}}}$$

where:

- s: life-cycle stages;
- i: emitted gas;
- $m_{s,i}$: mass of gas i emitted at stage s;
- E_{useful}: useful energy produced over the lifetime.

Typical stages: extraction, transport, manufacturing, construction, operation, fuel supply, maintenance, decommissioning, end of life.

Numerical Example: Electricity

Assume an electricity consumption of:

$$E = 10\ \mathrm{MWh} = 10{,}000\ \mathrm{kWh}$$

If the carbon intensity is:

$$I = 400\ \mathrm{gCO_2e\,kWh^{-1}}$$

then:

$$\mathrm{emissions} = 10{,}000 \times 400 = 4{,}000{,}000\ \mathrm{gCO_2e}$$

that is:

$$4\ \mathrm{tCO_2e}$$

Why the Time Horizon Changes the Message

Methane has a shorter atmospheric lifetime than CO_2, but a strong short-term radiative effect.

Therefore:

- with GWP_{20}, methane appears much more critical;
- with GWP_{100}, its impact is averaged over a century;
- for climate neutrality, one must also reason in terms of time trajectories, not only in tonnes of $\mathrm{CO_2e}$.

$\mathrm{CO_2e}$ is useful for aggregation, but it hides different climate dynamics.

One-Sentence Synthesis

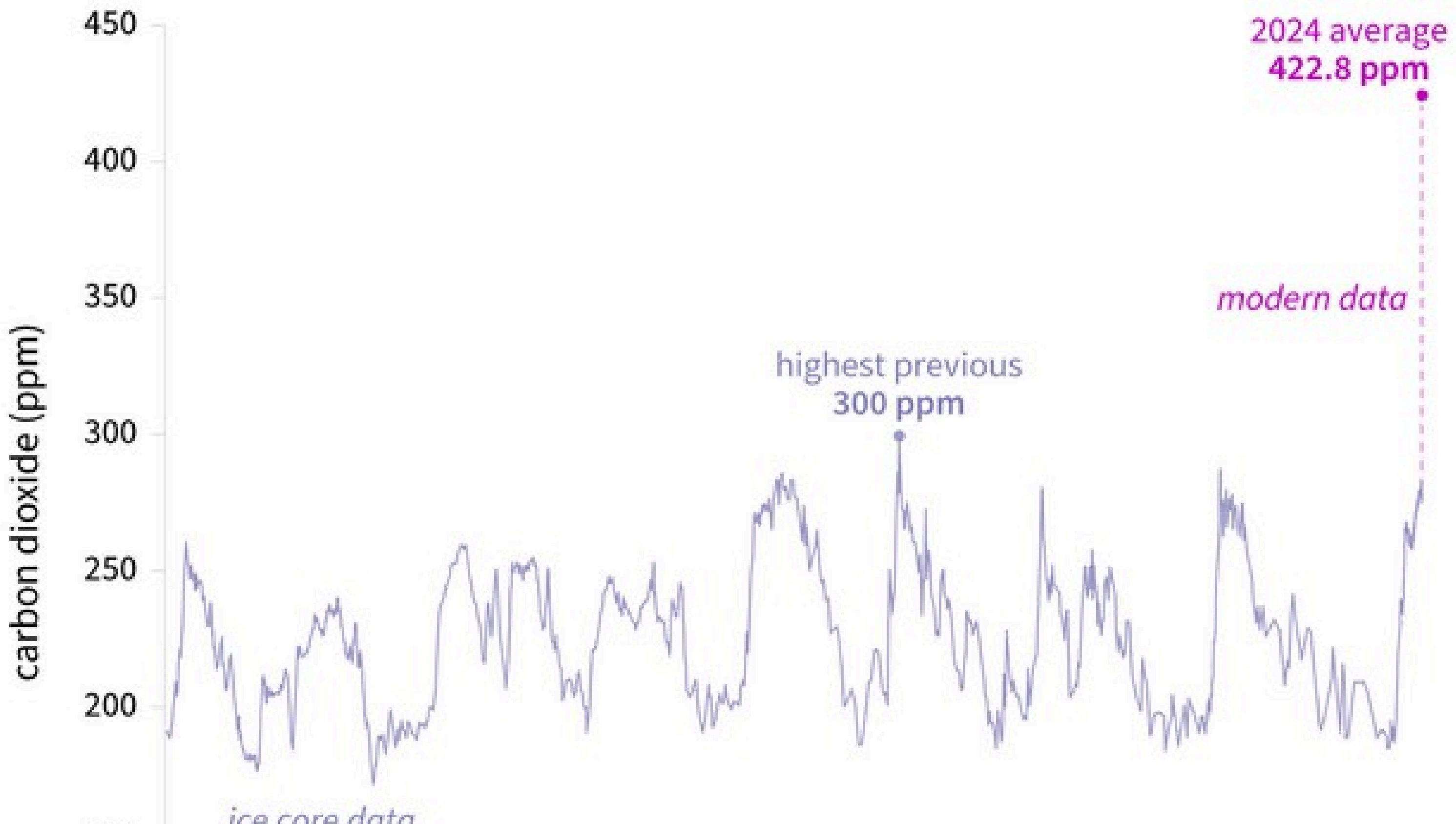
CO_2 acts directly on the radiative balance; the initial warming increases water vapor, which amplifies the effect; as long as positive forcing is not compensated by increased infrared emission, the Earth accumulates energy and temperature rises.

For energy sources, the relevant indicator is not an “energy GWP”, but a life-cycle intensity in $\mathrm{gCO_2e\,kWh^{-1}}$, calculated by converting each emitted gas using its GWP.

CO_2 in the atmosphere (Mauna Loa–type curve)

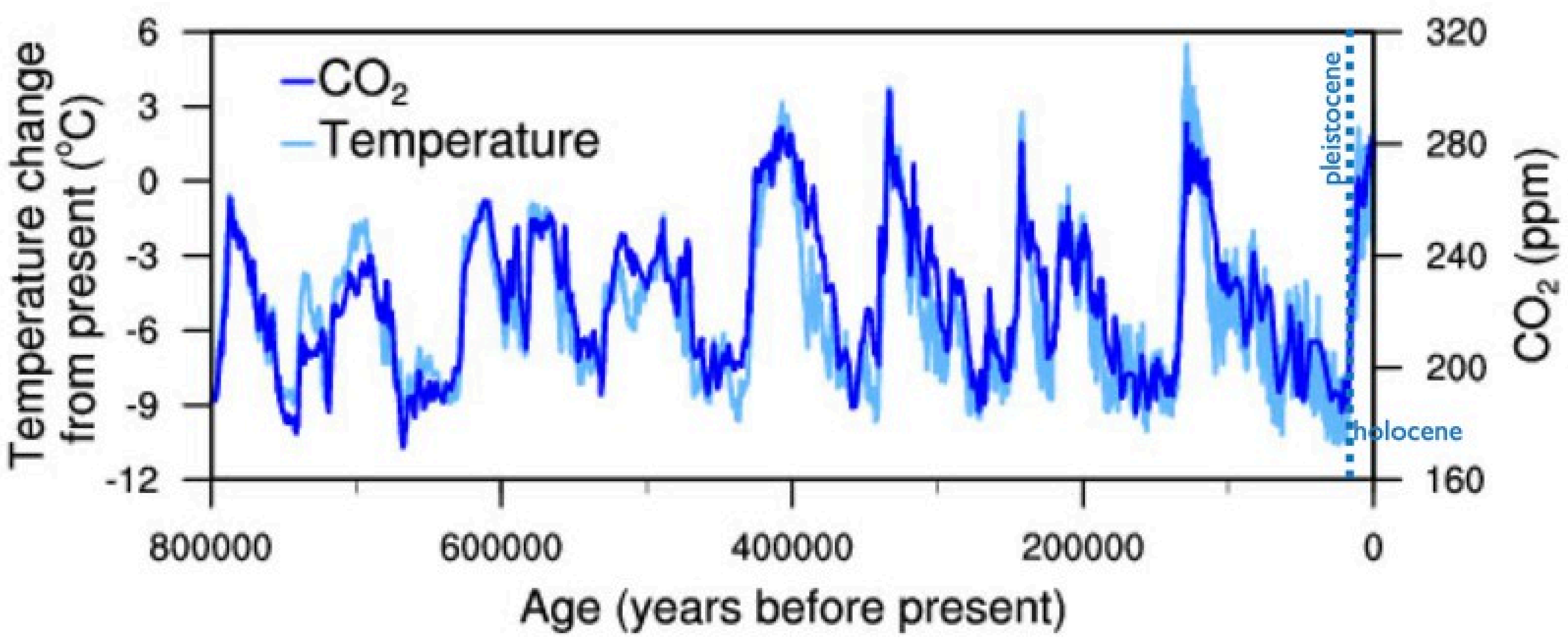
Long-term rise + seasonal cycle (Northern Hemisphere land biosphere). Stock of CO_2 matters for radiative forcing.

Here is the evolution of the CO2 concentration in the atmosphere over 800,000 years.



CO_2 is good for vegetation growth but the problem is: it is highly correlated to global temperature.

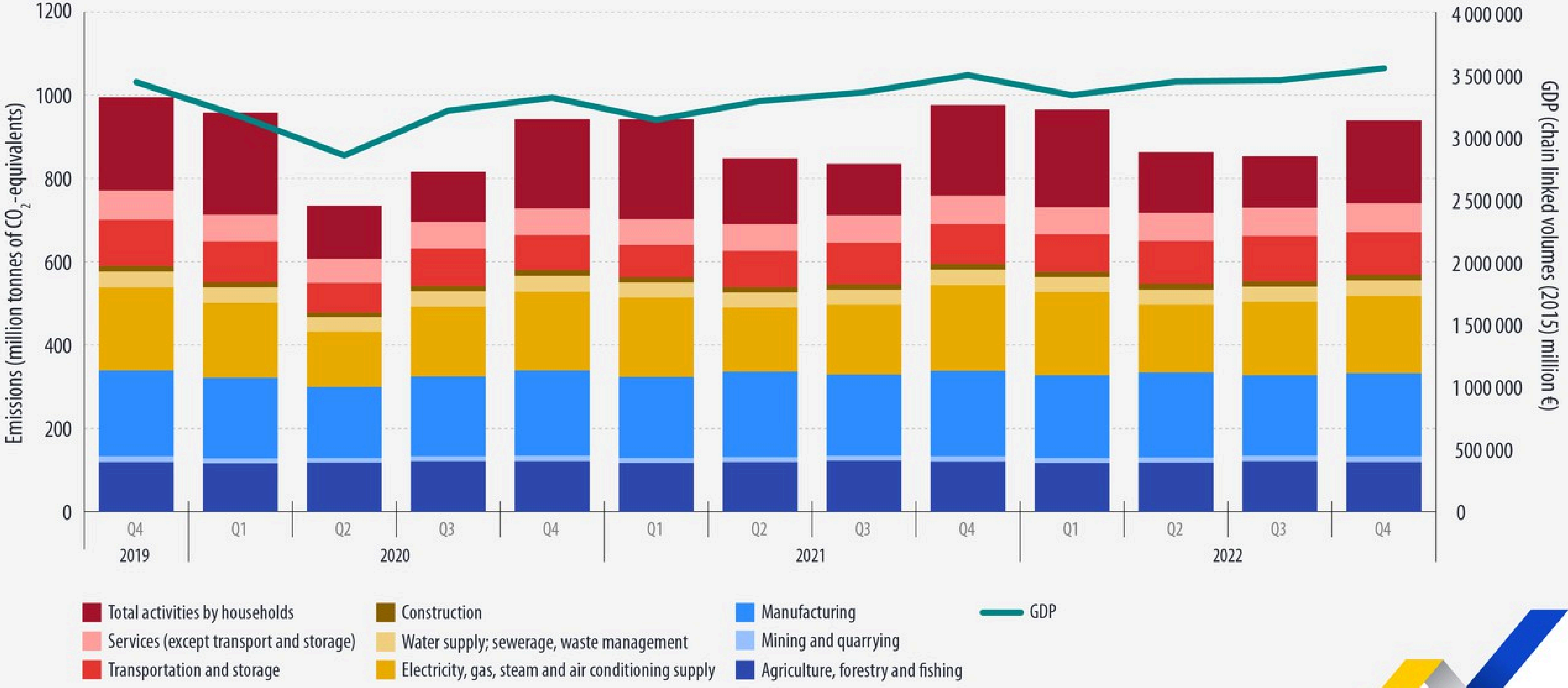
Correlation on long time scales; attribution uses models + process evidence. Use this figure as motivation for climate sessions (`slides02_climate`).



Thin atmosphere (scale intuition)

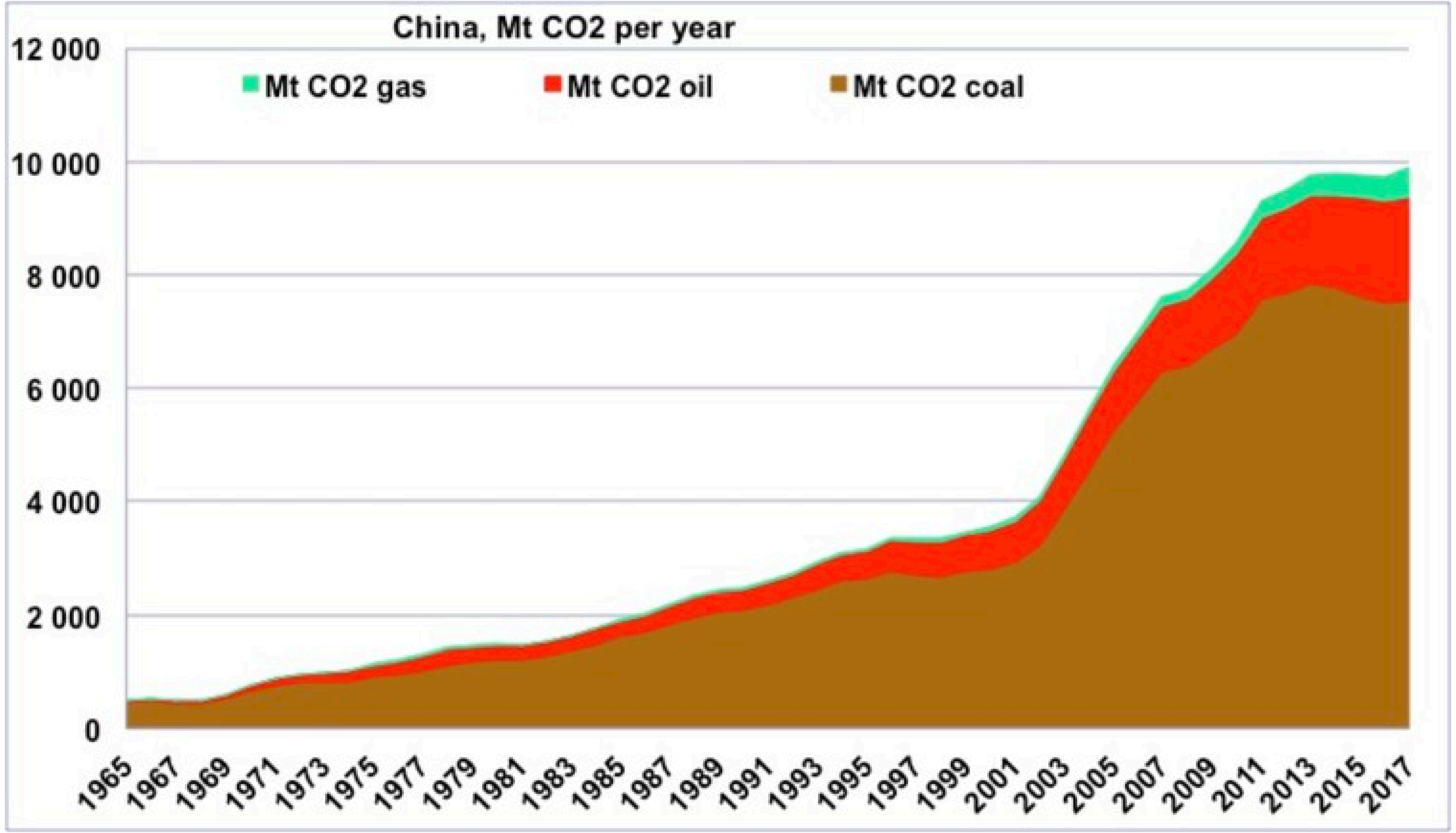
Greenhouse gas emissions by the economy and GDP, EU, Q4 2019 - Q4 2022

(million tonnes of CO_2 equivalents, chain linked volumes (2015) million €)

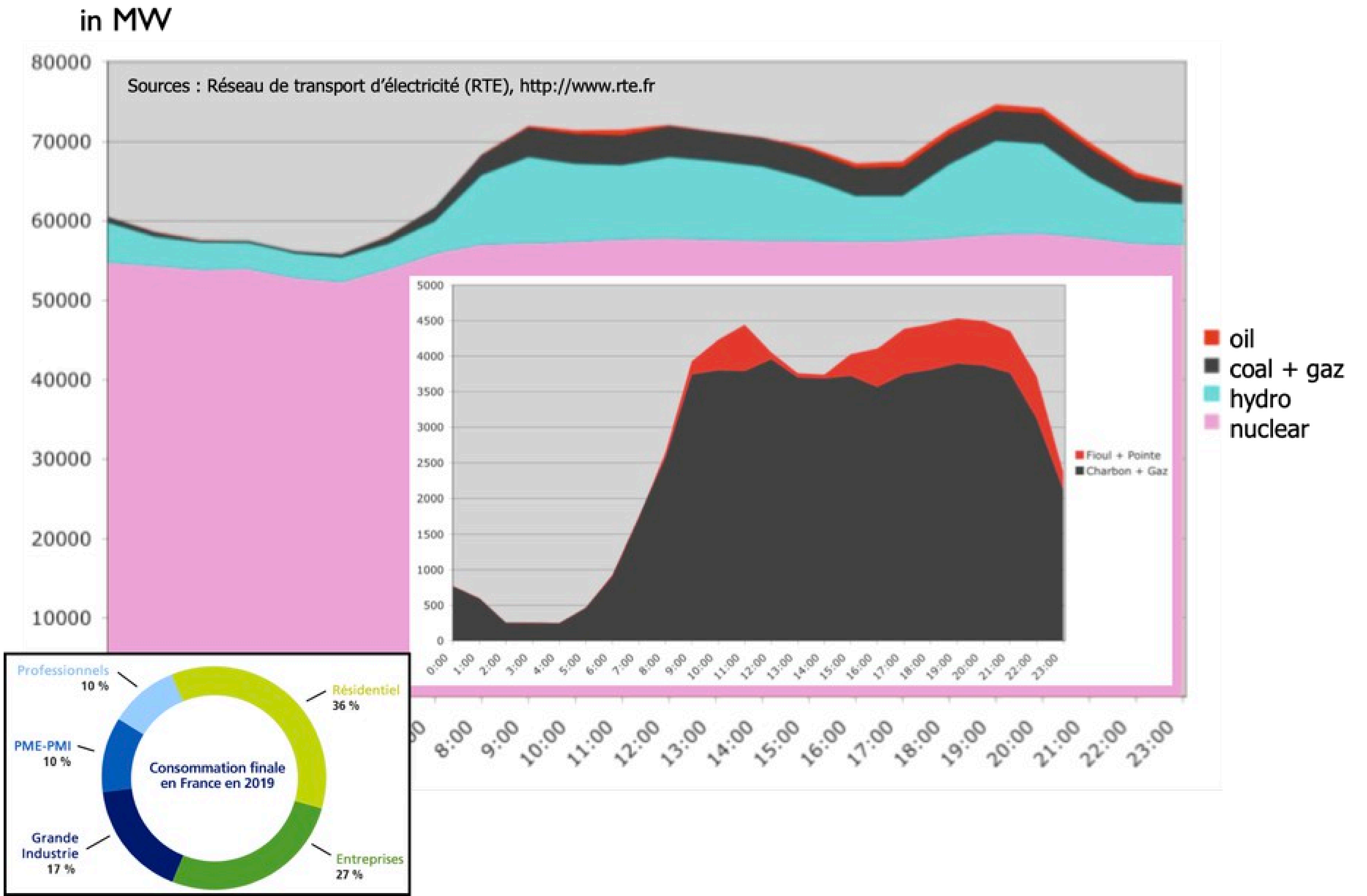


China — CO_2 (example trajectory)

Same warning: absolute vs per capita, and accounting boundaries.

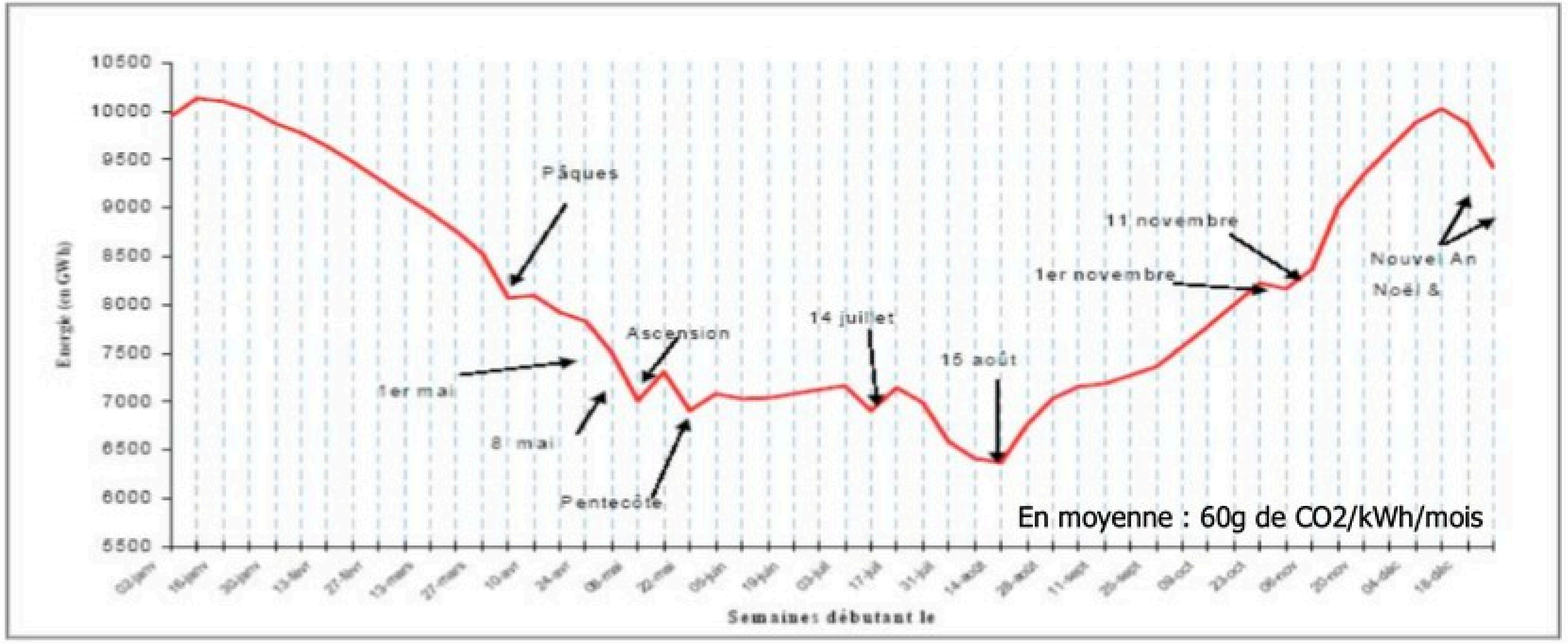


typical evolution of infra-day production



Same useful energy, different carbon intensity

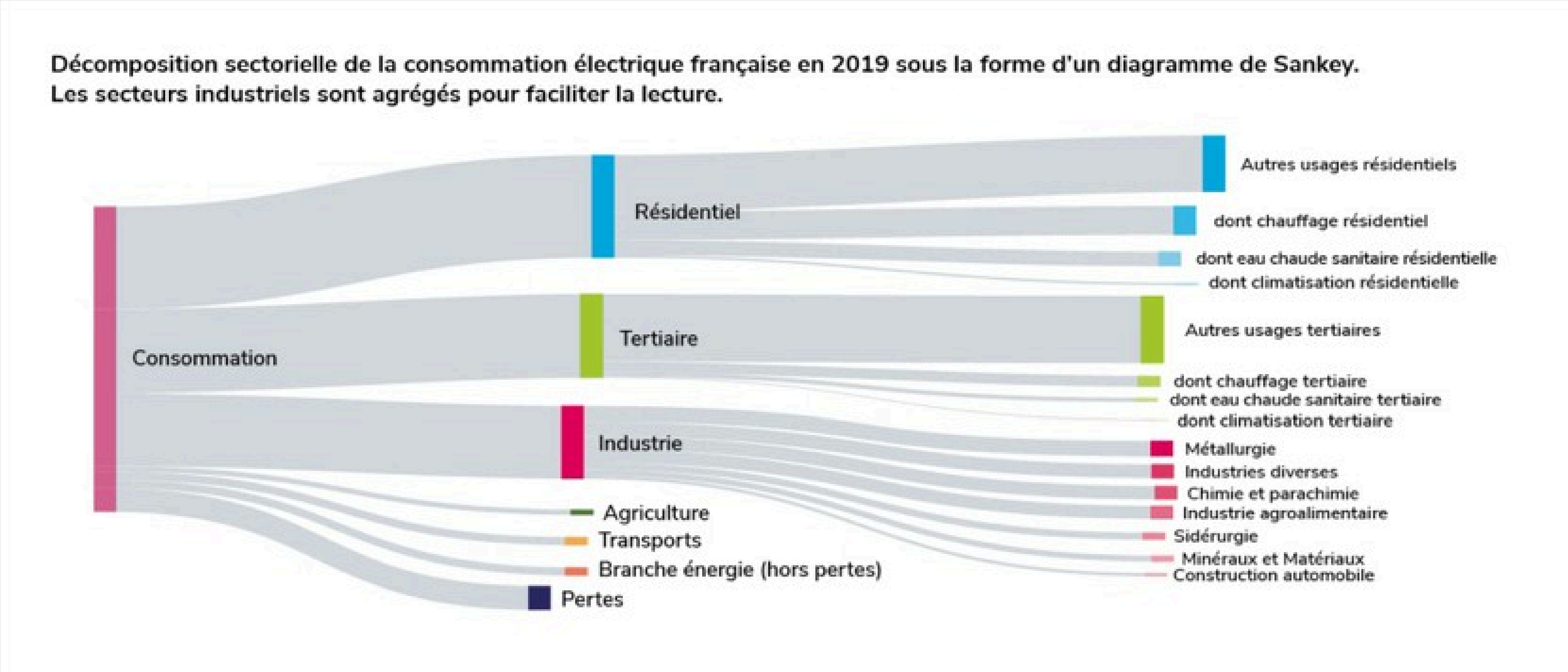
Vectors matter: 1 kWh from coal vs 1 kWh from wind do not carry the same CO_2.



Sources : Réseau de transport d'électricité (RTE), http://www.rte.fr

Electricity end-uses in France (example split)

Residential shares: heating, hot water, appliances — where efficiency and flexibility bite.



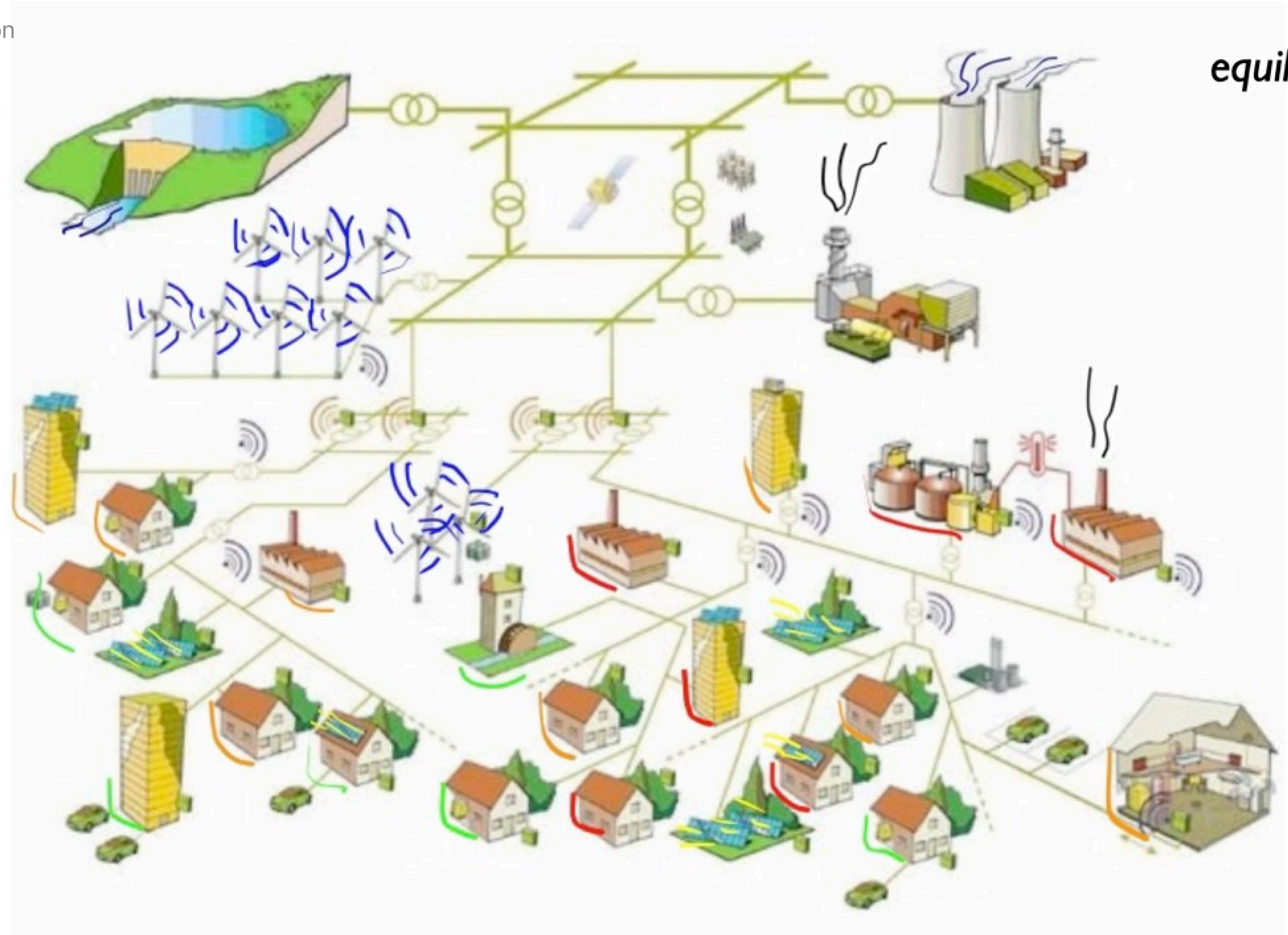
Power grid (infrastructure)

- The electric grid has always to balance production and consumption of electricity.
- Developing renewable energy sources, like wind and solar, makes the grid more complex to balance.
- The consequence is that actors have to be more flexible to balance the production and the consumption of electricity.

This can be achieved by:

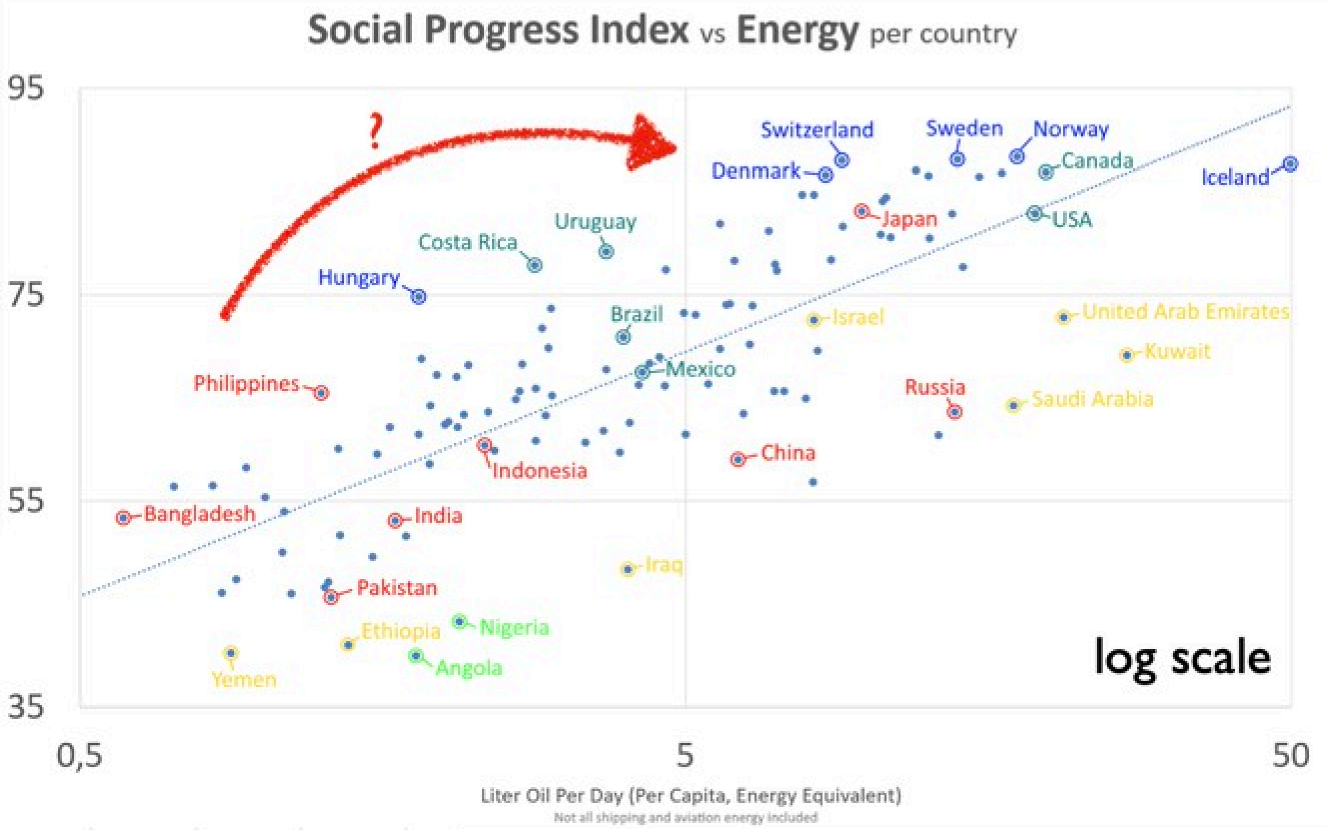
- increasing the flexibility of production means (e.g. gas turbines, hydroelectric power plants, nuclear plants, hydro dams in mountains,...)
- using pumping and turbine station (PTS or STEP in France) for hydropower
- increasing the use of storage systems
- developing the use of flexible loads (e.g. electric vehicles, industries, HVAC systems)

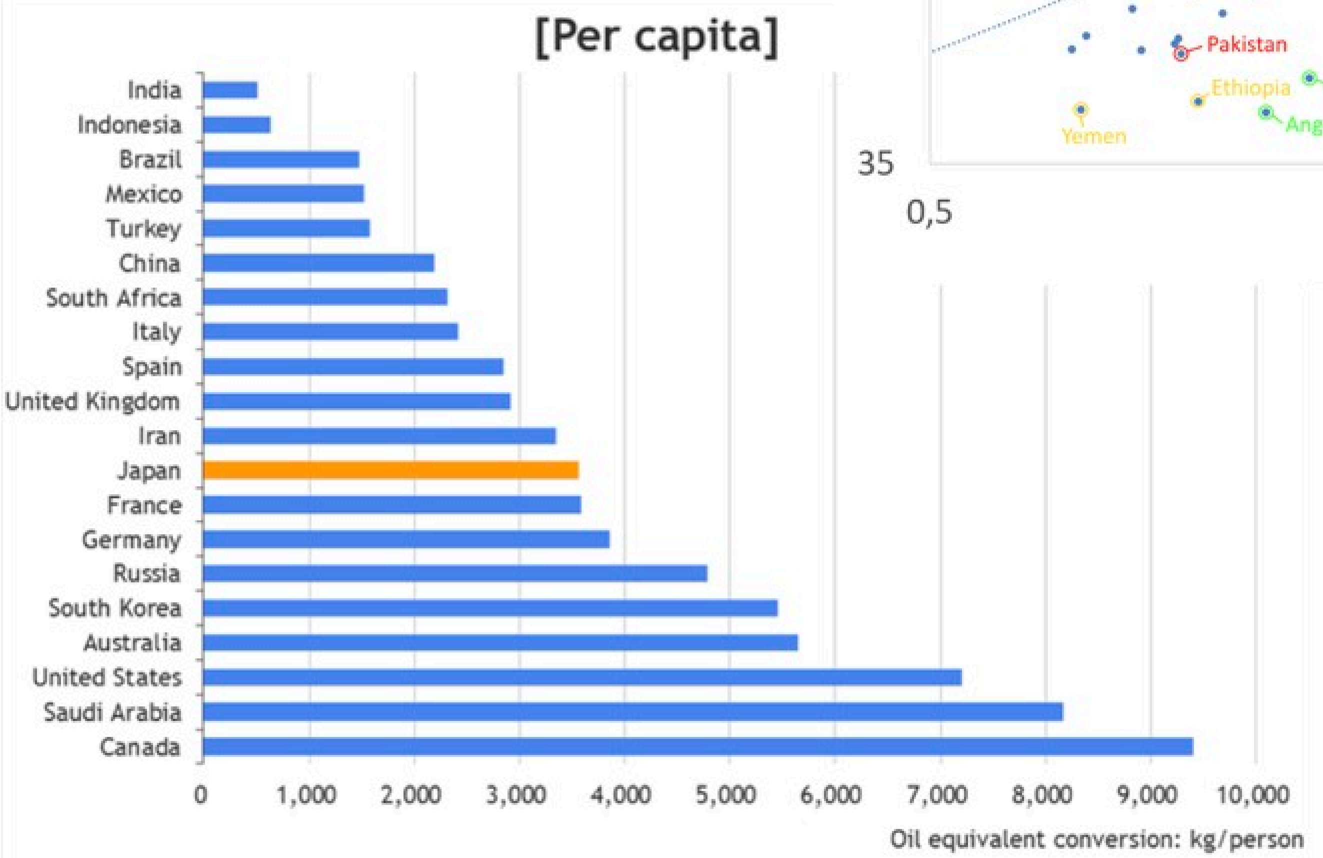
equilibrium



Social / development indices (context only)

Energy access correlates with development metrics — but sustainability adds climate and resource constraints.


Social Progress Index vs Energy per country
95
75
55
35
0,5
5
50
?
Switzerland
Sweden
Norway
Denmark
Canada
Iceland
Japan
USA
Uruguay
Costa Rica
Hungary
Brazil
Israel
United Arab Emirates
Kuwait
Mexico
Philippines
Russia
Saudi Arabia
Indonesia
China
Bangladesh
India
Iraq
Pakistan
Ethiopia
Nigeria
Angola
Yemen
log scale
Liter Oil Per Day (Per Capita, Energy Equivalent)
Not all shipping and aviation energy included


[Per capita]
India
Indonesia
Brazil
Mexico
Turkey
China
South Africa
Italy
Spain
United Kingdom
Iran
Japan
France
Germany
Russia
South Korea
Australia
United States
Saudi Arabia
Canada
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
Oil equivalent conversion: kg/person

Regulations: the French way

A high-performance energy construction or renovation aims at reaching DPE (Energy Performance Assessment) class A or B

- It generally covers six work packages:
    - walls, floors, roof
    - windows and external joinery
    - ventilation
    - heating and domestic hot water

The Environmental Regulation 2020 (RE2020)

For New Buildings

RE2020 applies to new construction. It replaces RT2012 and introduces three main objectives to improve the energy performance of buildings:

- reduce energy needs
- reduce energy consumption of non-renewable primary energy
- reduce carbon impact over the building life cycle
- improve summer comfort
- deploy renewable energy sources aiming at being positive over the year

Main Indicators

- Bbio: bioclimatic design and energy needs
- Cep: primary energy consumption
- Cep,nr: non-renewable primary energy
- Ic energy: carbon impact of energy use
- Ic construction: carbon impact of materials and construction
- DH: discomfort degree-hours in summer

For Existing Buildings

There is no “RE2020 for existing buildings” in the same sense.

Existing buildings are mainly governed by:

- RT existing buildings, element by element
- RT existing buildings, global approach
- DPE, energy audit, renovation obligations and incentives

New buildings	Existing buildings
RE2020	RT existing buildings
Energy + carbon + summer comfort	Minimum performance during renovation
Whole-building design logic	Work-package or global renovation logic
Life-cycle carbon assessment	Mainly thermal and energy requirements

DPE and Energy Audit in France

- The DPE is legally binding and required for sale or rental
- It progressively restricts rental of energy-inefficient dwellings
- Energy audits prescribe coherent renovation pathways
- Main target: move from poor classes toward class E, then class B

Limits of Standard Assessment

- The 3CL-DPE method is conventional, not based on real consumption
- Occupant practices and sufficiency are weakly represented
- Results are sensitive to input data
- Reliability is debated for old, complex, or atypical buildings
- Small dwellings may be disadvantaged by DHW in kWh/m².year
- The performance gap
    - Real consumption often differs from simulated consumption
    - Poor dwellings may consume less than predicted due to under-heating
    - Efficient dwellings may consume more than predicted
    - Gap direction depends on building stock, calculation method, and practices

Efficiency vs Sufficiency

- Energy efficiency improves service per unit of resource
- Energy sufficiency changes practices to preserve well-being with fewer resources
- Examples:
    - adaptive use of rooms
    - shading and ventilation practices
    - mobility, food, tourism, and service-based choices

How can sufficiency be encouraged in renovation decisions without relying only on regulation?

IPCC estimates than improvement in efficiency can lead to a reduction from 20% to 40% of the energy demand by 2050 (reference year 1990).

It also estimates that developing sufficient behaviours can lead to a reduction from 40% to 70% of the energy demand by 2050 (reference year 1990).

Key issues:

- social justice, acceptability
- real capacity to act
- collective decision-making
- inclusion
- value choices for society

A new idea the Sufficiency-Oriented Design

- Human actors make and interpret cases
- Data are collected, annotated, and analyzed
- Services are adapted through experimentation
- Cognitive dissonance acts as a trigger for learning and change

Main Loop

1. Collect data
2. Operate services
3. Make cases
4. Analyze situations
5. Adapt services
6. Choose focus
7. Handle experiments
8. Return to data collection

Human-Centered Processing

At the center of the loop, services must:

- capture human implicit knowledge
- sense and process contextual signals
- display understandable information
- reveal hidden effects
- explain consequences and trade-offs

Role of Cognitive Dissonance

Cognitive dissonance appears when there is a gap between:

- habits and expected outcomes
- perceived comfort and actual impacts
- individual choices and collective consequences

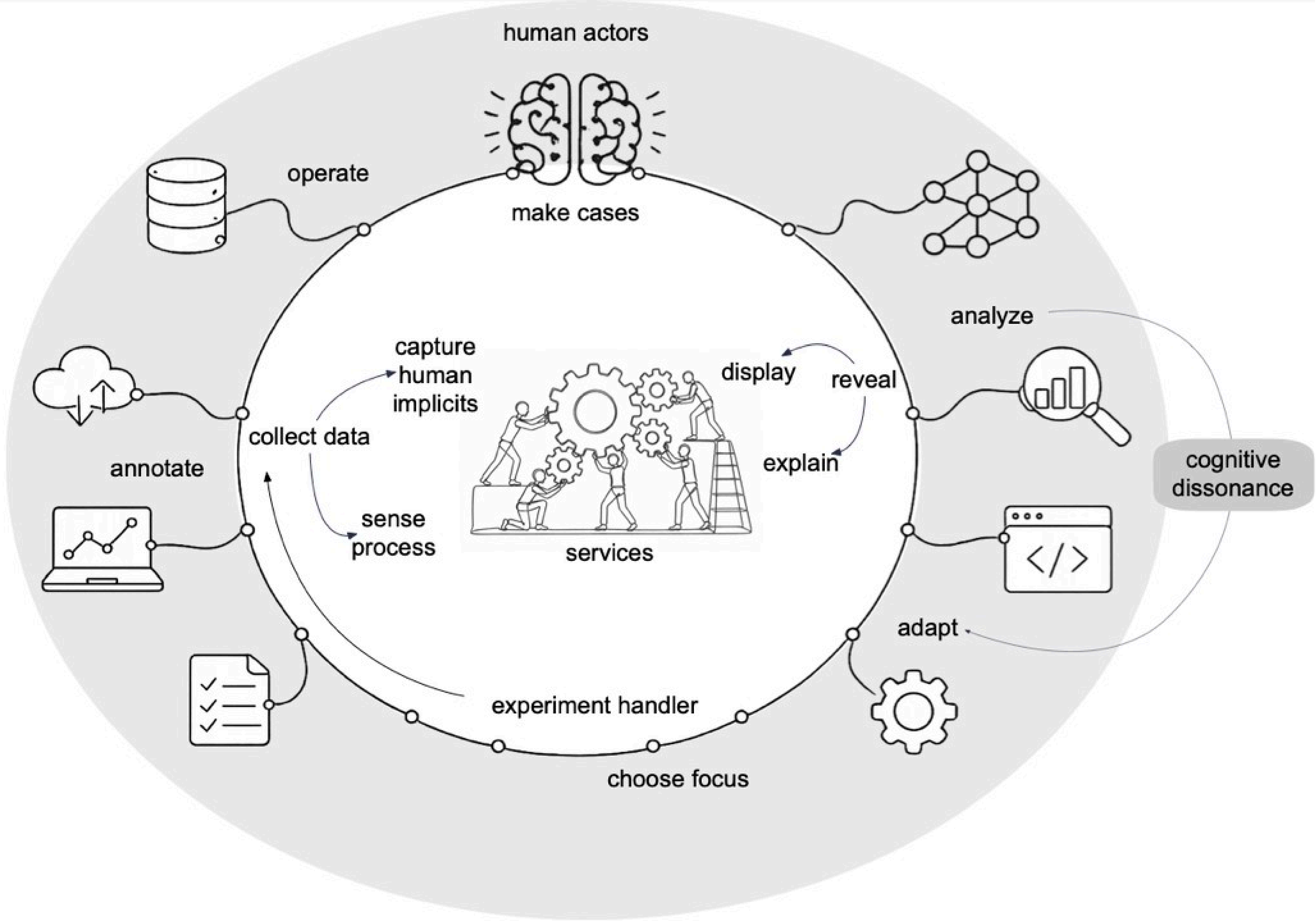
It becomes a lever for reflection, adaptation, and sufficiency-oriented decisions.

Design philosophy

The system should not aim only at developing efficient technologies.

It should help inhabitants to understand, question, and adjust practices through:

- meaningful data
- situated feedback
- explainable services
- progressive experimentation
- inclusive decision-making


human actors
operate
make cases
analyze
capture
human
implicits
display
reveal
collect data
annotate
explain
cognitive
dissonance
sense
process
services
adapt
experiment handler
choose focus

The energy phenomena

Concept of energy

Reminder (or introduction)

Learning goals (this block)

- Speak precisely: energy (J, kWh) vs power (W).
- Navigate orders of magnitude for equipment and regulatory examples.
- Recognise when primary vs final accounting changes a comparison.

Definition

In physics, energy is the capacity of a system to:

- perform work;
- produce motion;
- drive transformations (heat, light, chemistry, phase change…).

In an isolated system, total energy is conserved (transformed, not created from nothing).

Main “forms” (vocabulary)

- Kinetic $E_k = \frac{1}{2}mv^2$
- Potential (gravity, electric field…)
- Internal (thermal, chemical…)
- Radiant (electromagnetic)
- Mechanical (macroscopic kinetic + potential)

International System of Units vs building practice

- International System of Units: joule (J); power in watts (J/s).
- Buildings / utilities: kWh for amounts over time — write kWh, not “kW/h”.

$$1\,\mathrm{kWh} = 3.6 \times 10^6\,\mathrm{J}, \qquad 1\,\mathrm{J} = 1\,\mathrm{W}\cdot\mathrm{s}.$$

1 J = work of 1 N through 1 m in the direction of the force.

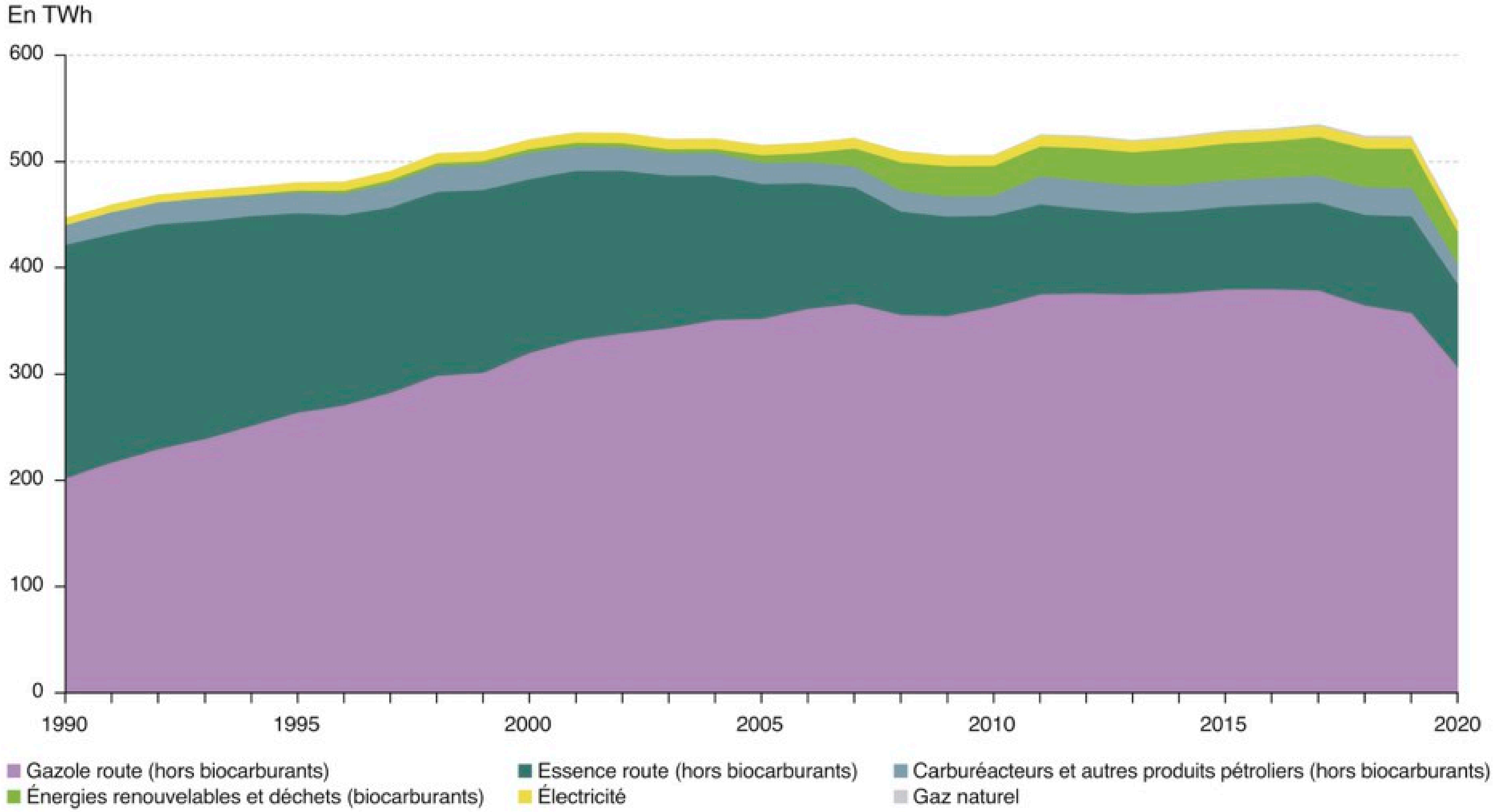
What 1 kWh “feels like” (illustrative)

- lift 1 t by ~367 m (idealised);
- heat ~10 L water by ~86 °C (order of magnitude);
- warm ~180 m^3 of air by ~16 °C (very rough; depends on c_p, losses…).

Orders of magnitude — storage & mobility

- e-bike battery: up to ~2 kWh stored.
- EV pack: tens to ~100 kWh (model-dependent).
- ICE: ~85 kWh/100 km (gasoline example) / ~73 kWh/100 km (diesel example) on the slides.
- Regulated heating examples: ~20–50 kWh/m^2·year (see RT2012 slide).

Energy used for transportation



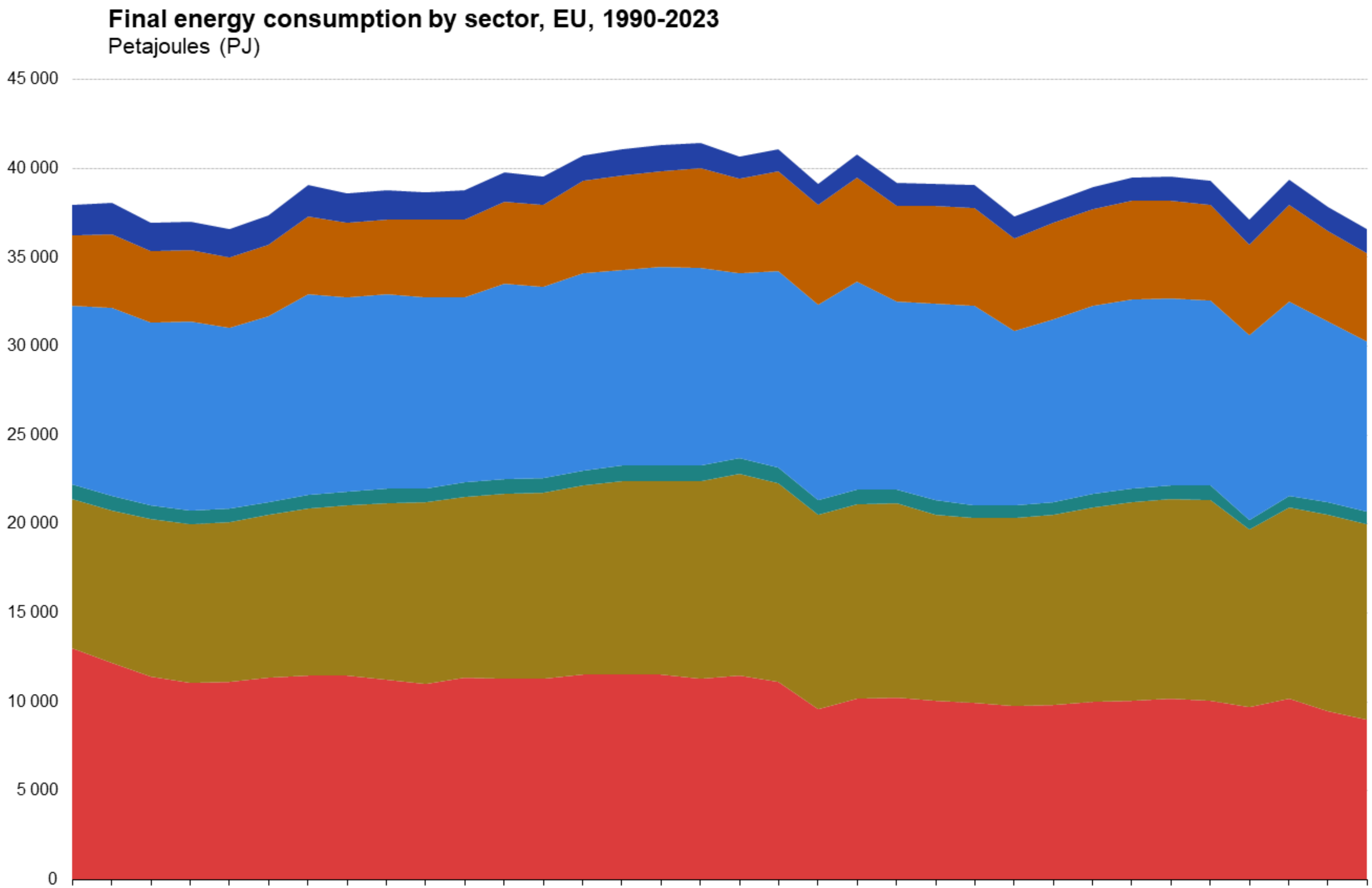
Champ : jusqu'à l'année 2010 incluse, le périmètre géographique est la France métropolitaine. À partir de 2011, il inclut en outre les cinq DROM.

RT2012 — regulatory order of magnitude

~50 kWh/m²·year (example reference level on the slides).

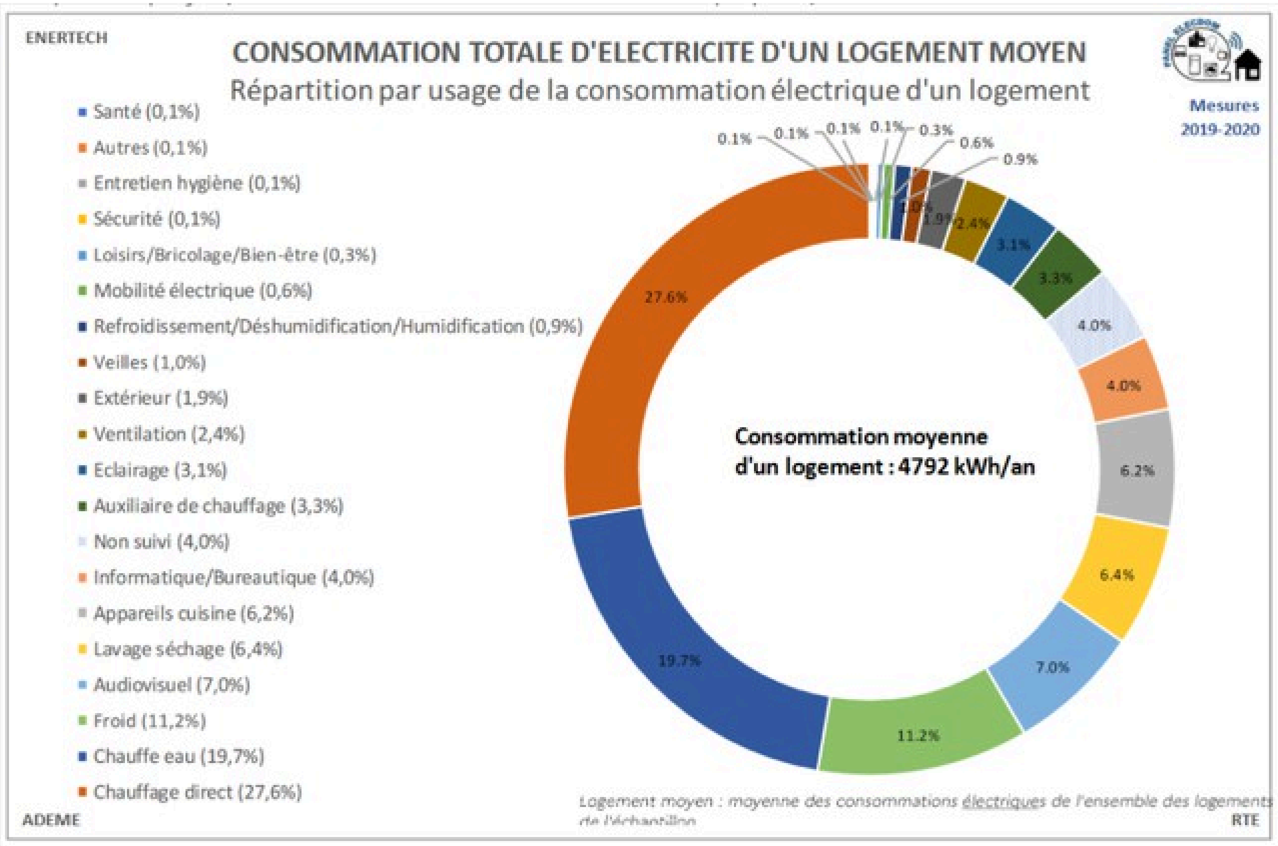
Primary vs final: 1 kWh final electricity ≈ 2.58 kWh primary in the French conversion example — vector-dependent.

Final energy by sector (example figure)



Domestic electricity (examples)

Typical standby, cold, wet appliances — useful to connect nameplate W to kWh/year on the bill.



Power (not the same as energy)

Power P is the rate of energy transfer or conversion (W = J/s).

$$E(t_2) - E(t_1) = \int_{t_1}^{t_2} P(t)\, dt, \qquad \frac{dE}{dt} = P(t).$$

Power in different domains (mnemonics)

- Mechanics: $P = \vec{F} \cdot \vec{v}$
- Electricity (DC): $P = U\,I$
- Conduction: heat flux $q'' = -\lambda\, dT/dx$; through area A, $P \approx |q''| A$ in simple 1D cases
- Radiation (grey body): emitted flux $\varepsilon\sigma T^4$; total power needs surface area
- Chemistry: power linked to reaction rates and electrochemical potentials (context-dependent formalism)

Typical electrical powers — home (1/2)

Device	Order of magnitude
Internet box	8–20 W
Laptop	15–80 W
TV	40–100 W
Desktop + screen	~60–140 W

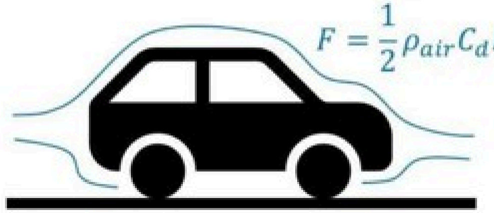
Typical electrical powers — home (2/2)

Device	Order of magnitude
Fridge	150–200 W nameplate; ~500 kWh/year typical
Microwave	~1000 W
Oven / hot plate / washer / dryer	~2–4 kW peaks
Cyclist (human)	~200 W sustained (order of magnitude)

Typical powers — infrastructure scale

- PV: ~100 W per m^2 panel (STC-ish ballpark)
- Home connection: 3–18 kW subscribed
- Car: ~80 kW motor level used in the slides' comparison
- Wind turbine / nuclear unit: MW to GW

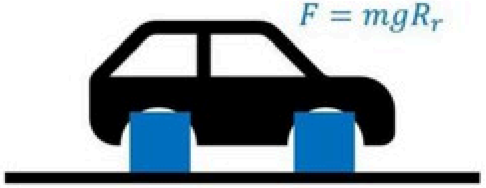
Aerodynamic Forces



$$F = \frac{1}{2}\rho_{air} C_d F_A v^2$$

The aerodynamic forces on the vehicle are proportional to velocity squared and hence become dominant at high speed. F_A is the frontal area and C_d is the drag coefficient. ρ_{air} is the density of air and we assume 1.225kg m^{-3}

Rolling Resistance

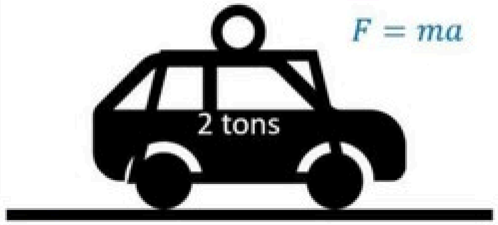


$$F = mgR_r$$

In the simplest terms the rolling resistance is a fixed term dependent on the vehicle mass, gravity and the tyre coefficient of rolling resistance (Rr).

Typical values for car tyres are an R_r ~ 0.006 to 0.01

Acceleration

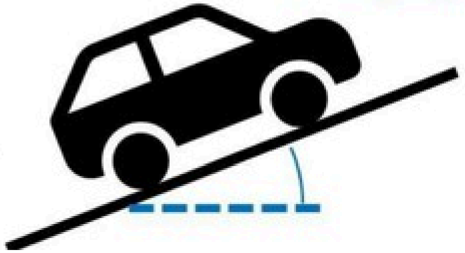


$$F = ma$$

If we accelerate the car very quickly we need to apply a force to do so.

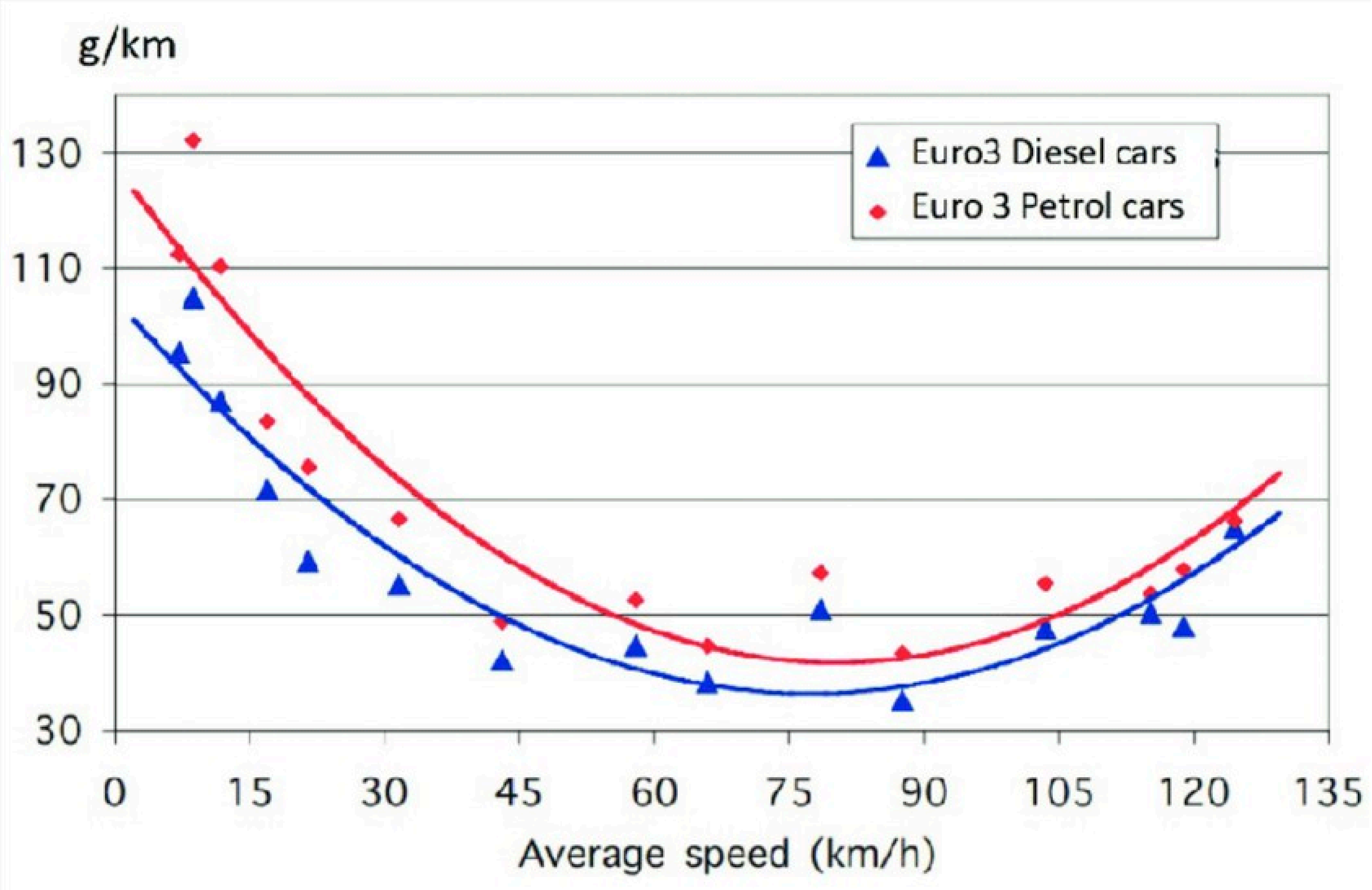
$$P(t) = \vec{F} \times \vec{v}$$

Gradients



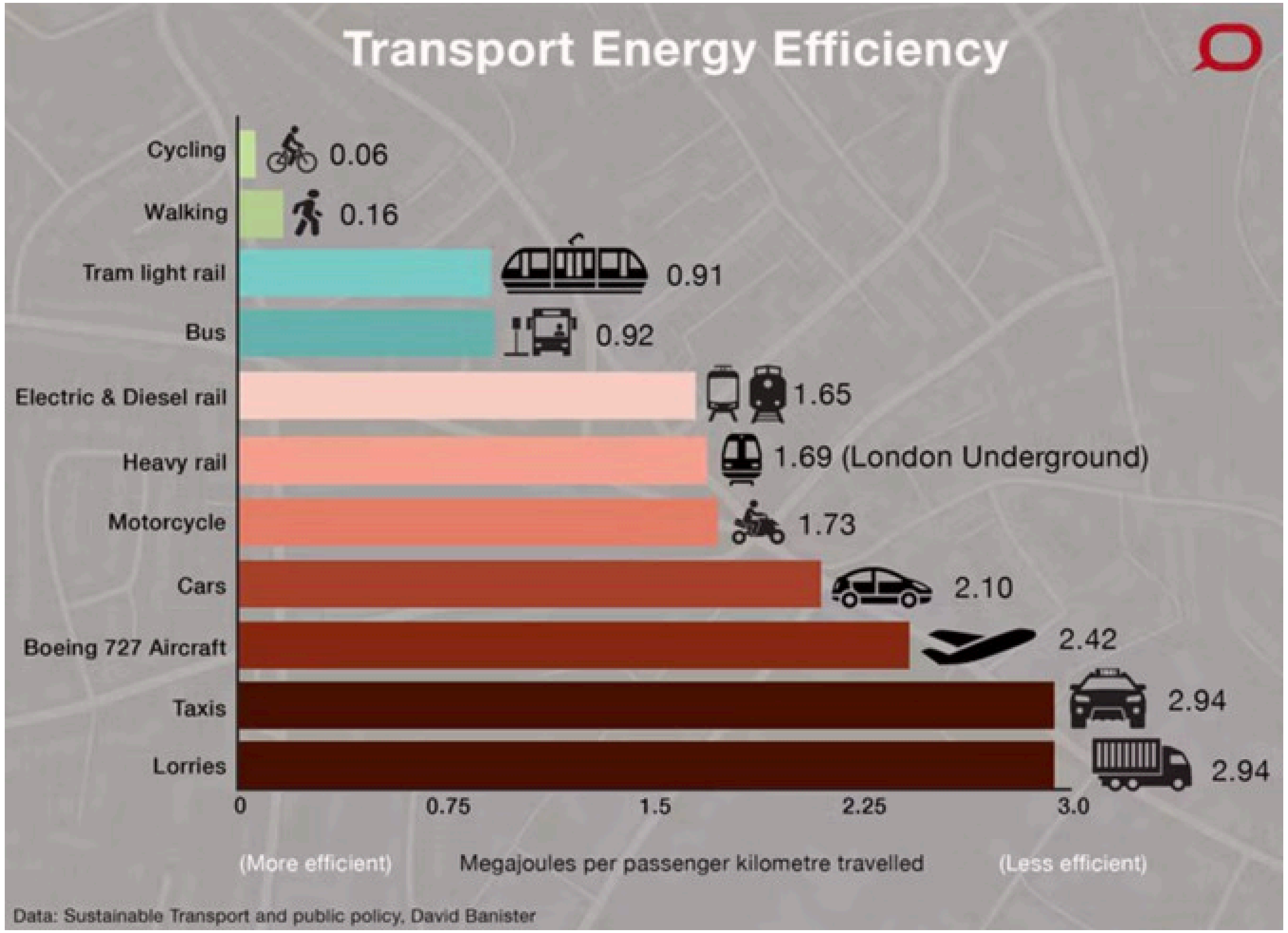
$$F = mgsin(\alpha)$$

Drive the vehicle up a slope and the additional force is dependent on the mass, gravity and the angle of the slope.



Average fuel consumption depending on the speed of the car Source: [OECD/ECMT 2007] 01_Gie_01

Energy consumed per passenger per km:



Self-check questionnaire

15 questions — topics match the lecture blocks

Choose the best answer each time.

(In class: discuss in pairs; answers on the last slide.)

Q1 — Radiative forcing (definition)

In climate science, radiative forcing (as used in IPCC-style summaries) is best described as:

- A. The annual-mean solar constant at 1 AU, with no reference to composition
- B. A perturbation to Earth's energy budget: the change in net radiative flux at a reference level (commonly tropopause or top of atmosphere) after stratospheric temperatures have adjusted, holding surface/troposphere fixed for the perturbation
- C. The global-mean surface temperature anomaly since pre-industrial
- D. Total absorbed shortwave radiation at the surface only

Q2 — Units of forcing

Effective radiative forcing is typically reported in:

- A. W/m^2 (watts per square metre)
- B. ppm/year only
- C. °C per century, by definition
- D. $kWh/m^2/year$

Q3 — Greenhouse effect (mechanism)

Which statement best matches the greenhouse effect in the atmosphere?

- A. Greenhouse gases are transparent to visible sunlight but interact strongly with infrared radiation, altering the vertical profile of emission to space and reducing outgoing longwave radiation at a given surface temperature compared to a no-atmosphere blackbody toy model
- B. Ozone blocks essentially all infrared from leaving Earth
- C. CO_2 absorbs most incoming visible solar radiation before it reaches the surface
- D. The effect is unrelated to infrared emission and is purely convective

Q4 — Global warming (attribution)

IPCC-style assessments attribute most of the global mean surface warming since the late 19th century primarily to:

- A. Natural Milankovitch glacial–interglacial cycles on multi-thousand-year time scales
- B. Anthropogenic increases in greenhouse gas concentrations (with aerosols, land use, and natural variability as modifiers of the pace and pattern)
- C. A long-term increase in Earth–Sun distance over decades
- D. Volcanic aerosols alone, sustained over the whole period

Q5 — Course outline

In the table of contents of this introduction deck, which numbered block comes immediately after “The Sun Earth system and solar radiation”?

- A. Building physics (`slides04_physics`)
- B. Analysis of climate change (`slides02_climate`)
- C. Heat pumps and emitters (`slides06_systems`)
- D. PV systems (`slides09_photovoltaic`)

Q6 — Anthropocene framing

In the lecture, the Anthropocene block is mainly used to illustrate that:

- A. Human activity has become a dominant driver of Earth-system-scale changes (energy, emissions, land use) on historical time scales
- B. Solar irradiance stopped varying before 1900
- C. Ocean area exceeds land area by a factor of ten
- D. GDP is unrelated to energy use

Q7 — Atmospheric CO_2

The long-term evolution of average atmospheric CO_2 since the late 1950s (as shown in the lecture) is best described as:

- A. A steady decrease toward pre-industrial levels
- B. Roughly constant within ±1 ppm
- C. A clear upward trend with seasonal oscillations superimposed
- D. Random walk with zero drift

Q8 — Energy (physics)

In an isolated system, total energy is:

- A. Always increasing
- B. Conserved (transformations only, no net creation/destruction)
- C. Proportional to temperature only
- D. Undefined unless the system is a perfect gas

Q9 — Units in buildings

For amounts of energy delivered or billed over time, the slides recommend using:

- A. `kW/h` (kilowatt per hour)
- B. kWh (kilowatt times hour)
- C. horsepower (hp) only
- D. bar × litre

Q10 — Joules and kilowatt-hours

Which relation is correct?

- A. $1\,\mathrm{kWh} = 1000\,\mathrm{J}$
- B. $1\,\mathrm{kWh} = 3{,}600{,}000\,\mathrm{J}$
- C. $1\,\mathrm{kWh} = 360\,\mathrm{J}$
- D. $1\,\mathrm{kWh} = 1\,\mathrm{J/s}$

Q11 — Power

Power is best defined as:

- A. Energy multiplied by duration
- B. Energy transferred or converted per unit time
- C. Mass times acceleration only
- D. The same quantity as torque in all cases

Q12 — Linking E and P

If $E(t)$ is energy in a control volume and $P(t)$ is the net power entering (sign convention as on the slides), which statement matches the lecture?

- A. $\frac{dE}{dt} = P(t)$ is presented as the local relation between energy rate and power
- B. Power is always independent of time
- C. $\frac{dE}{dt}$ must be zero if P is measured in kW
- D. Energy is the time derivative of power

Q13 — Regulation reminder (RT2012 order of magnitude)

The slides cite a reference order of magnitude for RT2012 of about 50 $kWh/m^2/year$ and discuss primary energy conversion (e.g. 1 kWh final electricity ≈ 2.58 kWh primary in the example).
What is the main pedagogical point?

- A. Final and primary energy can differ; conversion factors matter when comparing vectors (electricity vs gas, etc.)
- B. Primary energy is always numerically smaller than final energy
- C. The factor 2.58 applies to any form of final energy identically in all countries and years
- D. RT2012 ignores electricity entirely

Q14 — Orders of magnitude

Which comparison is closest to the orders of magnitude used on the slides?

- A. A cyclist ≈ 200 W continuous useful power; a car traction level is often discussed around tens of kW (e.g. ~80 kW mentioned)
- B. A cyclist ≈ 80 kW
- C. A microwave oven ≈ 2 W
- D. One square metre of PV ≈ 10 kW in typical domestic conditions

Q15 — Forms of energy

According to the lecture, mechanical energy at the macroscopic scale is:

- A. Only radiant energy
- B. The sum of kinetic and potential energy at the macroscopic scale
- C. Only internal (thermal) energy
- D. The time integral of power divided by mass

Answer key (1/2)

Q	Answer	Short rationale
2	A	W/m^2.
3	A	IR interaction with GHGs; visible largely transmitted; emission-to-space structure matters.
6	A	Anthropocene: dominant human forcing at planetary scale.
1	B	Forcing = perturbation to net radiation (TOA/tropopause framing; strat. adjustment in standard definition).
4	B	Dominant long-term warming from anthropogenic GHGs (+ other forcings / variability).
5	B	After Sun–Earth → climate (`slides02_climate`).
8	B	Energy conserved in an isolated system.
7	C	Rising CO_2 + seasonal cycle.

Answer key (2/2)

Q	Answer	Short rationale
9	B	kWh; not “kW/h”.
10	B	3.6×10^6 J.
11	B	Energy per unit time.
12	A	$dE/dt = P$ on the slides.
13	A	Final vs primary / conversion factors.
14	A	Cyclist ~200 W; car ~80 kW (examples).
15	B	Mechanical = macro kinetic + potential.