

Energy and Buildings

Design of an efficient and resilient building considering global warming with `baterm`

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Installing the `batem` application

First, check if your computer understand Python from the command line interface (CLI) by running `

- `PowerShell` for Windows
- `Terminal` for MacOS (it also runs on Linux):

Then `python --version`.

You should get 3.12 minimum.

Once this check done, you can launch the installation of the regular pypi module with

```
python -m pip install -U batem
```

The full sources at https://wwiw.gricad-gitlab.univ-grenoble-alpes.fr/batem/batem_all but you don't need the source code to follow the tutorials

For Windows users, if the commands `python3.exe` or `pip3.exe` are not found, it's likely because these files are not in the `PATH` environment variable.

You can add them to the `PATH` by:

1. Opening the System Properties
2. Clicking on the "Environment Variables" button
3. Adding the path of the Python installation directory (e.g., `C:\Python313`) to the "Path" variable
4. Clicking "OK" to save the changes
5. Open a new terminal and check if the commands are found.

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 can also be used for developing researches and design of performant buildings or for learning and teaching purposes. It is a Python application (but you don't need to know Python to follow).

`batem` includes a command line interface to use it is named `baterm`

To launch baterm, type in the CLI: `python -m batem.baterm`

Note: if you want to update batem to the latest version, type again in the CLI:

```
python -m pip install -U batem
```

What is `baterm`?

- a way to use batem
  - access to the lectures with `lectures` or `lecture <number>`
  - access to the workshops with `workshops` or `workshops <number<`
- a **command line tool** to design **efficient building systems** with a fast learning curve.
  - analyze a **context** i.e. what is around **a building and/or a PV plant**?
  - simulate the **building performance**
  - simulate a **PV plant**
  - analyze the joint performance: **building + PV plant**

batem or baterm ?

- `baterm` is part of `batem`.
- `batem` is a Python module containing:
  - tutorials, named slidesXX-short_name.pdf
  - workshops, named workshopsXX-short_name.ipynb
- Each tutorial has a corresponding workshop (a Jupyter Notebook) to learn by practice.
- batem is also a tool for research to experiment new ideas

part I - Context

Anthropocene

A (short) history of Earth

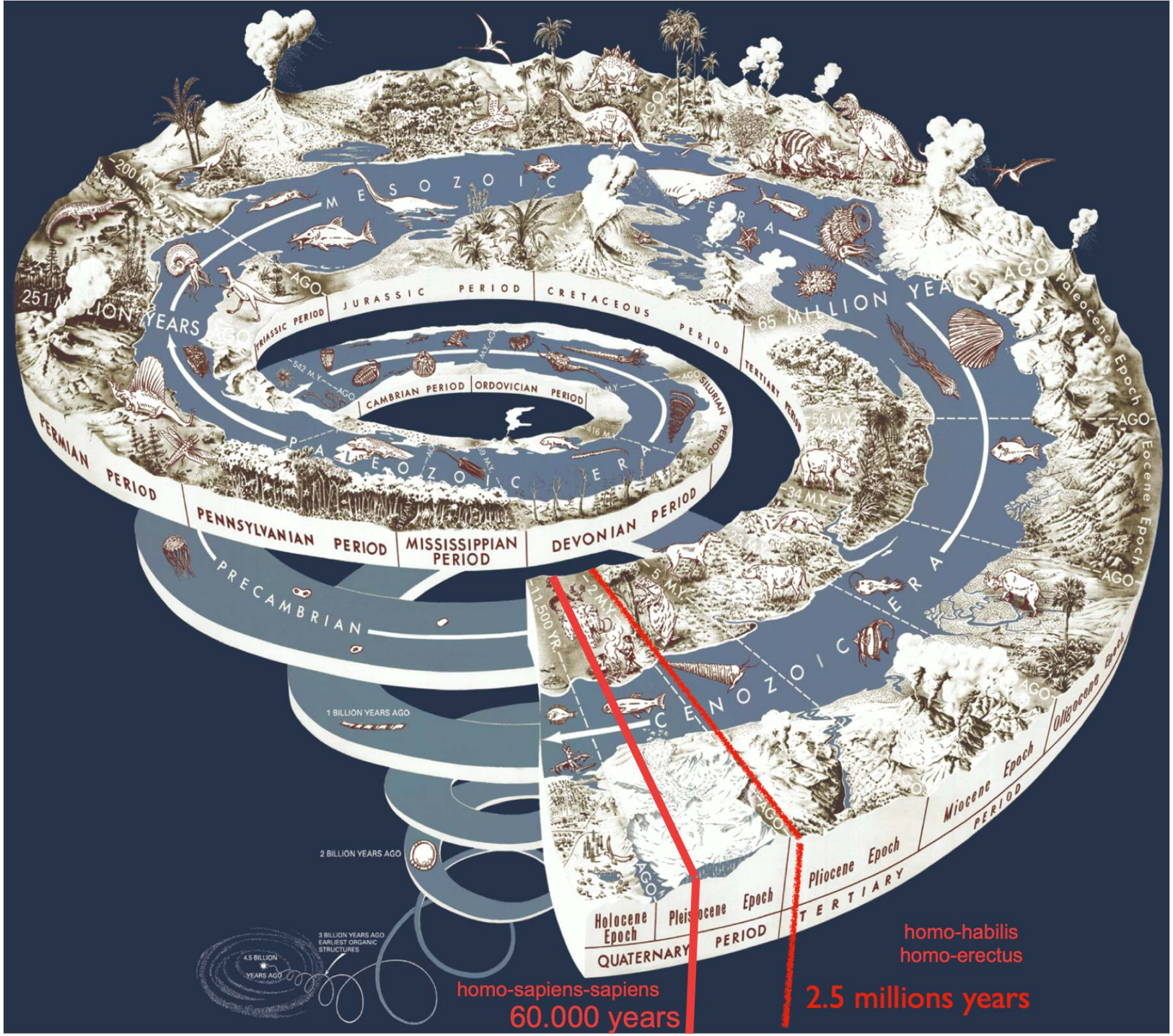
What this lecture connects

- 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
PALEOZOIC ERA
CENOZOIC ERA
PRECAMBRIAN
200 M.Y. AGO
251 MILLION YEARS AGO
65 MILLION YEARS AGO
542 M.Y. AGO
416 M.Y. AGO
56 M.Y. AGO
34 M.Y. AGO
5 M.Y. AGO
2 M.Y. AGO
11,500 YR. AGO
1 BILLION YEARS AGO
2 BILLION YEARS AGO
3 BILLION YEARS AGO
EARLIEST ORGANIC STRUCTURES
4.5 BILLION YEARS AGO
TRIASSIC PERIOD
JURASSIC PERIOD
CRETACEOUS PERIOD
TERTIARY PERIOD
CAMBRIAN PERIOD
ORDOVICIAN PERIOD
SILURIAN PERIOD
DEVONIAN PERIOD
MISSISSIPPIAN PERIOD
PENNSYLVANIAN PERIOD
PERMIAN PERIOD
Paleocene Epoch
Eocene Epoch
Oligocene Epoch
Miocene Epoch
Pliocene Epoch
TERTIARY PERIOD
Pleistocene Epoch
Holocene Epoch
QUATERNARY PERIOD
homo-habilis
homo-erectus
2.5 millions years
homo-sapiens-sapiens
60.000 years

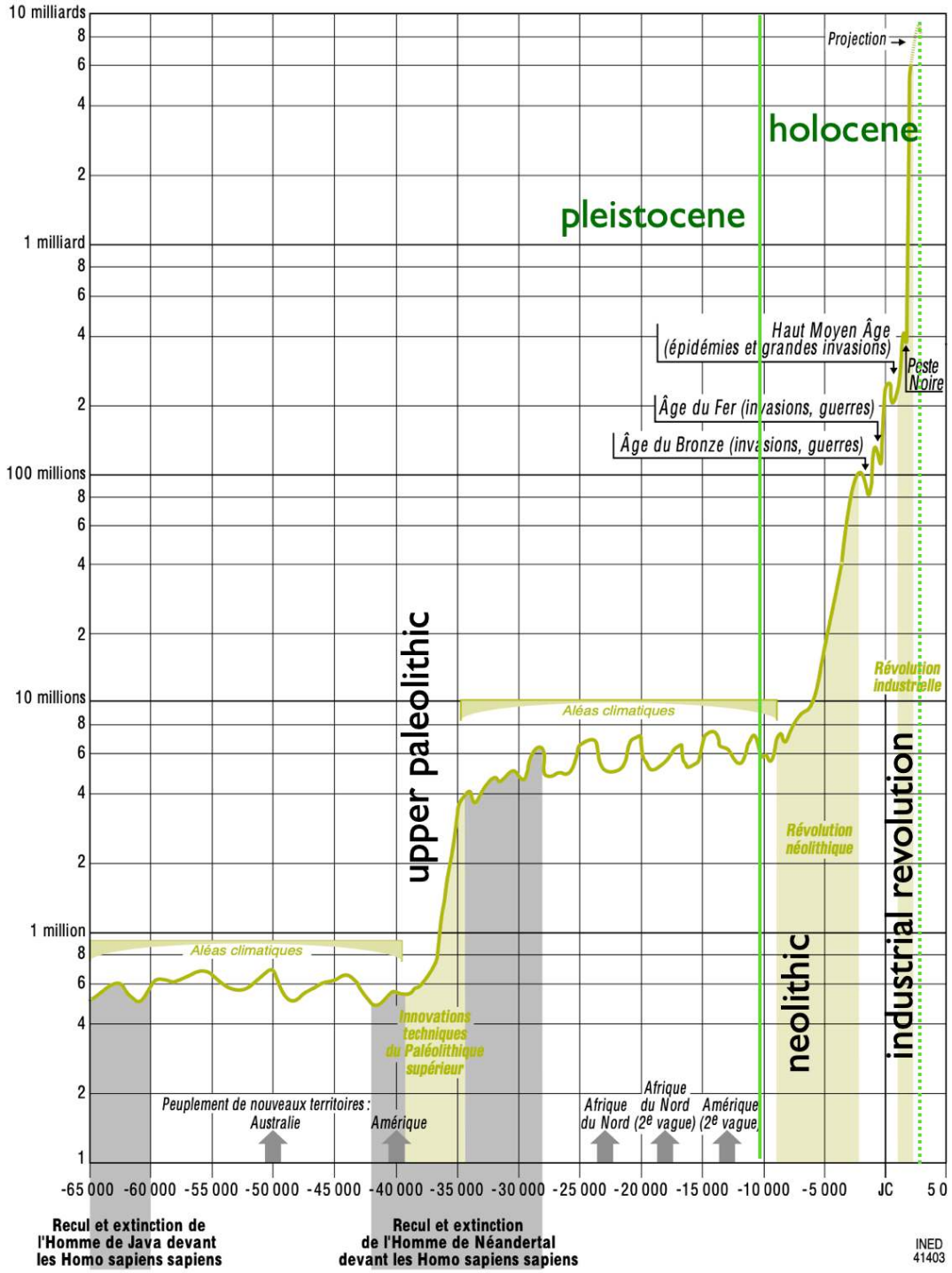
Exponential growth of humankind

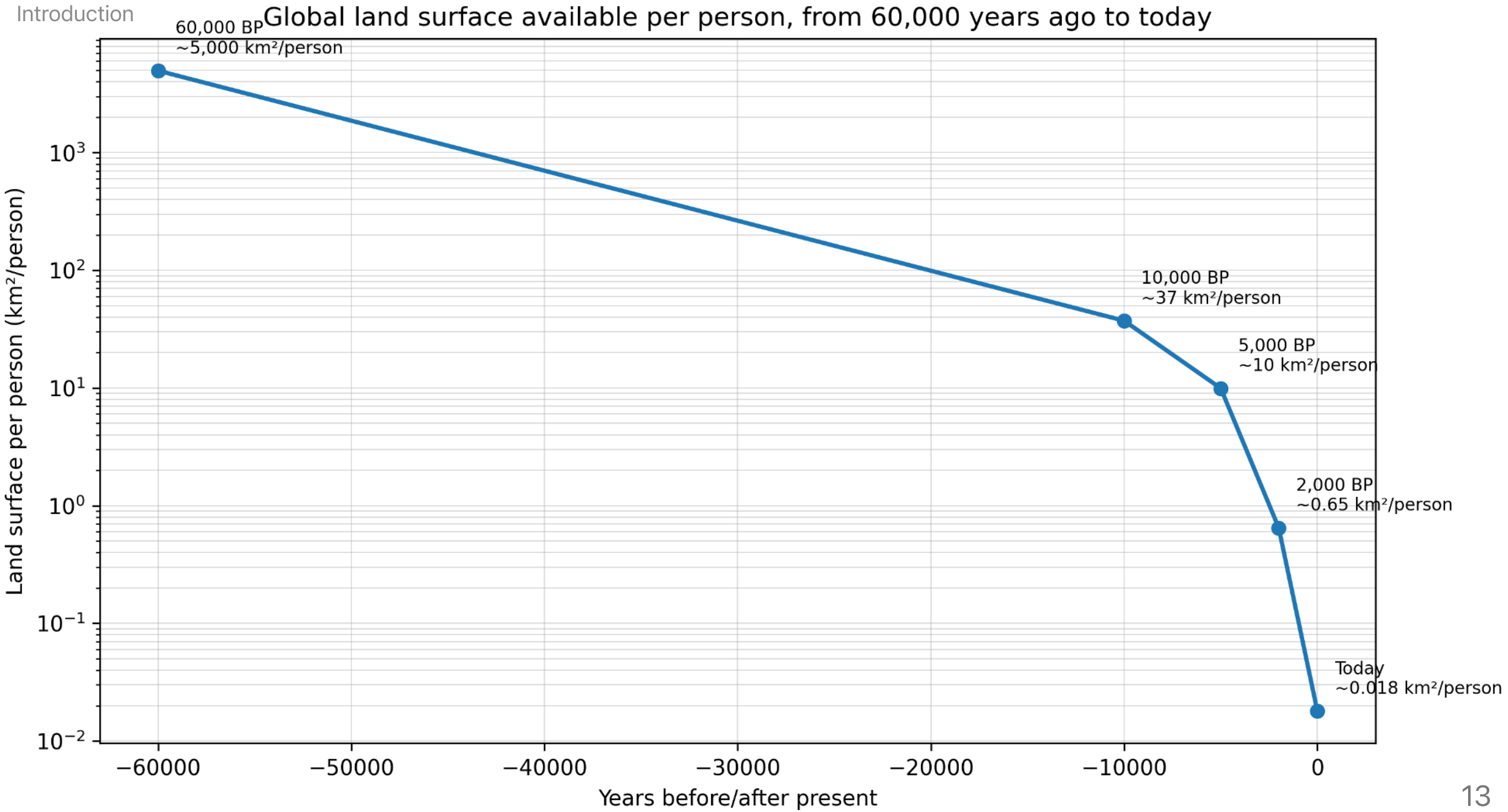
The next figure shows the exponential growth (pay attention to the log-scale of the y-axis) of humankind: it looks like the development of an parasitic species consuming resources.

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
8
6
4
2
1 milliard
8
6
4
2
100 millions
8
6
4
2
10 millions
8
6
4
2
1 million
8
6
4
2
1
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
neolithic
industrial revolution
Aléas climatiques
Innovations techniques du Paléolithique supérieur
Peuplement de nouveaux territoires :
Australie
Amérique
Afrique du Nord (2e vague)
Afrique du Nord
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)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
−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).

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

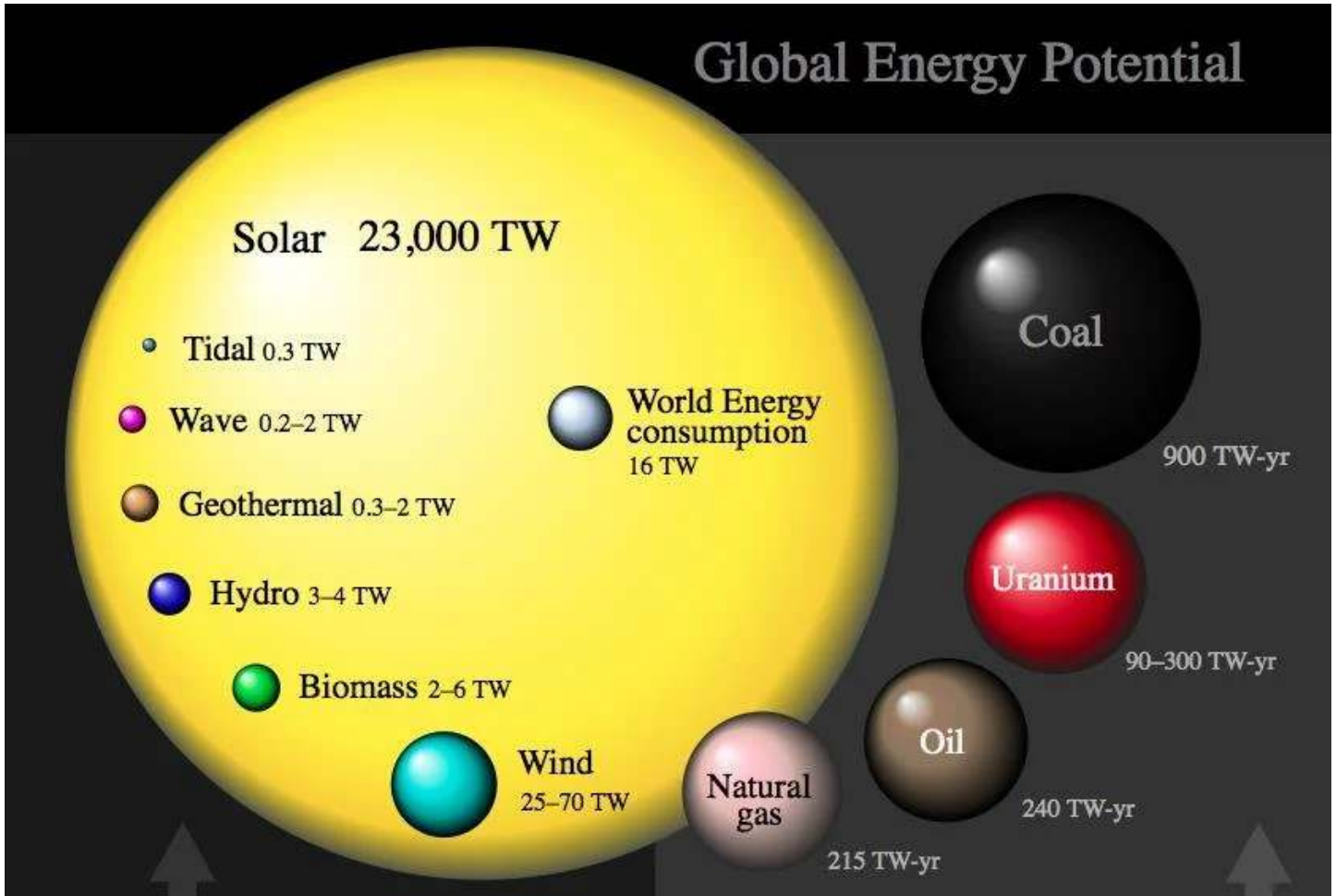
So absorbed solar throughput is thousands of times larger than human needs.

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).



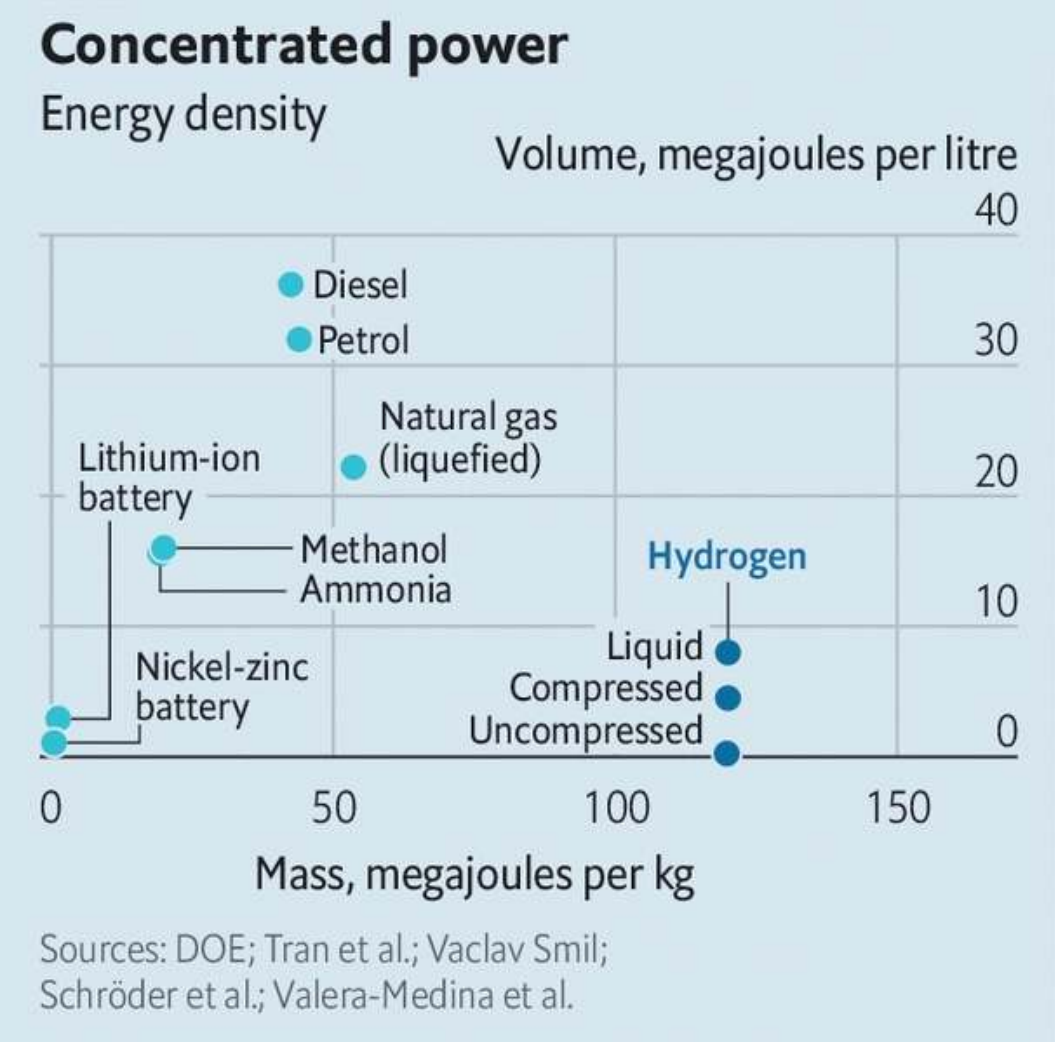
So why fossil fuels (historically)?

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..

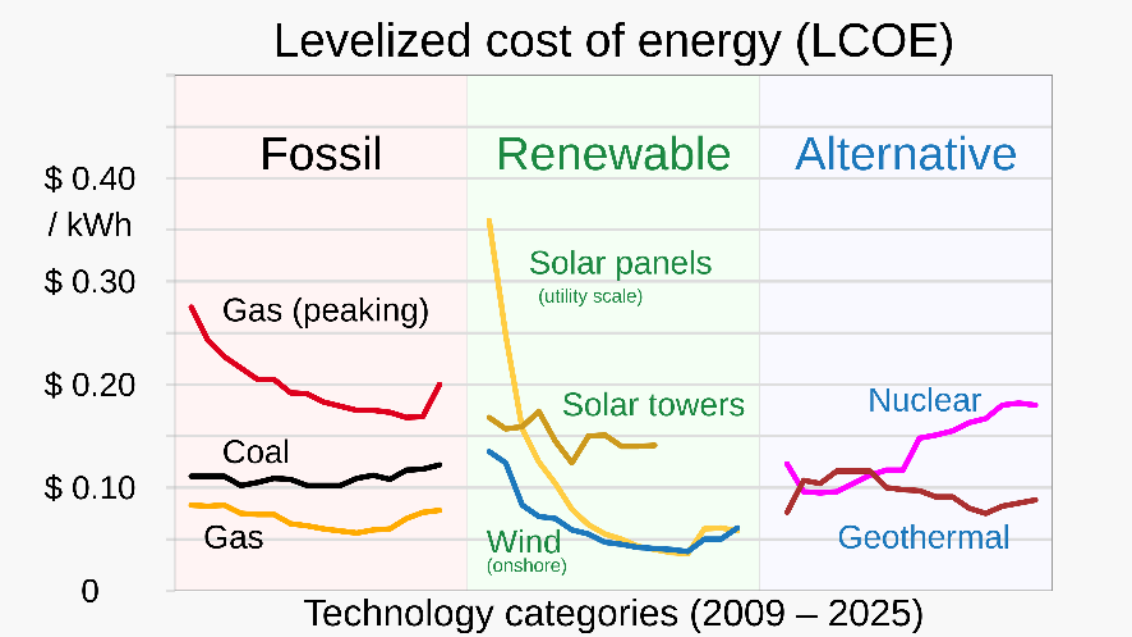
Volumetric / gravimetric power density

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.

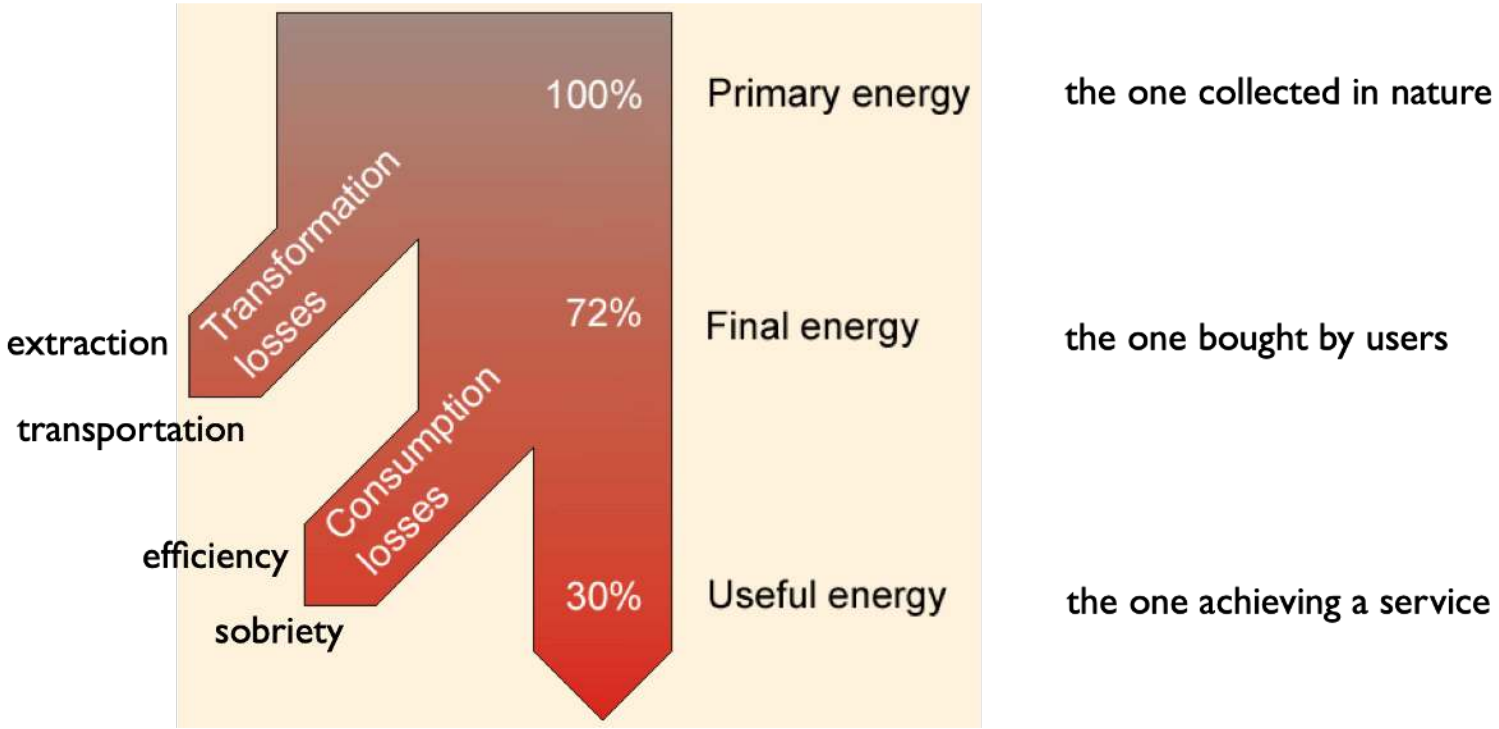
Buildings are central in this transition because they are spread all over the planet, are long-lived infrastructures, consume energy every day, and increasingly interact with several energy vectors: electricity, gas, heat networks, biomass, solar thermal, and photovoltaic systems.

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)

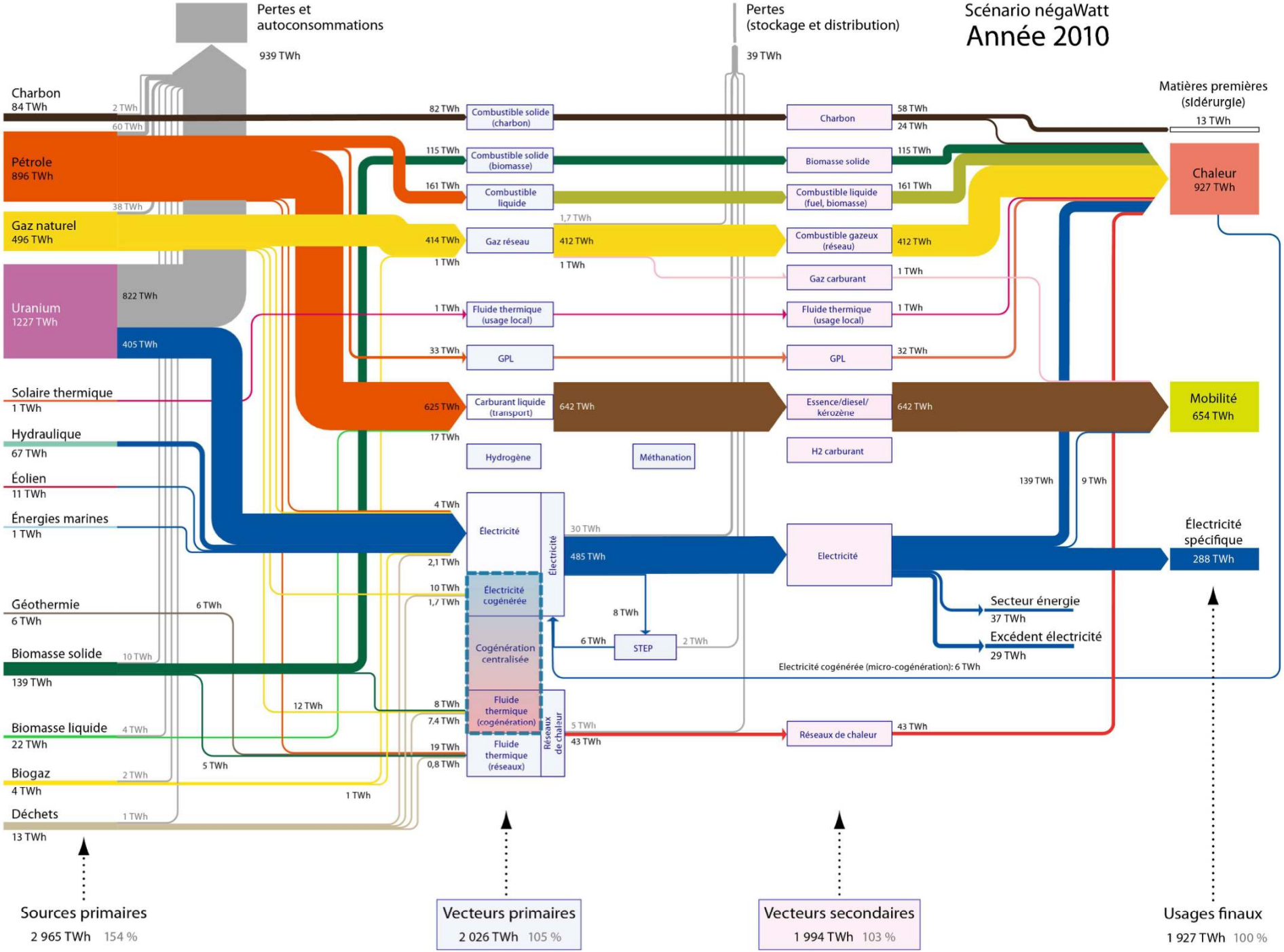
Primary → conversion / transport losses → final carriers used by end users. Electricity is secondary energy.



the one collected in nature

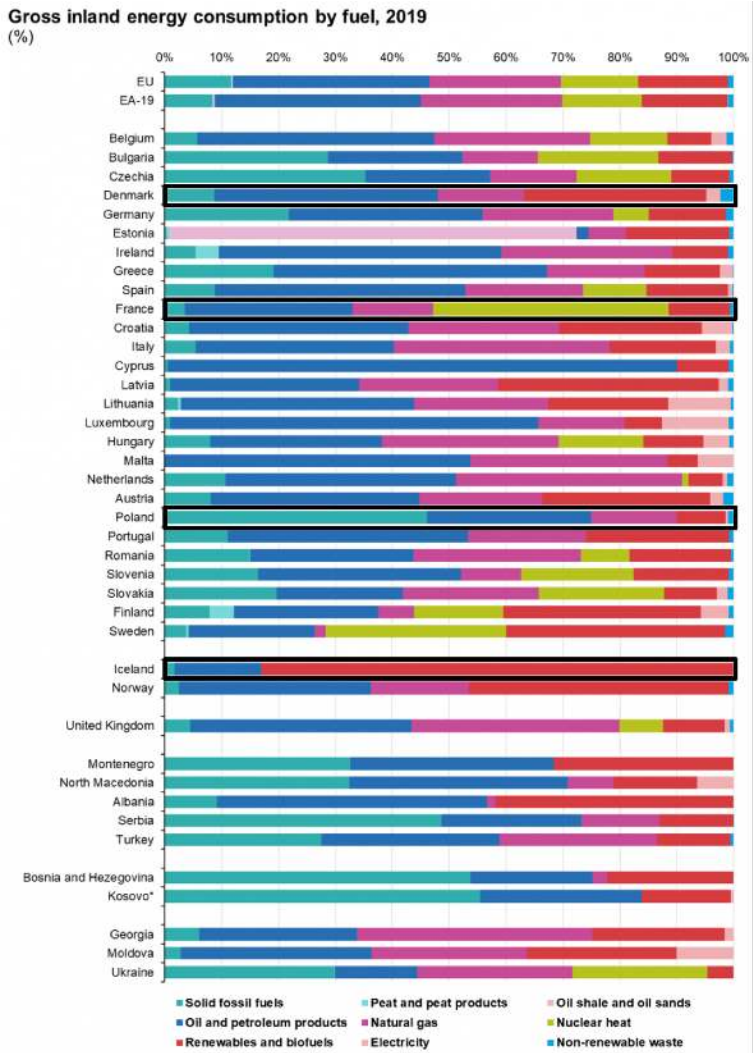
the one bought by users

the one achieving a service

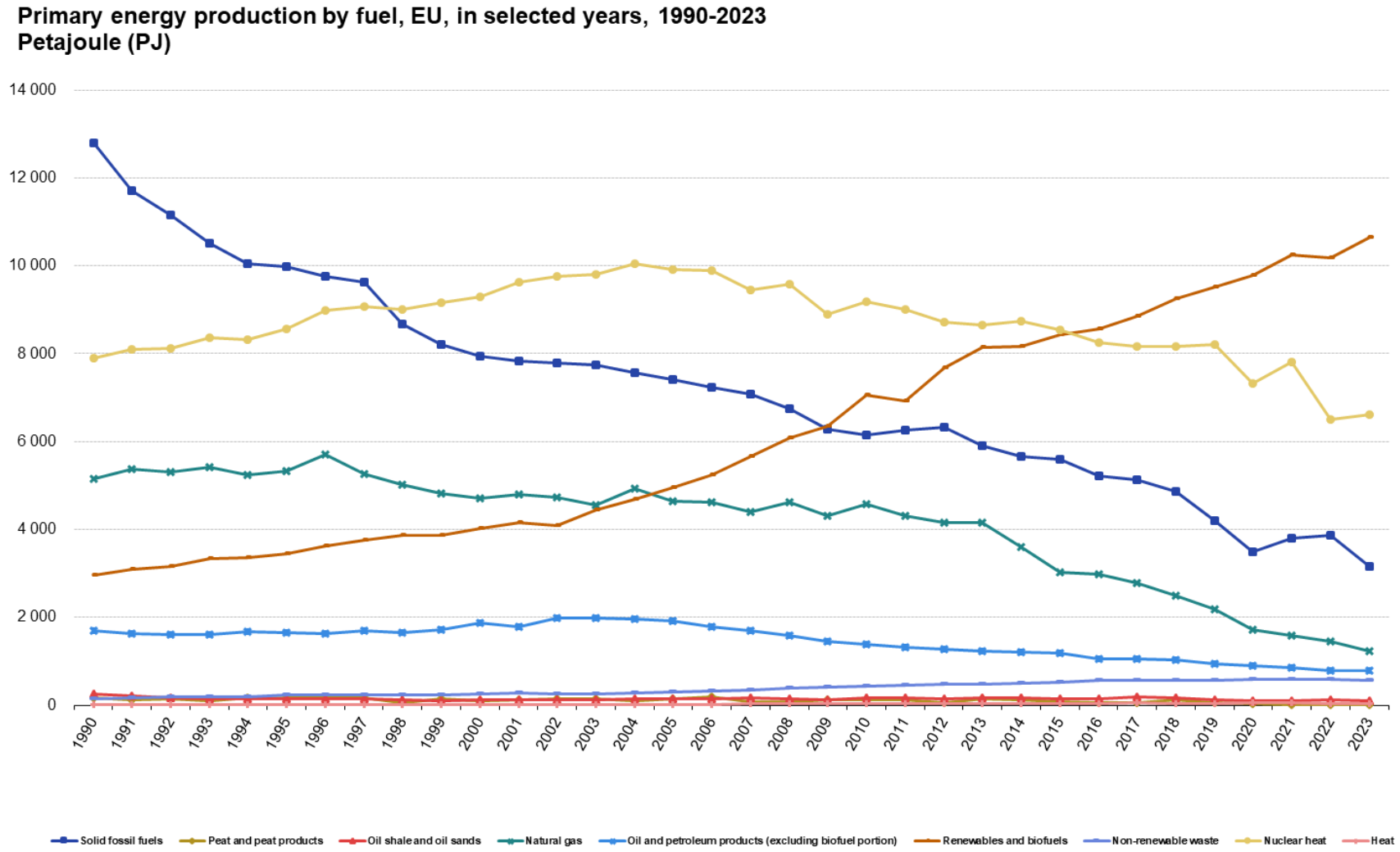

Scénario négaWatt
Année 2010
Pertes et autoconsommations
939 TWh
Pertes (stockage et distribution)
39 TWh
Charbon 84 TWh
Pétrole 896 TWh
Gaz naturel 496 TWh
Uranium 1227 TWh
Solaire thermique 1 TWh
Hydraulique 67 TWh
Éolien 11 TWh
Énergies marines 1 TWh
Géothermie 6 TWh
Biomasse solide 139 TWh
Biomasse 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/ kérozène
H2 carburant
Electricité
Réseaux de chaleur
Matières premières (sidérurgie)
13 TWh
Chaleur 927 TWh
Mobilité 654 TWh
Électricité spécifique 288 TWh
Secteur énergie 37 TWh
Excédent électricité 29 TWh
Electricité 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.

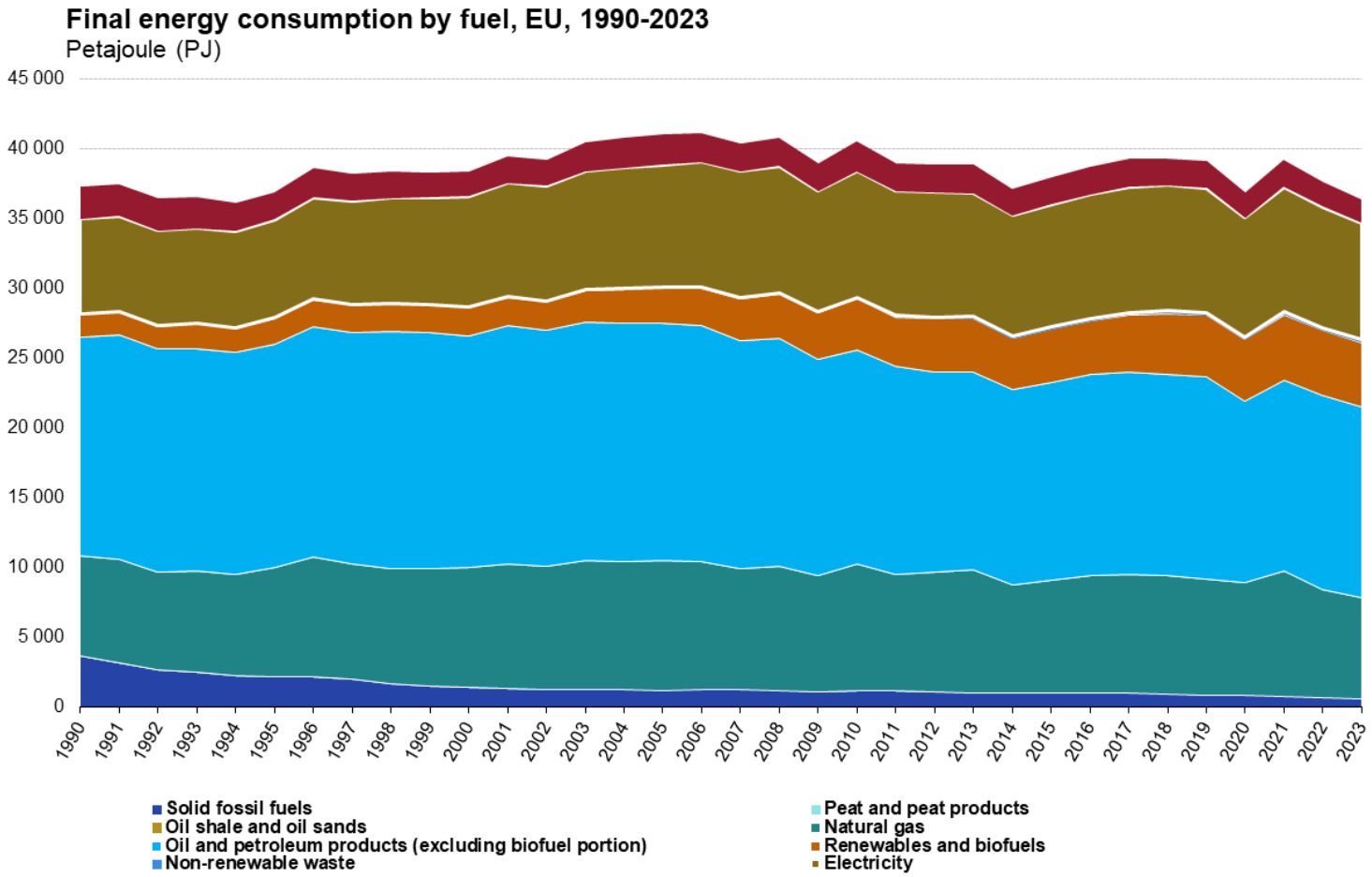


Primary energy production by fuel in EU (1990-2023)



Source: Eurostat (online data code: nrg_bal_c)

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

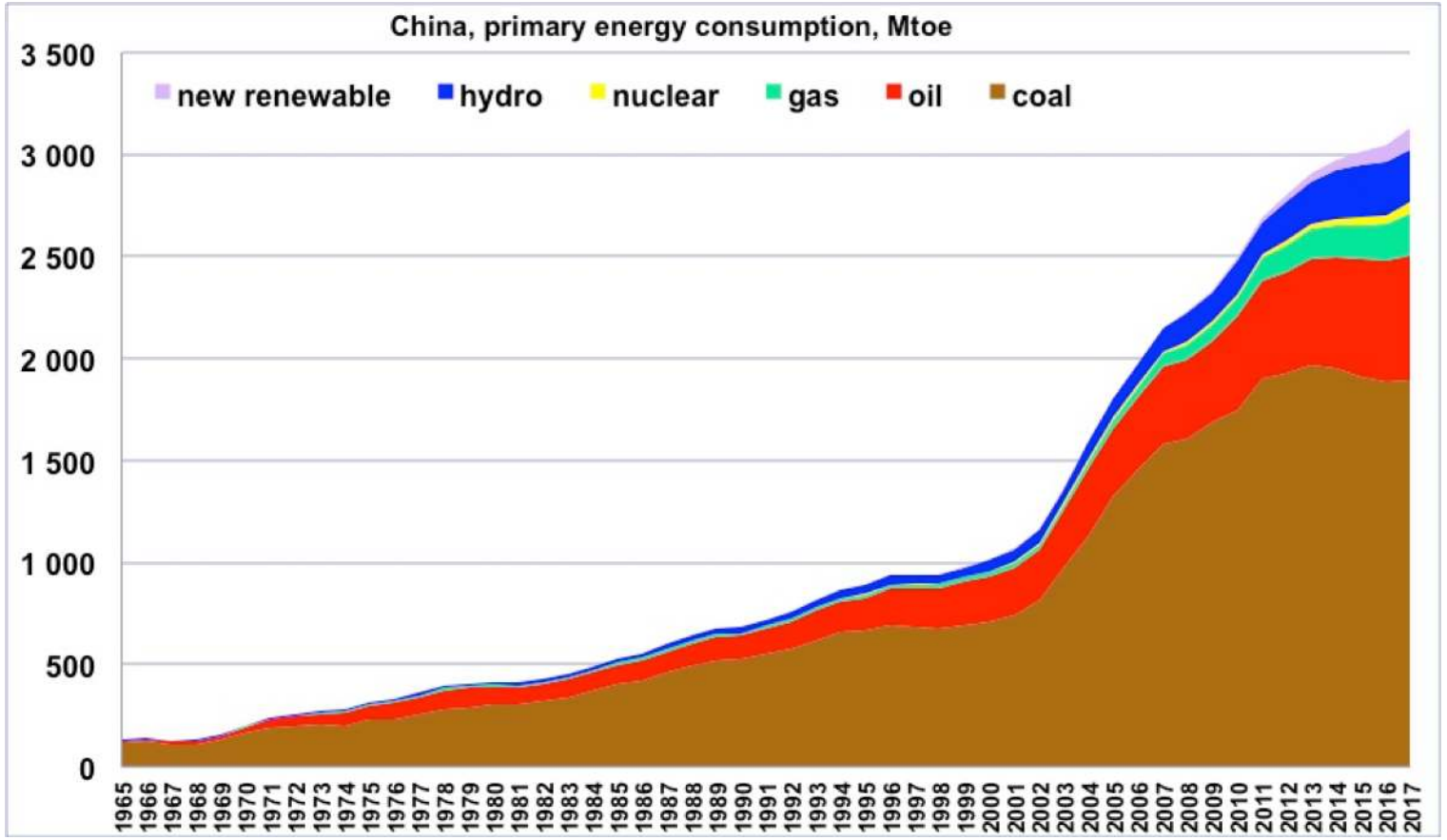


Source: Eurostat (online data code: nrg_bal_c)

eurostat

China — consumption context

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



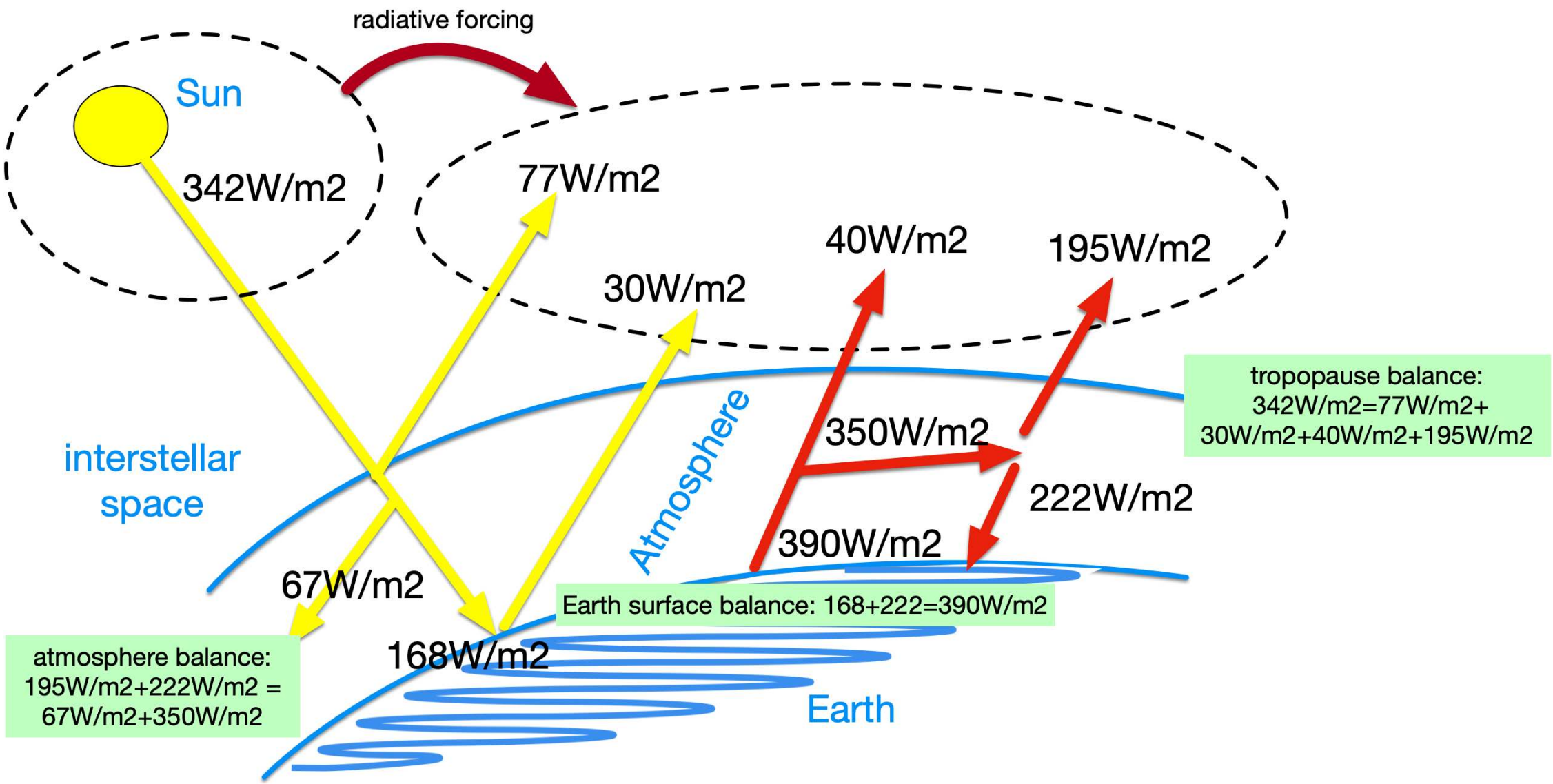
CO_2, Water Vapor, Radiative Forcing, and Global Warming

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>

CO_2: A Direct Greenhouse Gas

CO_2 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 CO_2 persists for a very long time in the climate system.

An increase in CO_2 reduces the net outgoing infrared flux to space, for an unchanged temperature. This is a positive radiative forcing.

But C_{O2} is not our enemy because it feeds vegetation: with 120ppm of CO2, during the middle-age was less fertile than todays.

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	CO_2 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

CO_2 is often the control knob; water vapor is a rapid amplification driven by temperature.

Radiative Forcing: Formalization

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

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

Examples of positive forcings: CO_2, CH_4, N_2O, some fluorinated gases.

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

Useful Approximation for CO_2

A classical approximation of CO_2 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;
- ΔF: forcing in $\mathrm{W\,m^{-2}}$.

A doubling of CO_2 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;
- λ: climate feedback parameter;
- ΔT: 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
        ↓
Radiative forcing
        ↓
Energy imbalance
        ↓
Warming
        ↓
Water vapor, clouds, ice, ocean, carbon cycle feedbacks
```

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:

$$1\ \text{kg fossil}\ \mathrm{CH_4} \approx 29.8\ \text{kg}\ \mathrm{CO_2e} \quad \text{over 100 years}$$

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 $\mathrm{g\,CO_2e\,kWh^{-1}}$.

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:

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

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

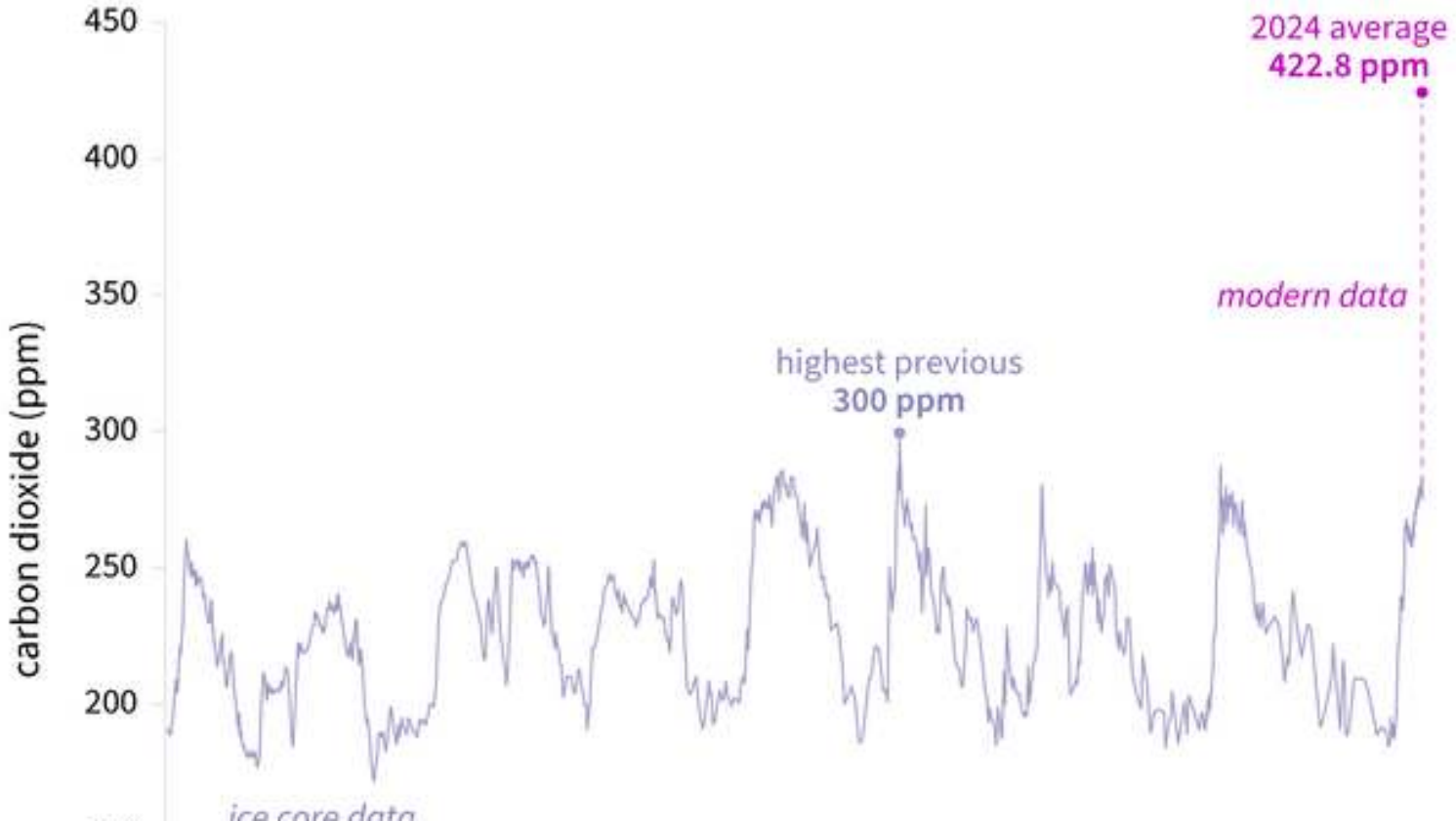
CO_2 acts directly on the radiative balance; the initial warming increases water vapor, which amplifies the effect; as long as positive forcing is not compensated by increased infrared emission, the Earth accumulates energy and temperature rises.

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)

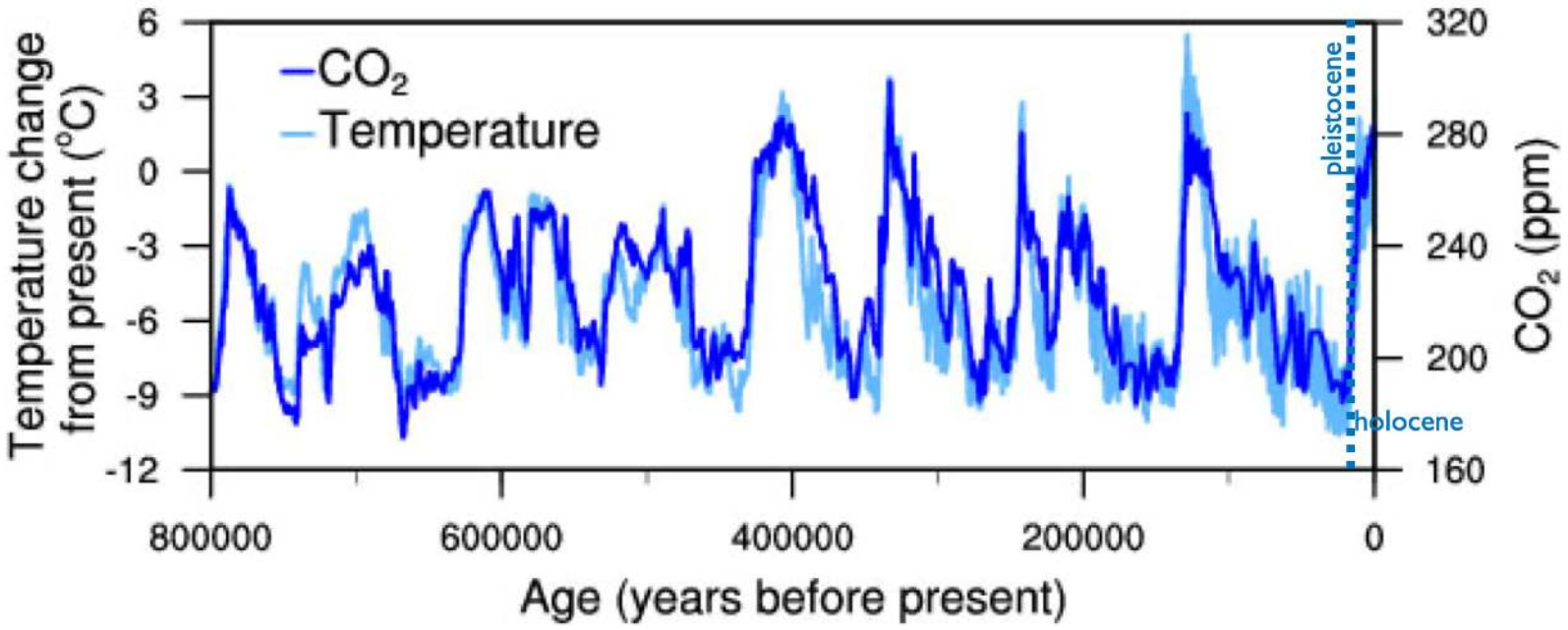
Long-term rise + seasonal cycle (Northern Hemisphere land biosphere). Stock of CO_2 matters for radiative forcing.

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`).

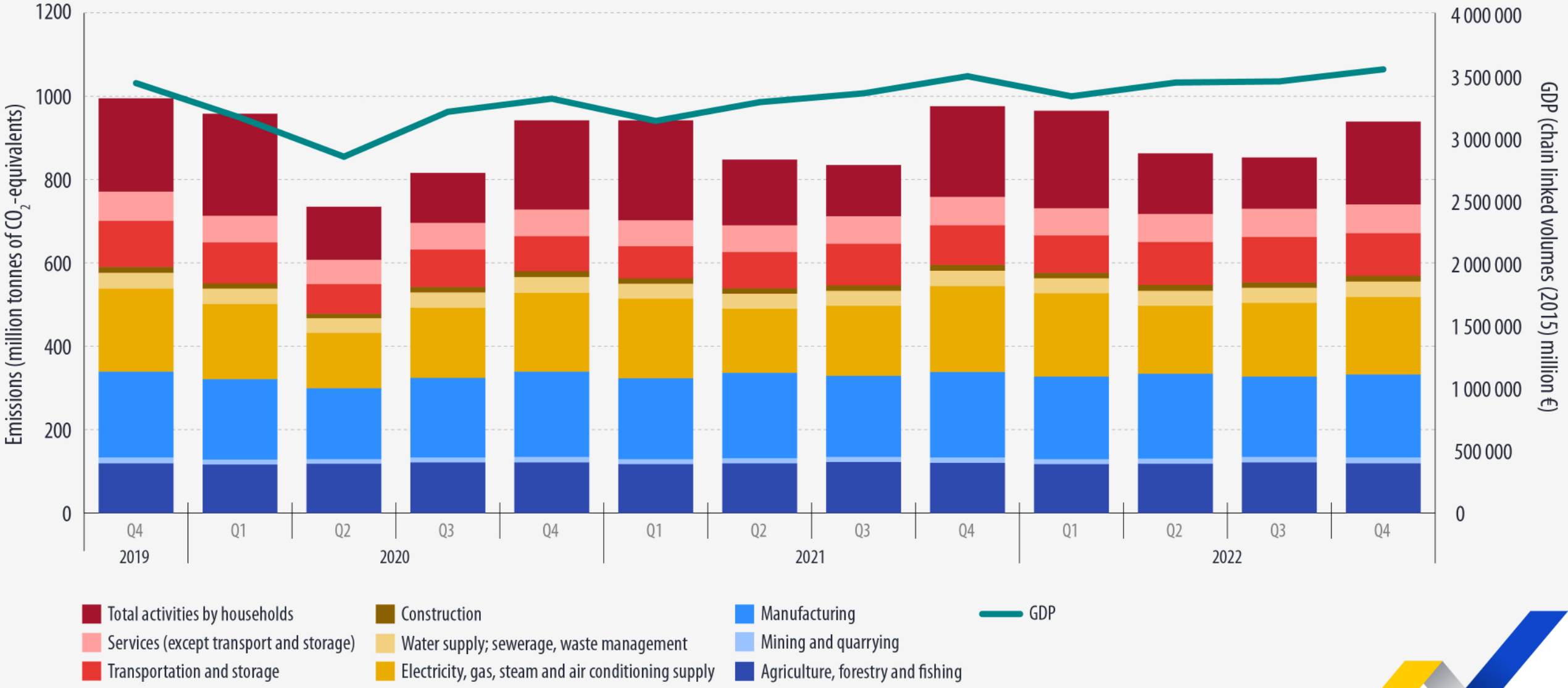


Thin atmosphere (scale intuition)



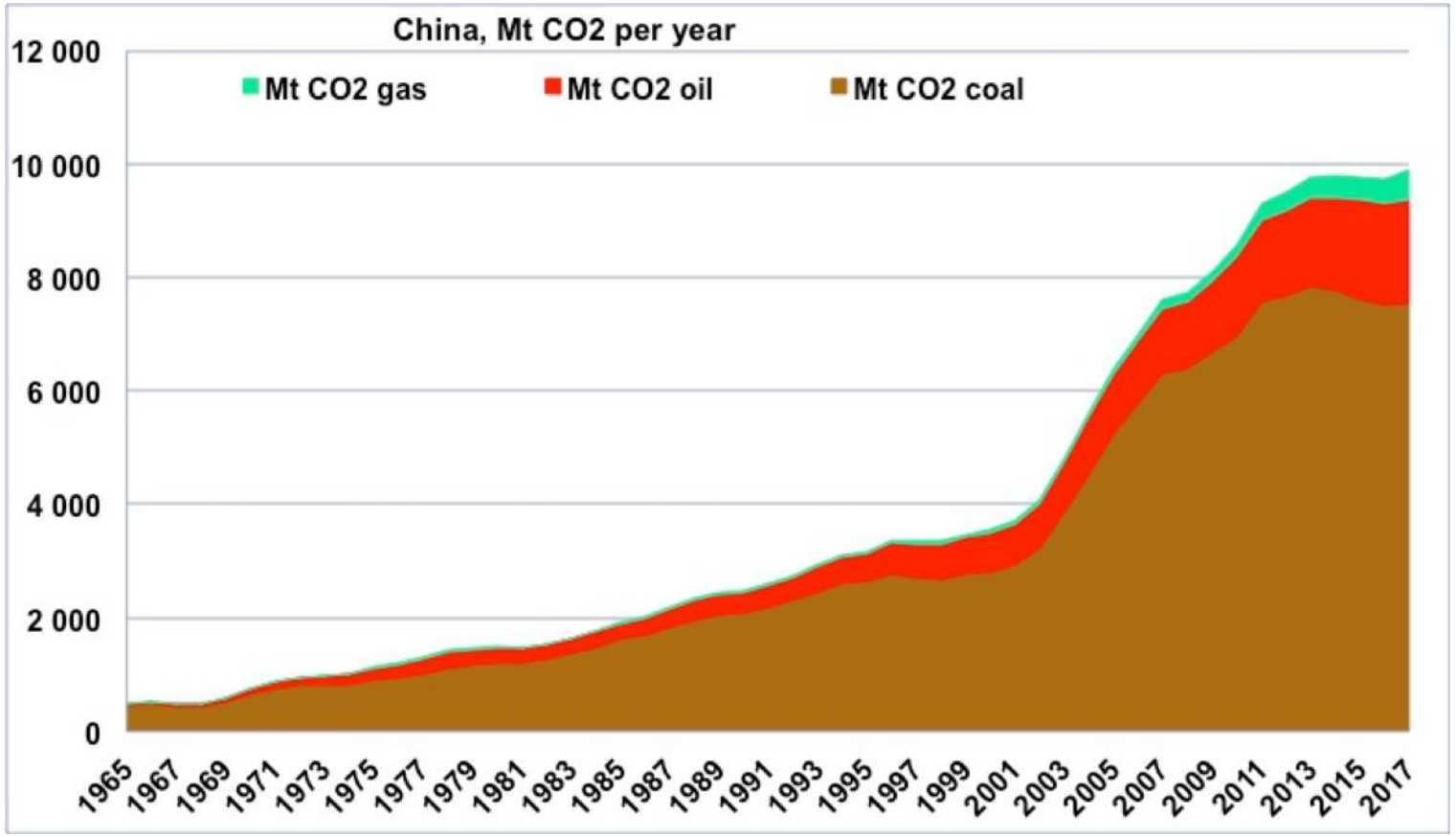
Greenhouse gas emissions by the economy and GDP, EU, Q4 2019 - Q4 2022

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

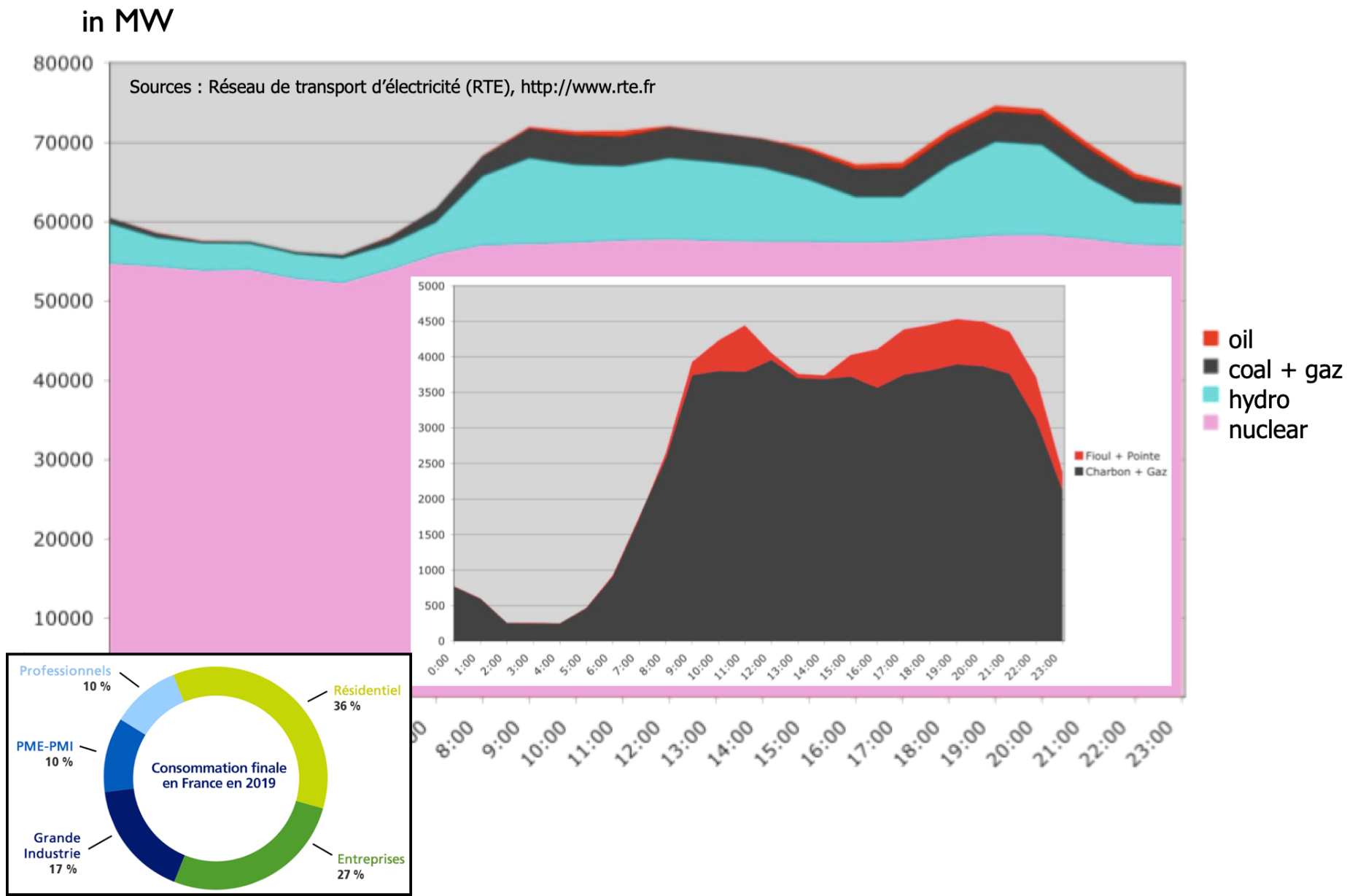


China — CO_2 (example trajectory)

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

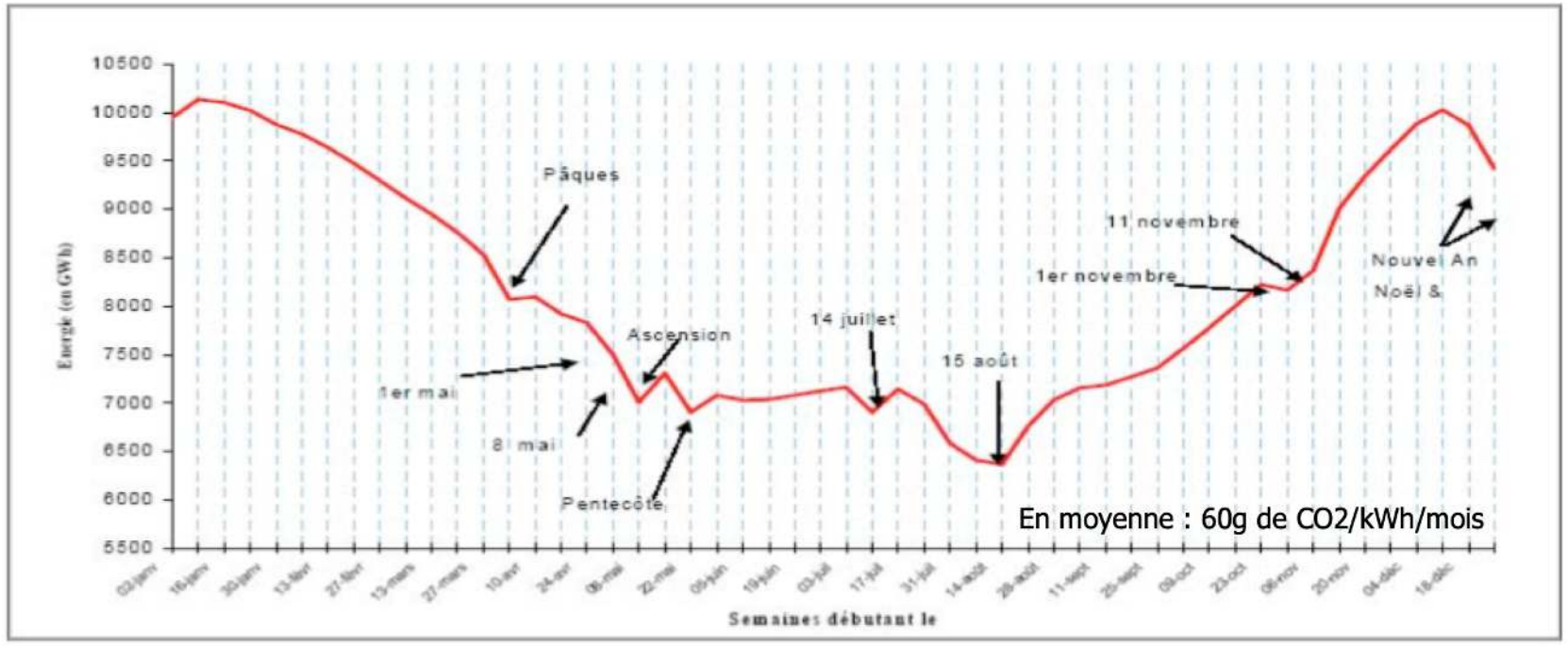


typical evolution of infra-day production



Same useful energy, different carbon intensity

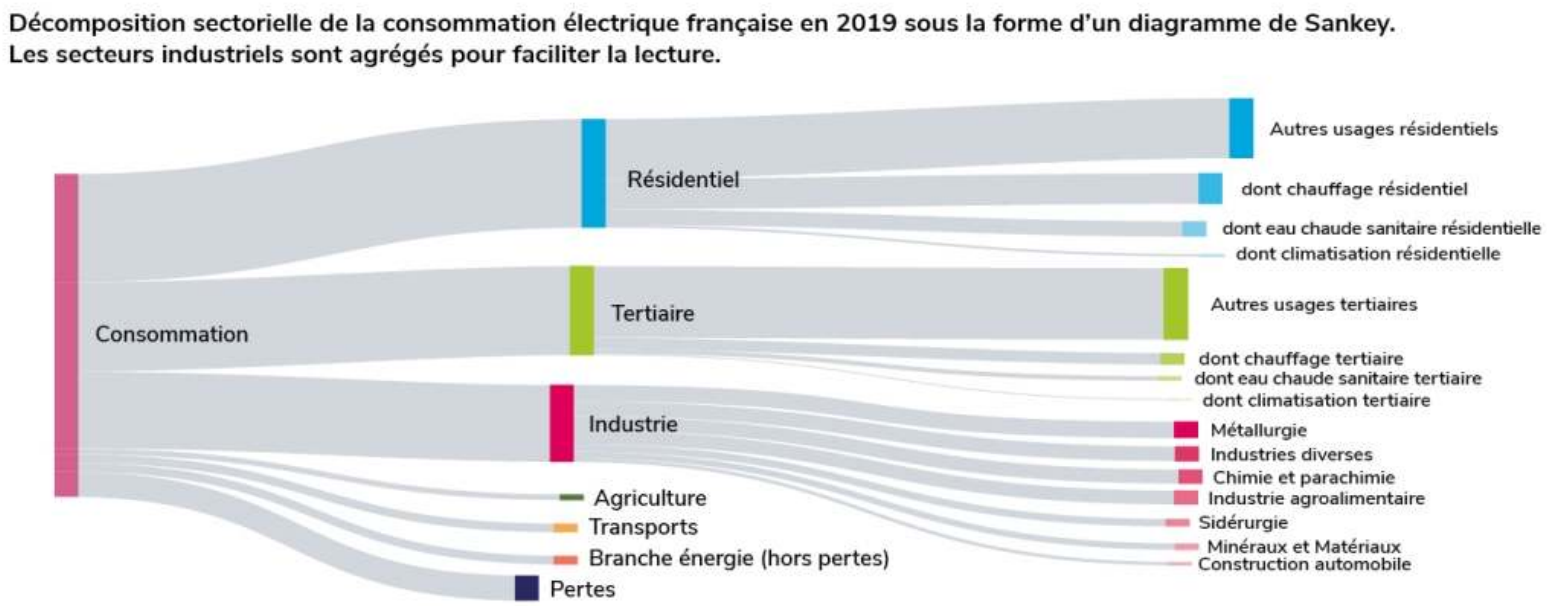
Vectors matter: 1 kWh from coal vs 1 kWh from wind do not carry the same CO_2.



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.

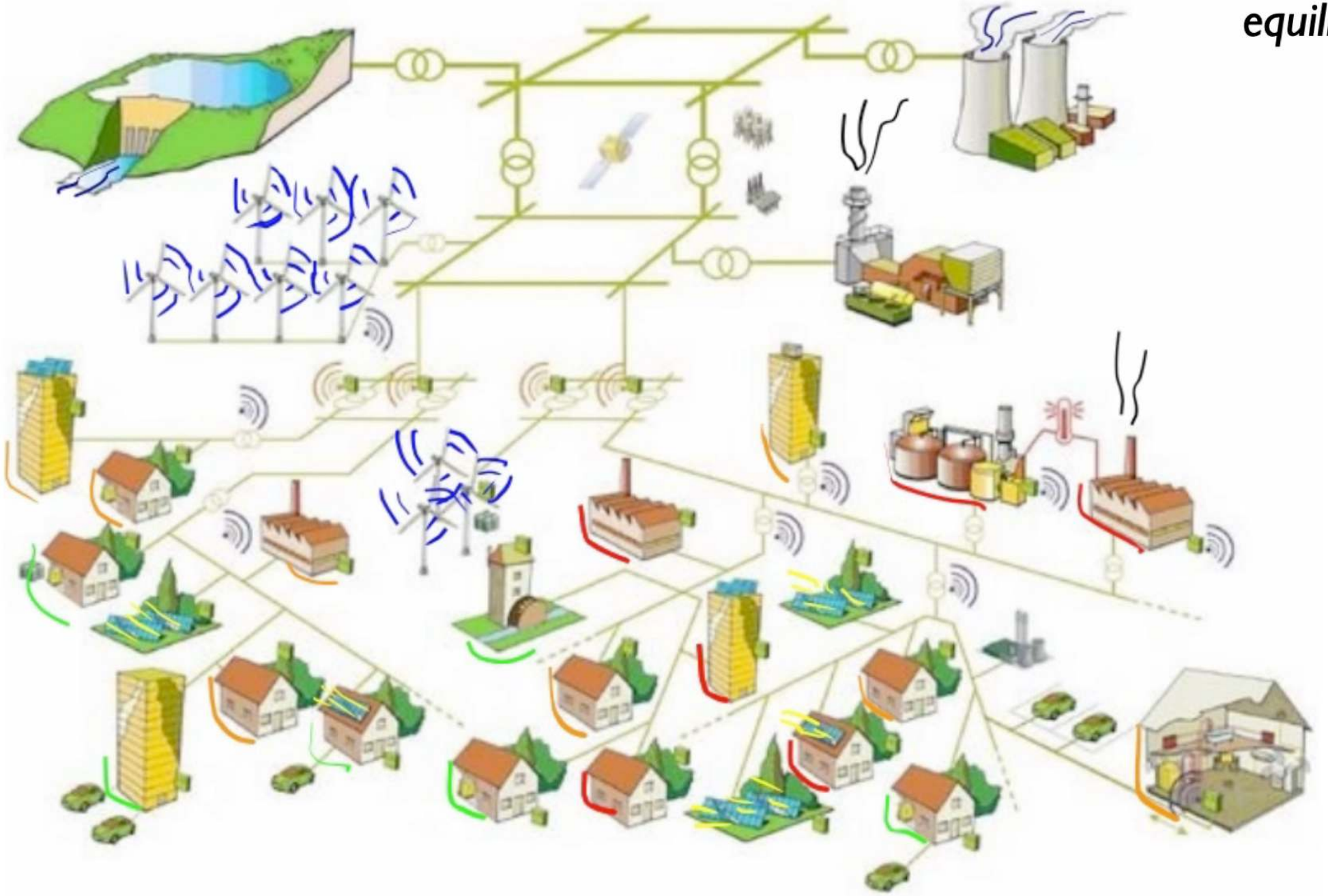


Power grid (infrastructure)

- 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.

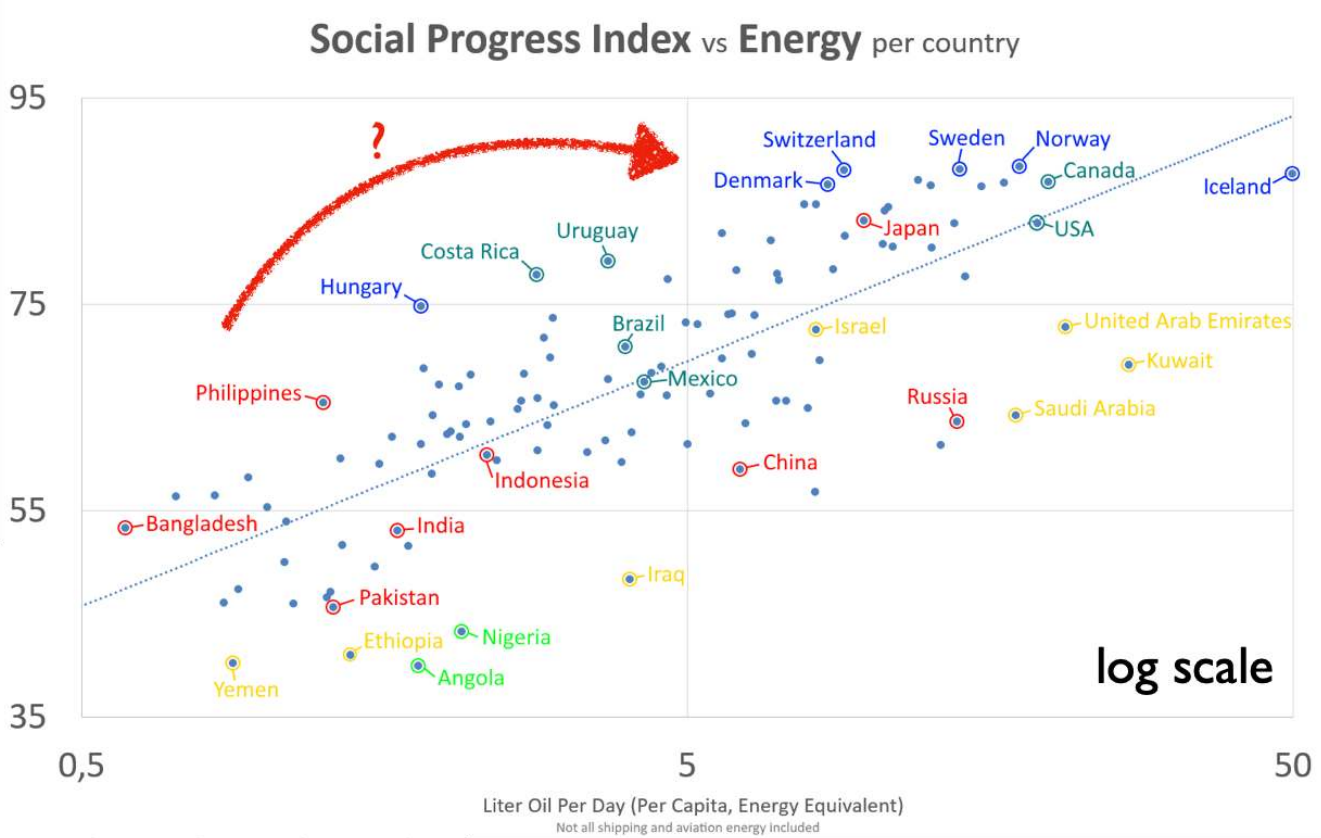
This can be achieved by:

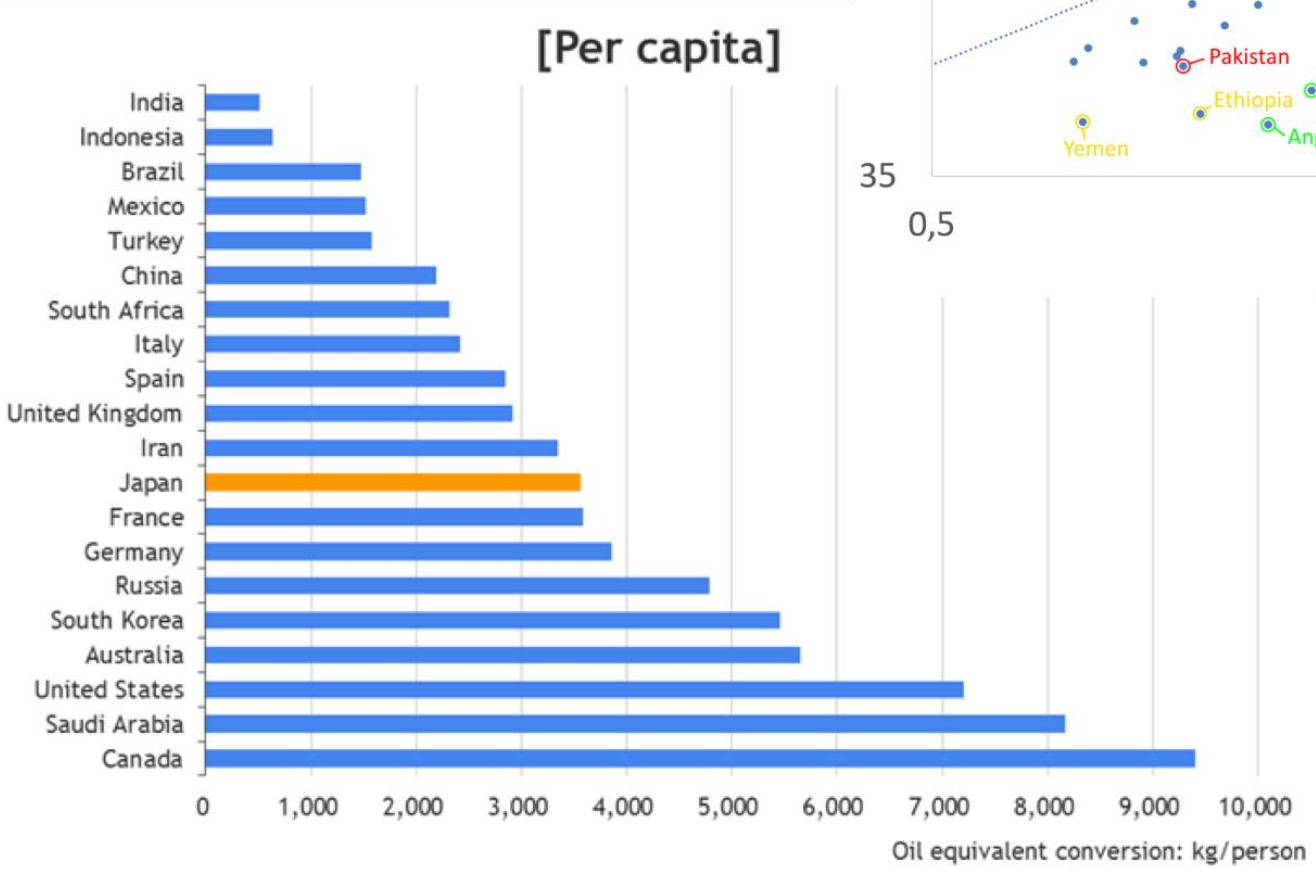
- increasing the flexibility of production means (e.g. gas turbines, hydroelectric power plants, nuclear plants, hydro dams in mountains,...)
- using pumping and turbine station (PTS or STEP in France) for hydropower
- increasing the use of storage systems
- developing the use of flexible loads (e.g. 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
Canada
Iceland
Denmark
Japan
USA
Uruguay
Costa Rica
Hungary
Brazil
Israel
United Arab Emirates
Kuwait
Mexico
Philippines
Russia
Saudi Arabia
China
Indonesia
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

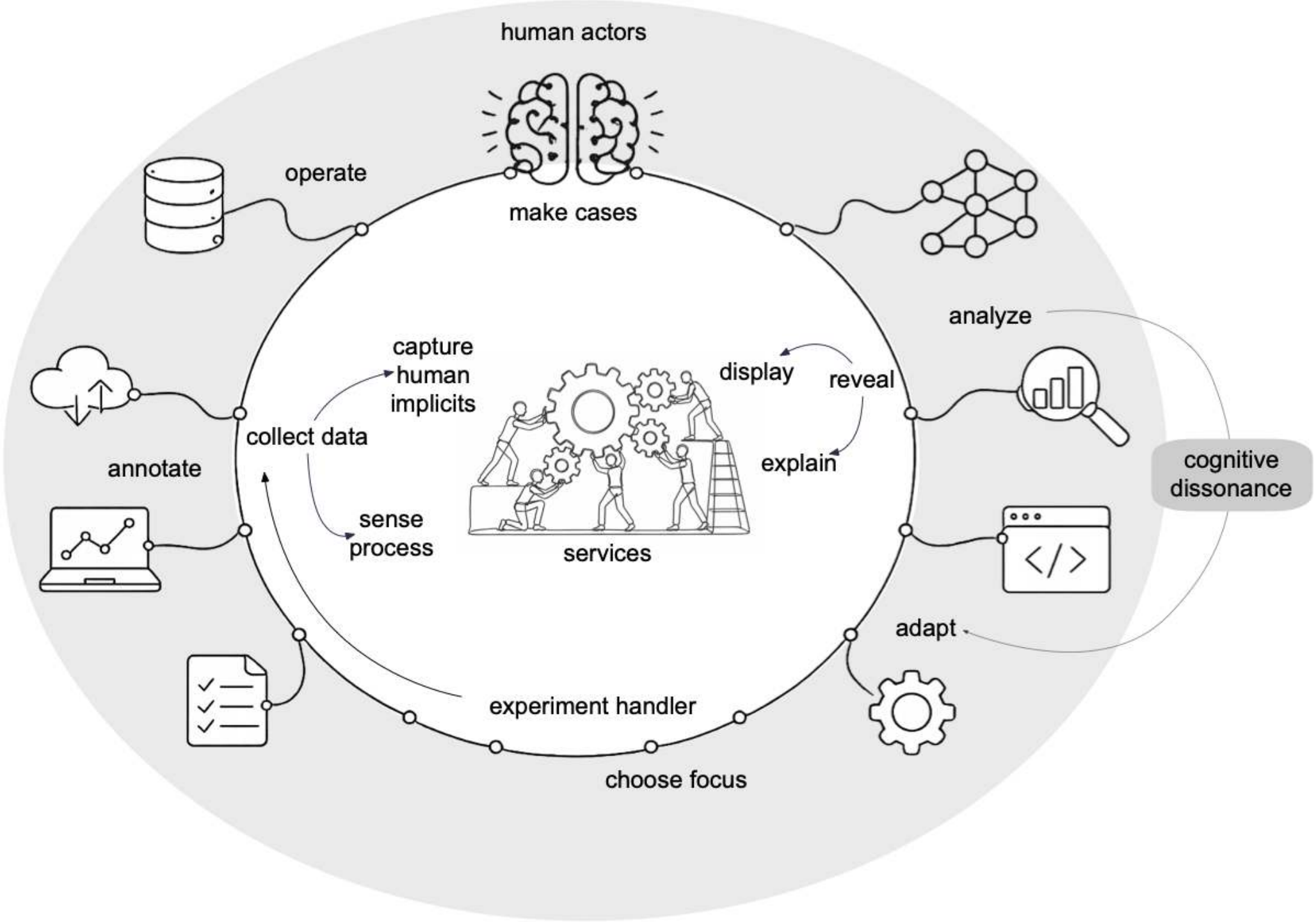
It becomes a lever for reflection, adaptation, and sufficiency-oriented decisions.

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
explain
annotate
sense
process
services
cognitive
dissonance
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.

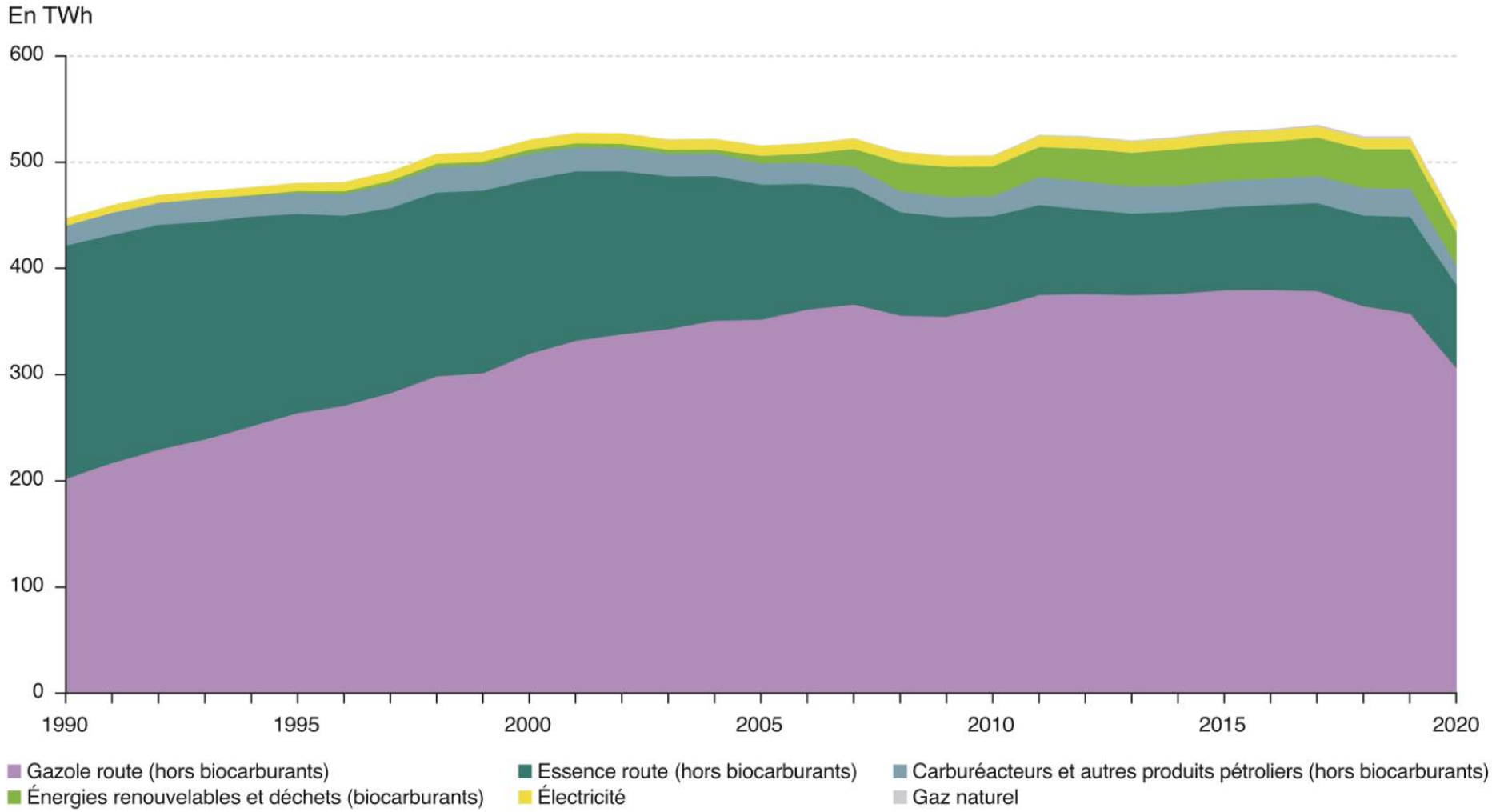
What 1 kWh “feels like” (illustrative)

- lift 1 t by ~367 m (idealised);
- heat ~10 L water by ~86 °C (order of magnitude);
- warm ~180 m³ 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/m²·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.

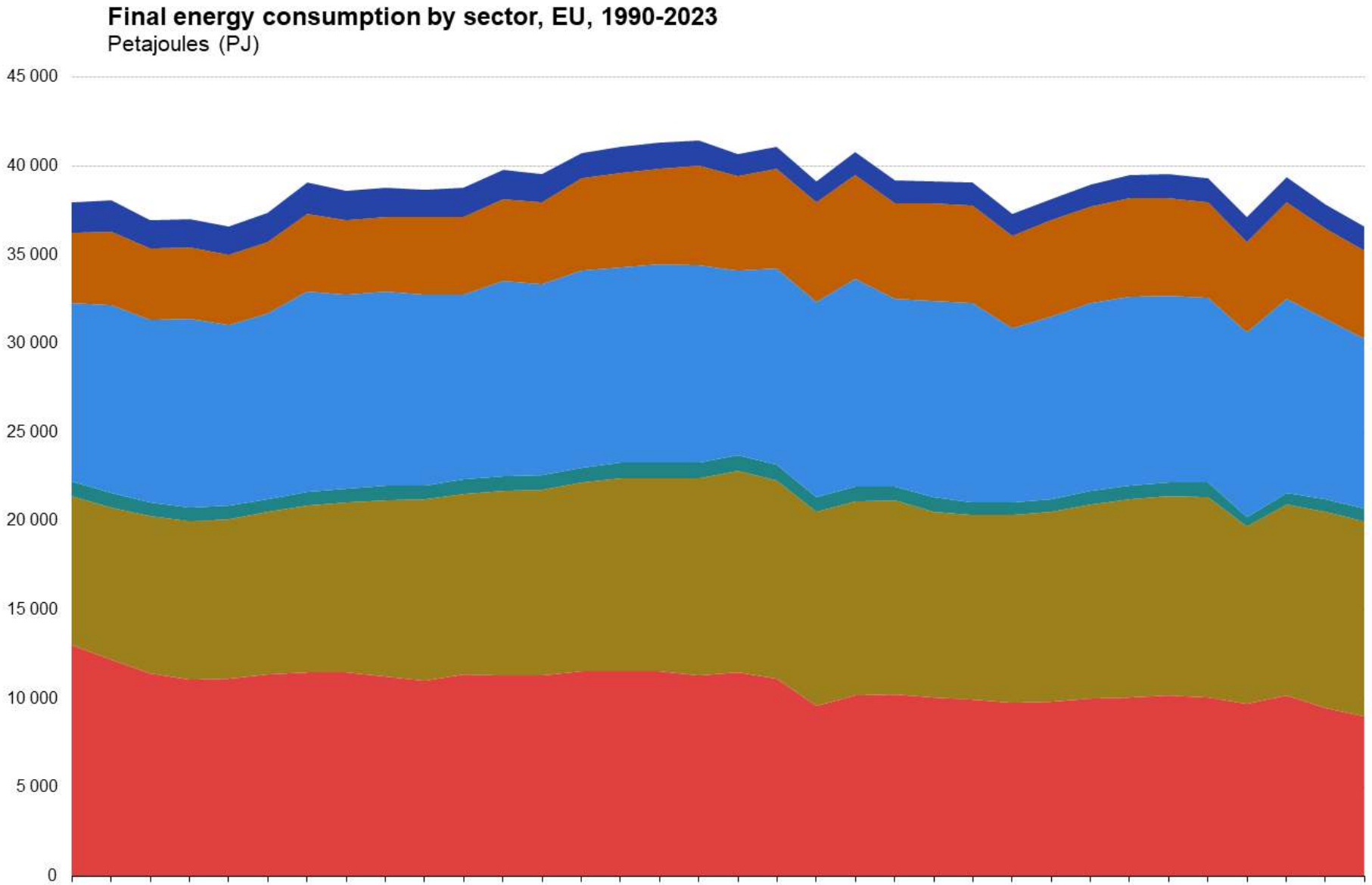
RT2012 — regulatory order of magnitude

~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.

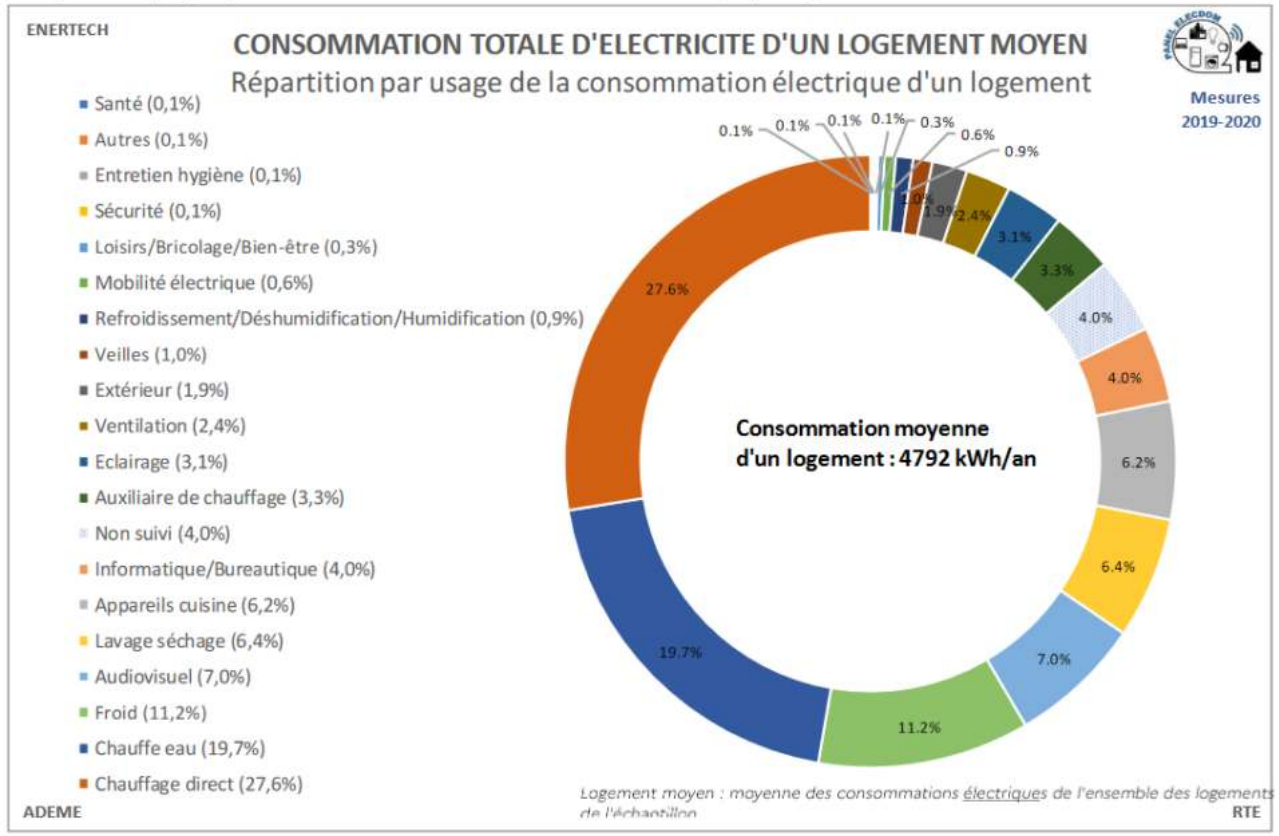


Final energy by sector (example figure)



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

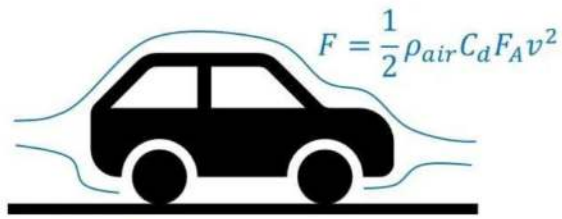
Typical electrical powers — home (2/2)

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

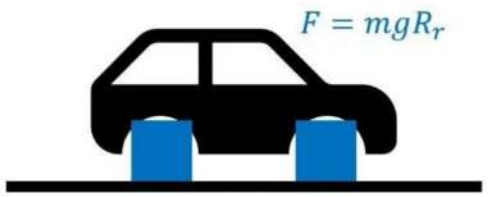
- PV: ~100 W per m² panel (STC-ish ballpark)
- Home connection: 3–18 kW subscribed
- Car: ~80 kW motor level used in the slides' comparison
- Wind turbine / nuclear unit: MW to GW

Aerodynamic Forces



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}

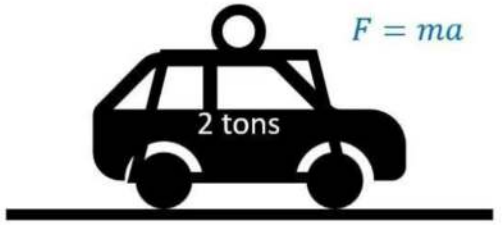
Rolling Resistance



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

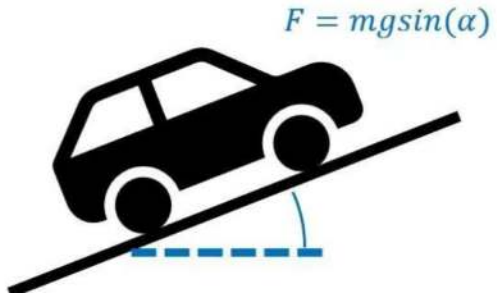
Acceleration



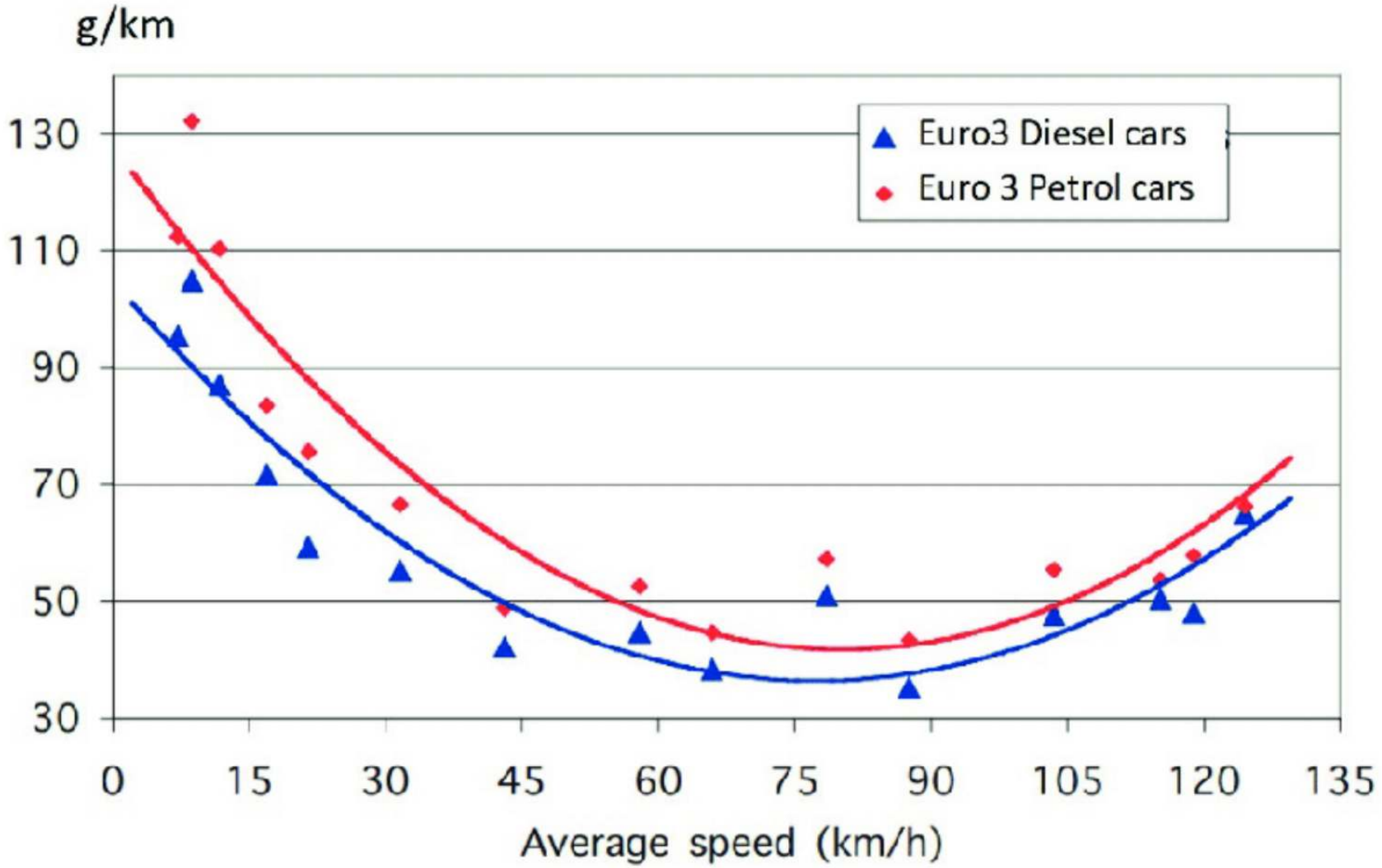
If we accelerate the car very quickly we need to apply a force to do so.

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

Gradients

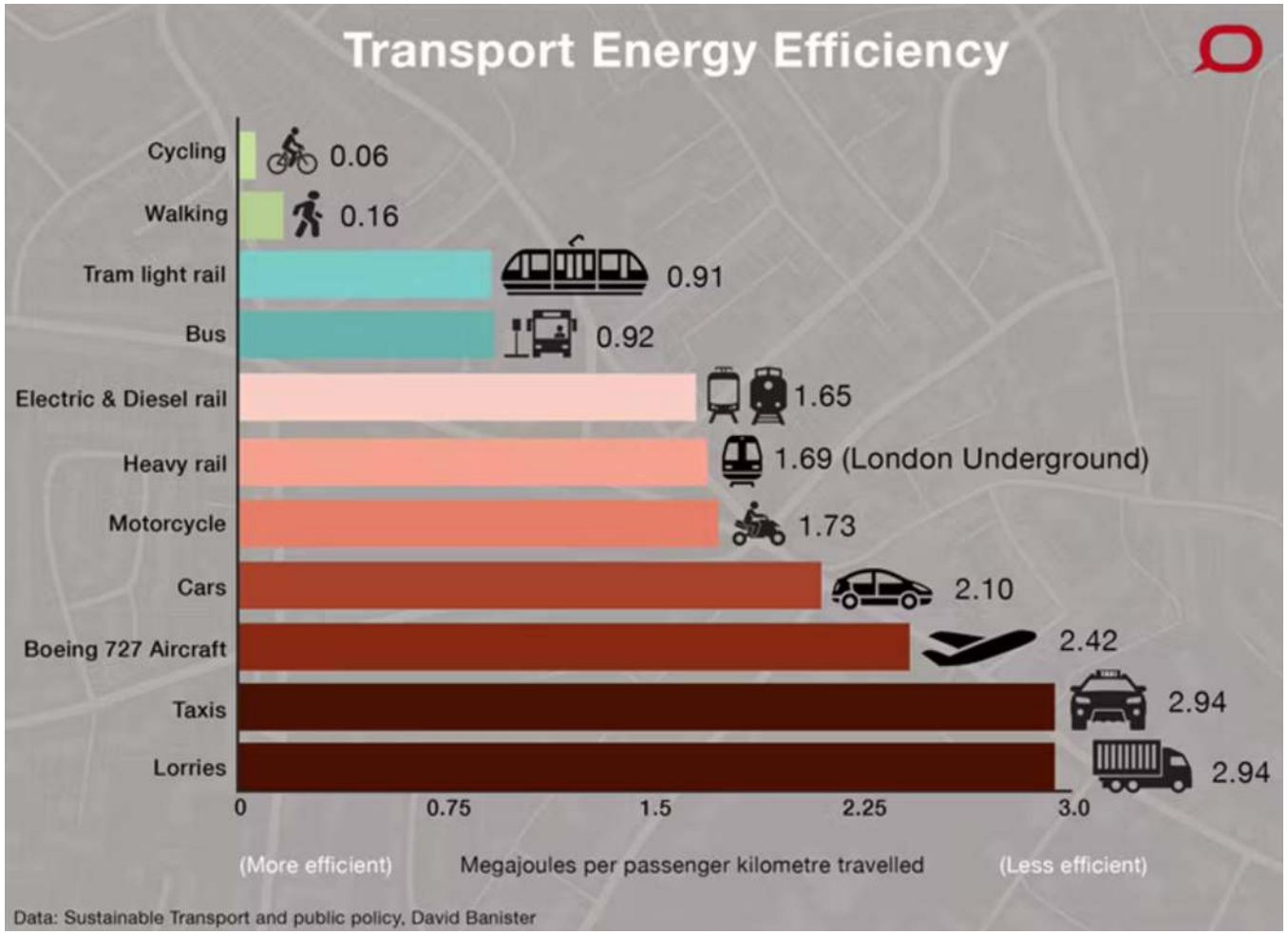


Drive the vehicle up a slope and the additional force is dependent on the mass, gravity and the angle of the slope.



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/m² (watts per square metre)
- B. ppm/year only
- C. °C per century, by definition
- D. kWh/m²/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/m²/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/m².
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.

part II - Intuitive approach of building design

Intuitive building design

Design of an efficient and resilient building considering global warming with `baterm`

author: stephane.ploix@grenoble-inp.fr

You are going to use `baterm` to discover the building design

`baterm` is a tool to easily design buildings but it is based on the precise simulation model of `batem`

- heat transfer by conduction, convection and radiation
- solar gains through windows, walls and PV panels considering solar masks
- close (building itself, surrounding buildings) and far (mountains) shadings
- air infiltration and forced ventilation
- HVAC system for cooling and heating
- types of roofs
- thermal inertia
- cell connections in photovoltaic panels and impact of temperature
- mounting type of PV panels

Understanding what matters in building design

Building efficiency is not just a matter of insulation

- location, shape and direction of the building (including roof)
- adjacency to other buildings
- location and glazing surfaces
- materials used
- tuning of the HVAC system
- occupancy and comfort demands
- PV plant and autonomy
- ...

Thanks to `baterm`, it's easy to understand what matters in building design

The basic commands of `baterm`

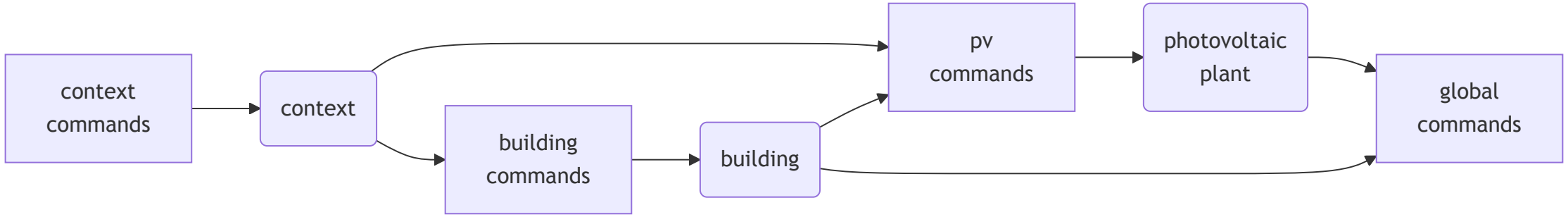
command	description
help	show help for a command (`help alias` , for instance)
alias	list all aliases (replace a string by another)
dir	list all directories in the working folder
cd	change the working directory
pwd	print the current working directory
history	show the history
manual	show the manual
quit or exit	quit the program

command	description
shell	run a shell command
macro	list all macros (batem scripts)
→ macro create	create or overwrite a new macro
→ macro delete	delete a macro
→ macro list	list all macros
load	load a macro (baterm script)
run	run a macro (baterm script)
shortcuts	list available shortcuts
ls	list all files
pyrun or run_pyscript	run a Python script

The batem commands

command	description
lectures	list all lectures
→ lectures 15	show the lecture 15
workshops	list all workshops
→ workshops 15	show the workshop 15

Commands are structured around 3 objects: context, building and photovoltaic plant.



A **context** is a location with a weather and possible solar **side masks** (modeling for instance, surrounding buildings).

The context commands

A context is mainly defined by a location:

- a latitude North and a longitude East in decimal degrees.

It is used to load the historical weather data from http://open-meteo.com, to get:

- the **elevation** of the location
- the far masks due to **surrounding mountains**.

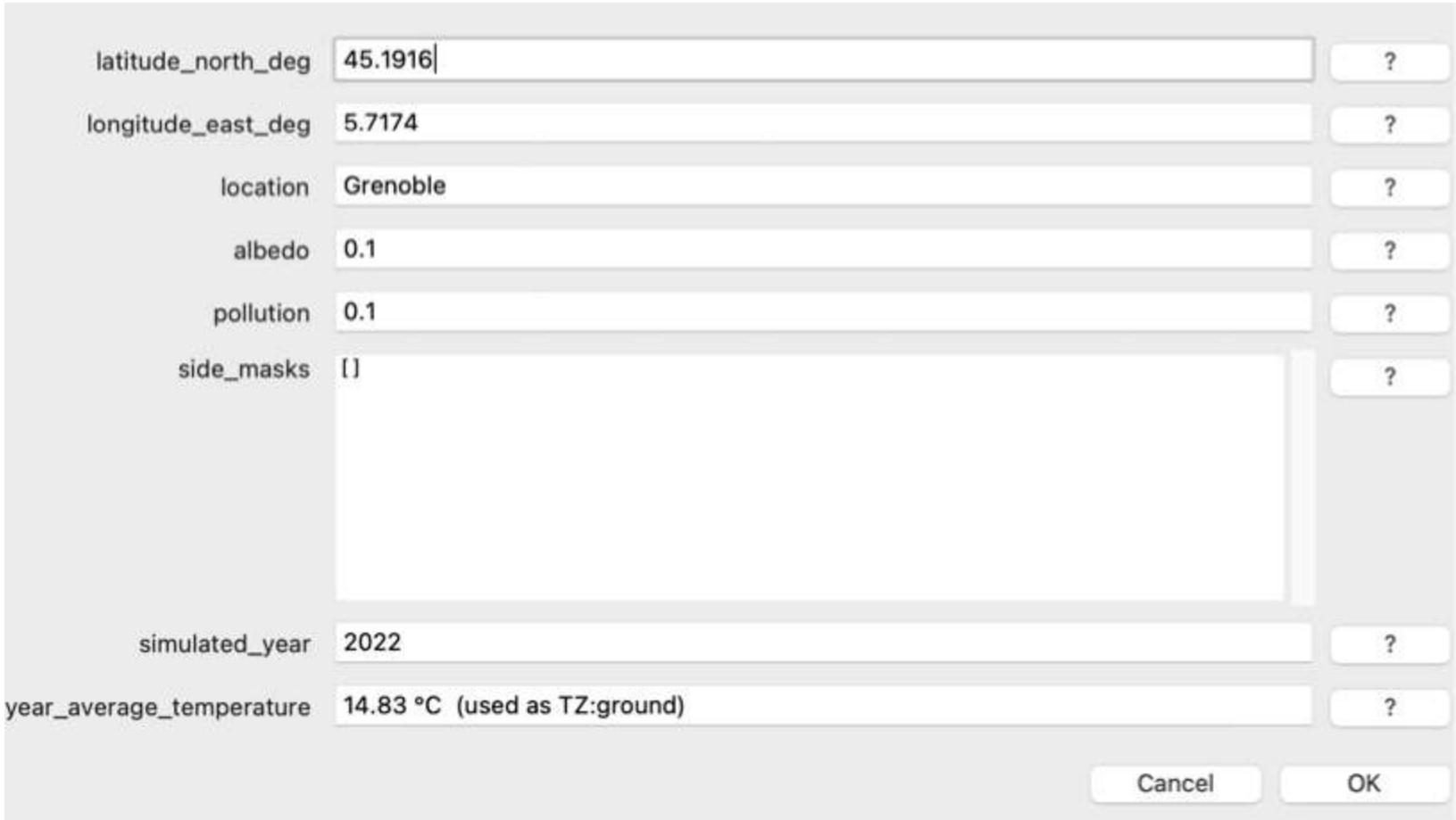
A context can be created with the command `context new`.

Default values are proposed. Then it can be modified with `context edit`.

Note the tip on the right hand side of each value: it is a documentation for the value.

The name appearing in the location field is used to save the collected data to avoid re-downloading them each time.

The context data are shown below: the historical weather data (from January 1st, 1980 till nowadays) will be saved in `Grenoble.json`.


latitude_north_deg
45.1916
?
longitude_east_deg
5.7174
?
location
Grenoble
?
albedo
0.1
?
pollution
0.1
?
side_masks
[]
?
simulated_year
2022
?
year_average_temperature
14.83 °C (used as TZ:ground)
?
Cancel
OK

Albedo is the average reflectivity of the surface: 0 means no reflection, 1 means full reflection. It is used to compute the solar radiation on the surface. (default value is 0.1)

The **pollution coefficient** is used to compute the solar radiation on surfaces.
The pollution level is a value between 0 and 1, 0 means no pollution, 1 means maximum pollution. (default value is 0.1)

Sidemasks are used to model the surrounding buildings. They are defined by a list of rectangular surfaces with their dimensions and angles.

The simulated year is the year of the historical weather data to be used. It should be between 1980 and the year before the current year because full year data is needed for the simulation.

The year average temperature is the average temperature of the year. It is used to compute the ground temperature but it can be changed if needed.

A documentation for the side-masks can be found in the file doc_sidemasks.

Here is an example of a side-mask (several side-masks can be defined ; they just have to be separated by a comma):

```
{     "name": "left",
      "x_center": 2.5,
      "y_center": -20.0,
      "width": 15.0,
      "height": 6.0,
      "elevation": 0.0,
      "exposure_deg": 180.0,
      "slope_deg": 90.0,
      "normal_angle_with_south_deg": 0.0,
      "normal_rotation_angle_deg": null,
      "tangent_x": NaN,
      "tangent_y": NaN,
      "facade_normal_x": NaN,
      "facade_normal_y": NaN
    }
```

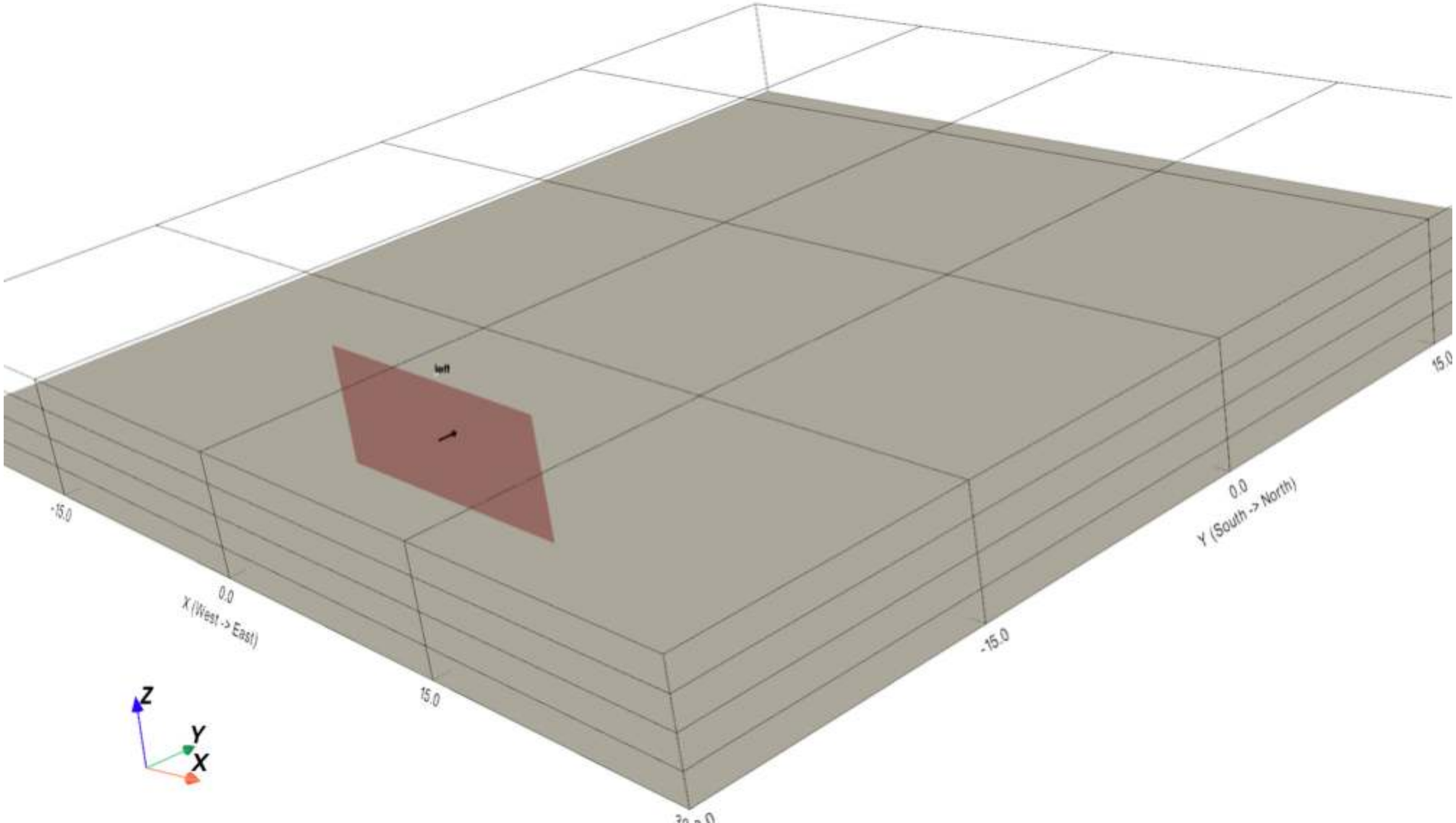
Here, side-masks are used to model vertical rectangular surfaces (slope = 90°) touching the ground (elevation = 0).

Only the lower middle position (at the center of the edge cutting the ground) has to be defined (x_center, y_center) and the dimension of the side (width, height). Finally the direction of the normal has to be defined: exposure_deg=0 (or ±180° or 360°) means South or North, exposure_deg= ±90° means East or West.

A side-mask for a wall requires only 5 values to be defined:

```
{ "name": "mask_name",
  "x_center": ?,
  "y_center": ?,
  "width": ?,
  "height": ?,
  "elevation": 0.0,
  "exposure_deg": ?,
  "slope_deg": 90.0,
}
```

You can see the result with the command `context 3d`:



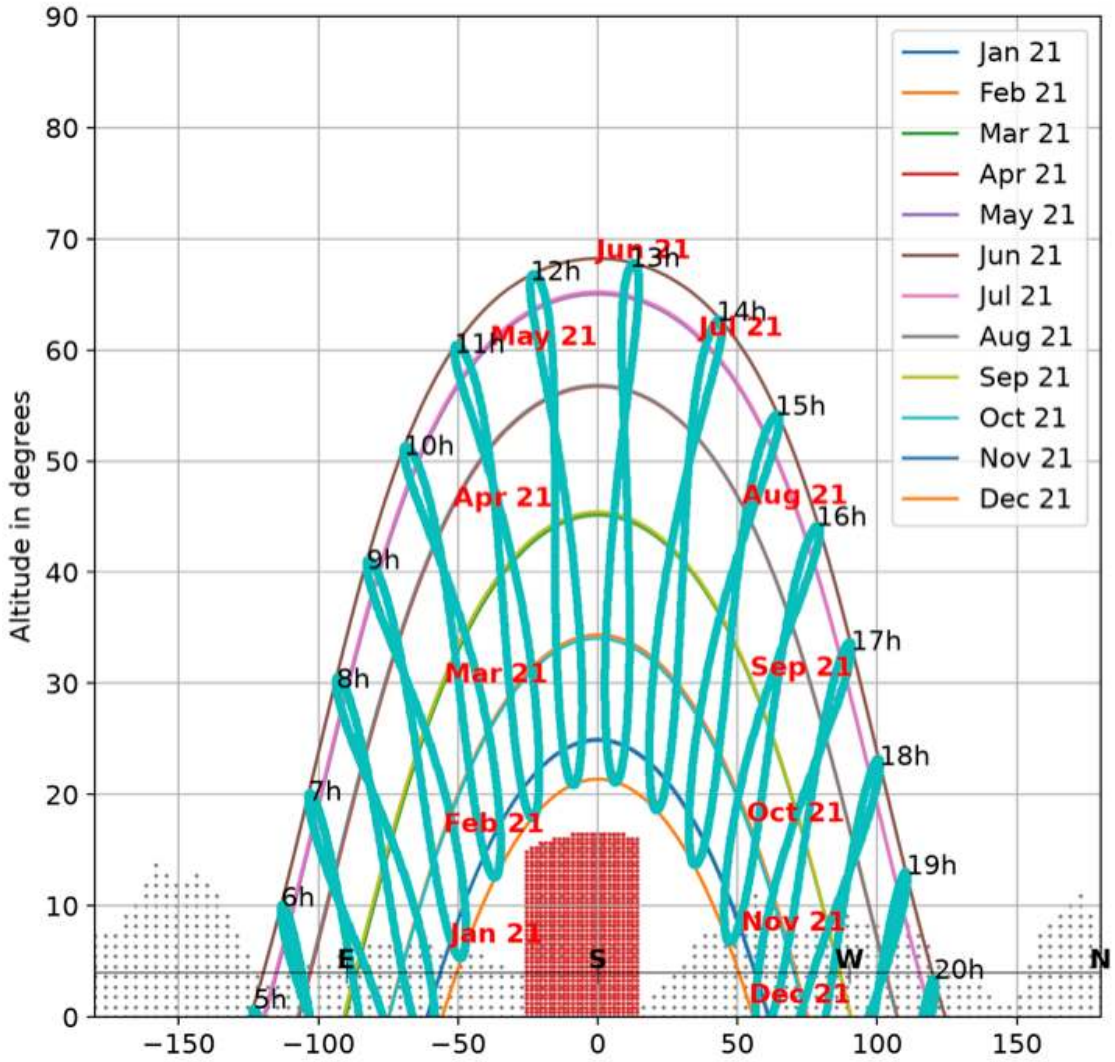
The heliodon, representing the sun path each 21st of months of the year, is shown with the command `context heliodon` knowing that the observer is located at the (0,0,0) position i.e. at the specified gps coordinates.

The red shape is the defined side-mask (sun is hidden behind it when it passes at this position).

The gray mask stands for the surrounding mountains.

As we can see, this mask is never hiding the sun.

Here is an example of heliodon for the context:



command	description
context	show the current context
context delete	delete a context
context new	create a new context
context edit	edit a context
context heliodon	show the heliodon
context 3d	show the 3d view of the context
context sidemasks	show the features of the defined side masks

Many other tools are available to analyze the context:

command	description
context rain	graphical tool to analyze the rain data
context temperature	graphical tool to analyze the temperature data
context wind	graphical tool to analyze the wind data
context solar	graphical tool to analyze the solar data
context psychro	psychrometric chart to analyze how the weather is comfortable
context evolution	graphical tool to analyze the evolution of the outdoor temperature since 1980

command	description
context vars	list all variables available in the context
context plot	plot any variables of the context

The building commands

A building is defined by its geometry (footprint, number of floors, heights), its envelope (wall / roof / floor / glazing compositions), its HVAC settings (setpoints, heating and cooling powers, air renewal) and its occupancy.

It needs a context first: the weather and the solar masks come from it.

A building can be created with `building new`. Default values are proposed. Then it can be modified with `building edit`.

As for the context, each field has a tip on the right-hand side.

The building is saved as a `.building` JSON file under `./data` (for instance `building save myhouse` → `./data/myhouse.building`).

The footprint is a list of 2D points in meters: `[0,0],[10,0],[10,5],[0,5]`. Axes: **+X East**, **+Y North**, **+Z up**. It can be visualized with the command `building footprint`.

Side indices start at 0 and follow the footprint edges. Use `building footprint` to check them. Sides can be visualized with the command `building footprint` too.

Glazing ratios can be one value same for all façades, or one value per side. It represents the fraction of the side that is glazed.

Compositions are stacks of layers **from indoor to outdoor**, for example:

`["plaster",0.013],["insulation",0.15],["brick",0.1]`

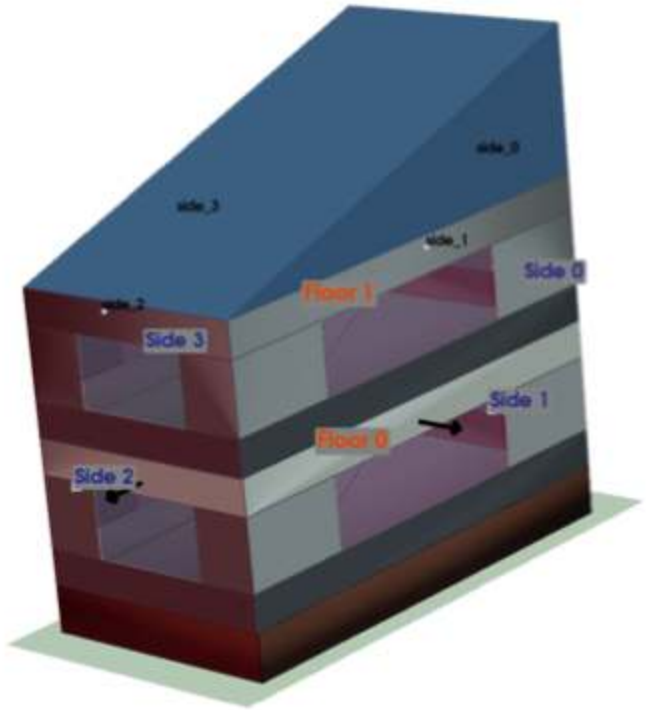
Material names come from `propertiesDB.xlsx` (see `material list thermal`) but only the ones with a star in front are loaded. If you load another one, use the command `material load <a_name> <row_number>`.

Roofs

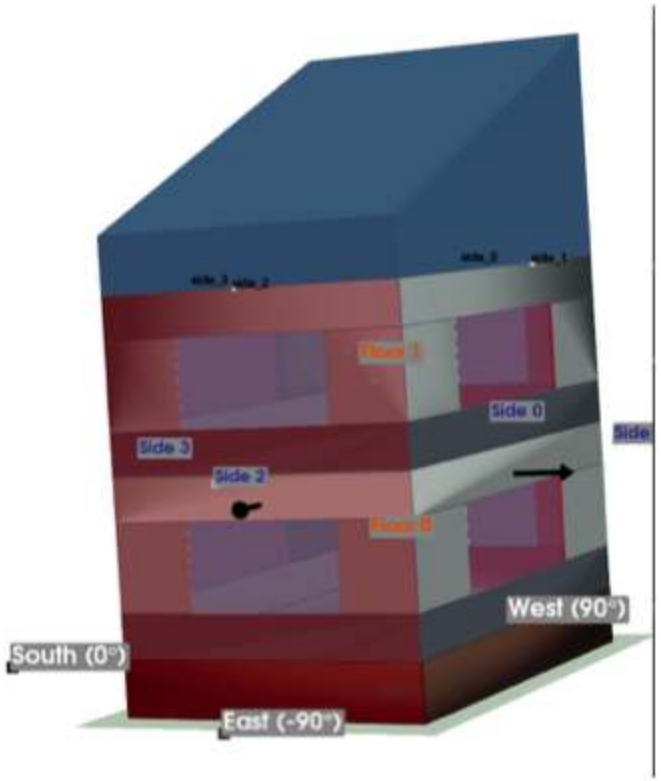
A roof can be extruded along a given height: `roof_extrusion: 1.0`. There will be an additional 1 m strip in roof material in the continuity of the walls.

It can have a wall ratio: `roof_wall_ratio: 0.4`. It represents the fraction of the side that is considered as a wall. The rest is considered as a roof.

Moreover, if `attic` is set to `True`, a passive attic zone (no HVAC, glazing, or occupants) is defined: it constitutes a buffer zone between the last inhabited floor and the attic: the last floor composition is `lowup_floor_composition`.



attic: False
extrusion: 0
wall_ratio: 0.0



attic: True (not visible on the 3D plot)
extrusion: 1
wall_ratio: 0.4

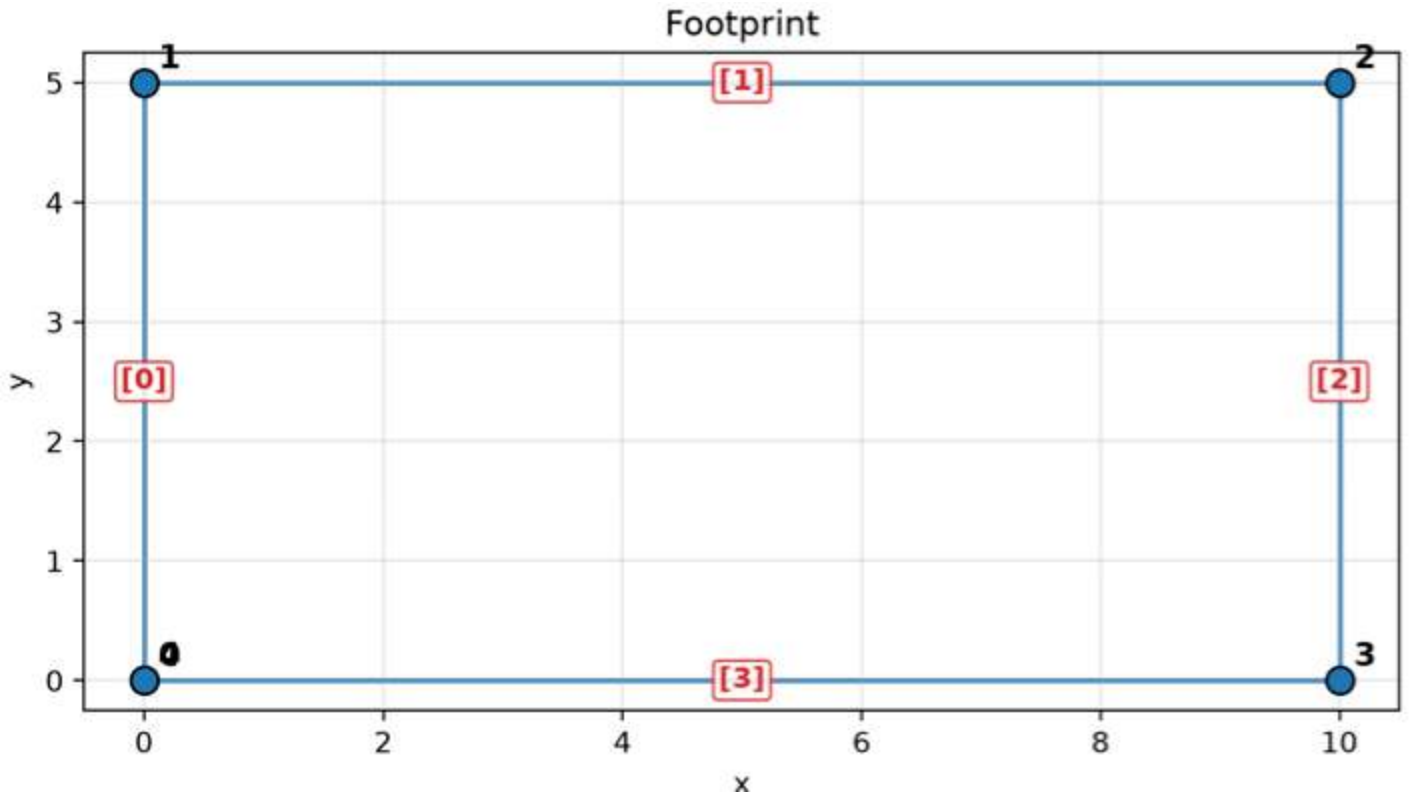
In the building form, 2 kinds of roof shapes can be defined: the aperiodic roofs (periodic=False) and the periodic roofs (periodic=True). Defaults keep a flat ceiling: `"roof_points": []` and do not depend on the kind of roof shape.

Aperiodic roof is defined by:

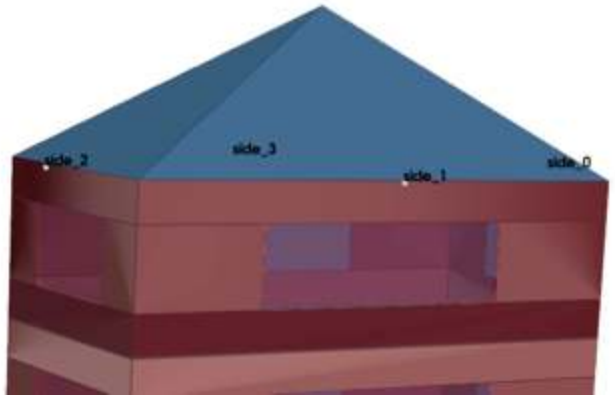
- `roof_points` — ridge / apex `(x, y, z)` in meters (same axes as the footprint in meters) define a convex hull on the roof surface where z=0 stands for the top of the building without roof but keeping the footprint.
- `roof_extrusion` — height of the vertical roof base above the top storey [m]
- `roof_wall_ratio` — lower fraction of each vertical roof side counted as **wall** (0...1); the rest is **roof**
- `attic` — if true, a passive attic zone (no HVAC, glazing, or occupants)

Check the shape with `building 3d`.

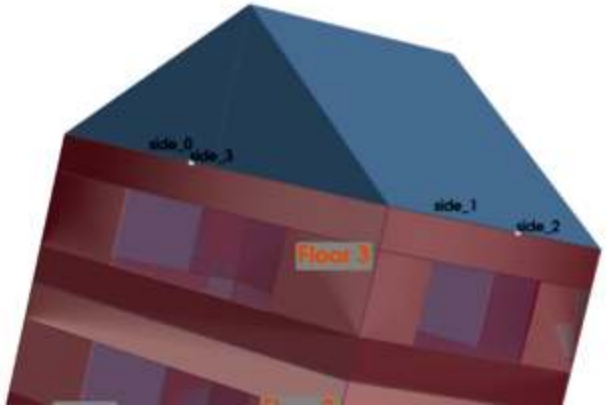
For example, the following roofs are defined for a building whose footprint is `[0,0,0], [10,0,0], [10,5,0], [0,5,0]`.



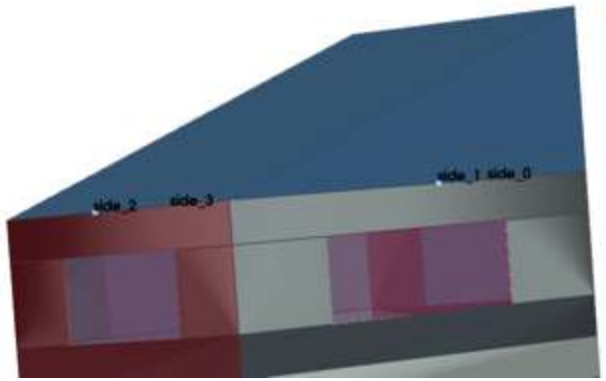
A pointed roof can be defined by one point: `[5, 2.5, 3]`.



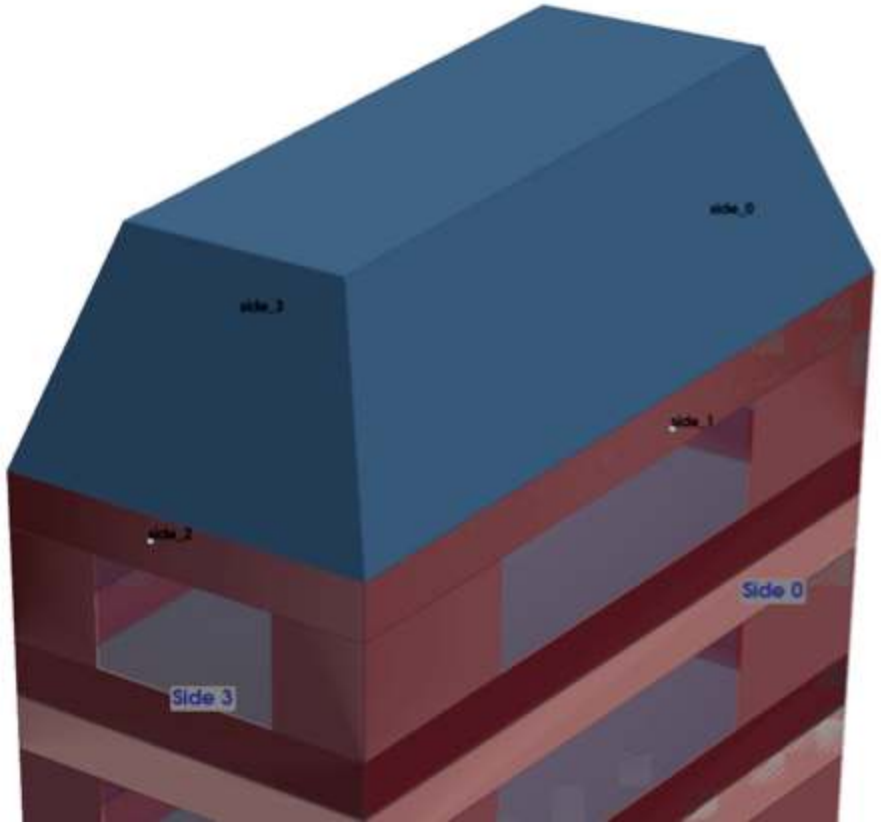
A hip roof can be defined by two points: `[5,0,3], [5,5,3]`.



Another hip roof: `[0, 0, 3], [0, 5, 3]`:



A ridge roof can be defined by 4 points: `[1,1,3], [9,1,3], [9,4,3],[1,4,3]`.



Periodic roof shapes

Set `periodic: True` to build a repeating height profile instead of a convex hull.

In this mode, `roof_points` are **not** `(x, y, z)` apexes. They are breakpoints of **one period**:

```
(fraction, z)
```

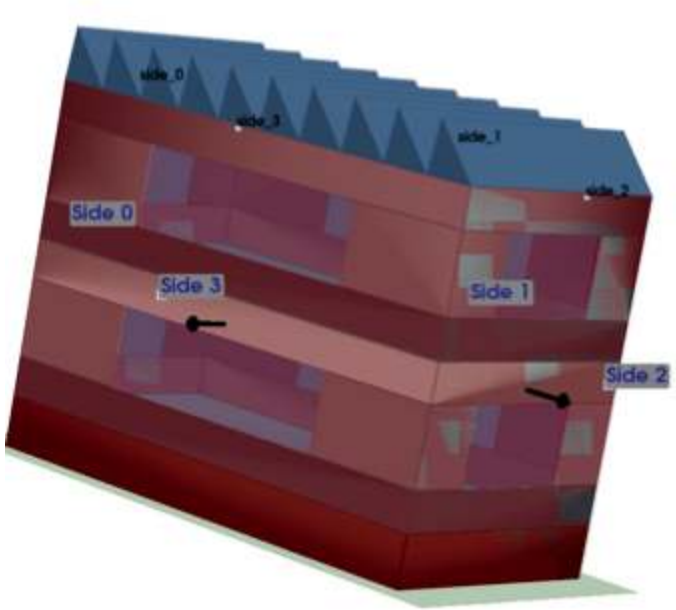
- `fraction` — position along one period (`0` = start, `1` = end of the period)
- `z` — roof height above the top of the extrusion [m]

That profile is repeated `periodic_n_repeats` times along `periodic_direction` (`"x"` , `"y"` , or a 2D vector `[dx, dy]`).

`roof_extrusion` , `roof_wall_ratio` and `attic` work as for aperiodic roofs.

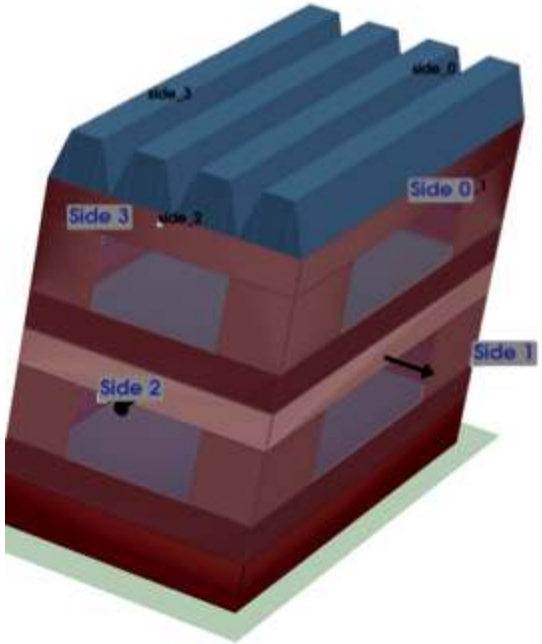
Saw-tooth / shed periods (10 repeats along `x`):

```
"periodic": true,
"periodic_n_repeats": 10,
"periodic_direction": "x",
"roof_points": [[0, 0], [0.1, 1.0], [1, 0]],
"roof_extrusion": 0
```



Trapezoid periods (4 repeats):

```
"periodic": true,
"periodic_n_repeats": 4,
"periodic_direction": "y",
"roof_points": [[0, 0], [0.25, 1], [0.75, 1], [1, 0]]
```



Check with `building 3d`. Prefer this mode for industrial saw roofs or any shape that repeats along one axis.

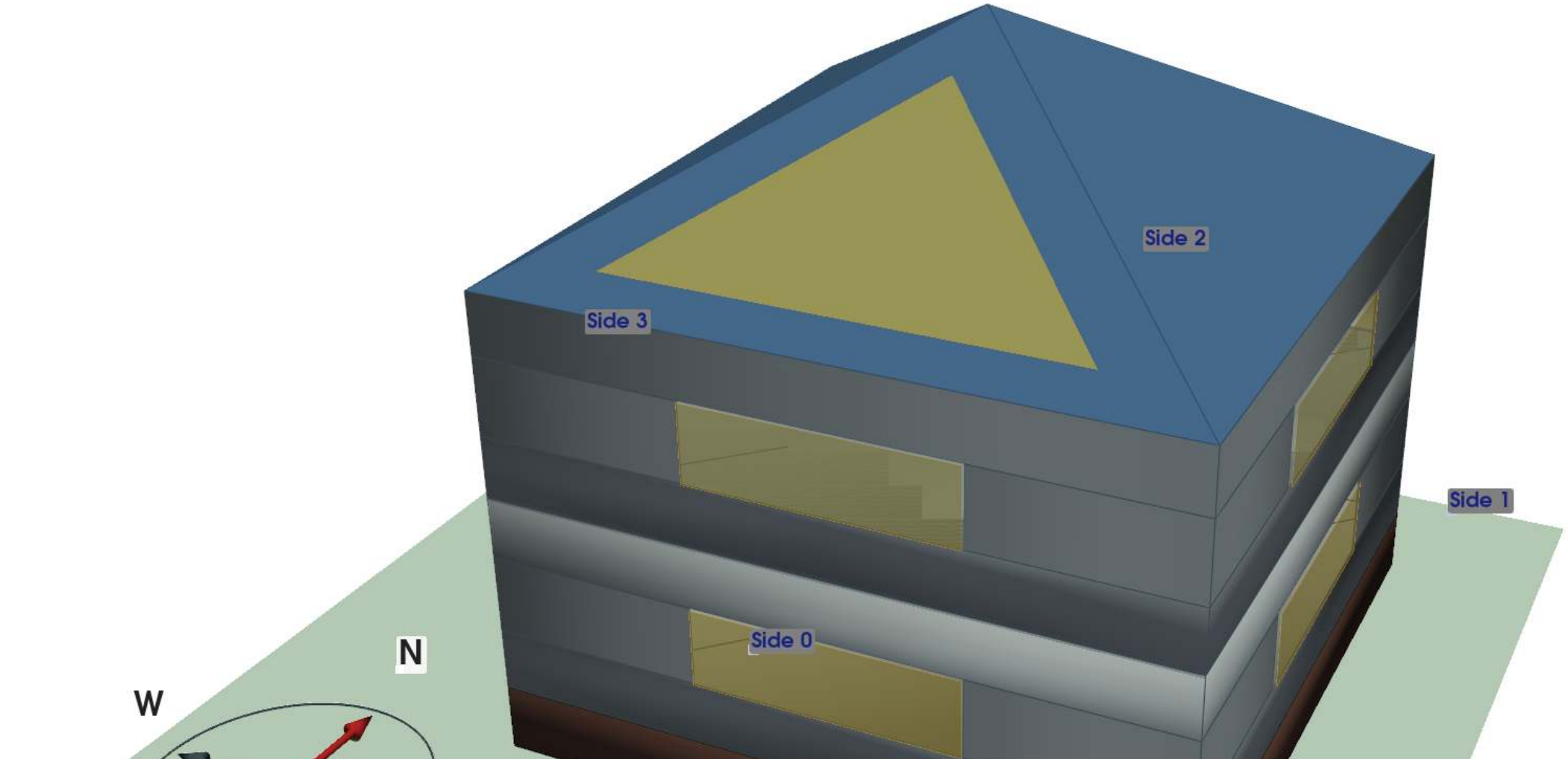
Roof windows

Optional glazing on a **non-periodic** pitched roof (`periodic: false`, with `roof_points`).

Enter a full JSON list in the building form (outer `[]` included), or use the ✎ editor:

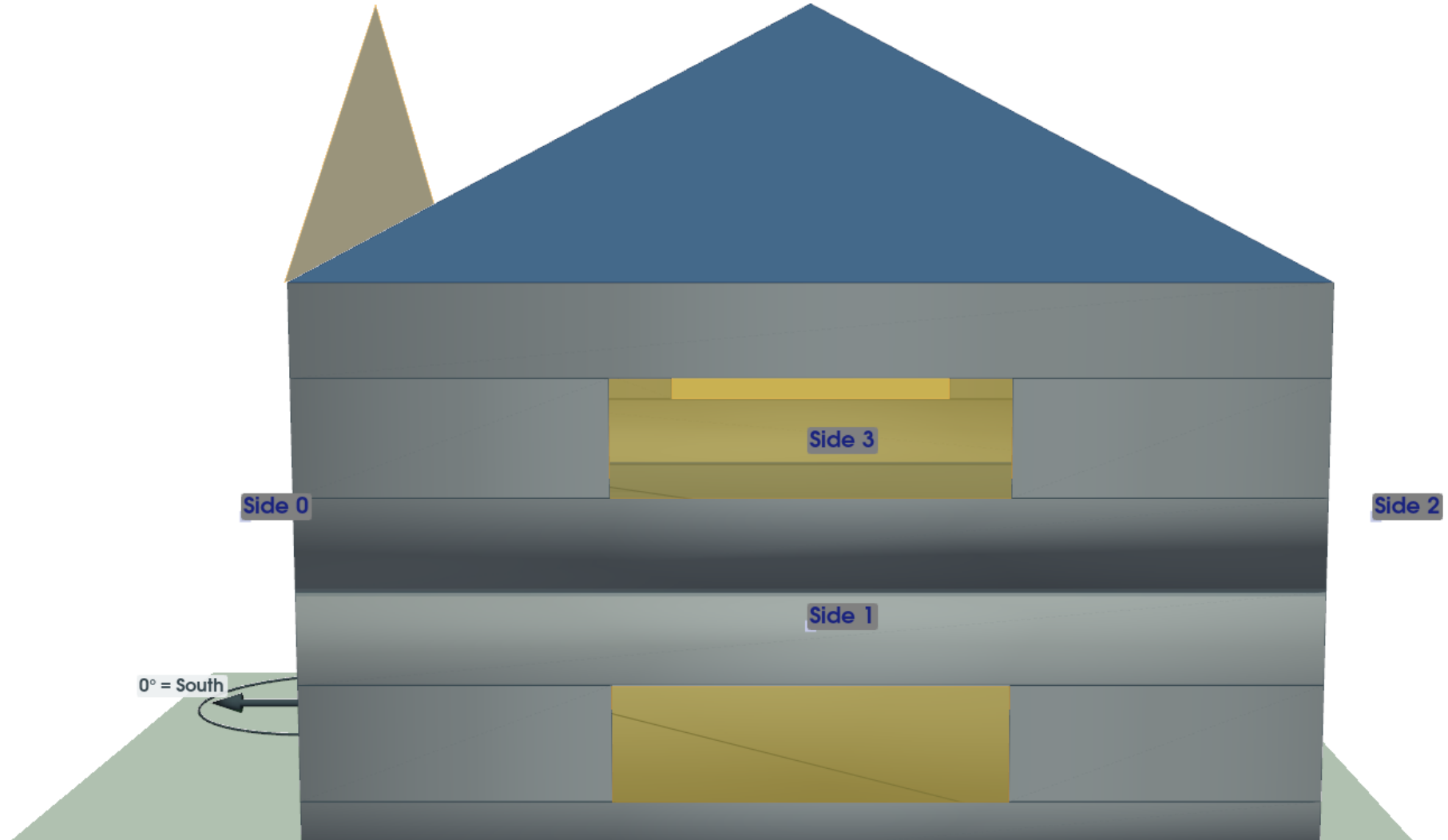
```
"roof_windows": [
  {
    "facet": ["$0", "$1", "$4"],
    "glazing_ratio": 0.5,
    "aligned": true,
    "solar_factor": 0.5
  }
]
```

- `facet` — coplanar points on **roof mesh nodes**, or shortcuts `"$N"` (same indices as `building footprint`: `$0…$n−1` = footprint `(X,Y,0)`, then `roof_points`)

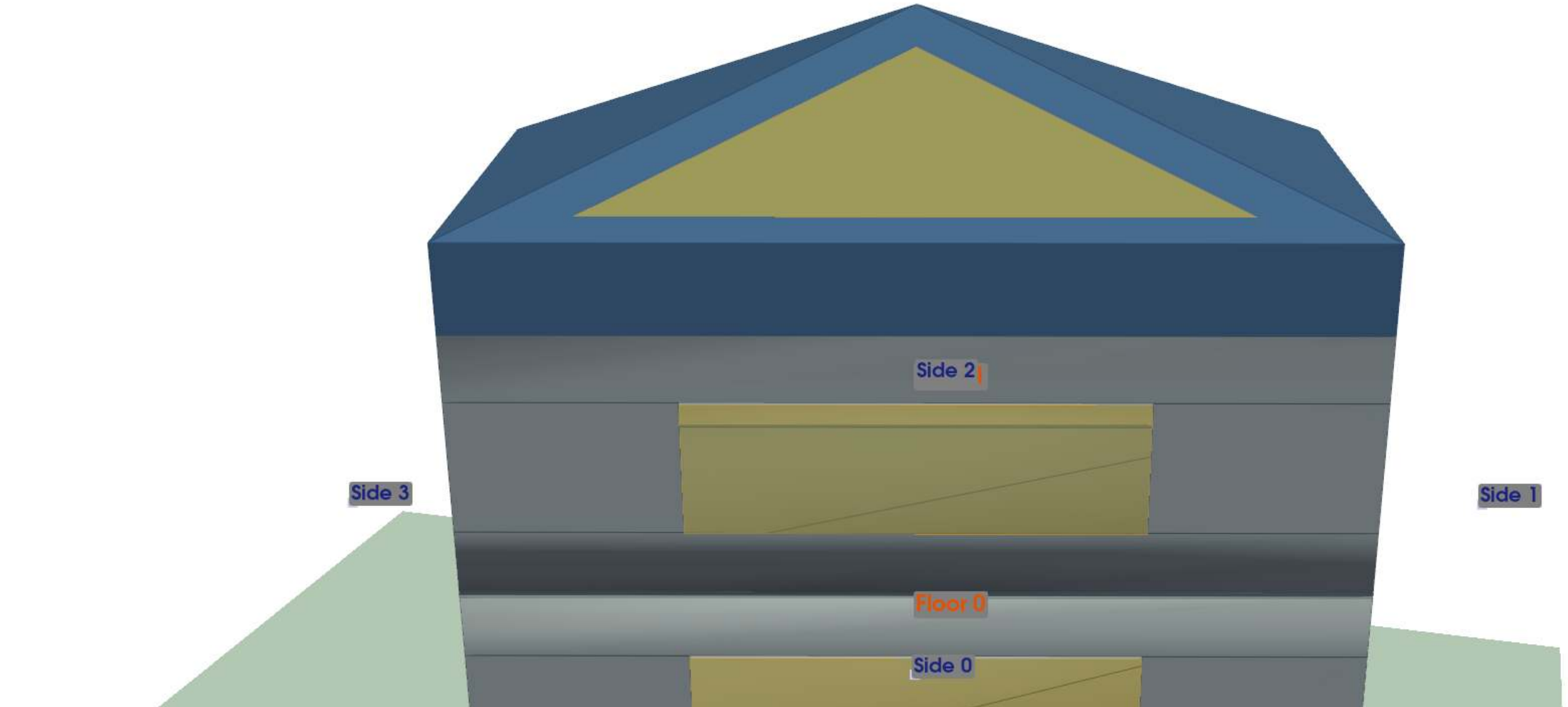

Side 2
Side 3
Side 1
Side 0
N
W

`aligned: false` — **vertical** glazing (slope 90°) on the lowest facet edge. Opaque roof unchanged; solar aperture = `glazing_ratio` × **vertical projection** of the facet (sill × rise).

In the next slide, one can see that the vertical windows are coming out of the roof by are not fully connected to the roof. Vertical windows are not changing the surface of the roof whereas the aligned windows are replacing the covered surface by the glass.


Side 3
Side 0
Side 2
Side 1
0° = South

Same idea on a hip roof (`aligned: true` on one facet):



Optional features:

- attic: set `attic: true` in the roof fields; needs the intermediate floor composition `lowup_floor`
- basement: when `base_elevation > 0`, a `basement_ground` composition is required
- wall contacts: neighbouring heated volumes on a façade (force glazing to 0 on the contacting floors)
- solar protections: `max_unshaded_protections` per side; 90° means no solar protection on that axis and 45° means the sun is hidden when it passes this altitude
- roof windows: `roof_windows` list on non-periodic roofs (see above)

Typical design loop:

```
context load project
building new
building 3d
building simulate --quick
building results
building edit
building simulate
building save project
```

command	description
building	show a summary of the current building
building new	create a new building (GUI)
building edit	edit the current building (GUI)
building load <path>	load a `.building` file from `./data`
building save <path>	save the building to `./data`
building delete	forget the building in memory (or delete a file)

command	description
building footprint	plan view with side indices
building 3d	3D view of the building
building heliodons	sun paths seen from central glazing of building façades
building simulate	hourly thermal simulation over the year specified in the context
building results	HVAC totals + comfort indicators
building vars	list building-related variables (+ `PV:power_W` after `pv simulate`)
building plot	plot building variables (+ `PV:power_W` after `pv simulate`)
building optimize	comfort-first tune of fields marked Tune in the building form

Parametric design is done with `building variation …`.

It sweeps one design parameter (or a full set) and opens figures with:

- left: HVAC energy (kWh/year)
- right: comfort percentiles on a reference floor

`glazing_ratio` sweeps include **all façades** (even currently opaque ones).

Examples:

```
building variation
building variation heat_recovery
building variation glazing_ratio side 0
building variation solar_protection side 0
```

Scalars include heat recovery, air renewal, solar factor, setpoints, rotation, …

Figures are also saved under `.baterm/variation_figures/`.

Full syntax: `help building variation`

command	description
building variation	full parametric sweep
building variation <param>	sweep one parameter
building variation …	limit to a few cases (fast)
building optimize	comfort-weighted optimize of Tune fields
material list thermal	browse thermal materials
material list glazing	browse glazing materials
material thermal load <name> <row>	load a material into the session

The pv (for photovoltaic) commands

A photovoltaic plant is defined by its orientation, tilt, mounting type, module efficiency and sizing.

It also needs a **context** (site + weather). If no context is loaded, `pv new` opens the context editor first.

A plant can be created with `pv new`, then modified with `pv edit`.

It is saved as a `.pv` JSON file under `./data` (for instance `pv save roof` → `./data/roof.pv`).

The plant embeds a copy of the context used at creation time. When you already have a session context, baterm keeps that period so building and PV stay on the same horizon.

Orientation conventions:

- `exposure_deg` : **0 = South**, +90 = West, −90 = East, 180 = North
- `slope_deg` : **0 = facing the ground**, 90 = vertical, 180 = facing the sky
  (a classic 35° tilt facing the sky corresponds to `slope_deg = 145`)

Sizing: give **exactly one** of:

- `number_of_panels`
- `peak_power_kW`
- `ground_surface_m2`

Mounting type (`flat` , `plan` , `back2back`) changes self-shading between rows. See slides01-sun.pdf for more details.

Typical PV loop:

```
context load project
pv new                              # Tune selected fields
pv 3d
pv best angles
pv optimize                         # max yield (no building PELEC yet)
building simulate
pv optimize                         # then match daily PV to daily PELEC
pv simulate
building plot                       # PELEC / HVAC + PV:power_W
balance
pv save project
```

`pv best angles` searches exposure/slope for maximum annual DC production of the current plant.

`pv optimize` has two modes:

- **no building PELEC yet** — maximize annual PV kWh (exposure, tilt, spacing, mount)

command	description
pv	show a summary of the current PV plant
pv new	create a new plant (GUI; needs context)
pv edit	edit the current plant (GUI; Lock/Tune on design fields)
pv load <path>	load a `.pv` file from `./data`
pv save <path>	save the plant to `./data`
pv delete	forget the plant in memory (or delete a file)
pv dir	list `.pv` files in `./data`

command	description
pv 3d	3D layout of the arrays
pv heliodon	sun path for the plant site
pv best angles	best exposure / slope for annual yield
pv simulate [--quick]	hourly PV production (building sim optional)
pv optimize [--passes K]	max yield, or match daily PELEC after building sim
pv results	annual totals + building–PV indicators
pv vars	list PV-related variables
pv plot	plot PV variables

After both `building simulate` and `pv simulate`, `pv results` prints indicators such as:

- self-consumption
- self-sufficiency (self-production)
- dependency
- year autonomy
- NEEG (net energy exchange with the grid)
- autonomous day ratio

These indicators need the building electricity demand `PELEC:building#sim` and the PV production `PV:power_W`.

The global commands

Global commands join the **building** and the **PV plant** on the same DataProvider.

They answer questions such as:

- when is production larger than demand?
- what is the annual electricity bill with a given tariff?
- how to export all series for further analysis?

```
flowchart LR
    B[building simulate] --> D[DataProvider]
    P[pv simulate] --> D
    D --> E[enercost]
    D --> F[balance]
    D --> X[export]
```

`balance`

`balance` draws a **day × month heatmap** of the daily net balance:

balance = PV production – building electricity demand

- **green**: surplus (PV covers the day)
- **red**: deficit (grid import needed)

Needs both simulations first:

```
building simulate
pv simulate
balance
```

`enercost`

`enercost` computes the annual electricity cost from:

- `PELEC:building#sim` (building demand)
- `PV:power_W` (PV production)

Default tariff is French **HP/HC** (off-peak roughly 22:00–06:00).

It writes series such as `ENERCOST:hour#sim`, `GRID_IMPORT:kWh#sim`, `GRID_EXPORT:kWh#sim`.

```
enercost
enercost hp_hc
enercost base --base 0.25 --export 0.12
```

Typical joined workflow:

```
context load mysite
building load myhouse
building simulate
pv load roof
pv simulate
pv results
balance
enercost
export my_study
```

`export <name>` writes all DataProvider series to `./<name>.xlsx` in the working directory.

command	description
balance	day×month heatmap PV – PELEC
enercost	annual electricity bill (default HP/HC)
enercost hp_hc	French peak / off-peak tariff
enercost base --base ... --export ...	flat buy / sell prices (€/kWh)
export <name>	export all series to Excel
status	show loaded context / building / PV
clear	forget context, building and PV in memory
vars	list variables (session DataProvider)
plot	plot any session variables

Wrap-up

Remember the dependency chain:

1. **context** (site + weather + masks)
2. **building** and/or **pv** (both need the context)
3. **simulate** each side
4. **global** tools: `balance`, `enercost`, `export`

Use `help <command>` at any time, and `manual` to open the PDF user manual.