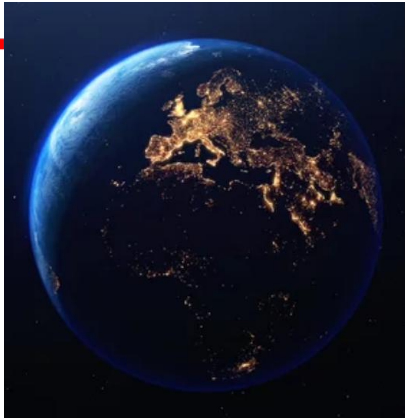
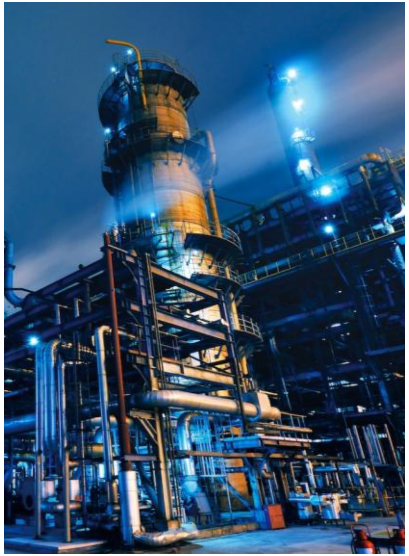



Energy supply, economics and transition



Prof. Christophe Ballif, Prof. Philippe Thalmann,
Prof. Claudia Binder,
Dr. Maria Hecher, Dr. Sascha.Nick,

With the support of of Francisco, Suzan, Gloria

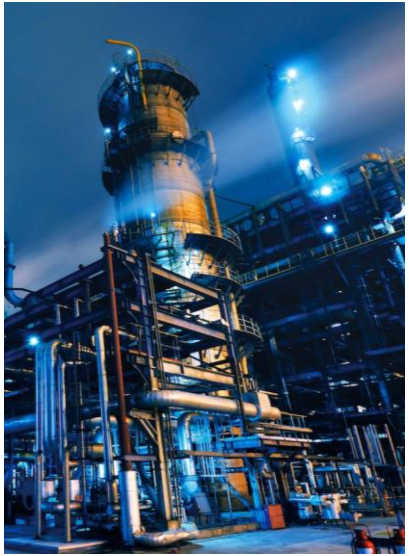
Assistants: Noémie Jeannin, Marie Courtant

noemie.jeannin@epfl.ch, marie.courtant@epfl.ch

Program (preliminary)

Date	Who	Theme
19.02.2025	Christophe Ballif	Introduction
26.02.2025	Christophe Ballif	Global warming / World Energy production & Usage
05.03.2025	Christophe Ballif	Mitigating CO2
12.03.2025	Christophe Ballif	Support to a decarbonized world
19.03.2025	Philippe Thalmann	Decoupling
26.03.2025	Philippe Thalmann	Economics
02.04.2025	Sascha Nick	Energy, Human Needs and Wellbeing
09.04.2025	Sascha Nick	Limits to market governance of energy in societal transitions
16.04.2025	Claudia Binder	Socio-technical perspective of the energy transition
23.04.2025	-	*Easter break*
30.04.2025	Maria Anna Hecher	Behavioral perspective on the diffusion of innovations
07.05.2025	Glòria Serra Coch	Proximity in the diffusion of innovations
14.05.2025	Francisco Felix Martin del Campo	Material perspective of the energy transition
21.05.2025	Susan Mühlemeier	The actors perspective: The « who is who » of the Swiss energy sector
28.05.2025	Christophe ballif + all	Swiss Scenario; Conclusion and discussion

Energy supply, economics and transition



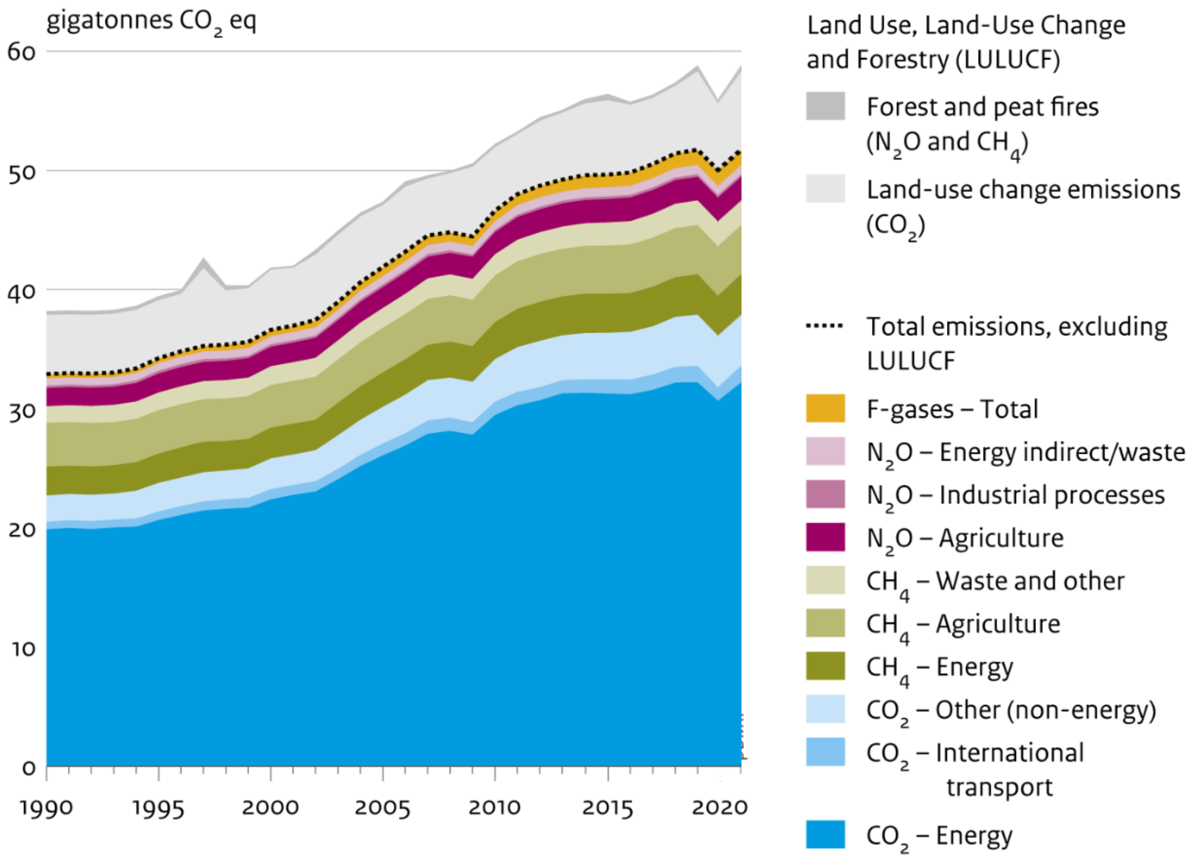
Introduction

I. World challenges

Christophe Ballif / Philippe Thalmann / Claudia Binder

EPFL

Global Greenhouse gases emissions 57 GT CO_2 eq



https://www.pbl.nl/

- **Energy** (inc transport) and methane leaks → large Part of the CO_2 equivalent emissions
- **CO_2** from cement and steel
- **Agriculture and land-use** also important

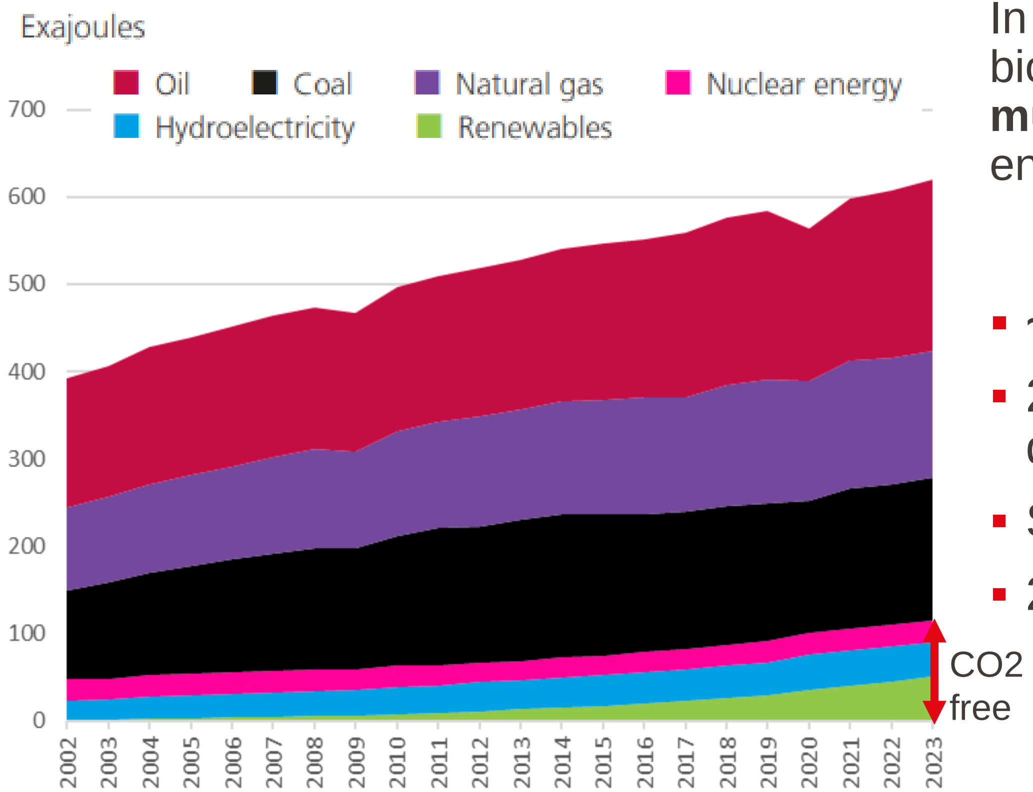
Strategic Dependancies

- Global warming
- Pollution and diseases
- Loss of biodiversity

EDGAR - The Emissions Database for Global Atmospheric Research (europa.eu)

Christophe Ballif / Philippe Thalmann / Claudia Binder

Primary energy consumption: the world challenge



In this representation: electricity in kWh of biomass, hydro, solar, nuclear wind is **multiplied by 2.5 to** be shown as primary energy source («BP» substitution method)

- ~ 172’000 TWh (CH ~ 320 TWh)
- 2% annual growth in the last 20 years driven mostly by China and India
- Still 80% fossile fuel
- 20% renewable and nuclear

Statistical review of world energy

World Energy Outlook 2024 – Analysis - IEA

Energy and environmental/societal transition: is it possible ? In this part ...

Does the Paris agreement mentions fossile fuels ?
(or coal or oil or natural gas) ?

Where do we stand ? Where should we go ? How fast ?

Should we bet on carbon sequestration
or geo-engeeniring ?

Is the oil peak reached and is it relevant ?

Is it true that an equivalent of 110 nuclear powerplants
of renewable electricity production installed in 2023?

Can nuclear energy solve most problems ?

Is hydrogen economy the best solution ?

Is the impact of renewable worth it ? (e.g. mining)

Can we still keep our target of 2°C global warming ?

What should happen ? What will happen ?

Can't we simply accomodate global warming ?

Will China save the world from climate change ?

Societal challenges related to energy

The Future of Food and its Origins

- Sustainability in managing land and water
- Clean water and food for all
- Preserving biodiversity

Secure, clean and efficient energy

- Reduce energy consumption and carbon footprint
- Low-cost and low-carbon energy supplies
- Energy security

Smart, green and integrated transport

- Resource-efficient
- Climate and environmentally friendly
- Safe and functional

Climate action, environment and resources

- Lower CO2 emissions on global level
- Prevent sea levels from rising
- Efficient resource usage
- Educate people

https://www.nice-eu.org/global-challenges

Christophe Ballif / Philippe Thalmann / Claudia Binder

The 2030 agenda for sustainable development

As identified by the United Nations in 2015. Adopted by all UN members in 2015

Christophe Ballif / Philippe Thalmann / Claudia Binder

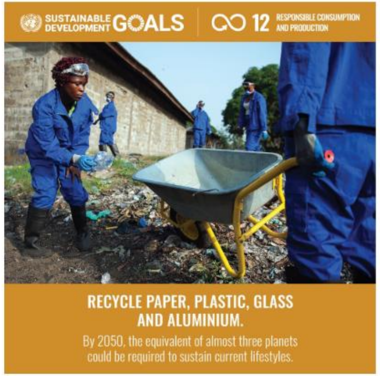
Energy-related sustainable development goals

As identified by the United Nations in 2015

Affordable and clean energy

Sustainable cities and communities

Climate action



Responsible consumption and production

https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Christophe Ballif / Philippe Thalmann / Claudia Binder

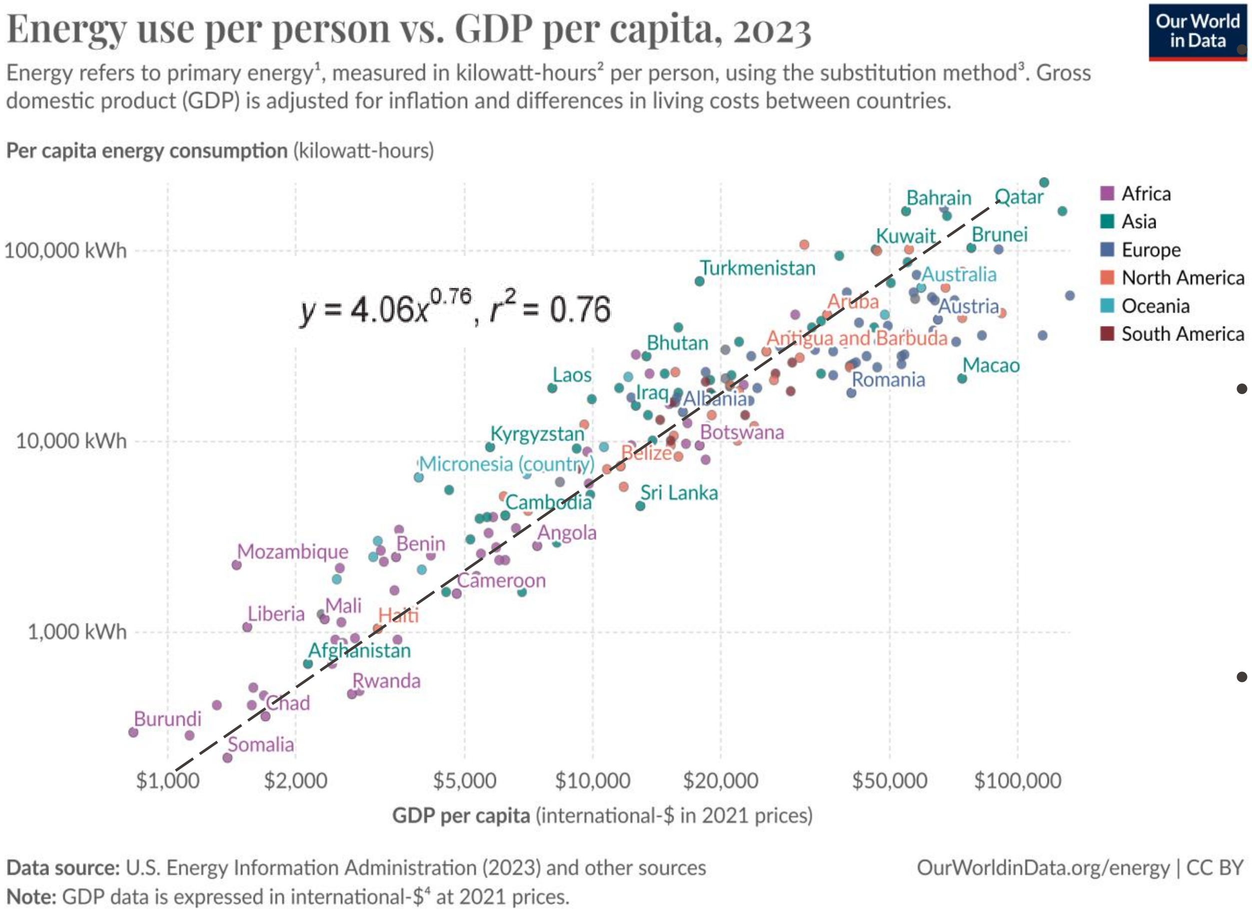
Key indicators to understand the state of the world

Extreme poverty	Hunger
GDP per capita	Education
Population	Access to water and sanitation
Child mortality	Energy access
Fertility rate	Energy use
Life expectancy	CO_2 emissions

https://ourworldindata.org/12-key-metrics

Christophe Ballif / Philippe Thalmann / Claudia Binder

Energy – key source of “economic growth”



Some countries over **10’000 Watts per capita power consumption (86’000 kWh/year)**
i.e. 1 liter of oil per hour, permanently

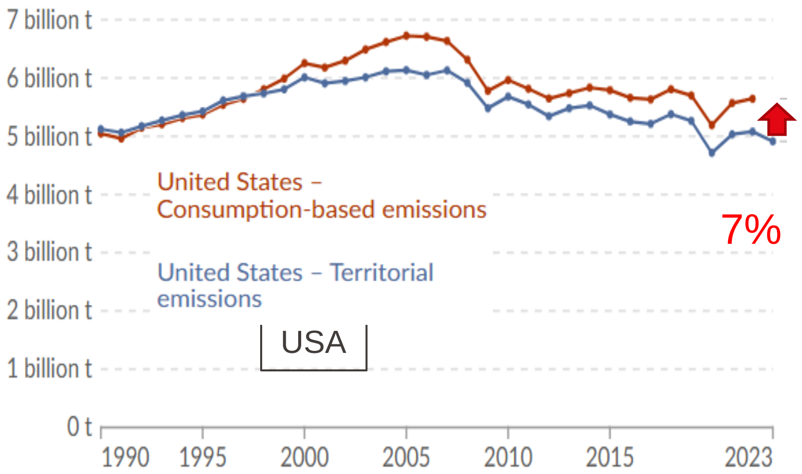
- Central role of energy in the economy – apparent positive relationship between energy use and economic growth
- Higher rates of energy consumption seem required to sustain and grow larger and more developed economies

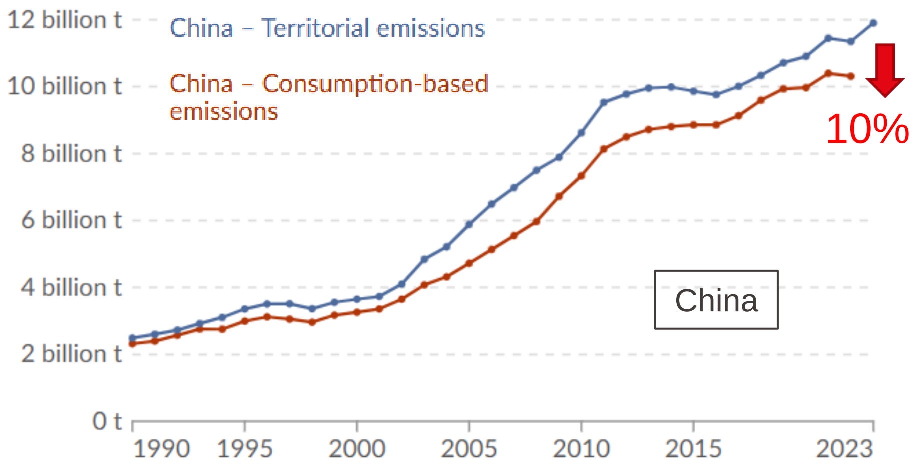
J. Brown et al. “Energetic limits to economic growth”, BioScience, 2011

https://ourworldindata.org/grapher/energy-use-per-person-vs-gdp-per-capita

Christophe Ballif / Philippe Thalmann / Claudia Binder

Production-based vs. consumption-based CO_2 emissions





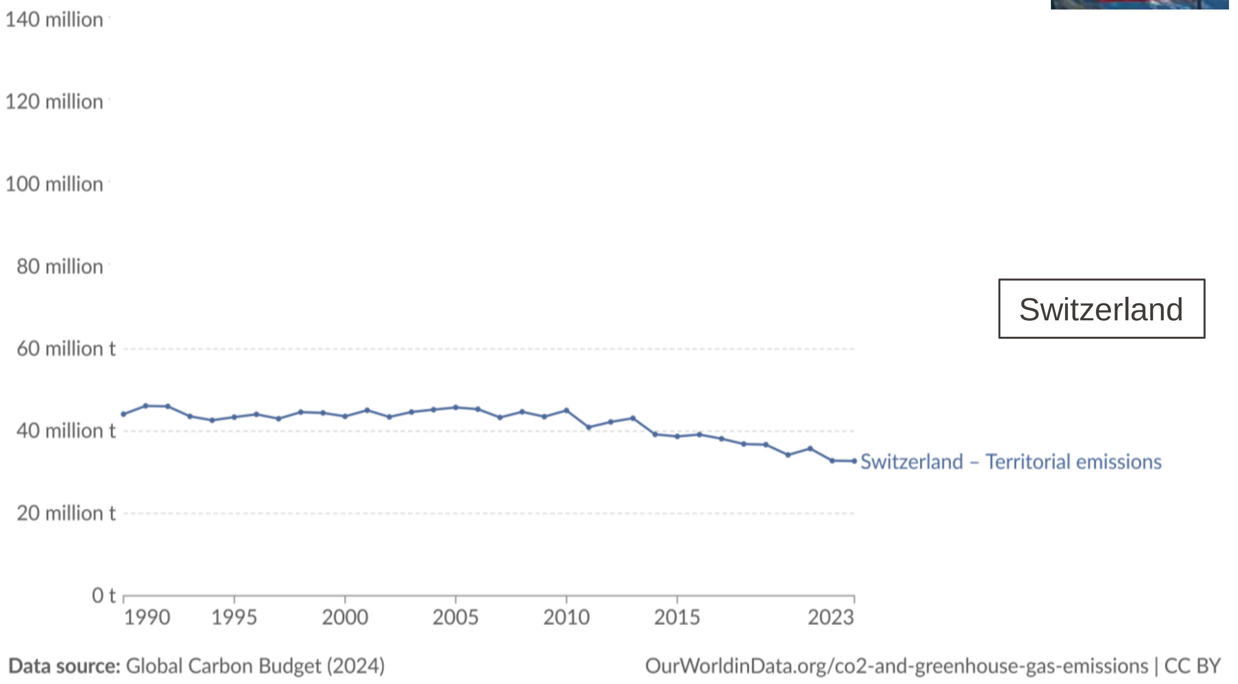
- **Production-based (territorial) emissions** are calculated within country boundaries, thus without accounting how goods are traded across the world
  Consumption-based emissions account for trade of goods
- Imported goods → need to **add** CO_2 emissions emitted in production of these goods
- Exported goods → need to **subtract** CO_2 emissions emitted in production of these goods
- Most of Western Europe, the Americas, and many African countries are *net importers*
- Most of Eastern Europe and Asia are *net exporters*

https://ourworldindata.org/consumption-based-co2#additional-information

Christophe Ballif / Philippe Thalmann / Claudia Binder

Production-based vs. consumption-based CO2 emissions

https://ourworldindata.org/consumption-based-co2#additional-information



Switzerland

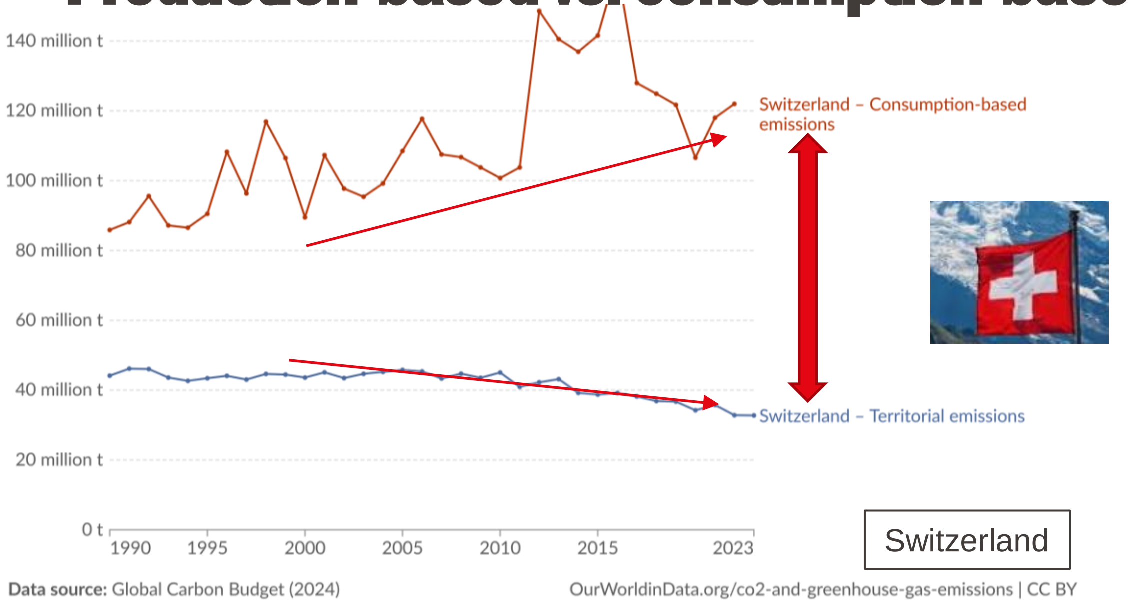
But we import smart-phone fridges, lamps, computers, Solar panels, Cars, metals, construction materials
Food, IT services, flights…
Switzerland his good at exportings its emission industry !

Even fuels have an import CO2 footprint !

Christophe Ballif / Philippe Thalmann / Claudia Binder

EPFL

Production-based vs. consumption-based CO2 emissions



Switzerland

https://ourworldindata.org/consumption-based-co2#additional-information

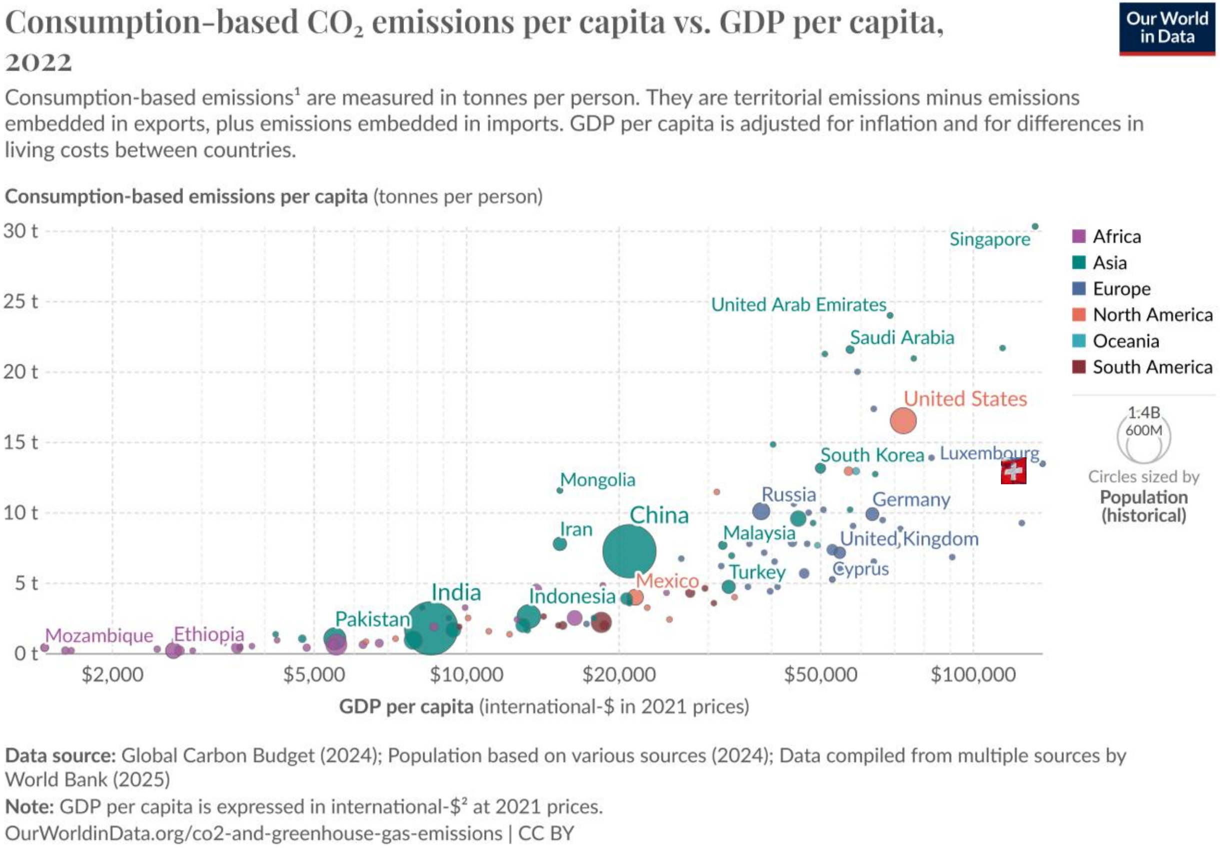
Annual emission from 4.2 tons to 12 tons of CO2 per capita if consumption based

12 tonnes/year = Permanent «fossile fuel burning» of 16 liters/kg oil/coal per day

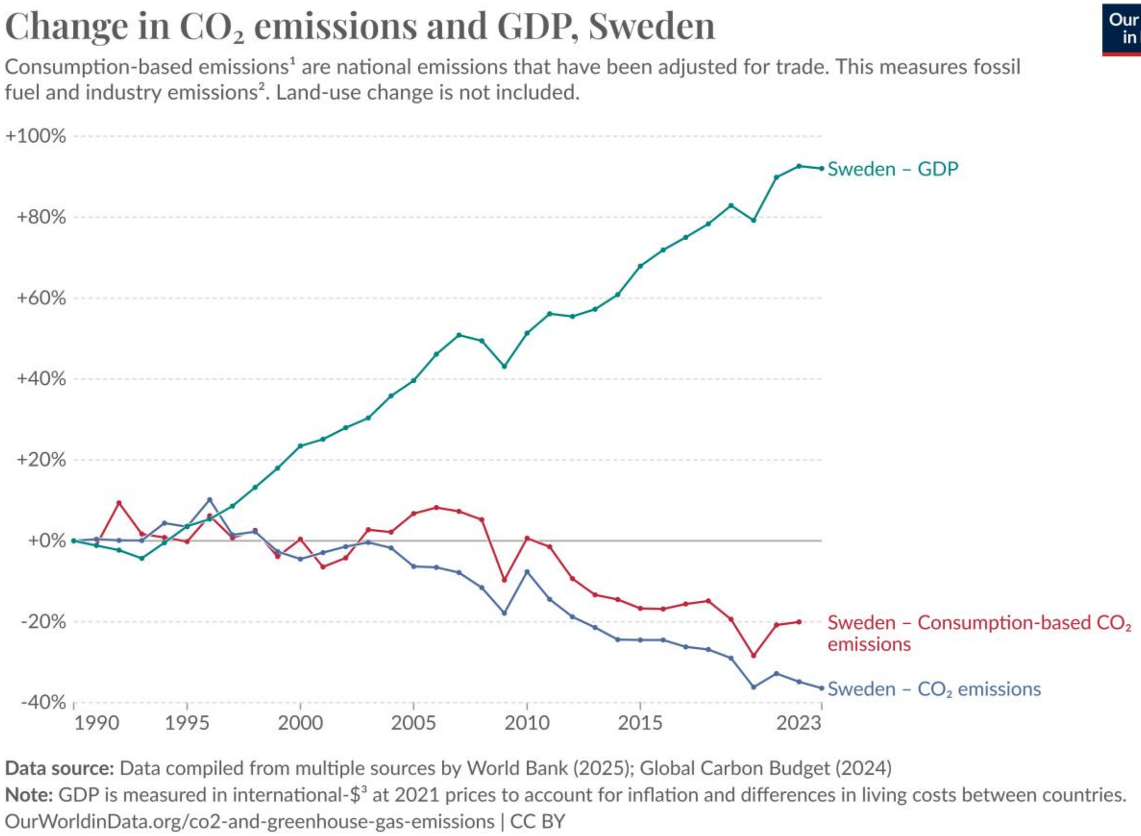
- Some countries adopt (voluntarily or not) the strategy of achieving emissions reduction by "offshoring" emission-intensive production to other countries: production-based emissions are stagnating, while consumption-based emissions are increasing → Switzerland, Norway, Ireland etc.
- Genuine CO_2 reductions (both production-based and consumption-based) have been achieved in UK, France, Germany, Sweden, USA etc.

CO_2 emissions vs. GDP per capita, 2022, consumption based

- Large inequalities in per capita emissions across the world
- Prosperity is a primary driver of CO_2 emissions: more developed countries have higher carbon footprint (Uganda vs. US)
- Across developed countries, **energy policy, choice of energy sources and technology** (house insulation) make a difference in per capita emissions (Switzerland vs. US)
- Here consumption based emissions (includes exports and imports)



- https://ourworldindata.org/grapher/consumption-co2-per-capita-vs-gdppc



Some elements

1. Growing Carbon Tax since 1991

 Increasing Renewable Energy Sources and electric vehicles

3. Improving Energy Efficiency:

4. Promoting Sustainable Transportation

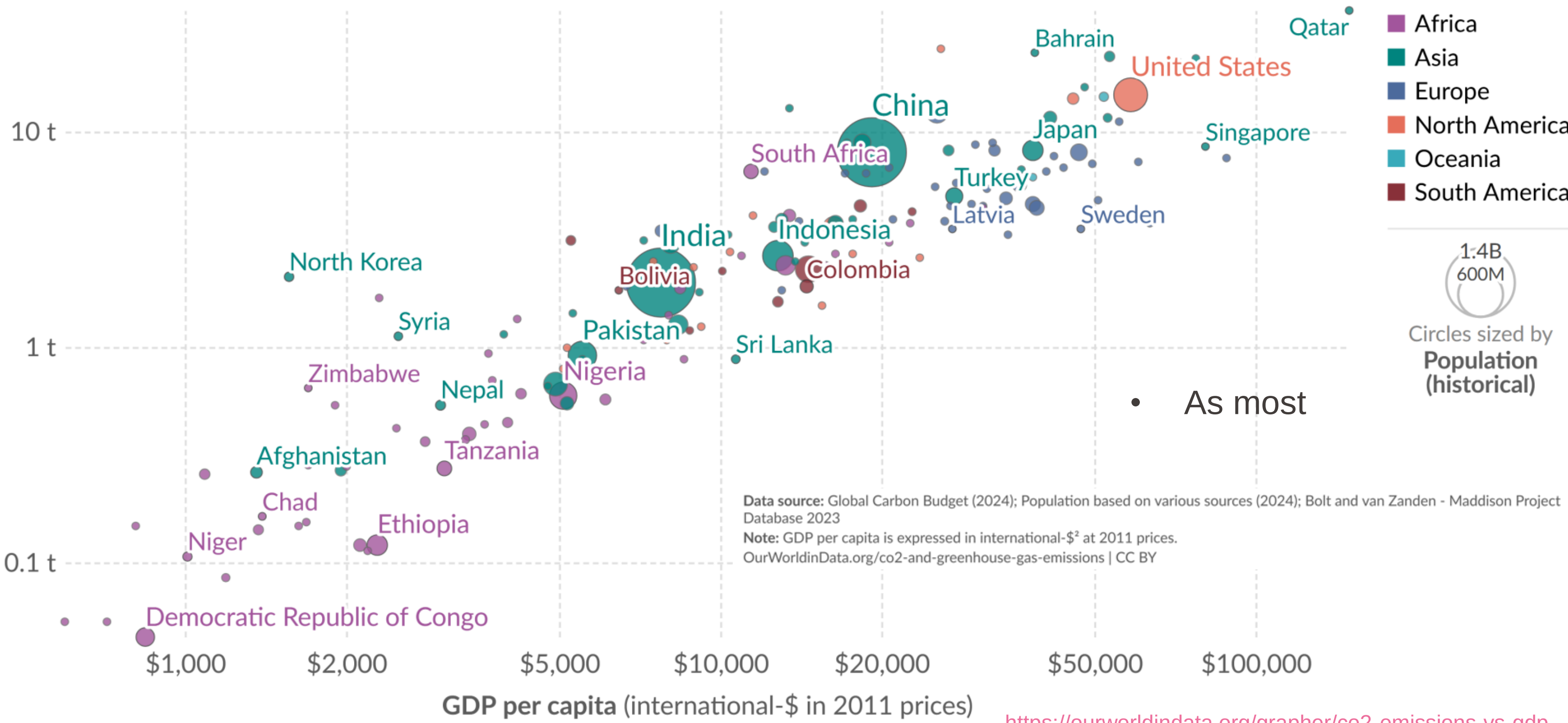
5. Encouraging Sustainable Consumption and production

https://ourworldindata.org/grapher/co2-emissions-and-gdp?country=~SWE

CO_2 emissions per capita vs. GDP per capita, 2022

Our World in Data

This measures CO_2 emissions from fossil fuels and industry[1] only – land-use change is not included. GDP per capita is adjusted for inflation and differences in living costs between countries.



- As most

Data source: Global Carbon Budget (2024); Population based on various sources (2024); Bolt and van Zanden - Maddison Project Database 2023
Note: GDP per capita is expressed in international-$[2] at 2011 prices.
OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

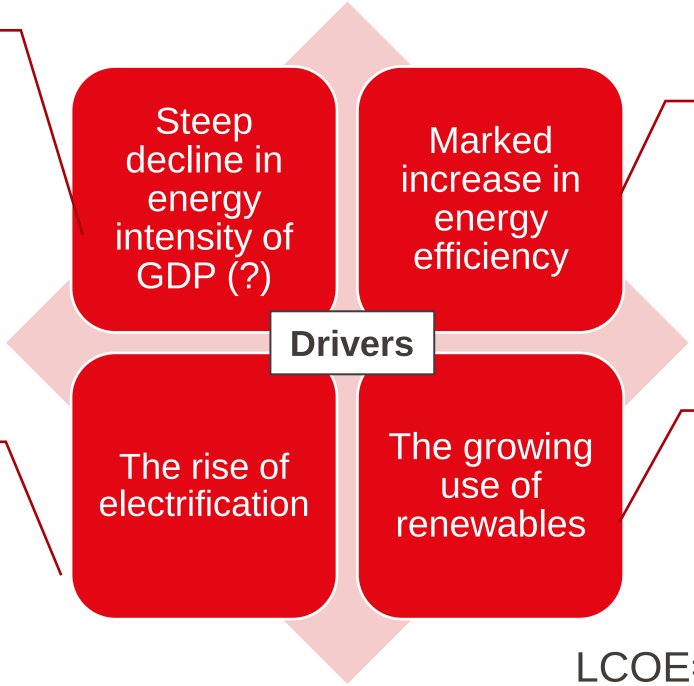
https://ourworldindata.org/grapher/co2-emissions-vs-gdp

Decoupling energy demand from economic growth

Maybe happen by 2035…?

Driven by switching from industrial to service economies. But risks to move energy demanding industries to other places

Driven by decreasing energy-intensity of buildings due to technology improvements and changes in users' mindsets



Driven by the rise of EV in the transportation sector.
Depends on how you count energy

Driven by decline in LCOE of renewables and decentralization. Depends on how you count energy

LCOE= levelised cost of electricity

Objectives:

- At least decarbonize economic activities
- Increase energy productivity
- Increase energy security

If economic growth, it should be with no CO2 increase and limited impact on nature

https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-decoupling-of-gdp-and-energy-growth-a-ceo-guide

Christophe Ballif / Philippe Thalmann / Claudia Binder

Key takeaways

Energy-related sustainable development goals:

- Affordable and “clean” energy
- Sustainable cities and communities
- Climate action
- Responsible consumption and production

- Energy has been central to economic growth
- Efficiency of energy usage on a per capita basis varies across developed economies

- Prosperity has been a primary driver of CO_2 emissions
- Difference between production-based and consumption-based CO_2 emissions

II. Energy units and important definitions

Christophe Ballif / Philippe Thalmann / Claudia Binder

Major Energy units

$$1 \text{ Joule} = \text{kg}\left(\frac{\text{m}}{\text{s}}\right)^2$$

$$1 \text{ kWh} = 3.6 * 10^6 \text{ J}$$

Power $1 \text{ W} = 1 \frac{\text{J}}{\text{s}}$

k (kilo) / M (Mega) / G (Giga)/
T(Tera) /P (Peta)

~1 liter of oil ~1 m^3 of natural gas ~10-11 kWh, 1litre of gasoline ~ 9 kWh

1 Ton of oil equivalent (Toe) = 41.868 GJ = 11’630 kWh
1 Gigaton of oil equivalent (Gtoe) = 11’630 TWh

Barrel of Oil Equivalent (BOE), the energy released by burning one barrel (159 liters) of crude oil. 1 BOE = 6.1 GJ = 1.7 MWh

1 British thermal unit (Btu)=1055.06 J =0 .293071 Wh

Levelized Cost Of Energy (Electricity) → LCOE, average net present cost of energy (electricity) generation for a generating plant over its lifetime (including construction, capital costs, maintenance, operation, fuel, …). Calculated in $Price$ / Unit Energy.

Christophe Ballif / Philippe Thalmann / Claudia Binder

Orders of magnitude

Christophe Ballif / Philippe Thalmann / Claudia Binder

$4 * 10^{7}\ J$

11 kWh

Combustion of $1m^{3}$of natural gas

$2 * 10^{9}\ J$

600 kWh

$61l$ ordinary gasoline tank

$2 * 10^{17}\ J$

61.5 TWh

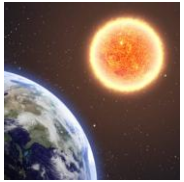
Swiss annual electricity consumption in 2023

$6 * 10^{20}\ J$

168'0000 TWh

Total world annual primary energy consumption in 2022

$5.5 * 10^{24}\ J$



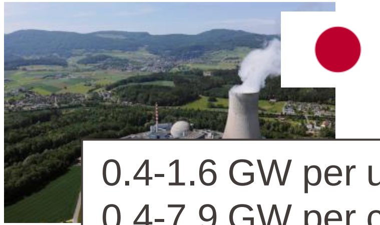
Annual energy received by Earth's surface from the Sun

$1.2 * 10^{34}\ J$

Total yearly energy output of the Sun

Orders of magnitude – production of “large” powerplant

Nuclear power plant



0.4-1.6 GW per unit
0.4-7.9 GW per complex

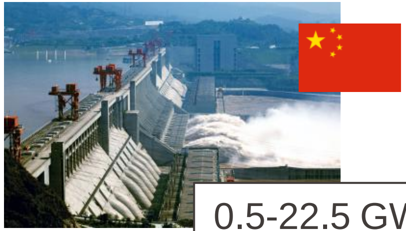
Kashiwazaki-Kariwa (7 units)

Coal-fired power plant

200 MW-1 GW per unit
2-6.7 GW per complex

Tuoketuo (12 units)

Hydroelectric power plant



0.5-22.5 GW

Three Gorges Dam

Wind power plant

200 MW-20 GW onshore
200 MW-1.2 GW offshore

Gansu

Solar power plant

200 MW-5 GW

Pavagada

Geothermal power plant

10 MW-250 MW per unit
50 MW -1.5 GW per complex

The Geysers (22 units)

Christophe Ballif / Philippe Thalmann / Claudia Binder

Orders of magnitude - consumption

Daily world oil demand

~100 Million barrels
or 160 TWh

Annual household electricity demand in EU

3000-5000 kWh
(without heating)

Total USA energy consumption in 2018

2.3 Gtoe
Or 26’000 TWh

Total world natural gas consumption in 2021

4’000 billion m^3
40’000 TWh

Total world electricity Production in 2022

28’600 TWh

Total world energy consumption in 2022

14.7 Gtoe
168’000 TWh

https://yearbook.enerd

Energy efficiency and capacity factor - definitions

$$\boldsymbol{Energy\ Efficiency} = \frac{Energy\ output}{Energy\ input} 100\%$$

$$\boldsymbol{Capacity\ Factor} = \frac{Actual\ output}{Potential\ output\ at\ nameplate\ capacity} 100\%$$

Christophe Ballif / Philippe Thalmann / Claudia Binder

Efficiency of large power plants in the 30-45% range

Average efficiency for Selected Electricity power plant

https://www.eia.gov/electricity/annual/html/epa_08_01.html

	Coal	Petroleum	Natural Gas	Nuclear
2008	32.9	31.0	41.1	32.6
2013	32.6	31.8	42.9	32.7
2018	32.5	30.8	43.6	32.6
2023	31.7	29.7	44.2	32.6

Best in class

- Best efficiencies up to **43-45%** for new «supercritical coal powerplant»
- Up to **62%** for gas combined cycled powerplants

One strategy of China: substitute old by new coal powerplants and Reach CO2 emission plateau by 2028 ! Likely reached before

Analysis: China's emissions set to fall in 2024 after record growth in clean energy - Carbon Brief

- From chemical or nuclear to thermal energy to electricity -> 65-68% average losses
- Part of heat could be used for heating purposes (co-generation)

2 GW out as heat in Gösgen

Christophe Ballif / Philippe Thalmann / Claudia Binder

Process efficiency

EV

Electricity to wheel

70-85%

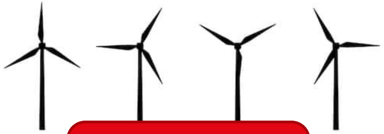
*including regenerative breaking

ICE

Fuel to wheel

16-25%

*best commercial motor can reach 40% at optimal speed. Some special diesel could reach 50%



Wind turbine

Wind to electricity

35-45%

Geothermal power plant

Heat to electricity

10-20%

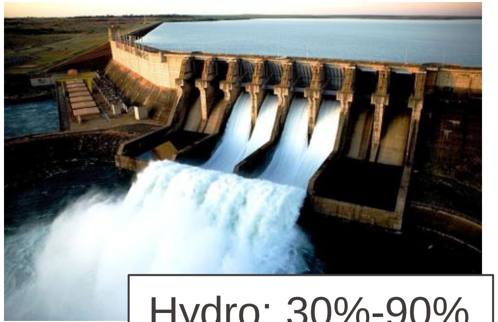
Capacity factor = percentage of the time at nominal capacity

Nuclear: 80%-90%

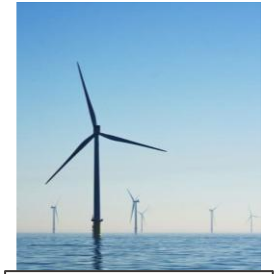
Geothermal: 65%-75%

Natural gas: 35%-93%

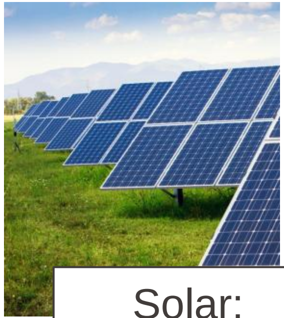
Coal: 70%-90%



Hydro: 30%-90%

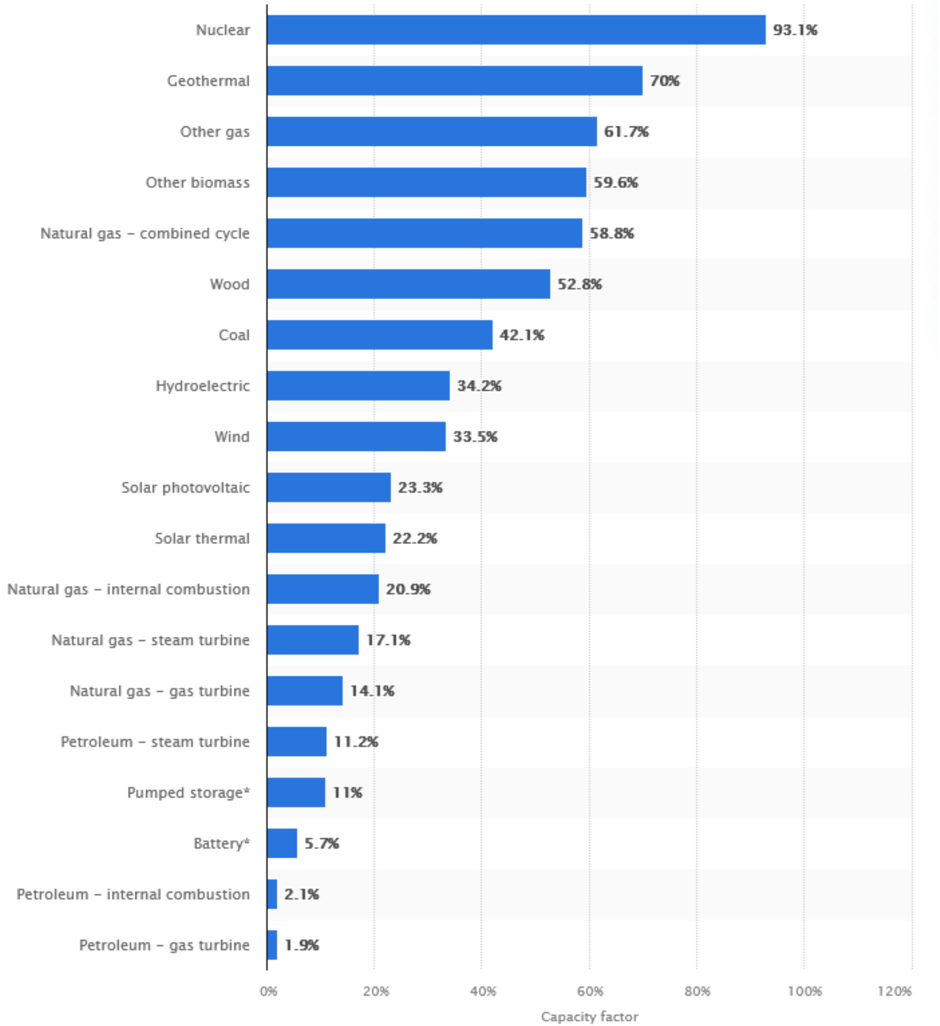


Wind: 25%-55%



Solar: 12%-30%

- Capacity factor varies throughout the year
- Capacity factor varies widely across the world
- Typical numbers given here. A gas peaker can be used only a few days per year



Example capacity factor 2023 USA

With attempts to reduce CO2
The target is to maximise the capacity factor of non-CO2 emitting sources

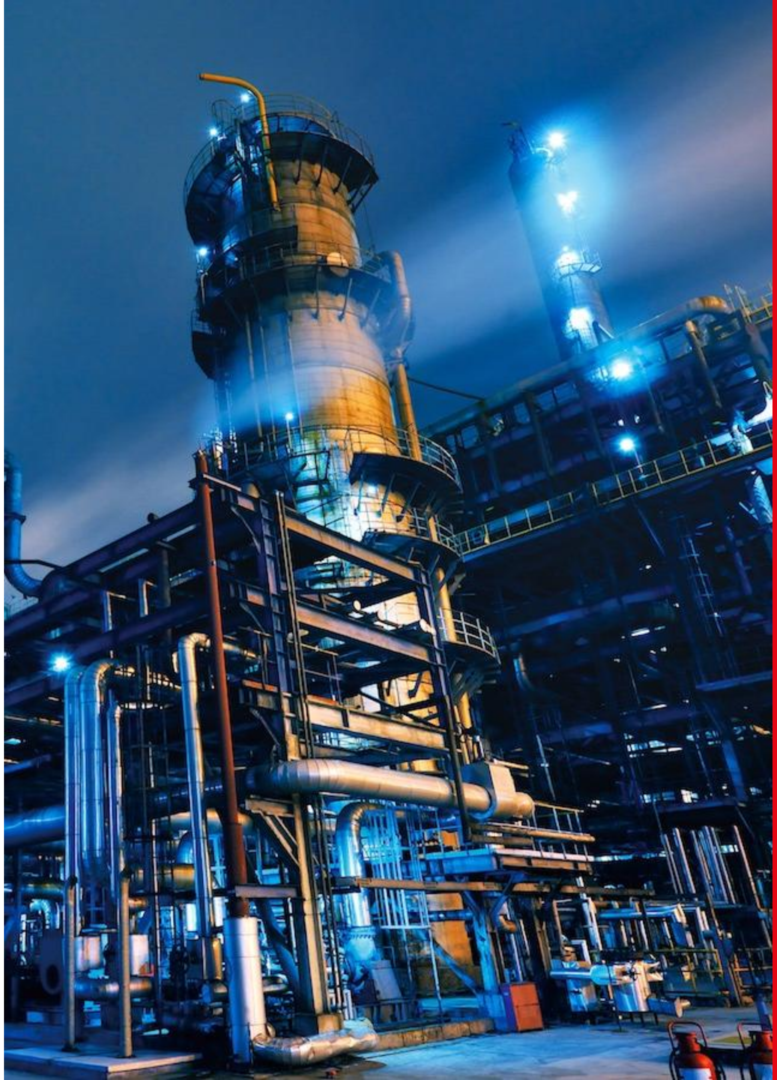
https://www.statista.com/statistics/183680/us-average-capacity-factors-by-selected-energy-source-since-1998/

Typical annual production

1GW Nuclear
→ 8 TWh/year
(8000 hours)

1GW solar
→ 1-2 TWh/year
(1000-2000 hours)

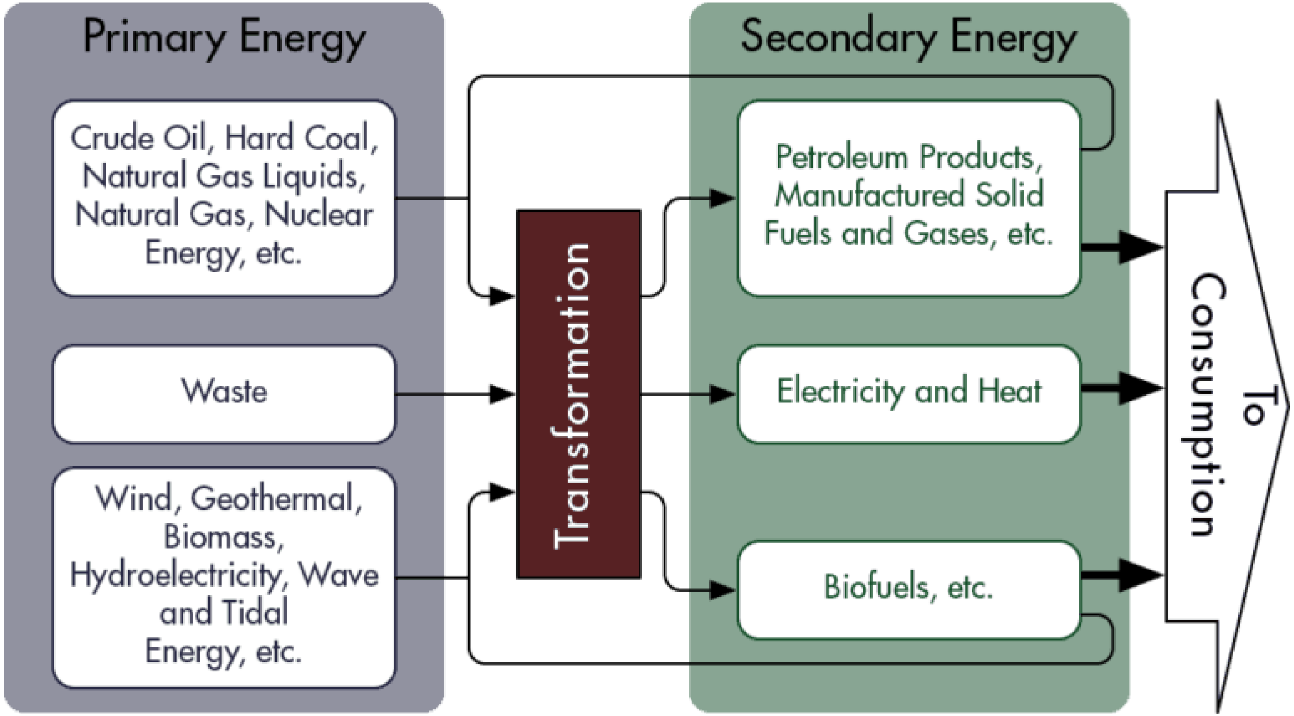
1GW Wind
→ 2-4 TWh/year
(2000-4000 hours)



III. Energy usage

Christophe Ballif / Philippe Thalmann / Claudia Binder

Primary and secondary energy



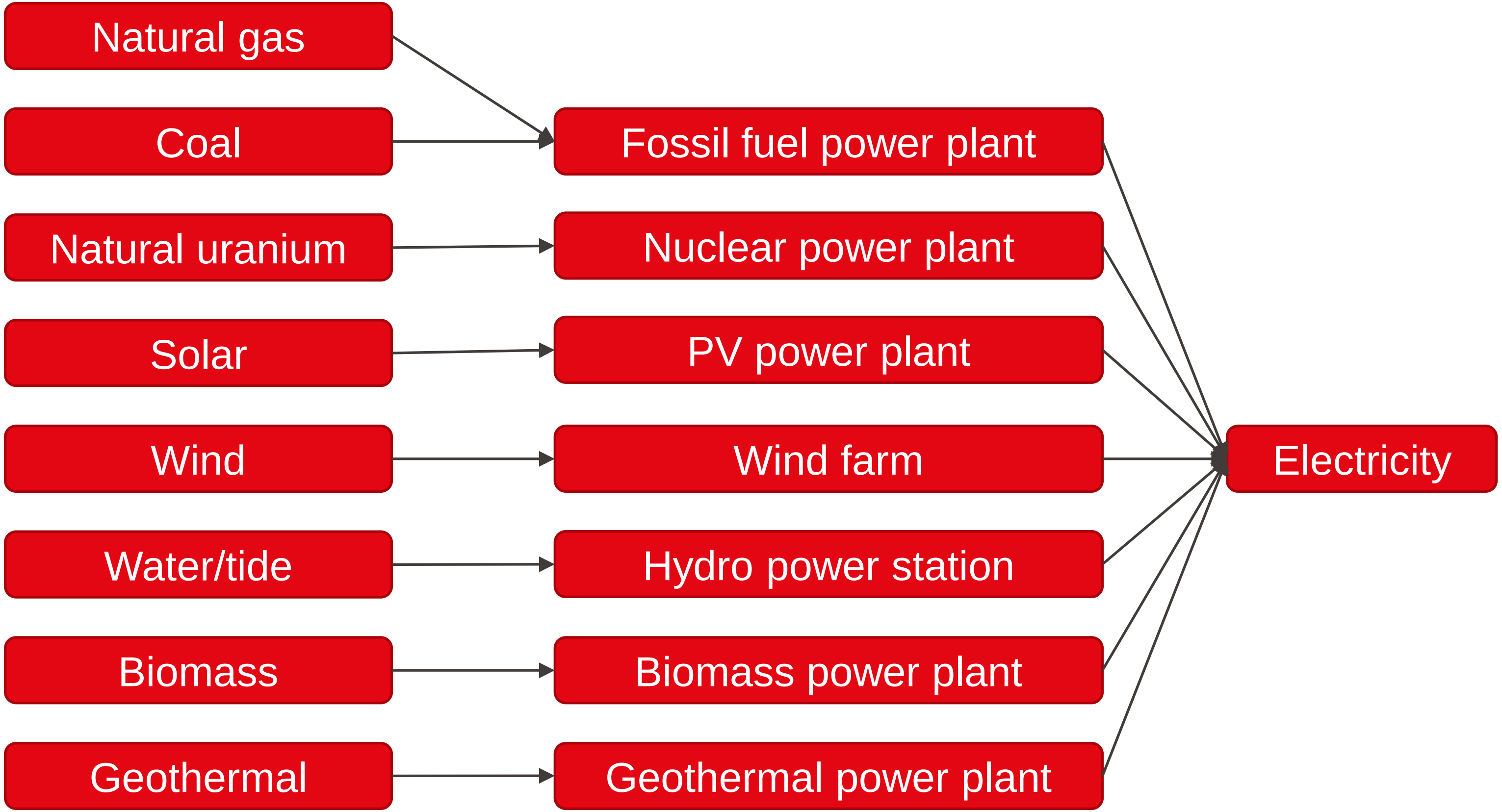
Primary energy (PE) is an energy form found in nature that has not been subjected to any human engineered conversion process. Primary energy can be non-renewable or renewable**.**

Total primary energy supply (**TPES**) is the sum of production and imports subtracting exports and storage changes

Secondary energy sources are energy carriers derived from the transformation of primary energy sources

Definitions adapted from Wikipedia

Electricity generation from primary energy sources



Christophe Ballif / Philippe Thalmann / Claudia Binder

Primary energy: how to count practically ?

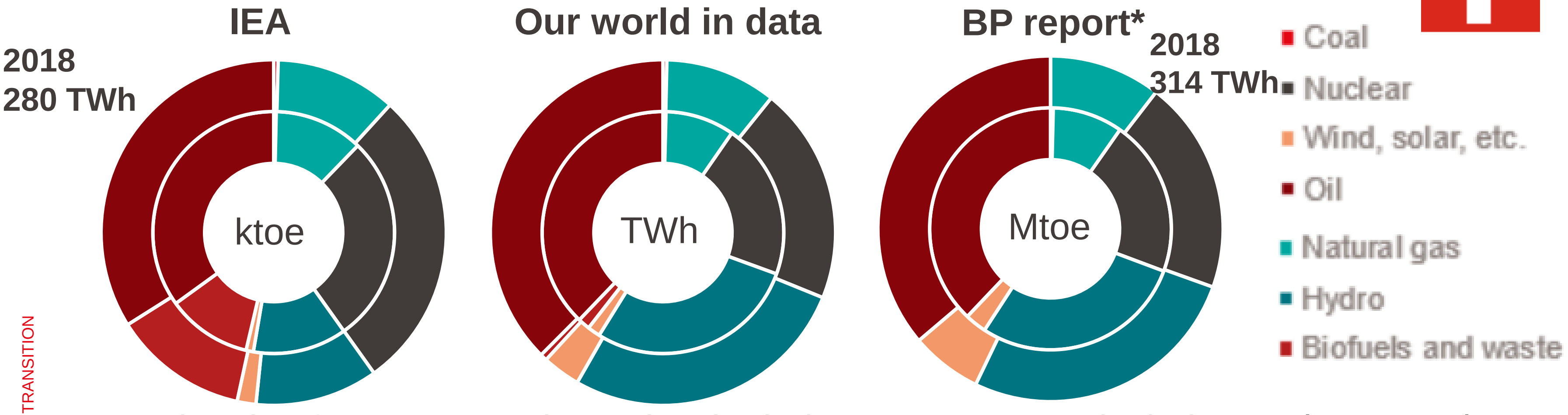
1. **The Direct Equivalent Method**
   - Distinguishes between combustion and non-combustion electricity generation
   - It assumes that electricity generated from all non-combustible energy sources – including **nuclear**, solar thermal, and geothermal – is primary energy (but not for electricity from biomass)

2. **The Physical Energy Content Method (IEA reports)**
   - Distinguishes between thermal and non-thermal sources of electricity (including nuclear).
   - It assumes that the thermal energy generated from **nuclear** fuels, geothermal sources, solar heat, and fossil fuels is primary energy (and applies conversion factors)
   - The electricity from non-thermal sources – such as wind, solar PV, and hydropower – is counted as primary energy.

3. **The Substitution Method (e.g. BP report, now Energy Institute report, "our world in data")**
   - Computes the primary energy content of non-combustible sources by determining how much fossil fuel would be necessary to generate the same amount of electricity (input equivalent-basis).
   - This method then 'substitutes' the efficiency of an average, hypothetical combustion power station for the efficiency of non-combustible sources, typically assuming ~ **40** % efficiency. It applies to **wind, Solar, Hydro, Nuclear**, and all other non-combustible methods….by multiplying by **2.5** the kWh electrical….

Primary energy - Swiss case 2022 (inside circle 2018)

There is no standard methodology !



- IEA takes data from SFOE* and uses the *physical energy content method*. They apply 33% nuclear conversion efficiency, 10% for geothermal electricity and 50% for heat, 33% for solar thermal electricity and 100% for heat. They use values for hydro, wind and PV directly as primary energy.
- BP applies 40% (x2.5) conversion efficiency (from heat to electricity) to nuclear, hydro, renewable electricity, as in *substitution method.* World in data uses values taken from BP report
- BP counts biofuels inside oil category, includes waste in renewables (but not our World in Data)

https://www.iea.org/data-and-statistics
https://ourworldindata.org/grapher/energy-consumption-by-source-and-country
https://elements.visualcapitalist.com/wp-content/uploads/2023/08/Statistical-Review-of-World-Energy-2.pdf

*SFOE= Swiss Federal office of energy

EPFL

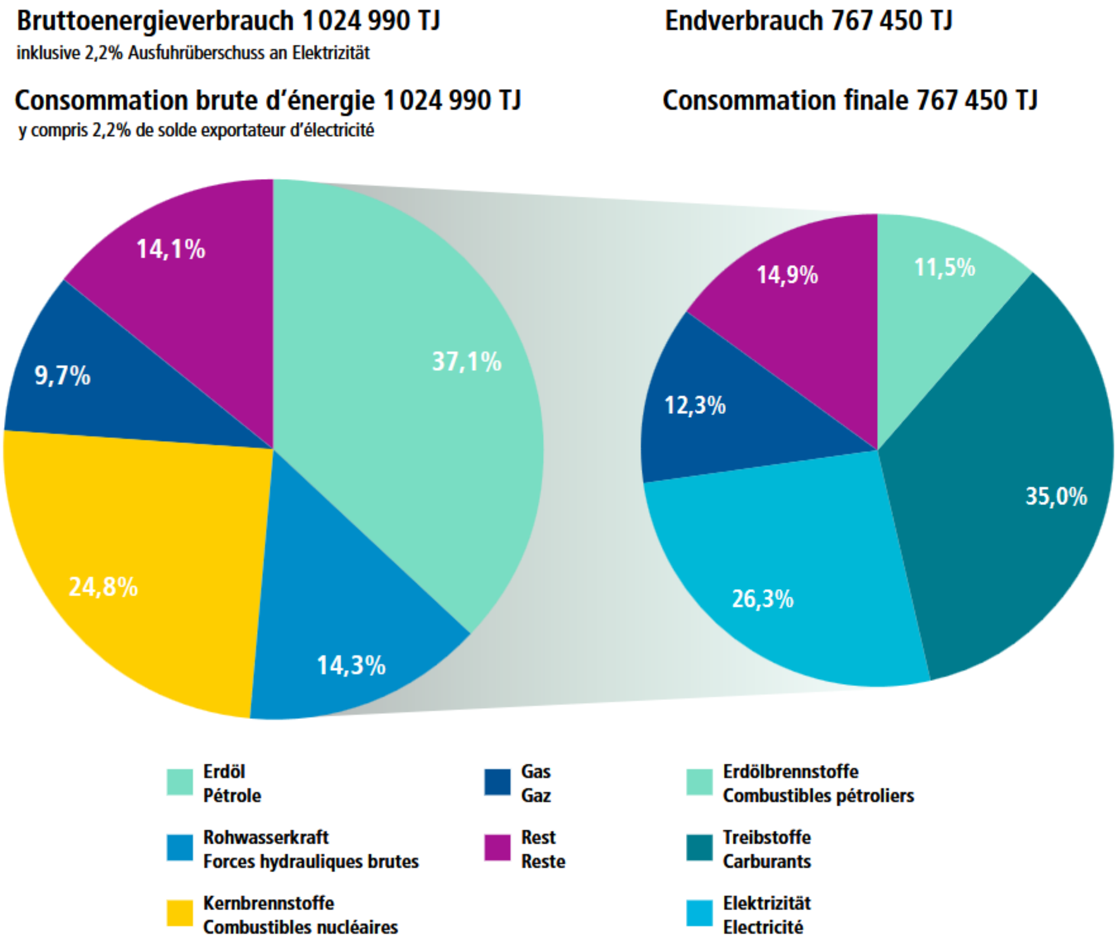
Switzerland 2023

In «primary energy consumption» (Physical energy content, IEA)
Total of **284 TWh** (counted with ~ 50% fossile, and around 25% nuclear)

In final consumption, Electricity (58 TWh) accounts for **26.3**% of a total 212 TWh (with around 60% fossile fuel)

https://www.bfe.admin.ch/bfe/fr/home/versorgung/statistik-und-geodaten/energiestatistiken/gesamtenergiestatistik.exturl.html/

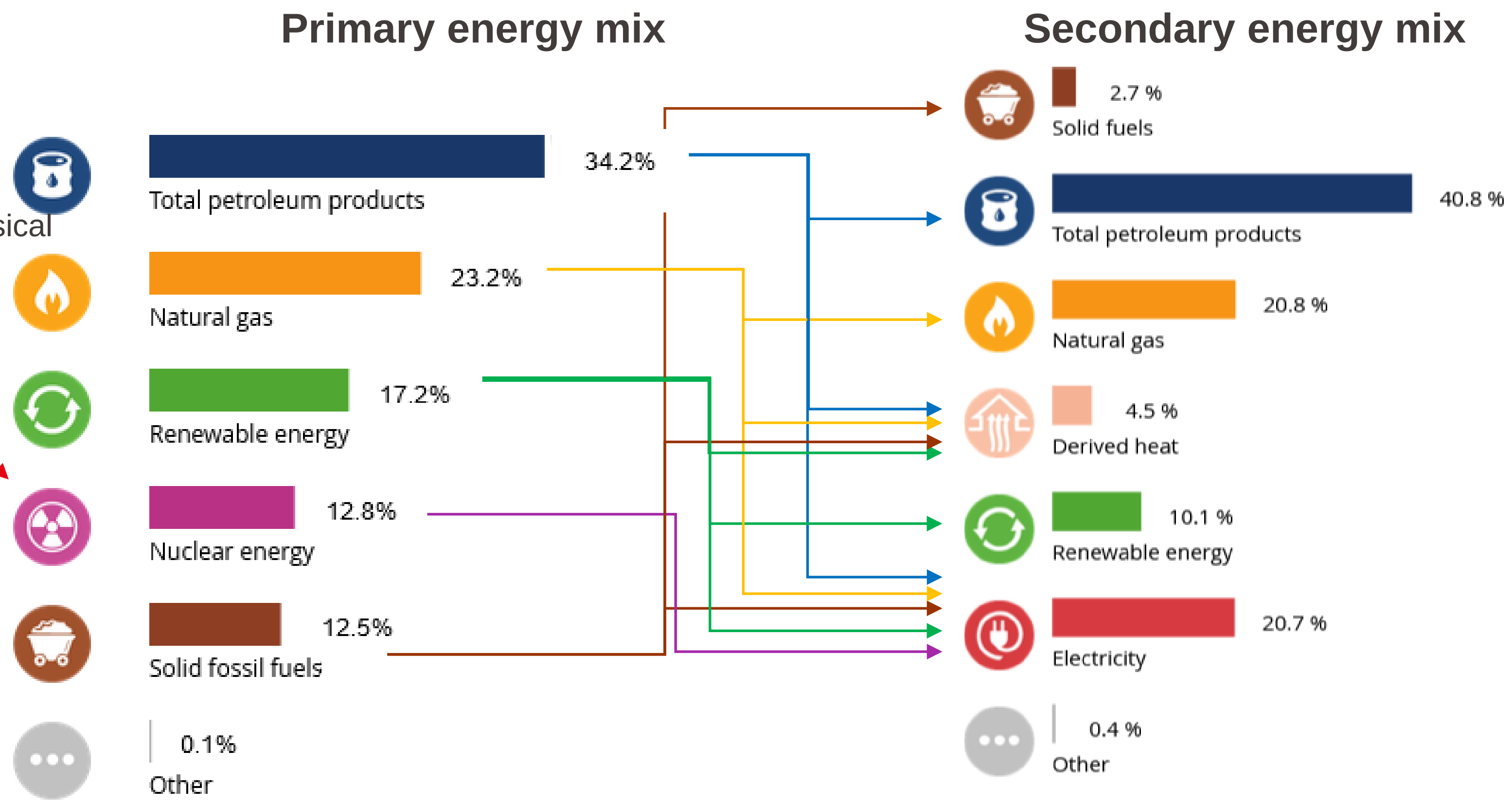
Fig. 6 Energieeinsatz und Endverbrauch der Schweiz 2023
Utilisation totale et consommation finale de la Suisse en 2023



BFE, Schweizerische Gesamtenergiestatistik 2023 (Fig. 6)
OFEN, Statistique globale suisse de l'énergie 2023 (fig. 6)

Consumption mix for EU – 28 countries (2023)

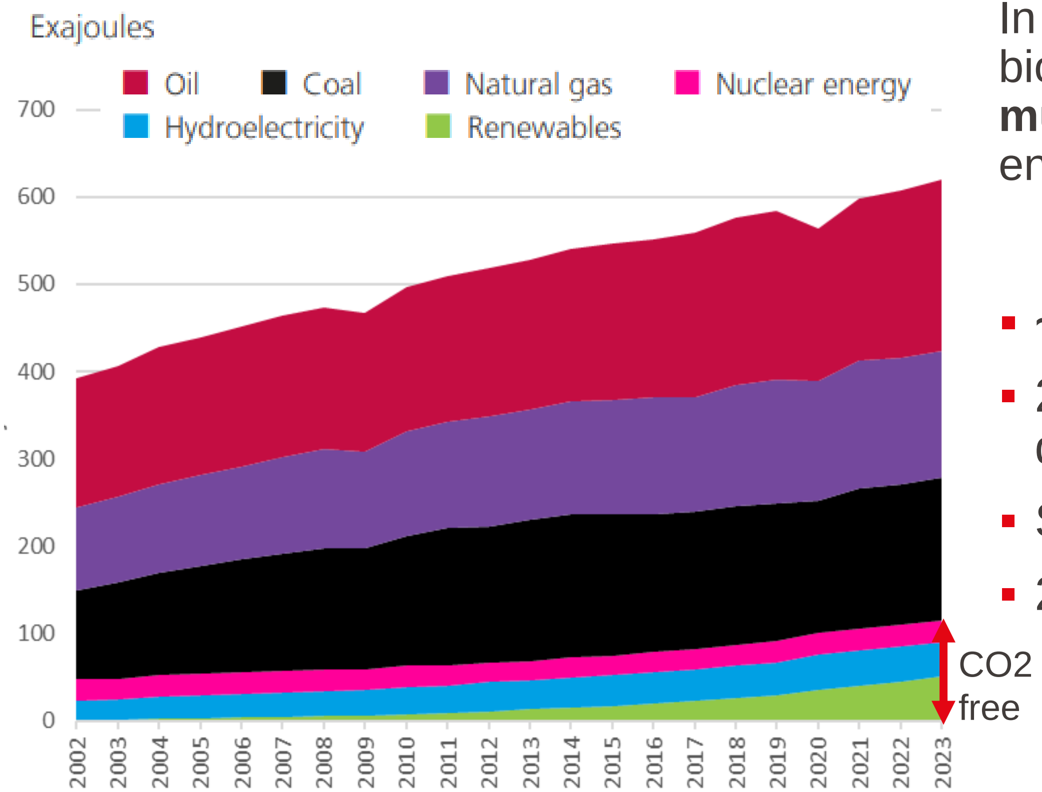
Likely
The Physical
Energy
Content
Method



https://ec.europa.eu/eurostat/web/interactive-publications/energy-2023#energy-sources

- Calculated in Toe units

Primary energy consumption: the world challenge



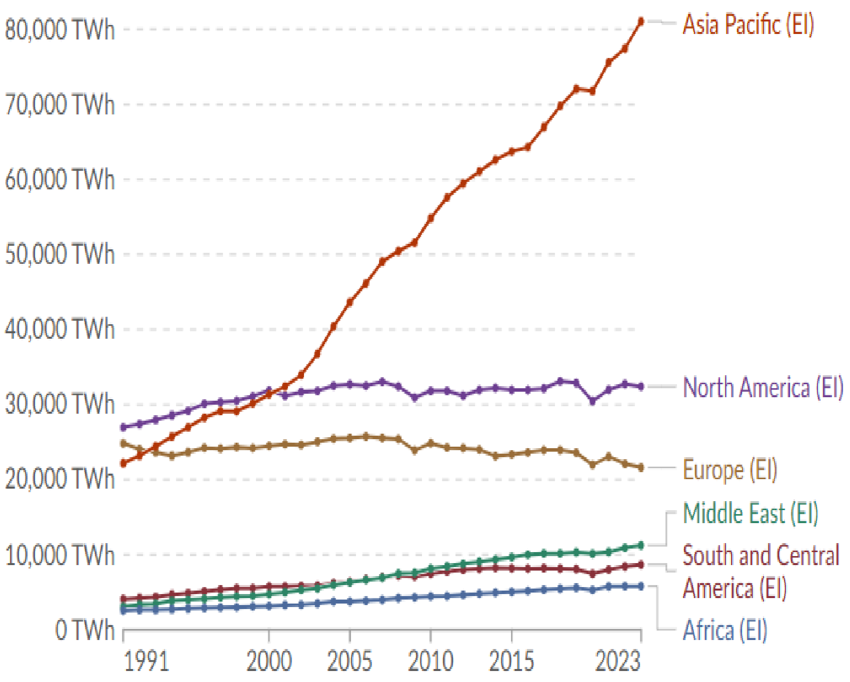
In this representation: electricity in kWh of biomass, hydro, solar, nuclear wind is **multiplied by 2.5 to** be shown as primary energy source («BP» substitution method)

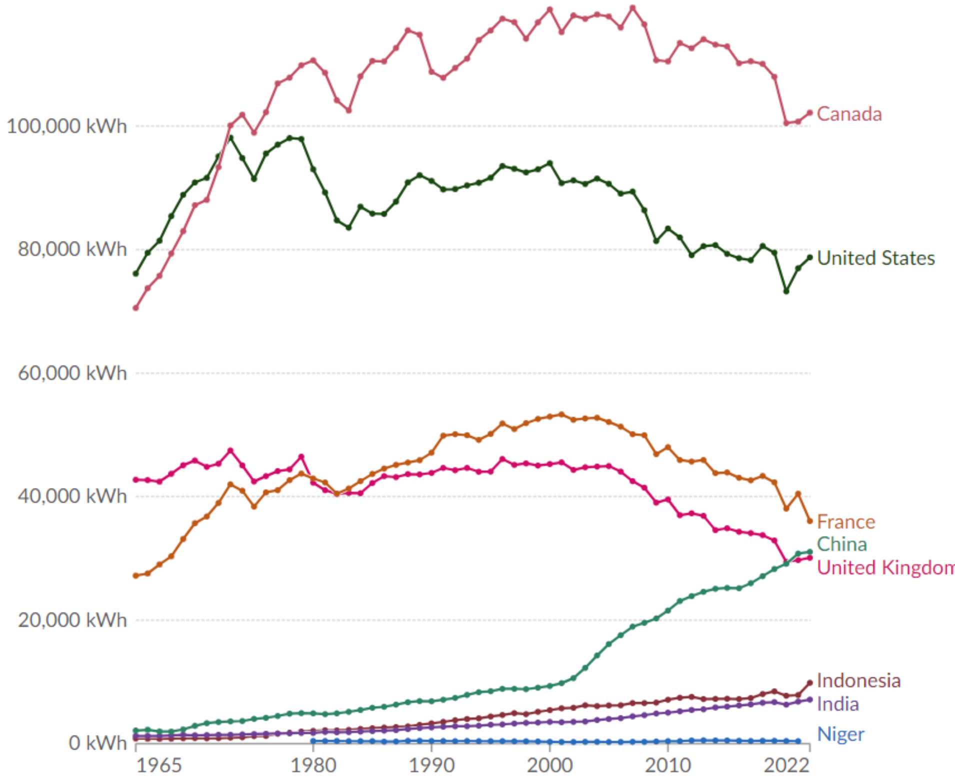
- ~ 172’000 TWh (CH ~ 320 TWh)
- 2% annual growth in the last 20 years driven mostly by China and India
- Still 80% fossile fuel
- 20% renewable and nuclear

Statistical review of world energy

World Energy Outlook 2024 – Analysis - IEA

Primary energy in the substution method





- [Primary energy consumption by world region (ourworldindata.org)]

Per capita and selected country

Primary energy (substitution method) most likely path

++ **Stagnating or going down in industrialised low growth countries** (thanks to efficiency, shift to renewables and partly sufficiency)

--- **But more than compensated by the still huge growth potential**

in China, in India, in Indonesia, and in growing African countries….. a majority of the habitants of the planet expect to see their standard of living raised an also dream of consuming….

Every persons lifted out of „poverty" will become a consumer of good and energy, even if it does it in a more efficient manner than in western countries

-- **Restrictions and limitations**

it is virtually impossible to cut energy usage by imposing restrictions or taxes (in democracy → protests). And non-democracy need energy for their economic growth and to avoid social unrest

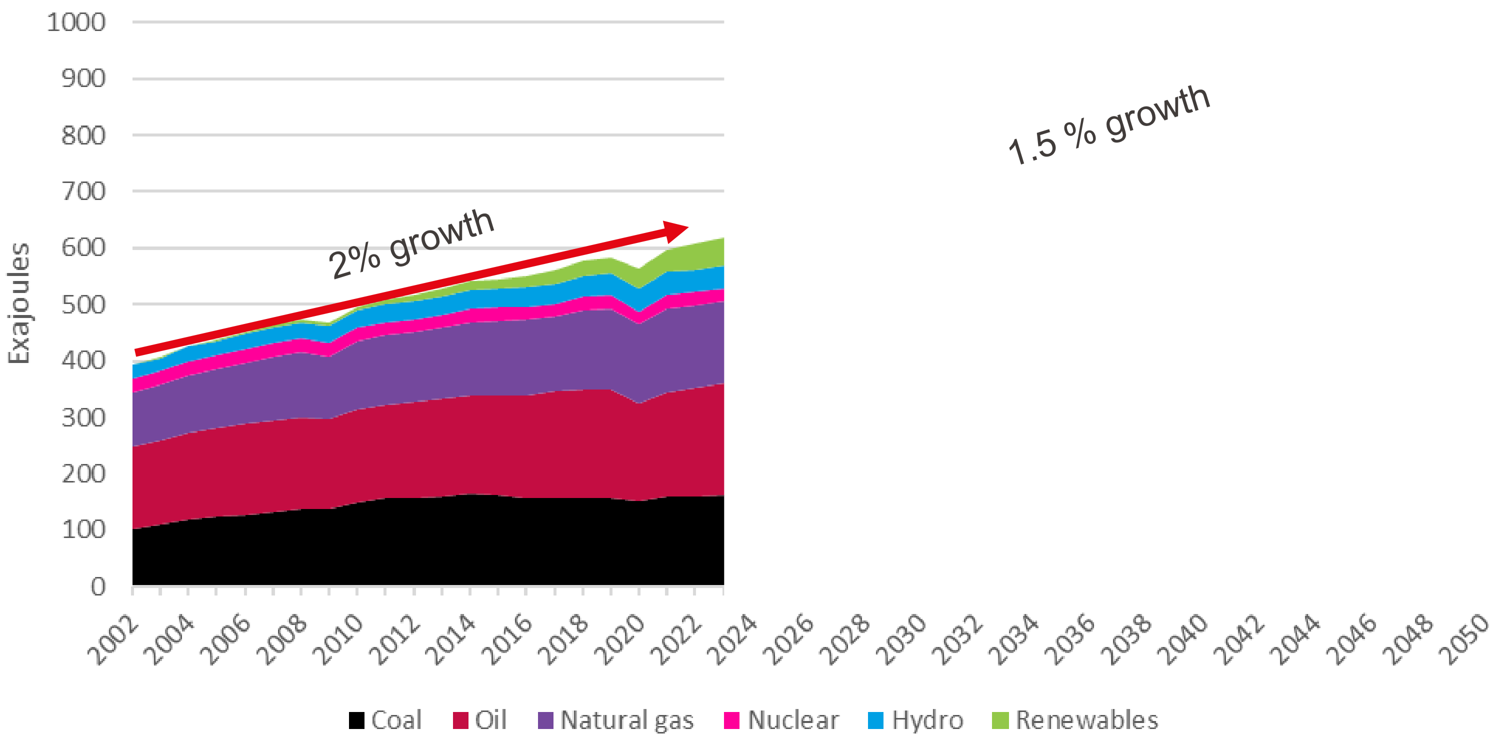
As soon as energy is too expensive Governement intervene (e.g. during war in Ukraine: 800 billions subsidies to EU households for energy bills*) or there is a risk of „not enough" (e.g. 500 millions CHF for renting generators for 250 MW in Switzerland, to prevent electricty cut). We'll mine more fossile rather than restrain

→ **Further growth ~ 1.5%-2%/year expected**

- Energy crisis: Europe's spend to shield consumers nears €800 billion. Where is the money going? | Euronews

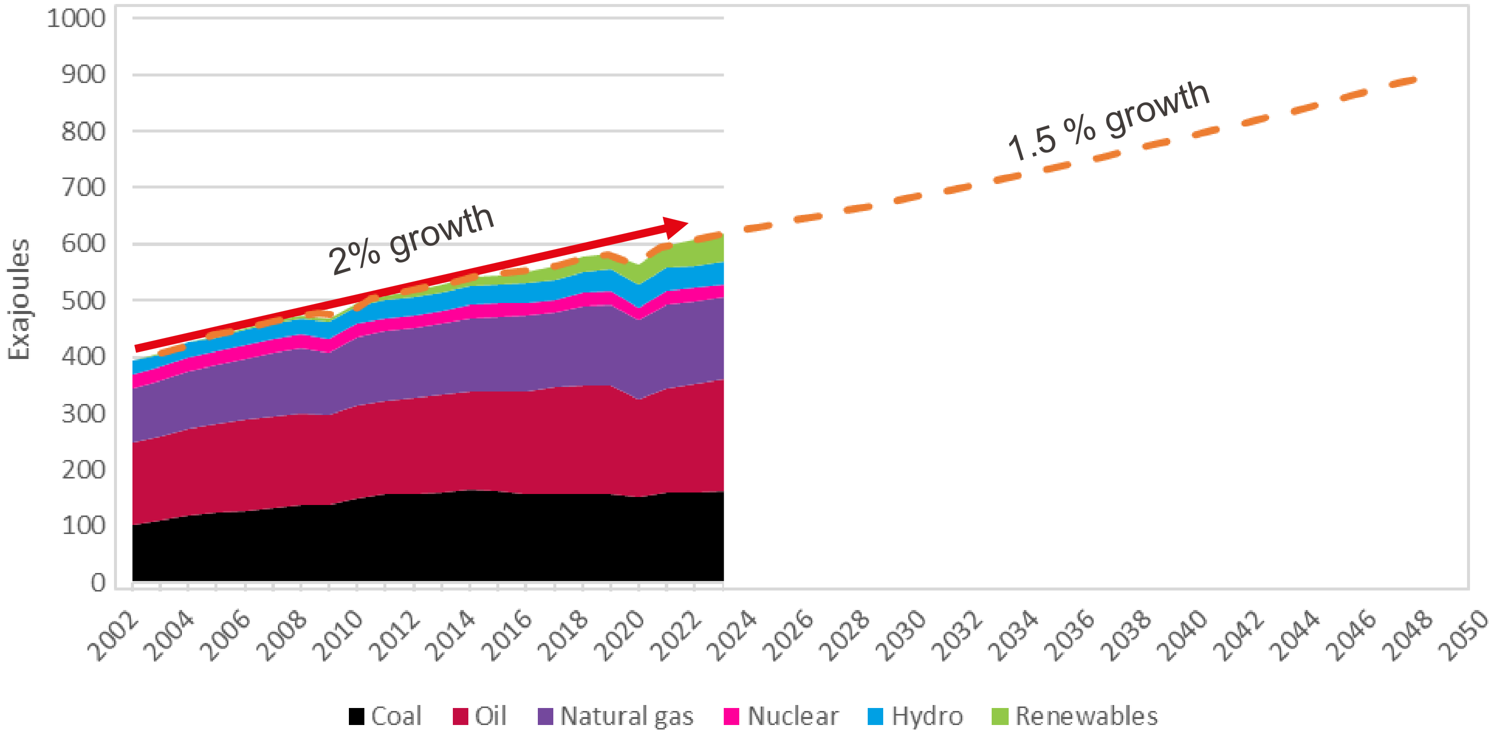
Primary energy consumption

(substitution method - BP)



https://files.investis.com/bp_acc_ia/stat_review_2008/htdocs/reports/report_19.html

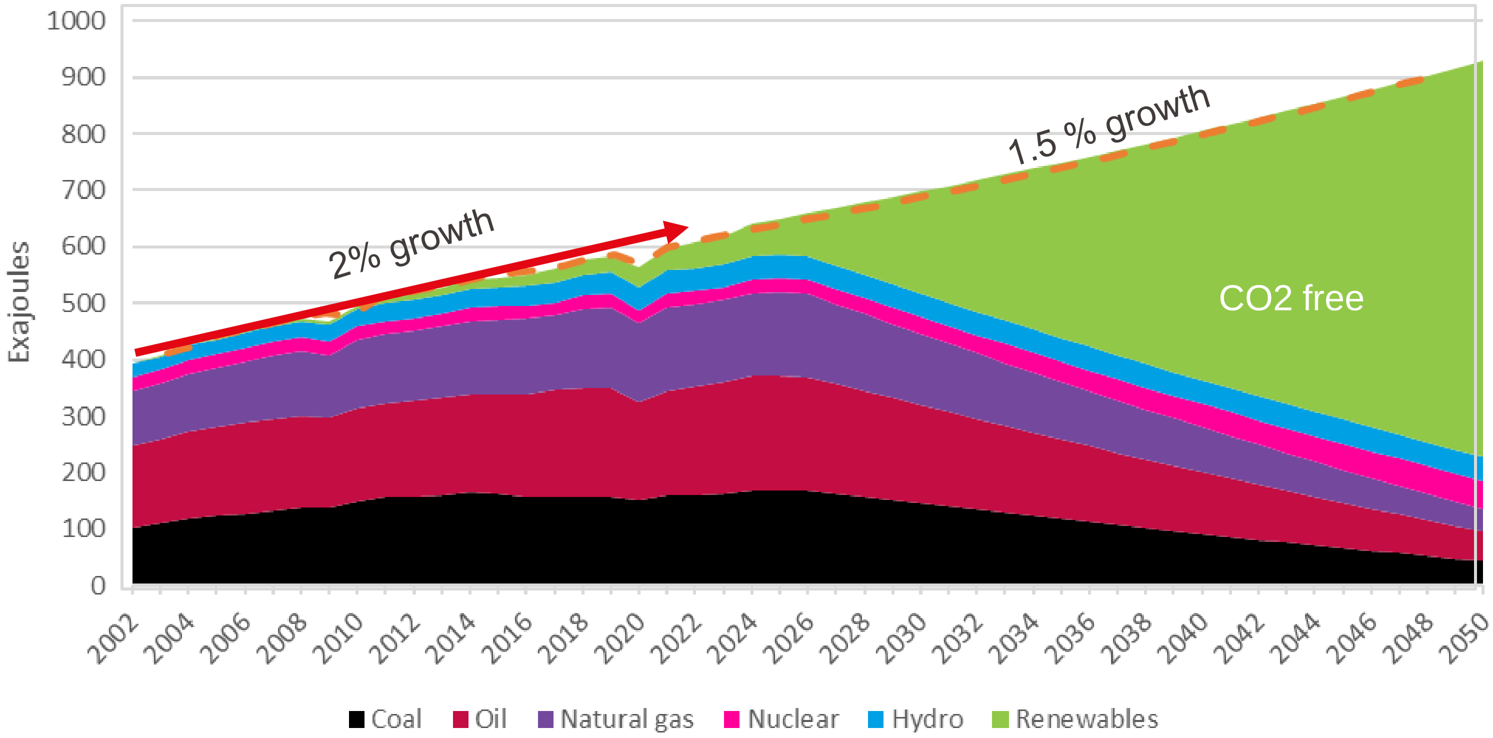
Primary energy consumption
(substitution method - BP)



https://files.investis.com/bp_acc_ia/stat_review_2008/htdocs/reports/report_19.html

Primary energy consumption
(substitution method - BP)

1000 GW/year solar (CF 0.18)
and 500 GW/year wind (CF 0.3)
15 GW/year Nuclear (CF0.9)



https://files.investis.com/bp_acc_ia/stat_review_2008/htdocs/reports/report_19.html

Primary energy consumption
(substitution method - BP)

Even in the 1.5% primary energy growth scenarion
By installing 27000 GW solar (CF 0.18)
and 12500 GW wind (CF 0.3)
And 375 GW Nuclear (CF0.9)

And shifting to electricity for transport and heating (with heat pump)

Energy sector quasi decarbonized by 2050
.

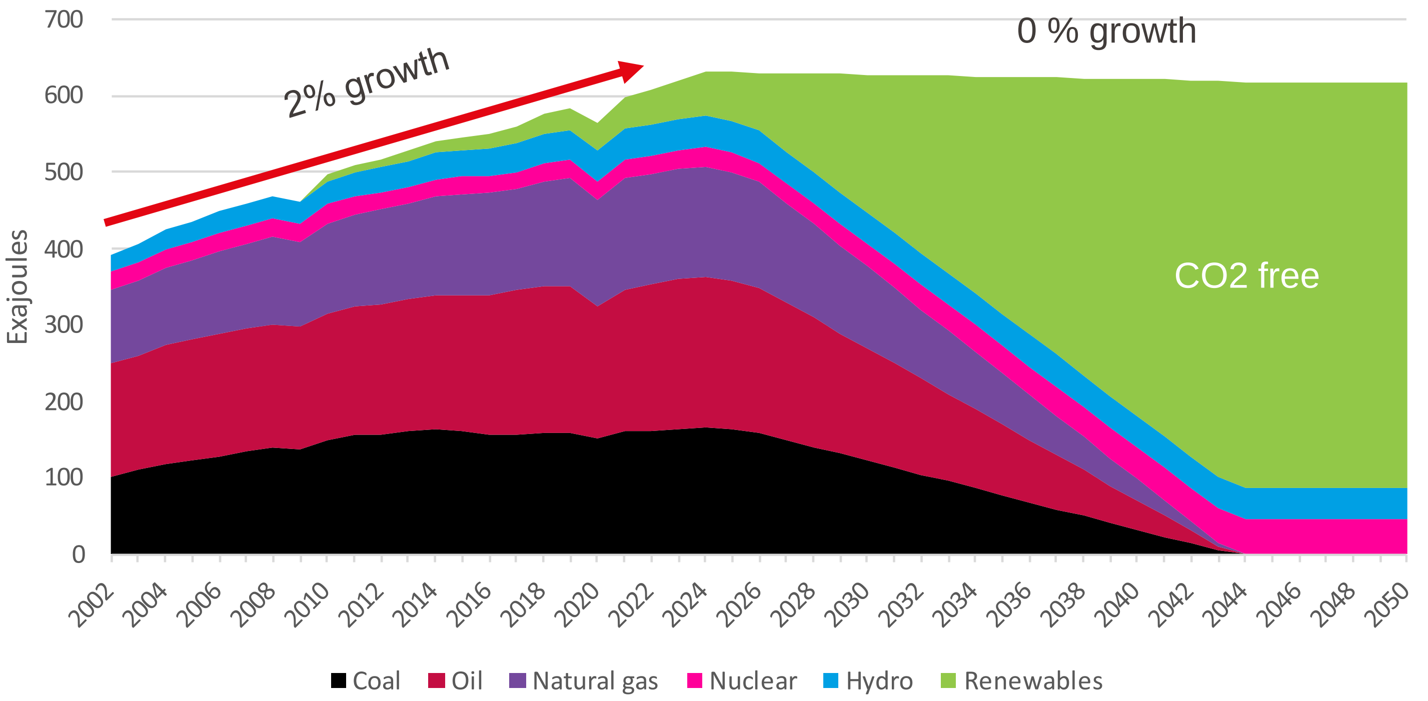
Easier/faster if less increase in Primary energy consumption (BP) !

https://files.investis.com/bp_acc_ia/stat_review_2008/htdocs/reports/report_19.html

Primary energy consumption

(substitution method - BP)

1000 GW/year solar (CF 0.18)
and 500 GW/year wind (CF 0.3)
15 GW/year Nuclear (CF0.9)

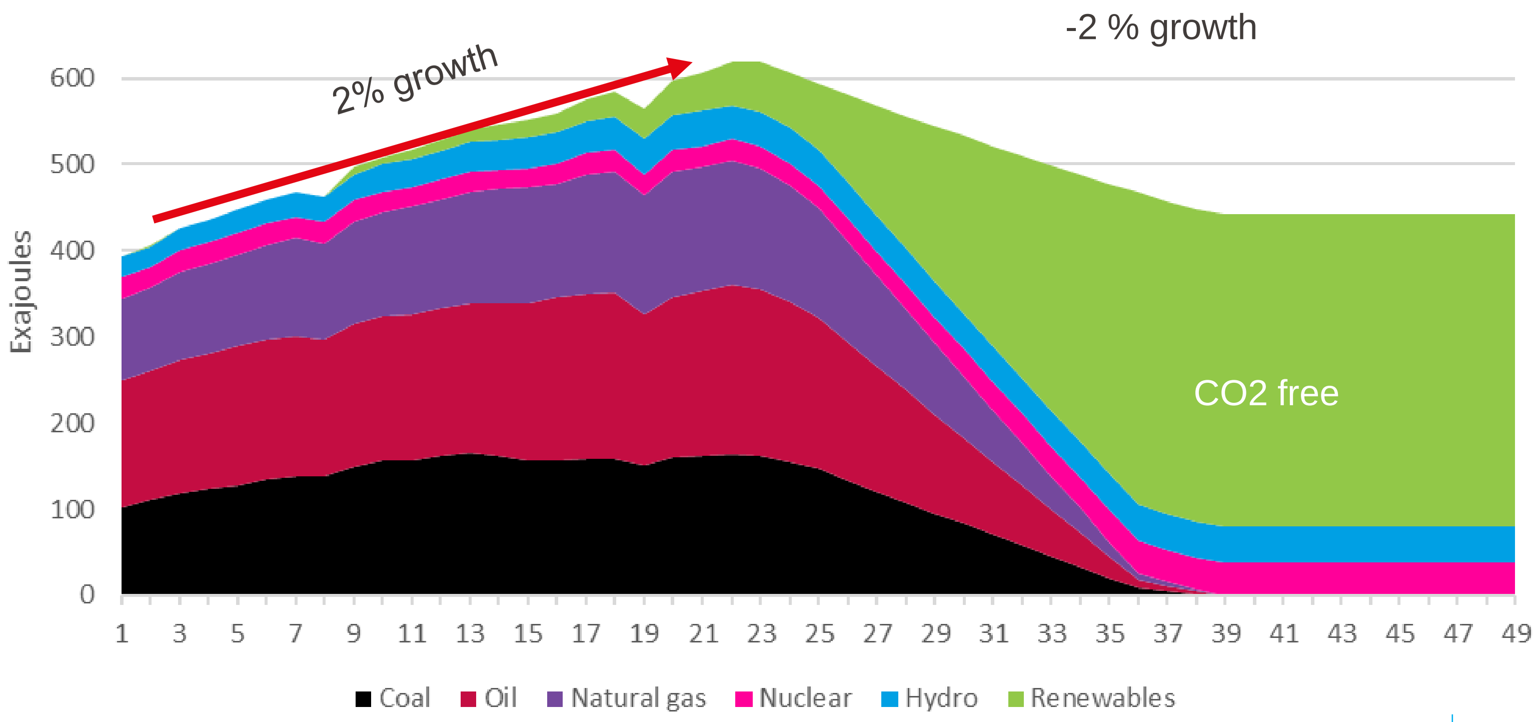


https://files.investis.com/bp_acc_ia/stat_review_2008/htdocs/reports/report_19.html

Primary energy consumption

(substitution method - BP)

1000 GW/year solar (CF 0.18)
and 500 GW/year wind (CF 0.3)
15 GW/year Nuclear (CF0.9)

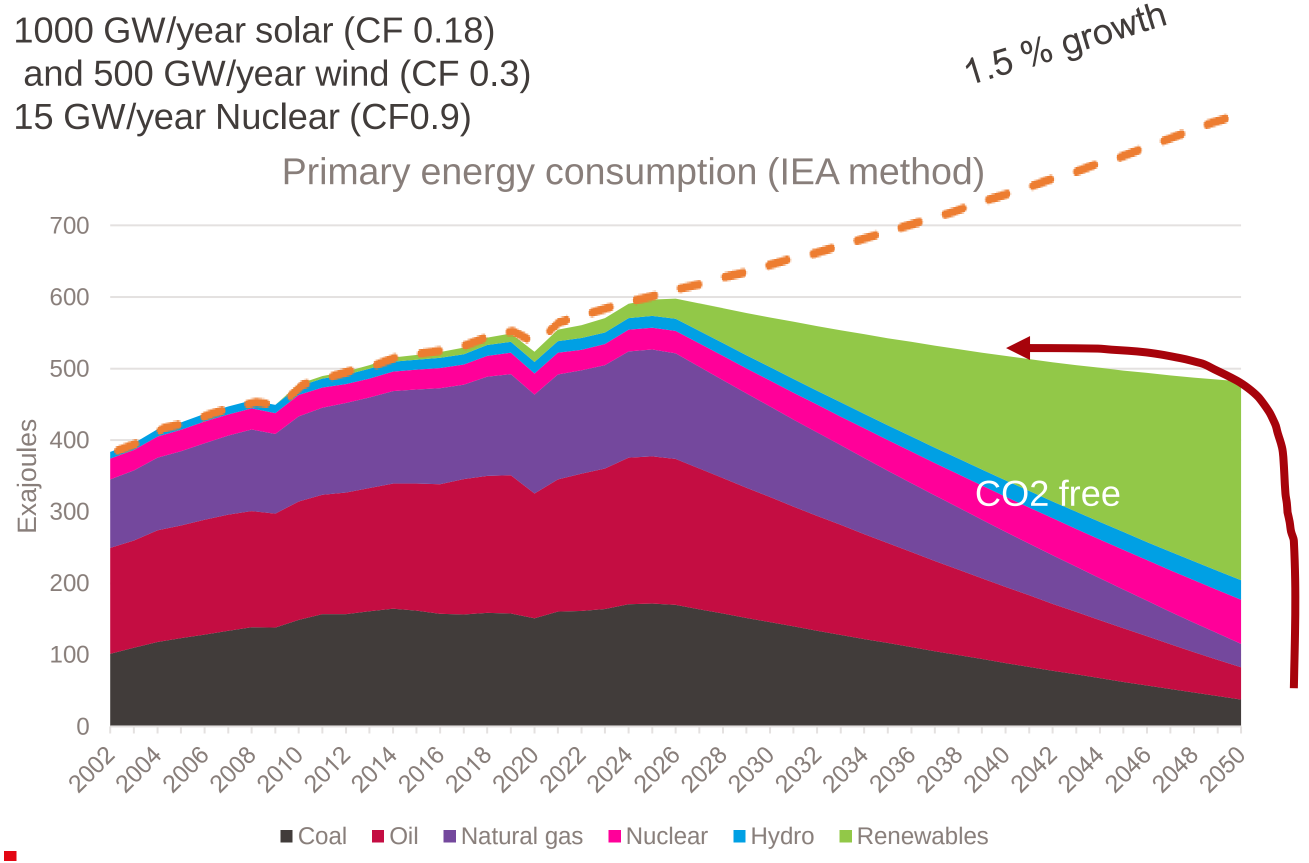


Important: when a scenarios shows a reduction

(IEA Method)

1000 GW/year solar (CF 0.18)
and 500 GW/year wind (CF 0.3)
15 GW/year Nuclear (CF0.9)

It is because Electricity
Is taken at value of one
(not multiplied by 2.5) !



If you multiply by 2.5
solar, Wind and hydro,…
as in substitution method.

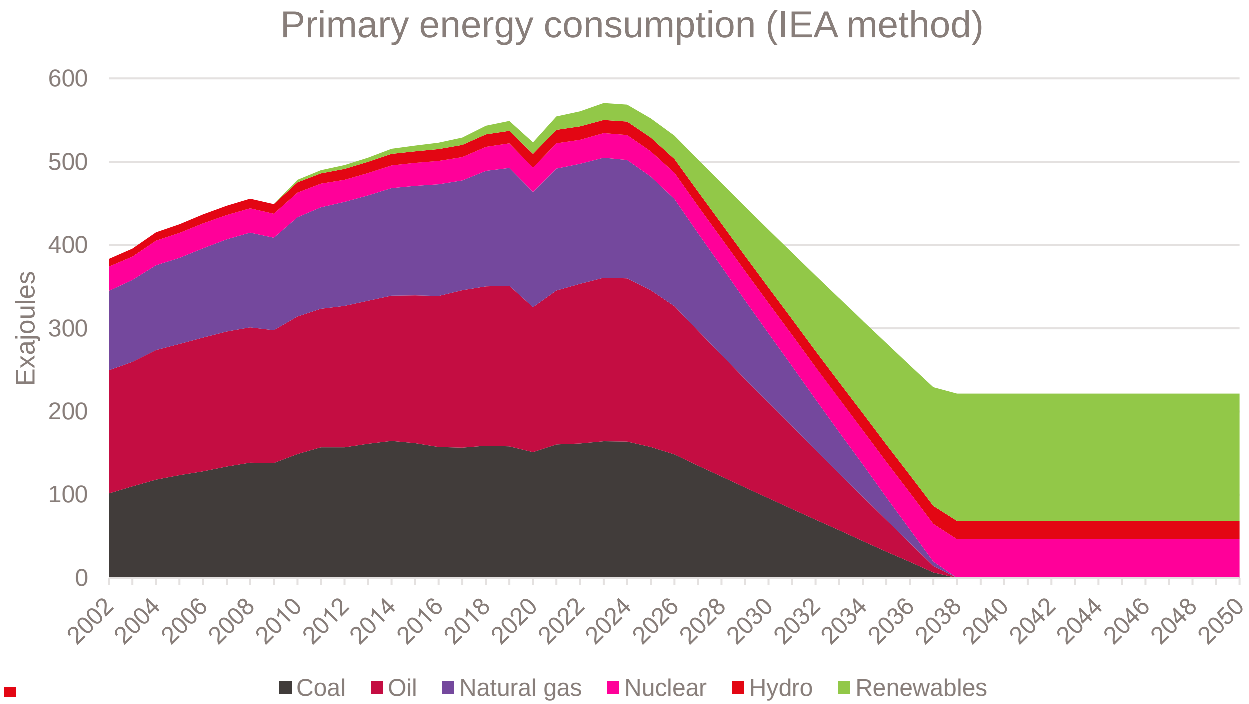
Check the error on nuclear!

Important: when a scenarios shows a reduction

(IEA Method)

1000 GW/year solar (CF 0.18)
and 500 GW/year wind (CF 0.3)
15 GW/year Nuclear (CF0.9)

-2 % growth

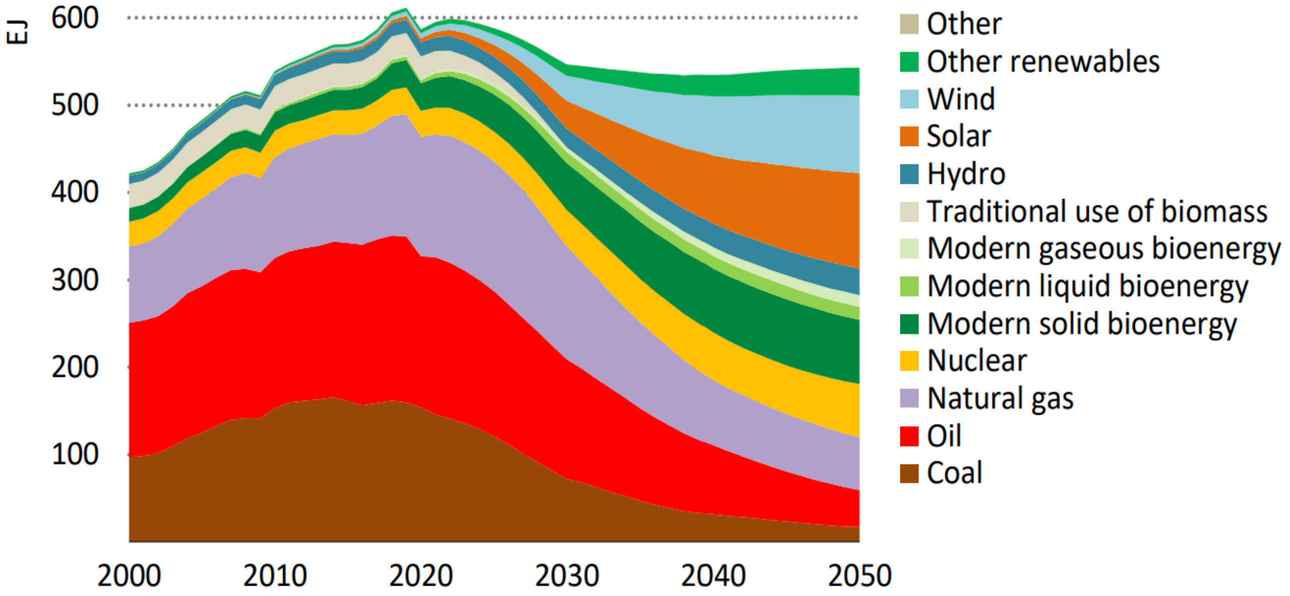


In 2038, installations « stopped »

It is because Electricity
Is taken at value of one
(not multiplied by 2.5) !

Important: when a scenarios shows a reduction

Figure 2.5 ▹ Total energy supply in the NZE



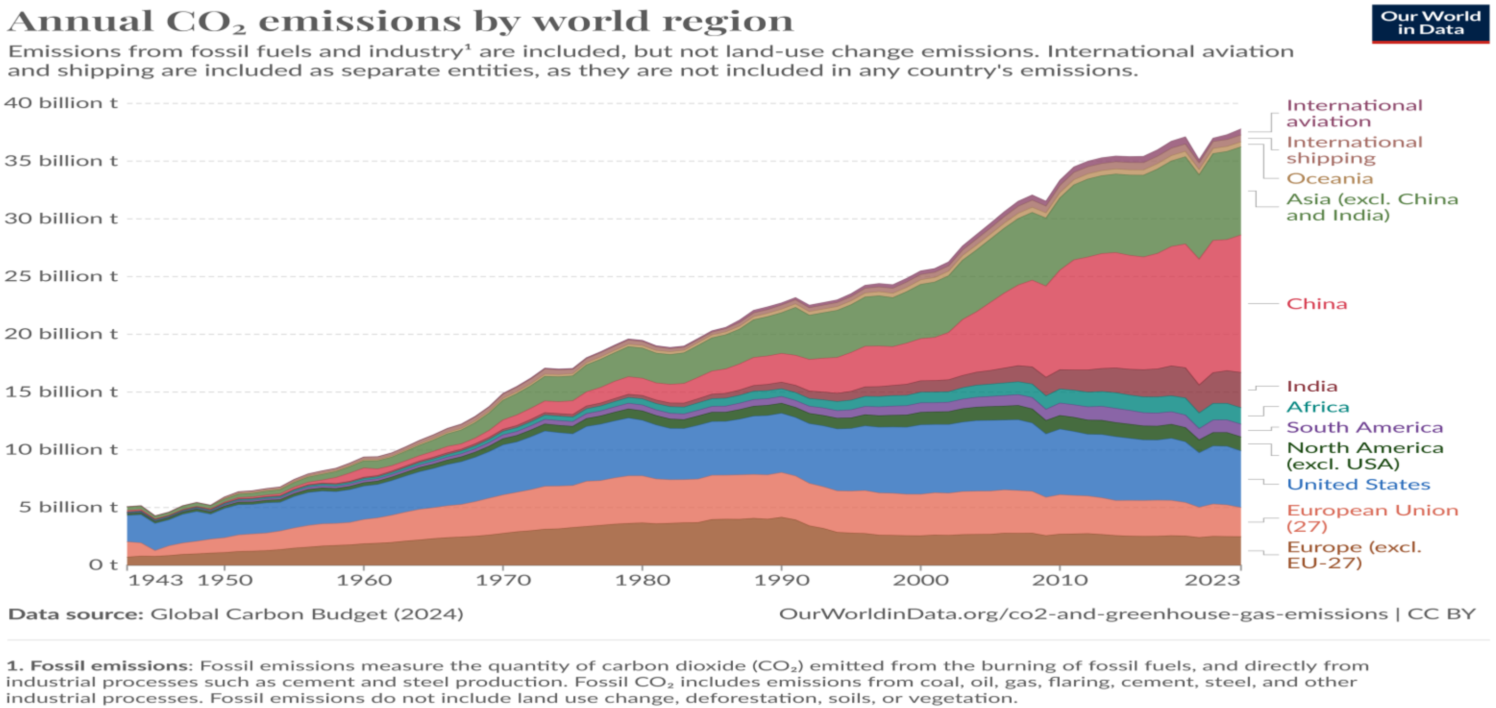
Renewables and nuclear power displace most fossil fuel use in the NZE, and the share of fossil fuels falls from 80% in 2020 to just over 20% in 2050

It is because Electricity
Is taken at value of one
(not multiplied by 2.5) !

Exemple
Net Zero Emission scenario of IEA (2021… already outdated)

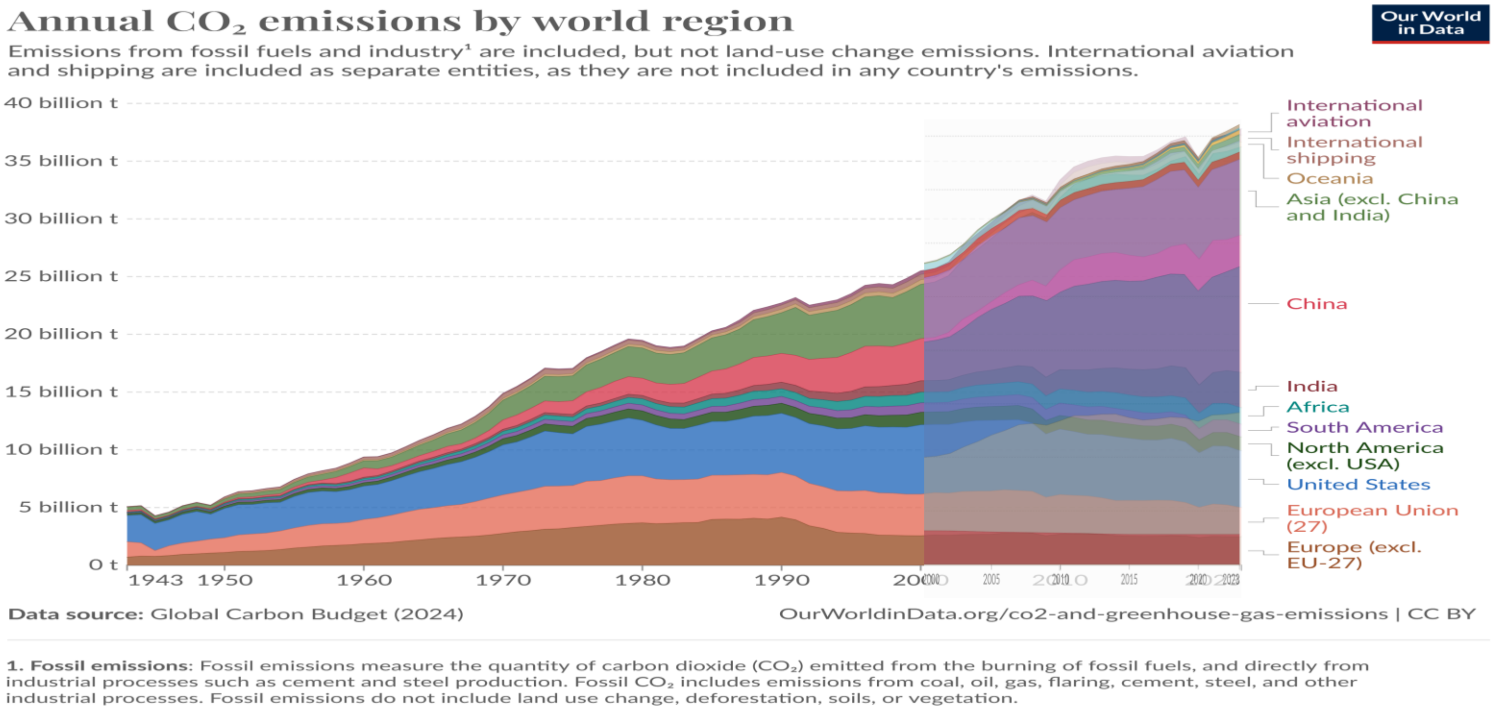
If you multiply by 2.5 solar, Wind and hydro,… as in substitution method.

End of the Growth of direct CO2 emission ?



Annual CO_2 emissions by world region (ourworldindata.org)

End of the Growth of direct CO2 emission ?



[Annual CO_2 emissions by world region (ourworldindata.org)]

Key takeaways

- Difference between primary and secondary energy (e.g. transformation to electricity)
- Attention to the way energy statistical datas are calculated and reported. Often impossible to find...
- Nuclear and renewables might look large or small depending on the representation

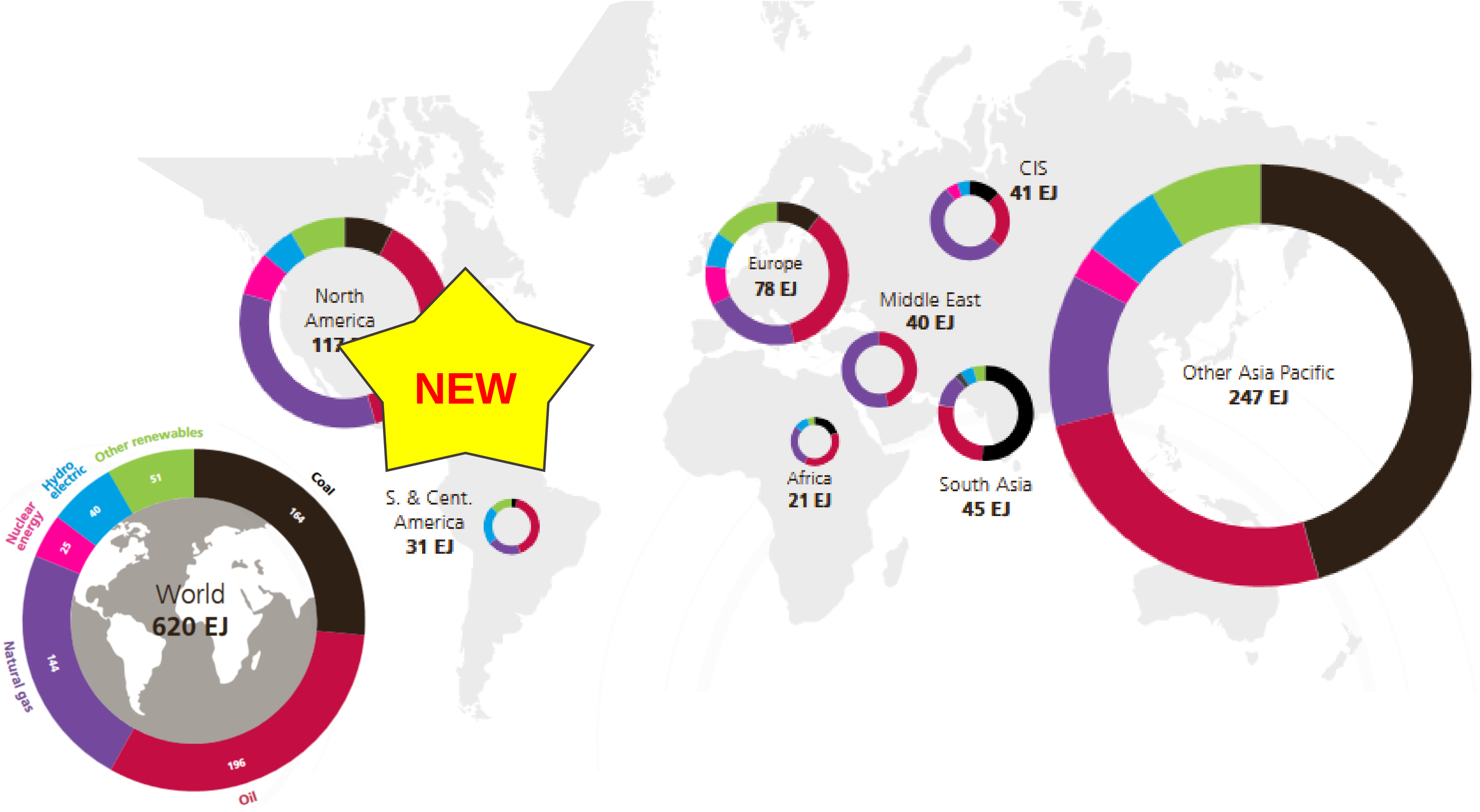
- Definition of energy efficiency
- Typical energy efficiency values of conversion technologies
- Typically factor 3 gains when using electricity rather than chemical energy

- Definition of capacity factor
- Typical capacity factor values of different power plant types
- Capacity factor varies throughout the year, depends on geography and usage

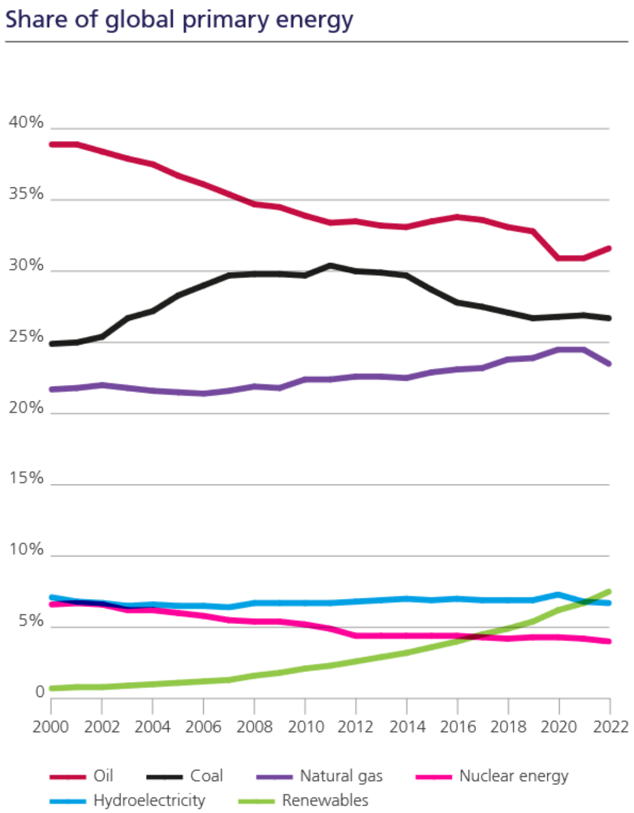
Christophe Ballif / Philippe Thalmann / Claudia Binder

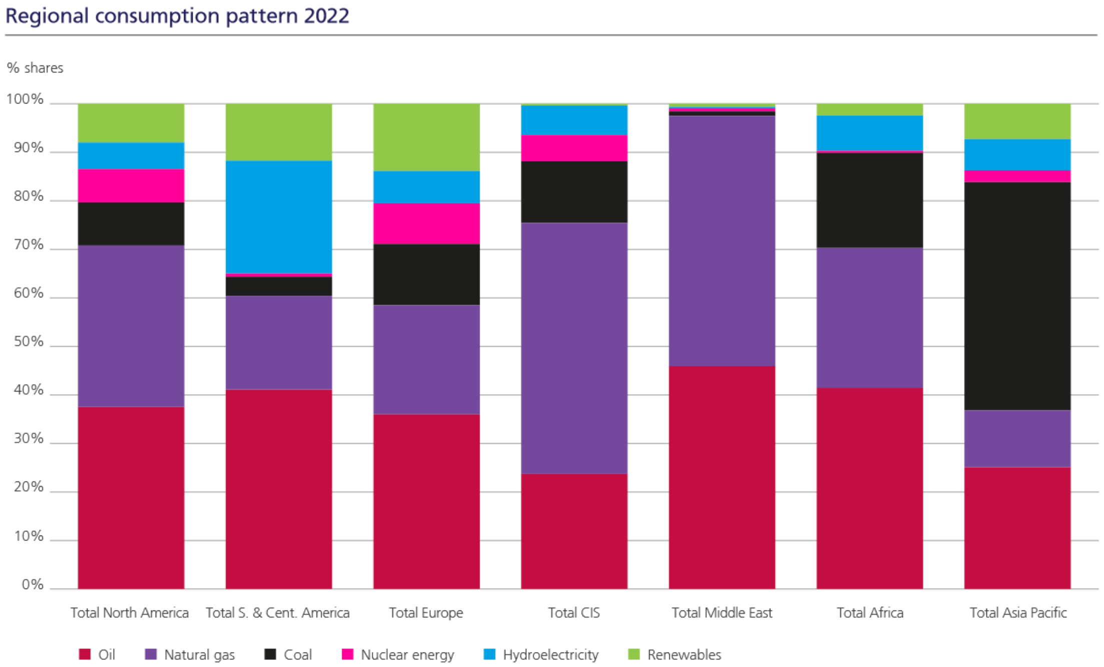
Appendix (just for information)

Primary energy consumption: the world challenge (cont.)



Primary energy consumption: the world challenge (cont.)

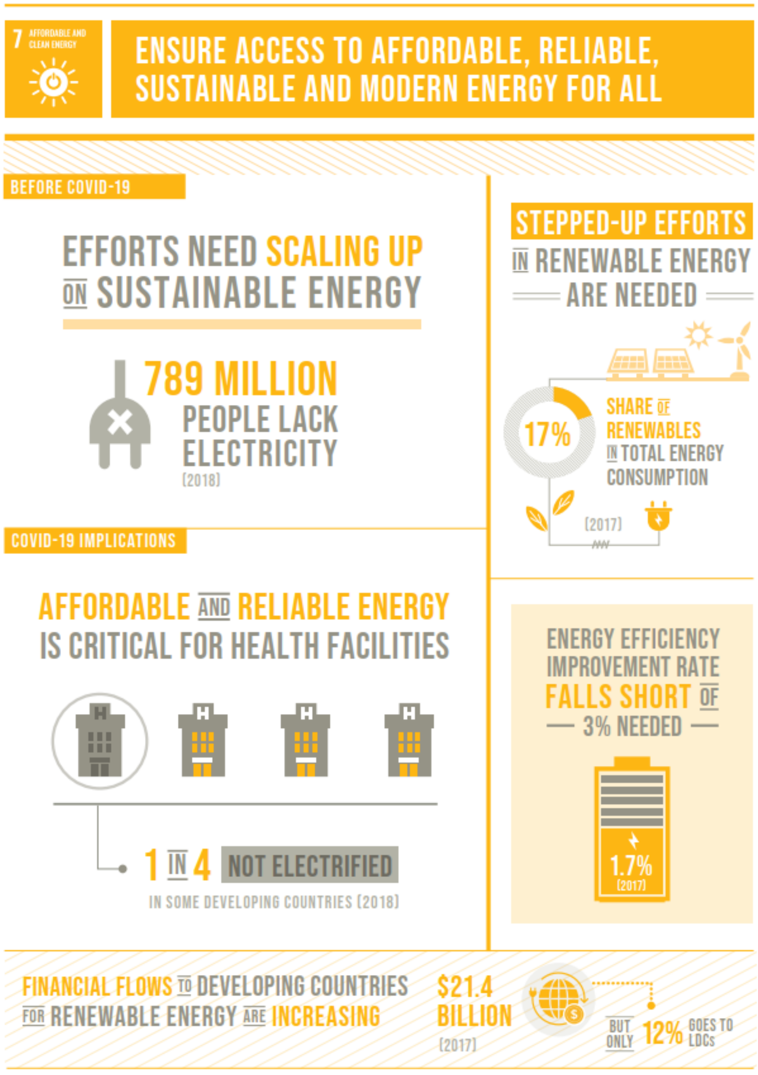




https://www.energyinst.org/__data/assets/pdf_file/IEA *World Energy Outlook 2023*

Affordable and clean energy

- Ensure universal access to **affordable, reliable and modern energy services**
- Increase substantially the share **of renewable energy in the global energy mix**
- Double the global rate of improvement in **energy efficiency**
- Enhance international cooperation to facilitate **access to clean energy research and technology** and promote **investment in energy** infrastructure and clean energy technology
- Expand infrastructure and upgrade technology for supplying **modern and sustainable energy services for all** in developing countries

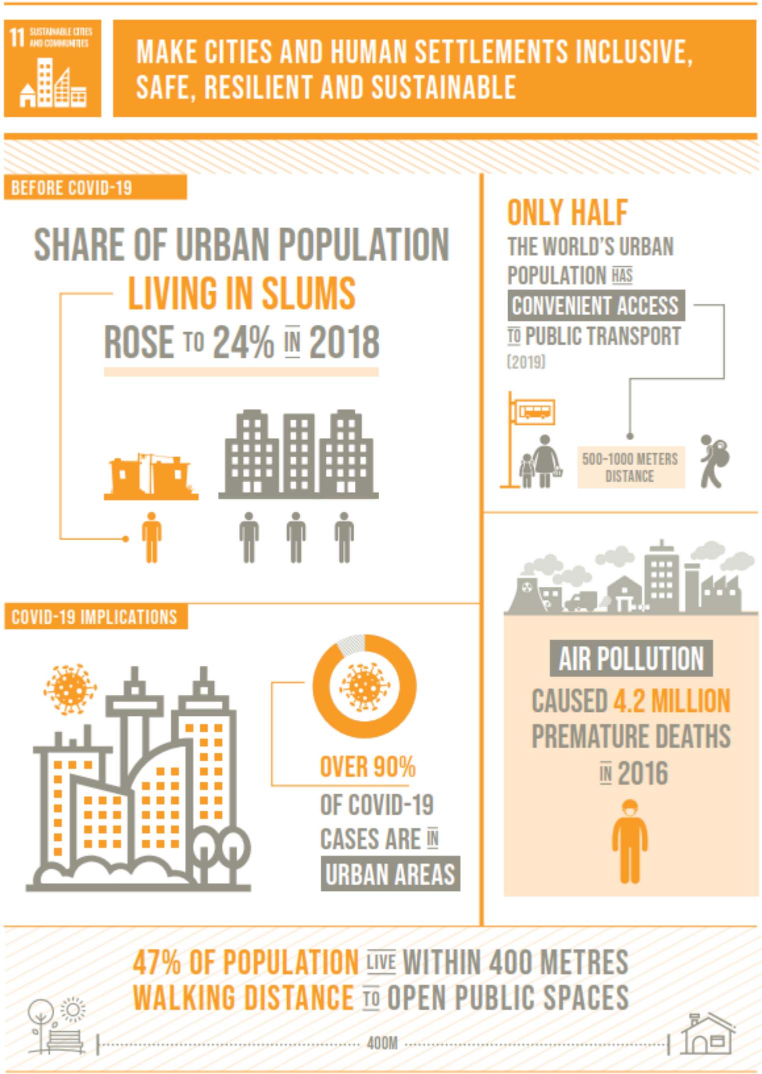


https://www.un.org/sustainabledevelopment/energy/

Sustainable cities and communities

- Provide access to safe, affordable, accessible and **sustainable transport systems** for all
- Enhance inclusive and **sustainable urbanization** and capacity for participatory, integrated and sustainable human settlement planning and management in all countries
- Reduce the adverse per capita **environmental impact of cities**, including by paying special attention to air quality and municipal and other waste management
- Substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, **resource efficiency, mitigation and adaptation to climate change**, resilience to disasters

https://www.un.org/sustainabledevelopment/cities/

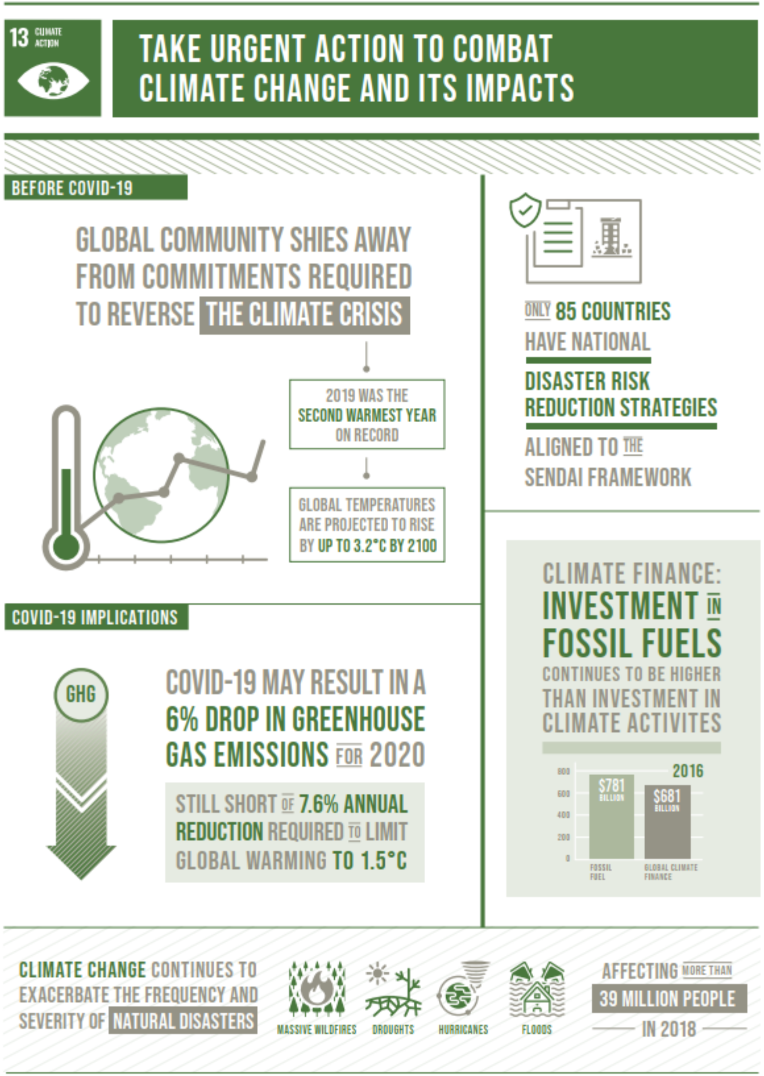


EPFL

Climate action

- Strengthen resilience and adaptive capacity to **climate-related hazards** and natural disasters in all countries
- Integrate climate change measures into **national policies**, strategies and planning
- Improve education, **awareness-raising** and human and institutional capacity on **climate change mitigation**, adaptation and impact reduction
- Mobilize jointly $100 billion annually by 2020 from all sources - **operationalize the Green Climate Fund** through its capitalization
- Promote mechanisms for raising capacity for **effective climate change-related planning and management** in least developed countries and small island developing States

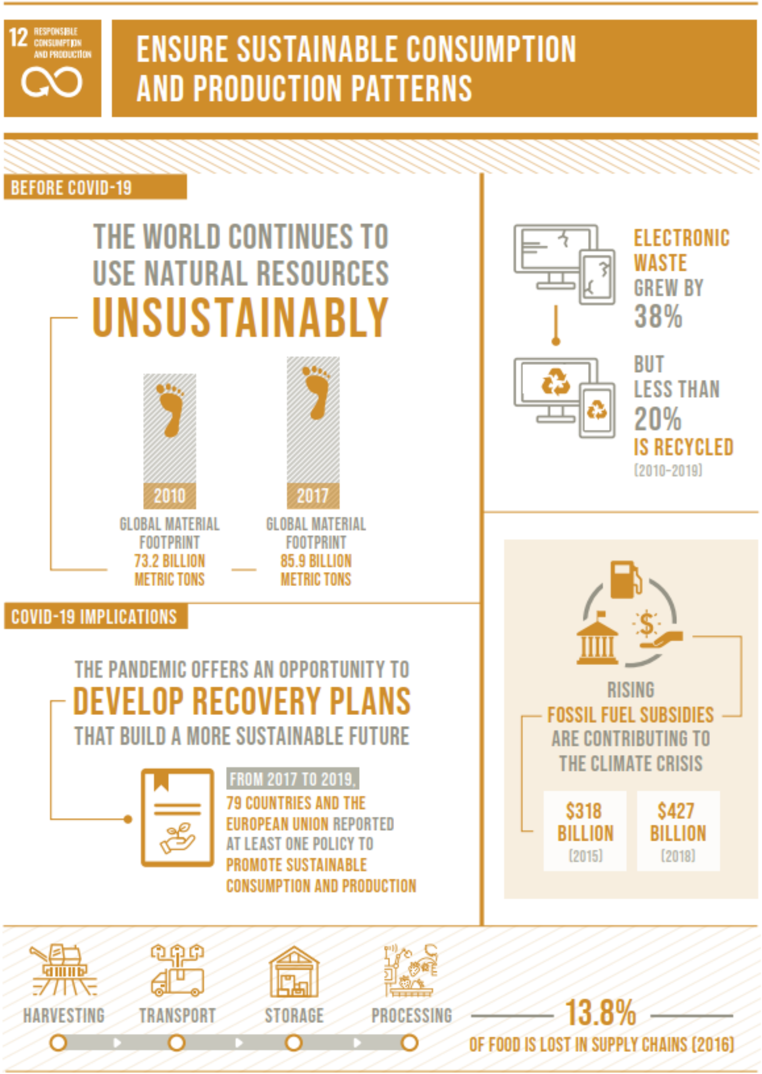
https://www.un.org/sustainabledevelopment/climate-change/



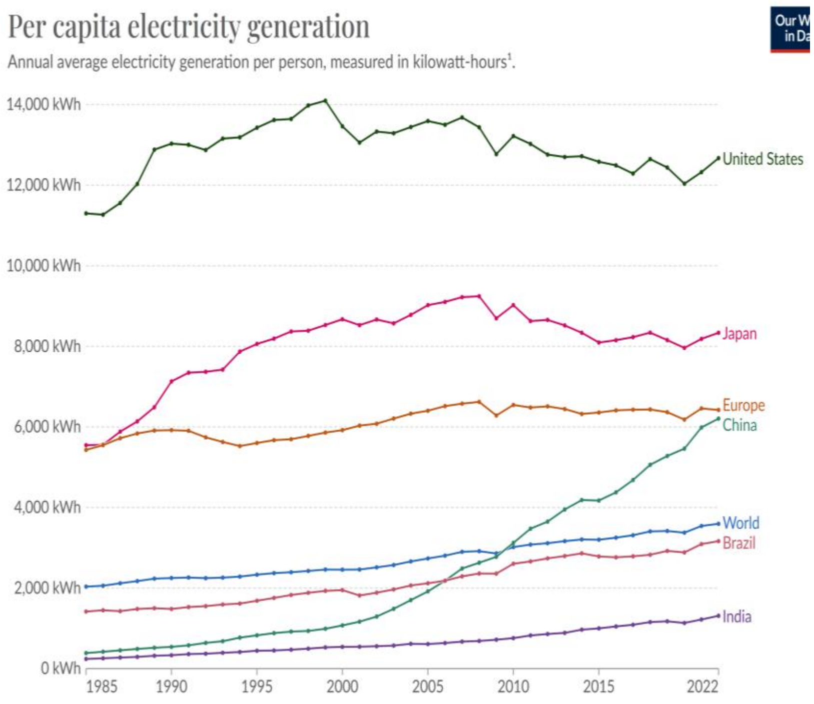
Responsible consumption and production

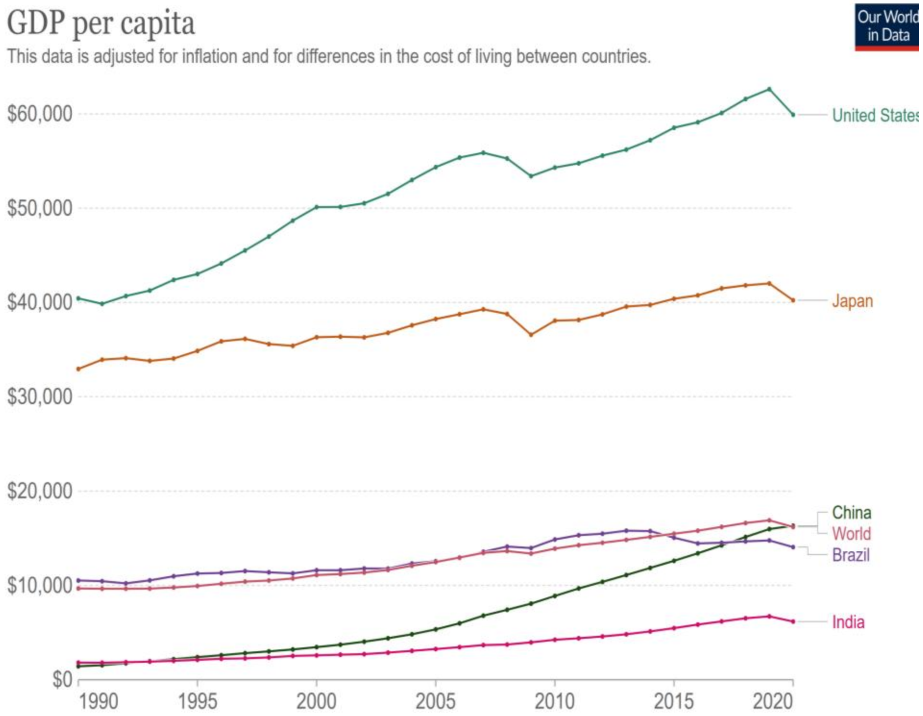
- Implement the 10-year framework of programs on **sustainable consumption and production**, all countries taking action, with developed countries taking the lead
- Achieve the sustainable management and **efficient use of natural resources**
- Support developing countries to strengthen their scientific and technological capacity to move towards more **sustainable patterns of consumption and production**
- Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions

https://www.un.org/sustainabledevelopment/sustainable-consumption-production/



Electricity consumption and GDP per capita





https://ourworldindata.org/grapher/per-capita-electricity-consumption?tab=chart&country=USA~IND~CHN~BRA~Europe~OWID_WRL~JPN
https://ourworldindata.org/grapher/gdp-per-capita-worldbank?tab=chart&time=earliest..2020&country=OWID_WRL~USA~JPN~BRA~CHN~IND~Euro+area

Christophe Ballif / Philippe Thalmann / Claudia Binder