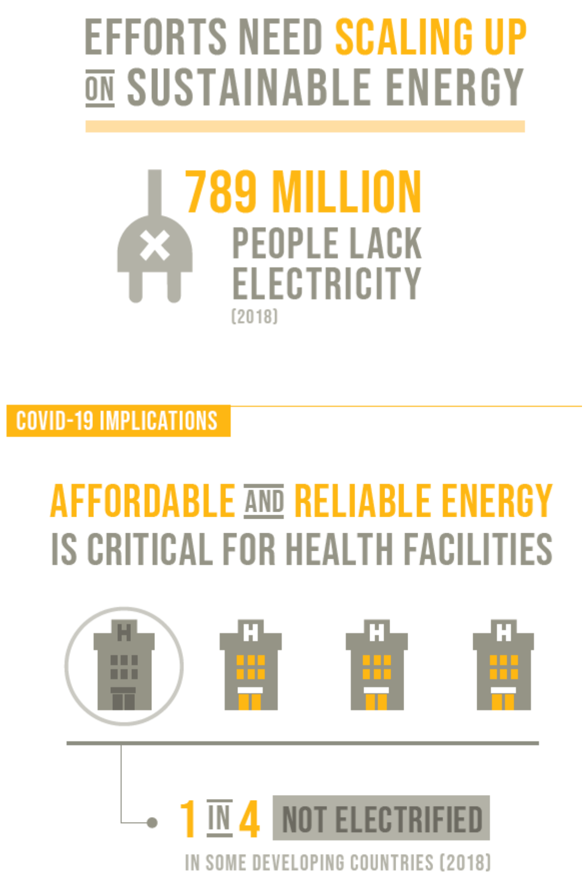
Energia e **Sustentabilidade:**
duas faces da mesma moeda?

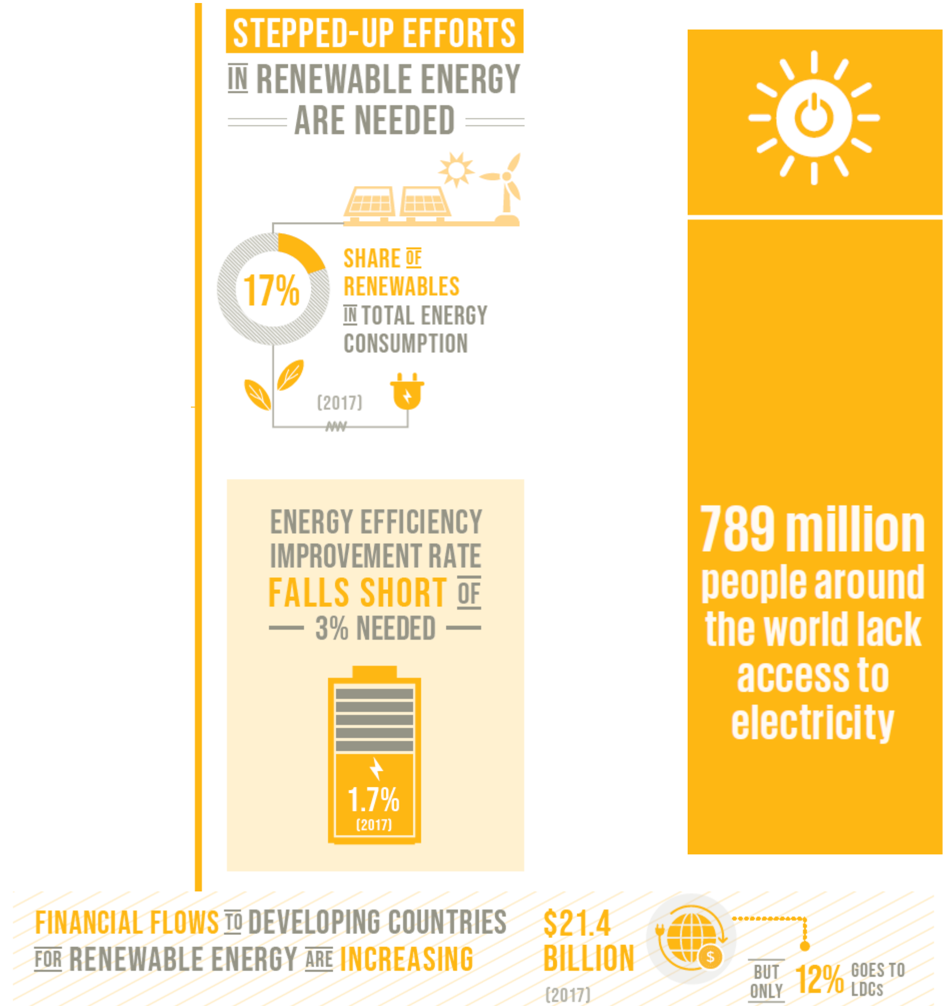
Energia e sustentabilidade

https://www.youtube.com/watch?v=LwjC073Y9oc

Energia e sustentabilidade

O progresso das sociedades está intrinsecamente associado à energia. O acesso a energia limpa e de baixo custo é um assunto crítico para a criação de melhores condições de vida!

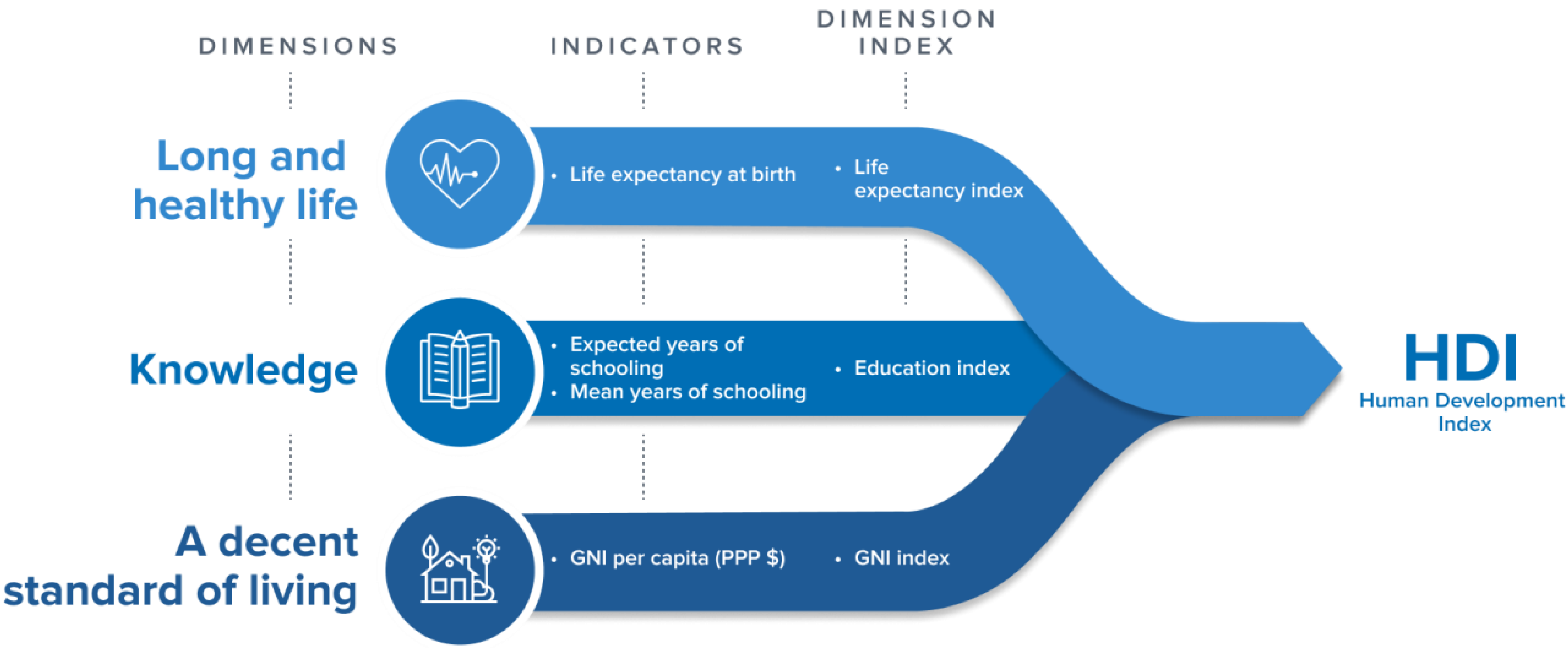




Fonte: https://www.un.org/sustainabledevelopment/energy/

Energia e sustentabilidade

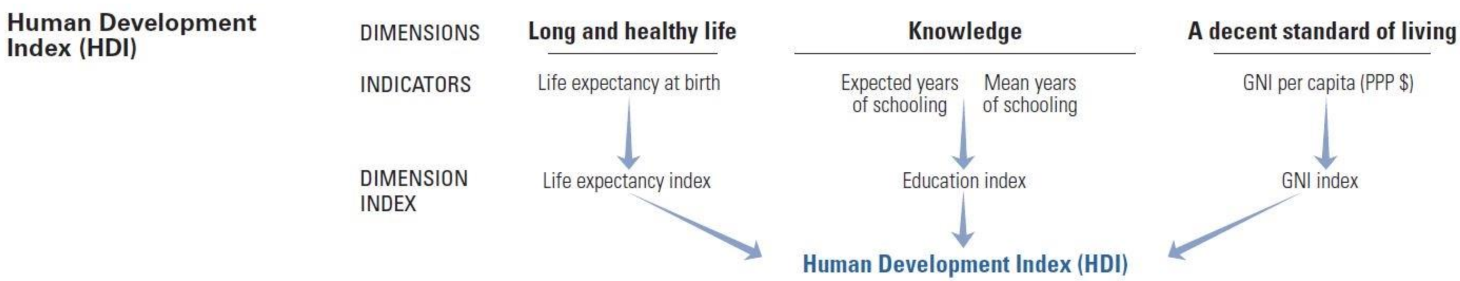
Human development Index (ONU)

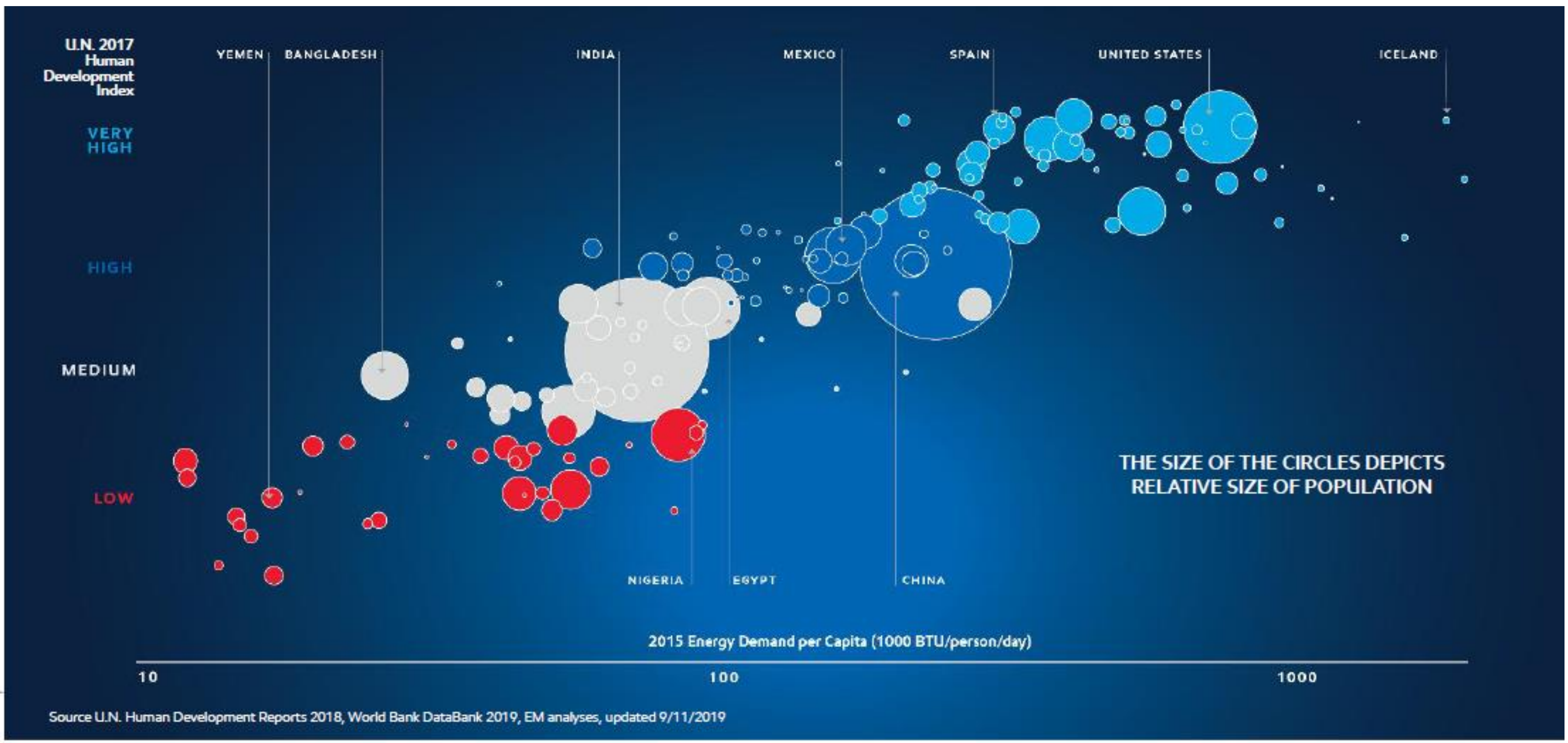


https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

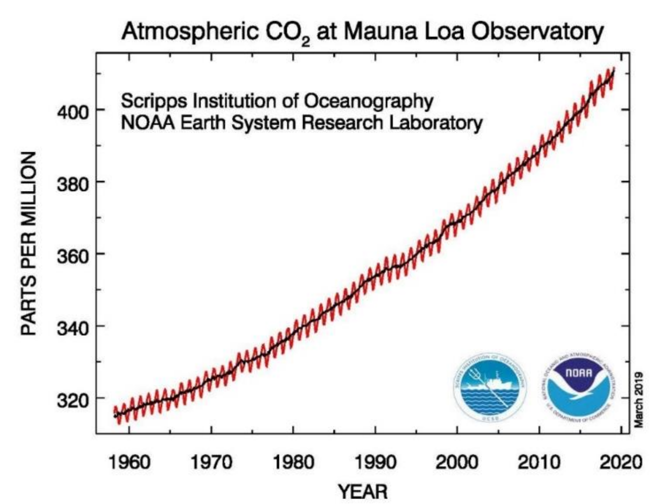
Energia e sustentabilidade

Human development Index (ONU)

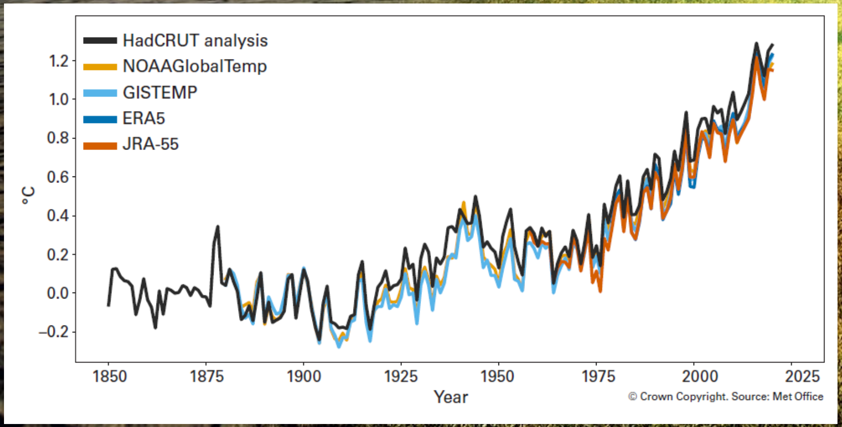




Where we are…

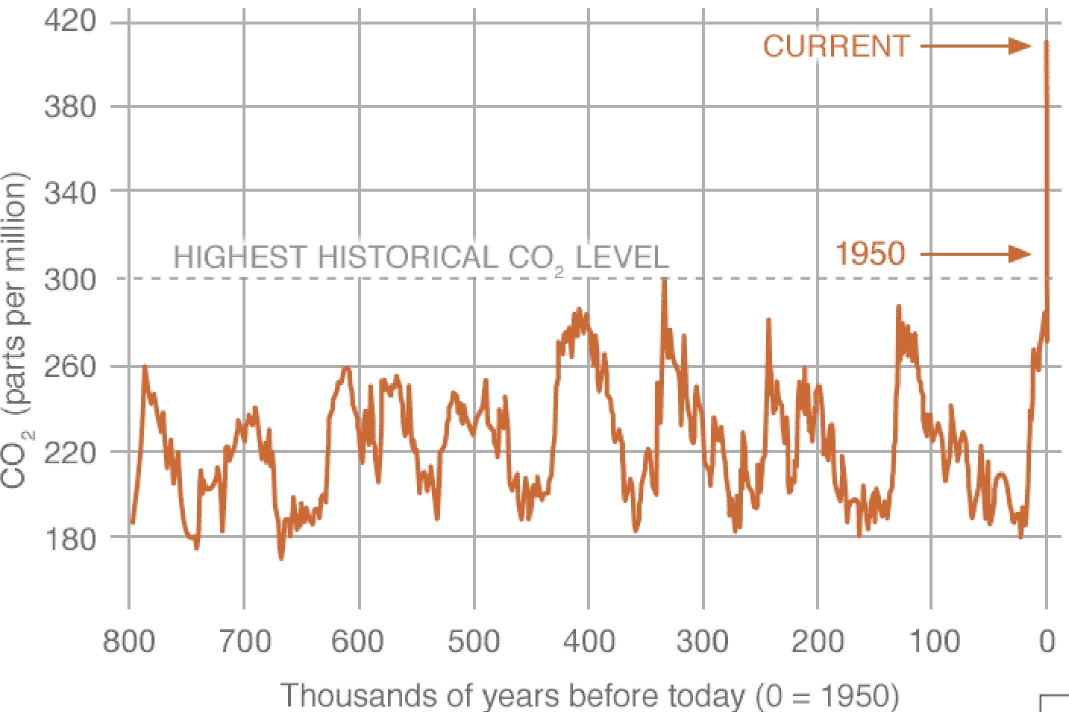


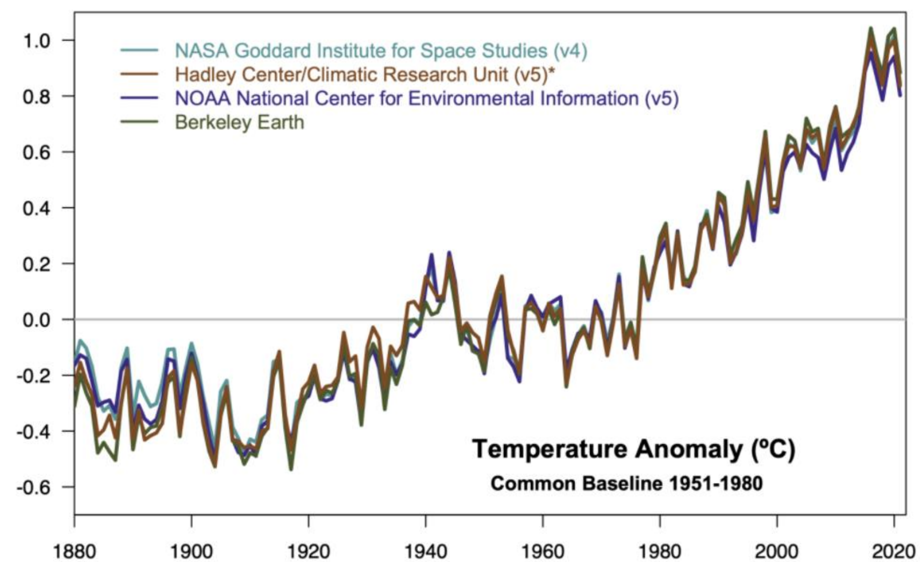
Retirado de: https://climate.nasa.gov/internal_resources/1914/



Fonte: "State of the global climate 2020", Organização Meteorológica Mundial.

Energia e sustentabilidade

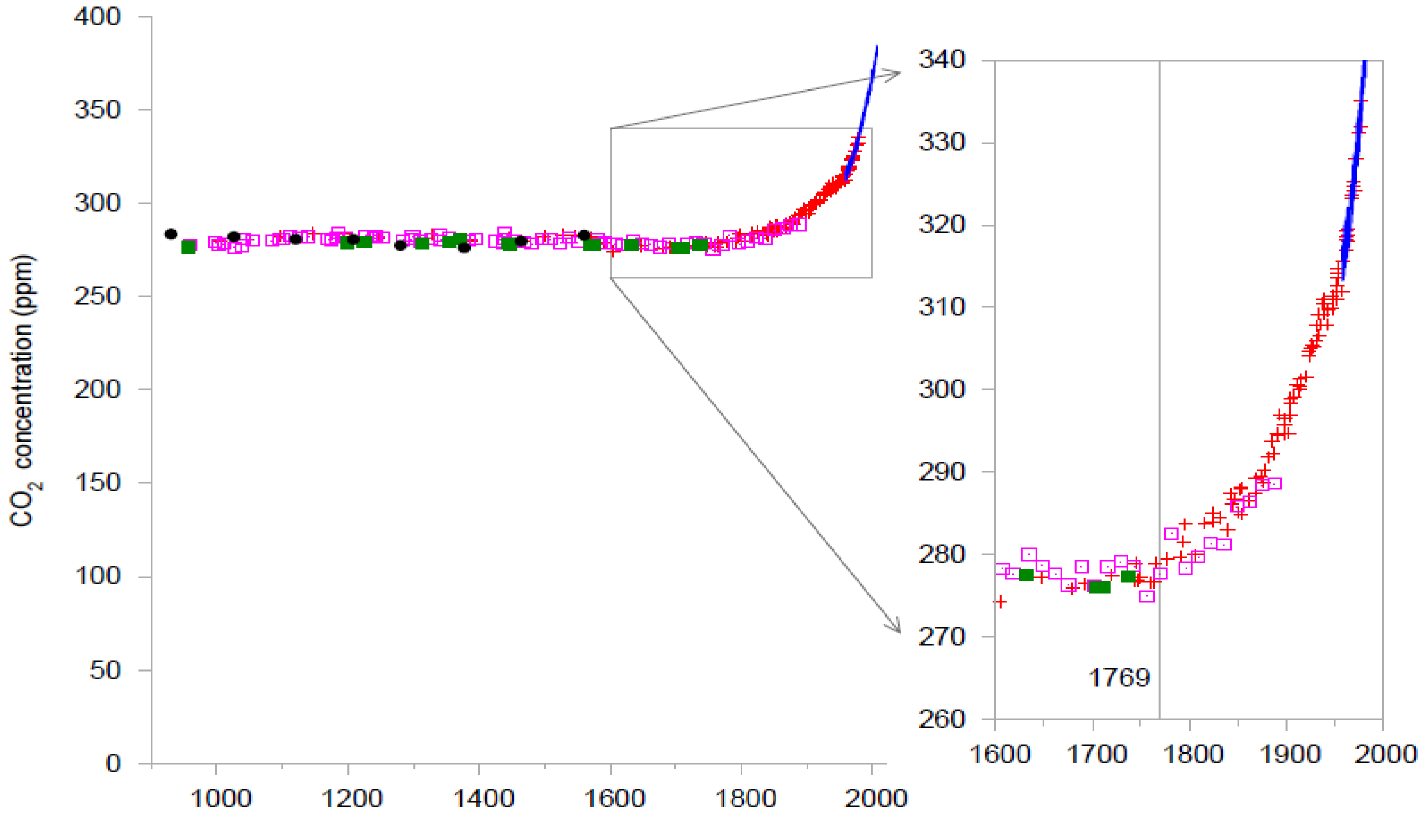




GLOBAL CLIMATE CHANGE
Vital Signs of the Planet

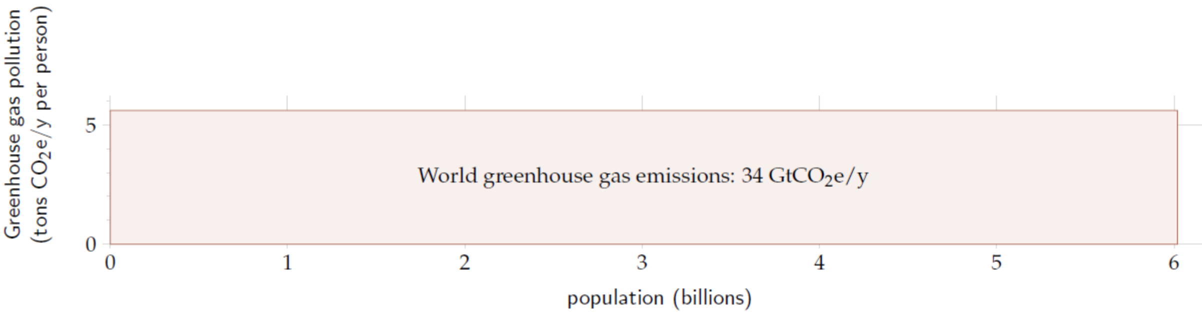
Energia e sustentabilidade

Carbon dioxide (CO_2) concentrations (in parts per million) for the last 1100 years, measured from air trapped in ice cores (up to 1977) and directly in Hawaii (from 1958 onwards).



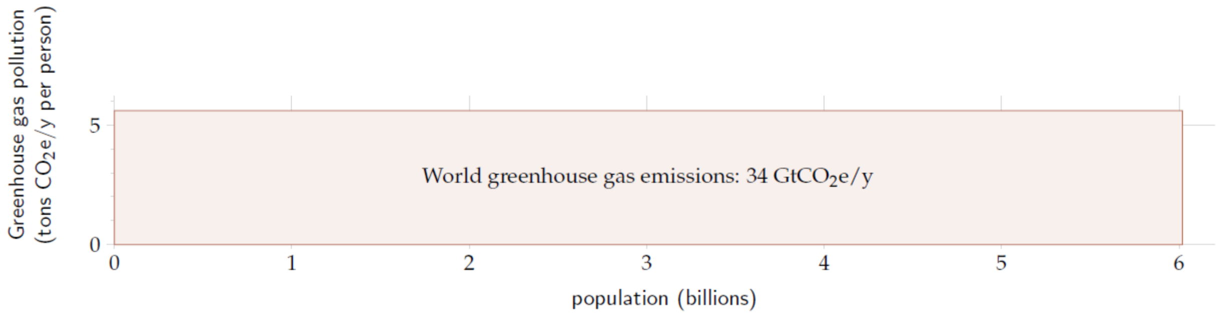
Energia e sustentabilidade

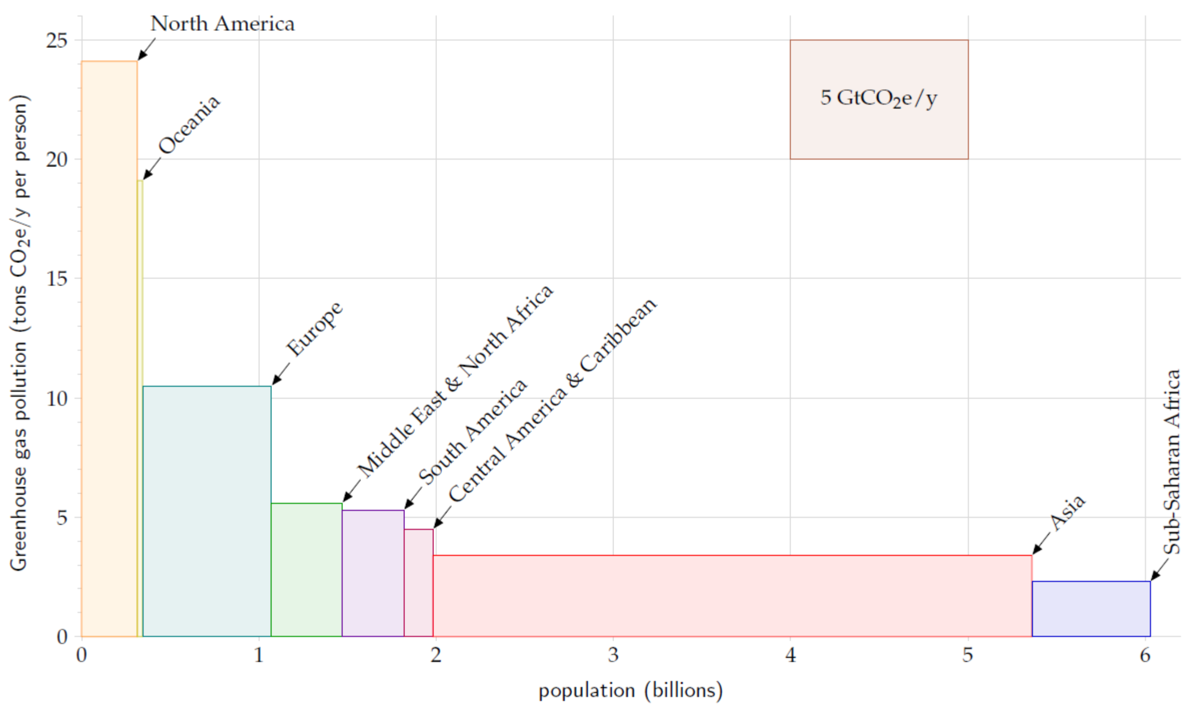
Emissões de CO_2



Energia e sustentabilidade

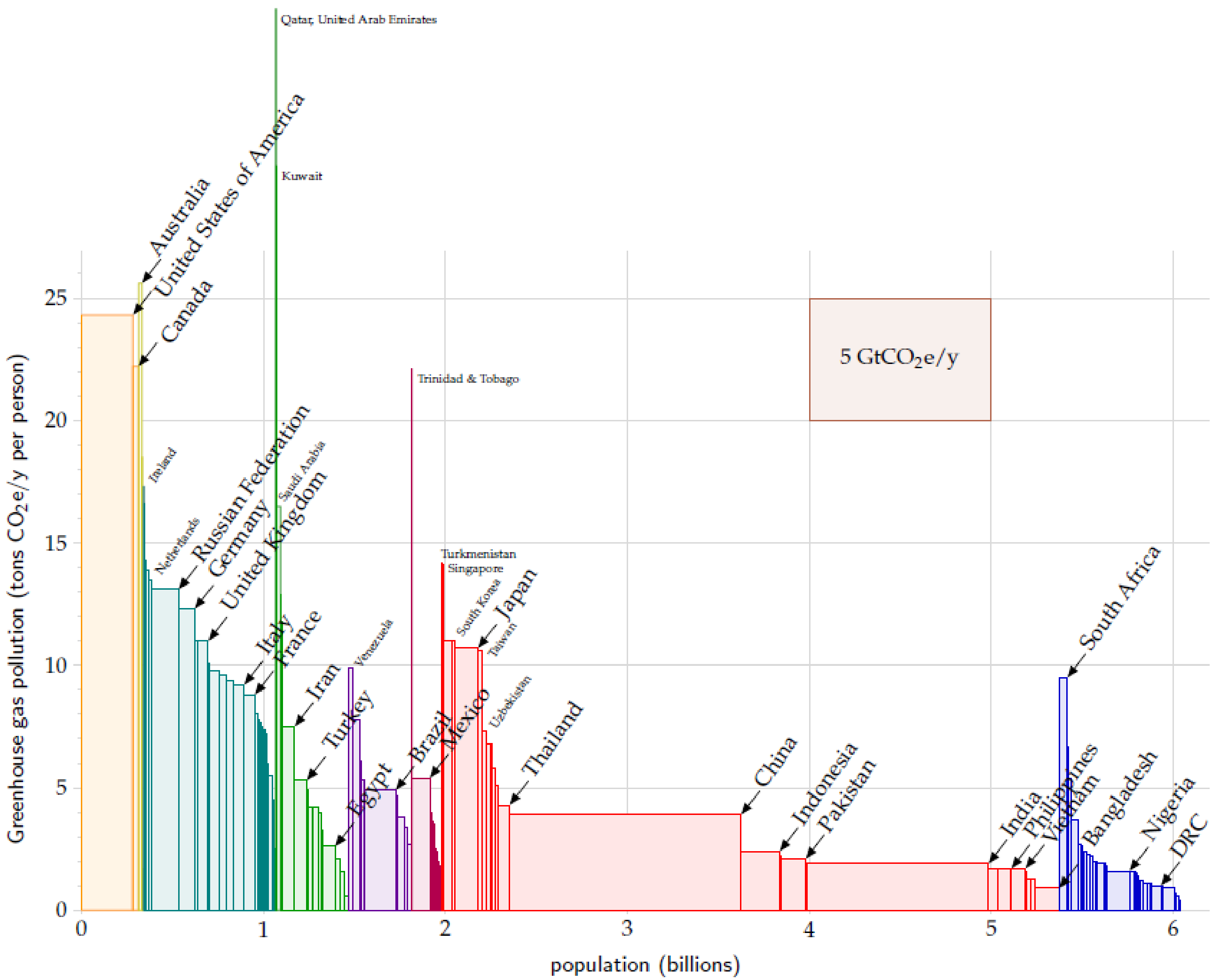
Emissões de CO_2





Energia e sustentabilidade

Emissões de CO_2



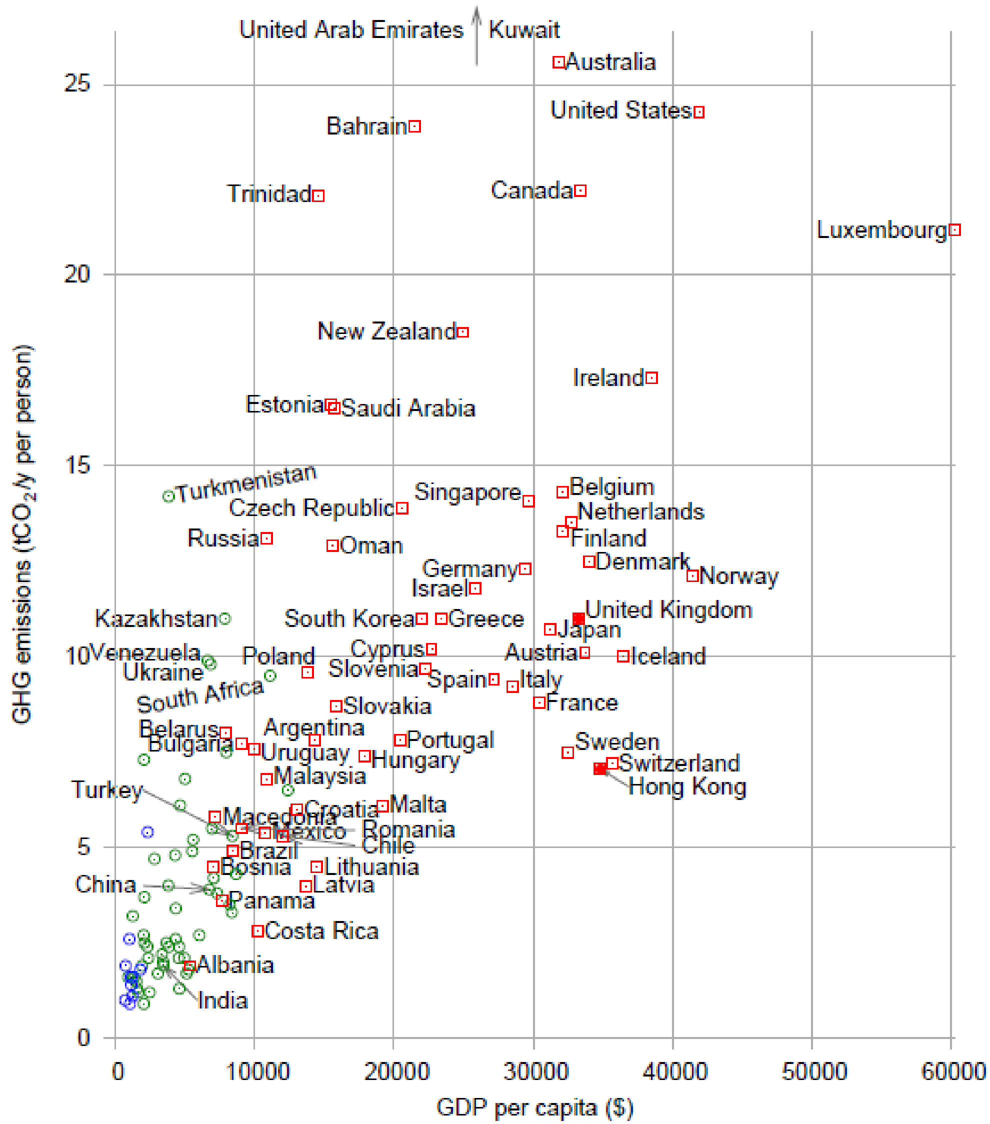
Energia e sustentabilidade

Emissões de CO_2

So, assuming that "something needs to be done" to reduce greenhouse gas emissions, who has a special responsibility to do something?

Energia e sustentabilidade

Emissões de CO_2



Energia e sustentabilidade

Emissões de CO_2 por atividade/setor

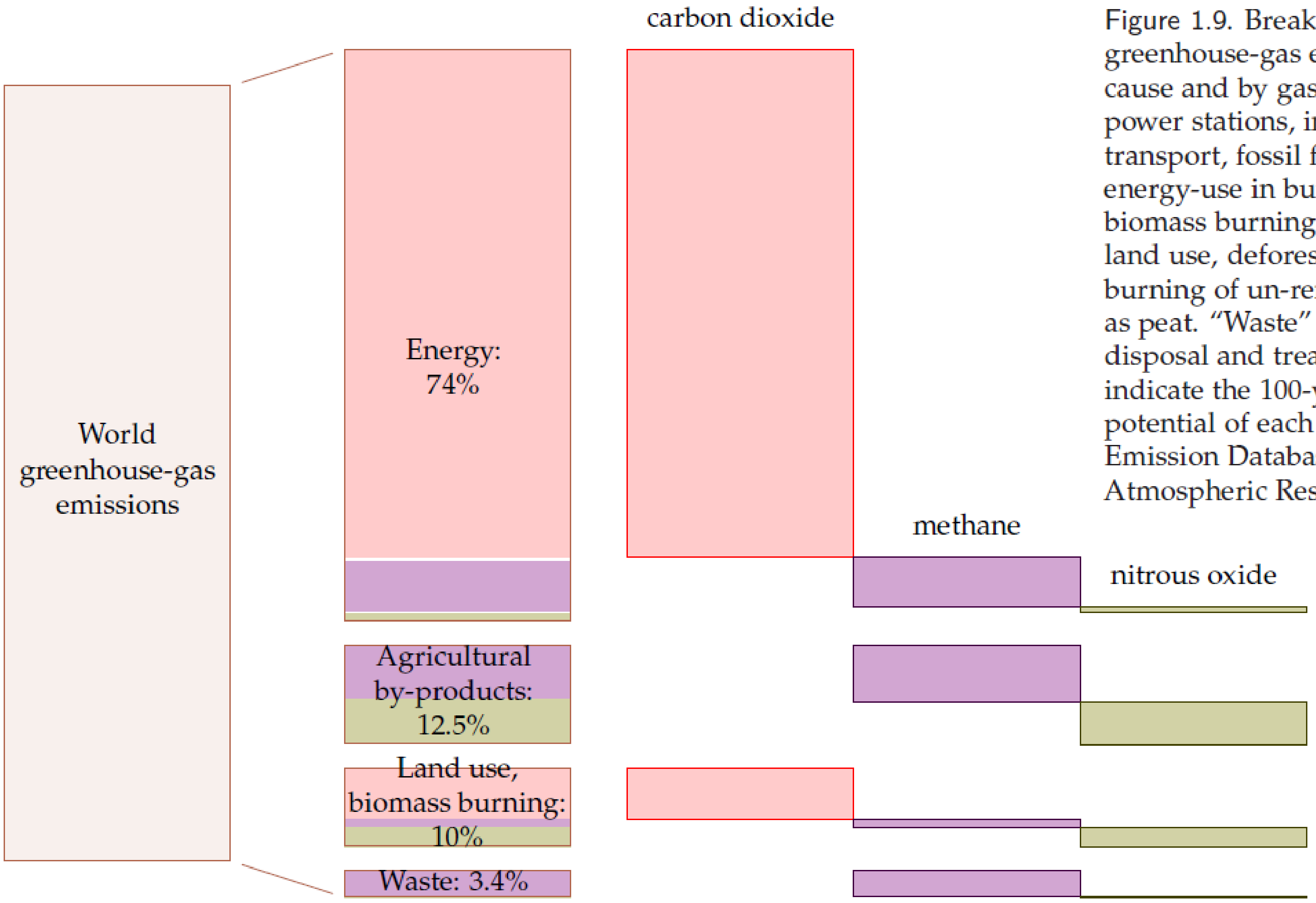
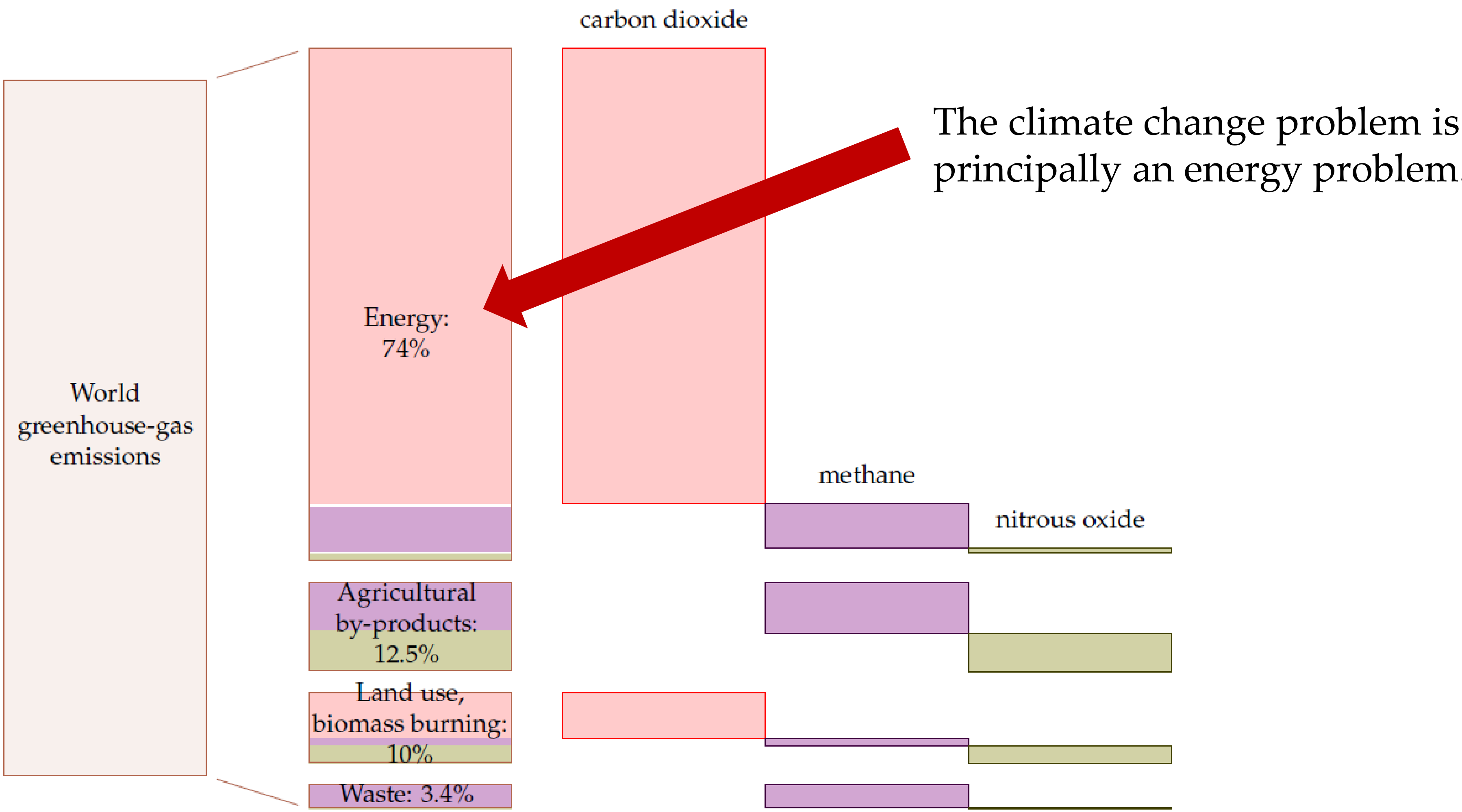


Figure 1.9. Breakdown of world greenhouse-gas emissions (2000) by cause and by gas. "Energy" includes power stations, industrial processes, transport, fossil fuel processing, and energy-use in buildings. "Land use, biomass burning" means changes in land use, deforestation, and the burning of un-renewed biomass such as peat. "Waste" includes waste disposal and treatment. The sizes indicate the 100-year global warming potential of each source. Source: Emission Database for Global Atmospheric Research.

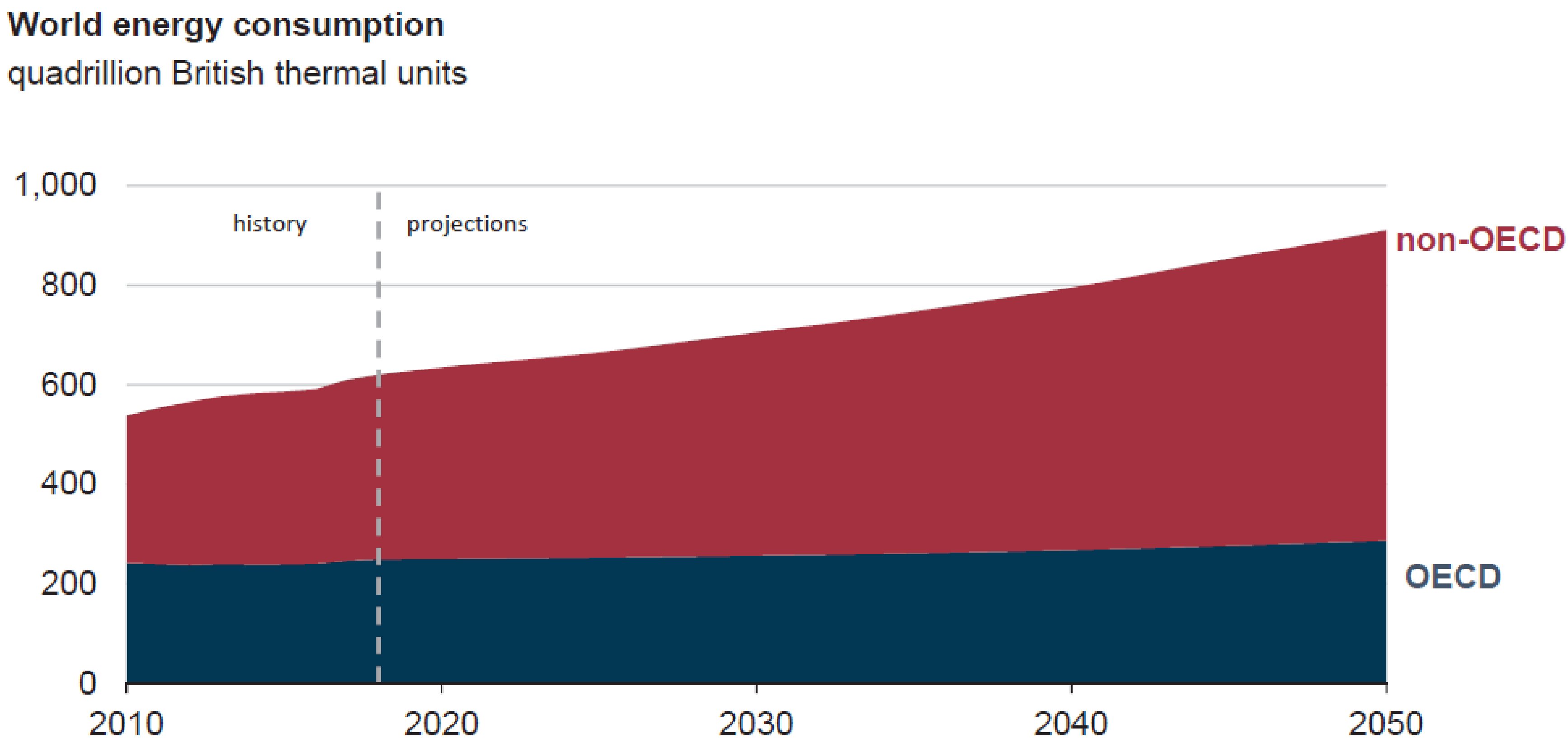
Energia e sustentabilidade

Emissões de CO_2 por atividade/setor



Energia e sustentabilidade

Estima-se que o consumo de energia aumente 50% entre 2018 e 2050!!



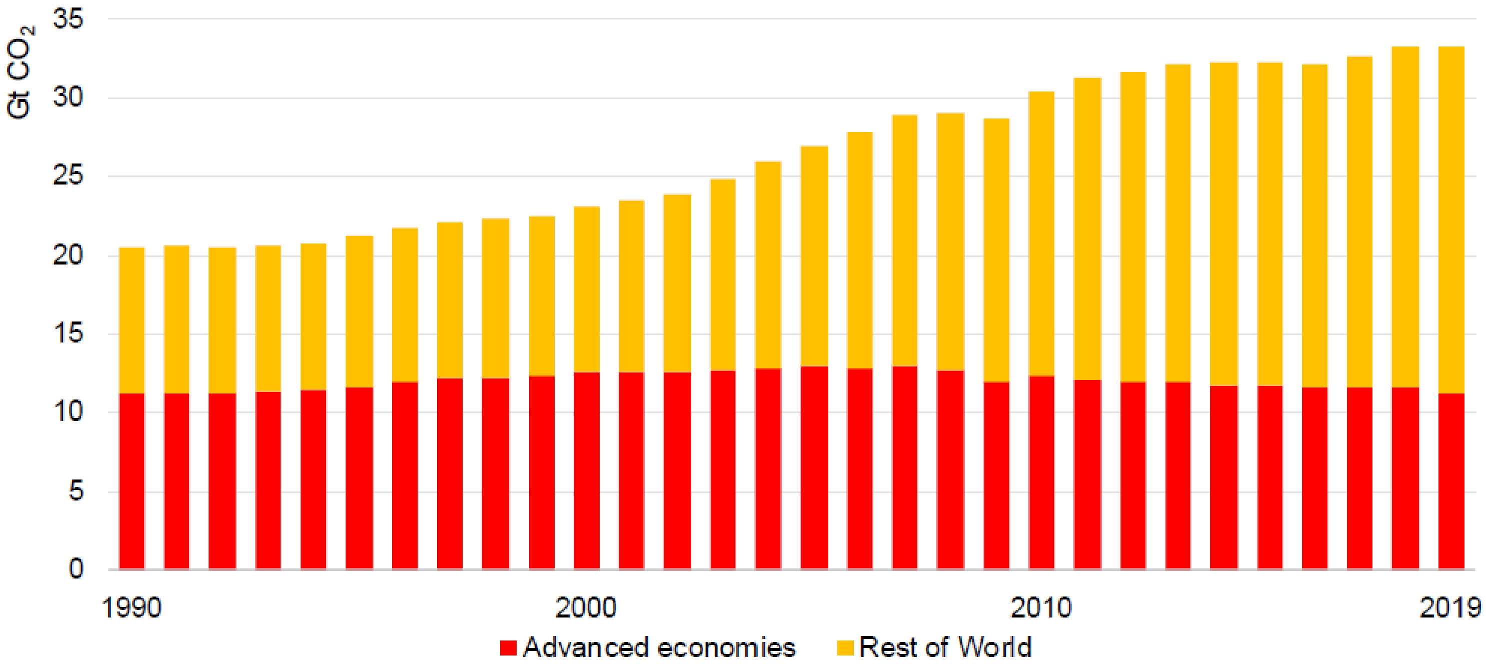
Nota: 1 BTU ~ 1055 J

Fonte: "International Energy Outlook 2019", US Energy Information Administration (2019).

Energia e sustentabilidade

Emissões de CO_2 associadas à produção de energia

Energy-related CO_2 emissions, 1990-2019



Global CO_2 emissions flattened in 2019 at around 33.2 Gt, after two years of increases. Lower coal-fired generation in advanced economies and rising output from lower-carbon sources underpinned the decline.

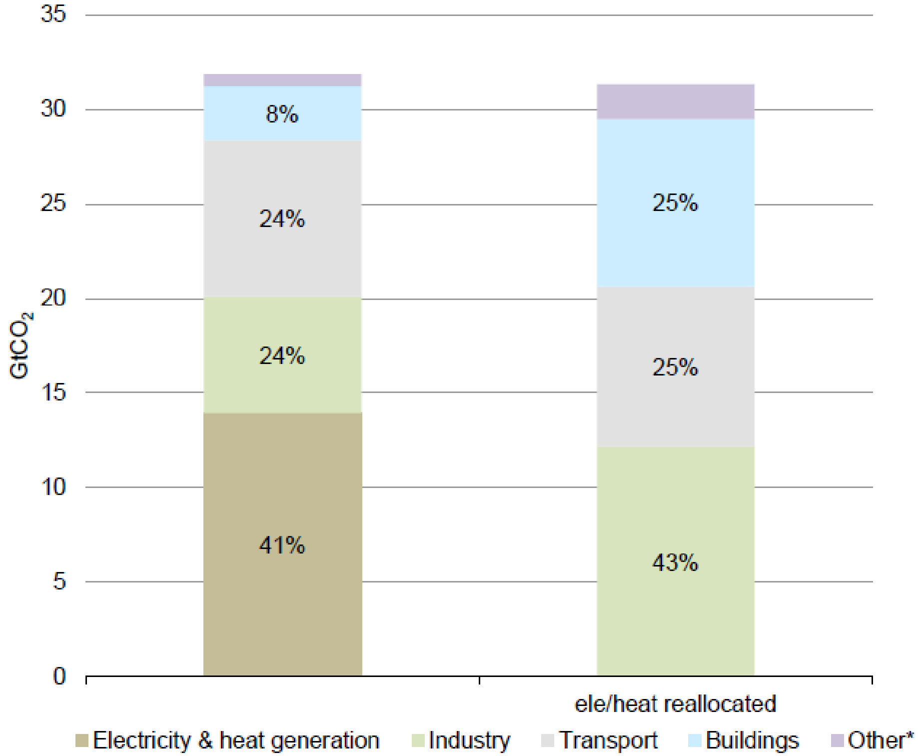
Fonte: "Global Energy Review 2019", IEA (2019).

Energia e sustentabilidade

- Para lá daquilo que o consumo de energia representa em termos de utilização das reservas fósseis não renováveis, a face menos visível e com mais impacto ambiental do consumo de energia, tem a ver com as emissões de carbono.
- A maioria destas emissões são geradas durante a queima de carvão e gás para produção de eletricidade nas centrais termoelétricas, no setor dos transportes e no setor industrial.

Energia e sustentabilidade

Emissões de CO_2 geradas pelas combustão de combustível -por setor de atividade



* Other includes agriculture/forestry, fishing and non-specified final energy consumption.

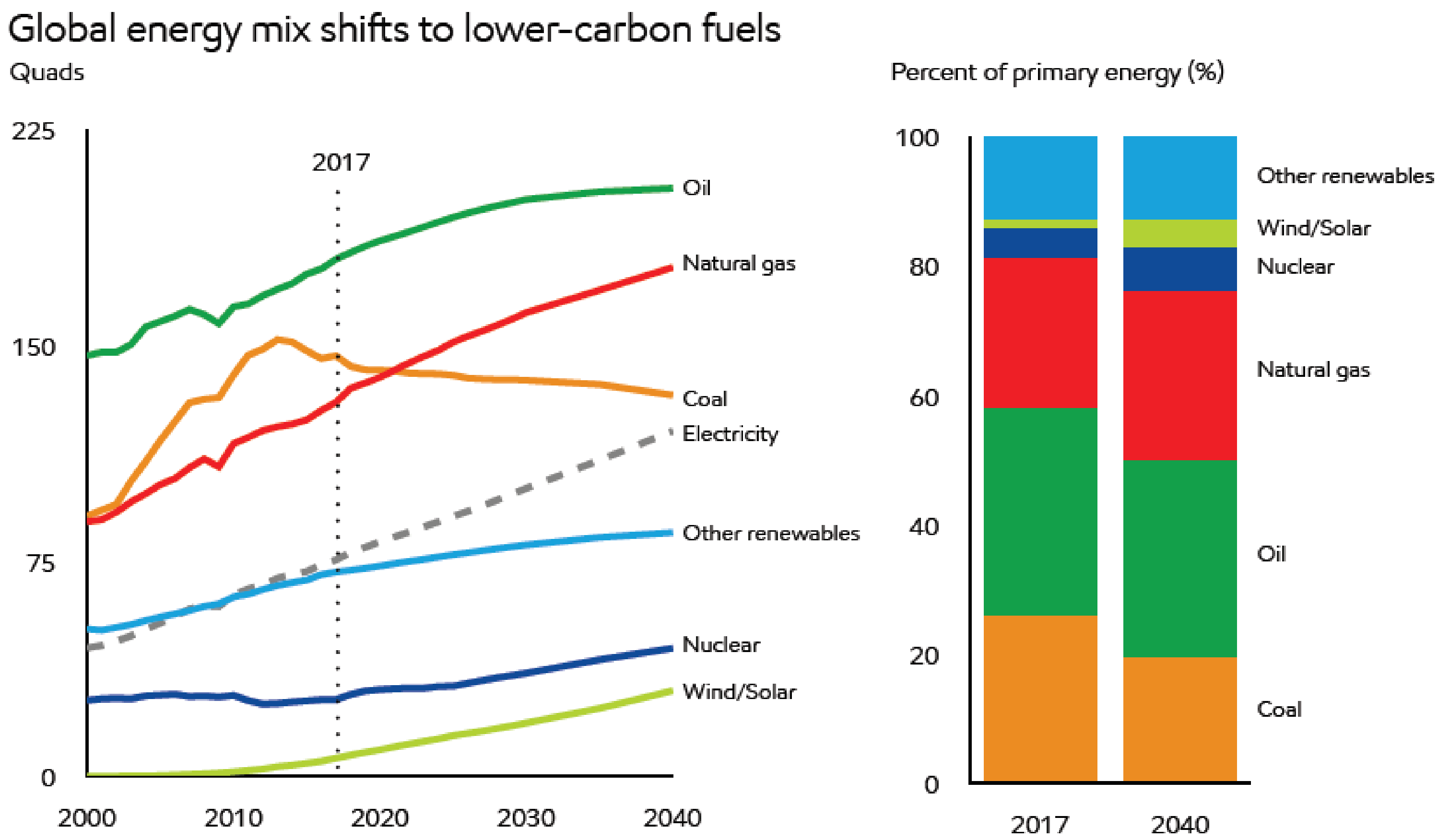
Power generation, together with transport, accounted for over two thirds of total emissions in 2018; industry was the largest final emitting sector.

Fonte: "CO_2 emissions from fuel combustion" IEA (2020)

Energia e sustentabilidade

Consumo mundial de energia por recurso

2017



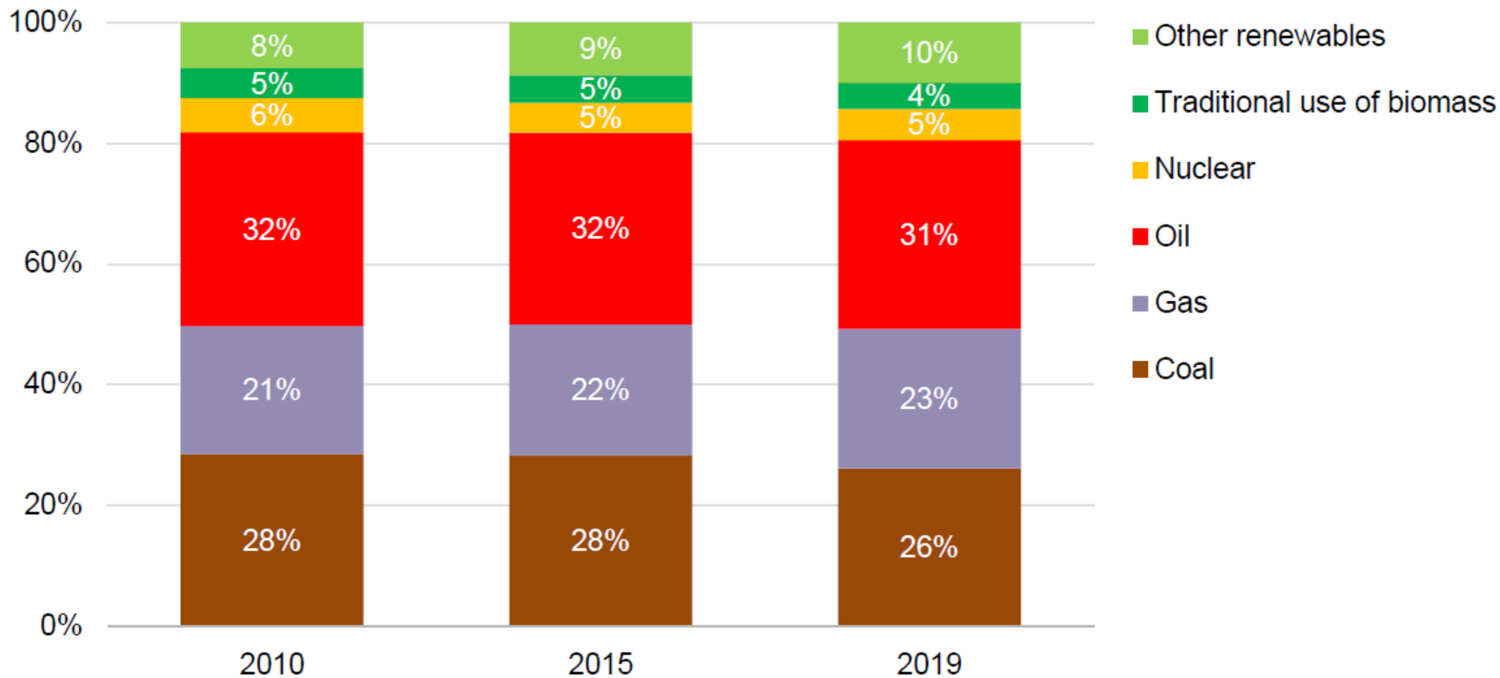
Nota: 1 Quad = 1,055 x 10^{18} J

Fonte: "2019 Outlook for energy: a perspective to 2040",Exxonmobile (2019).

Energia e sustentabilidade

Variação na procura de energia por tipologia

Share of total primary energy demand by fuel, 2010-19

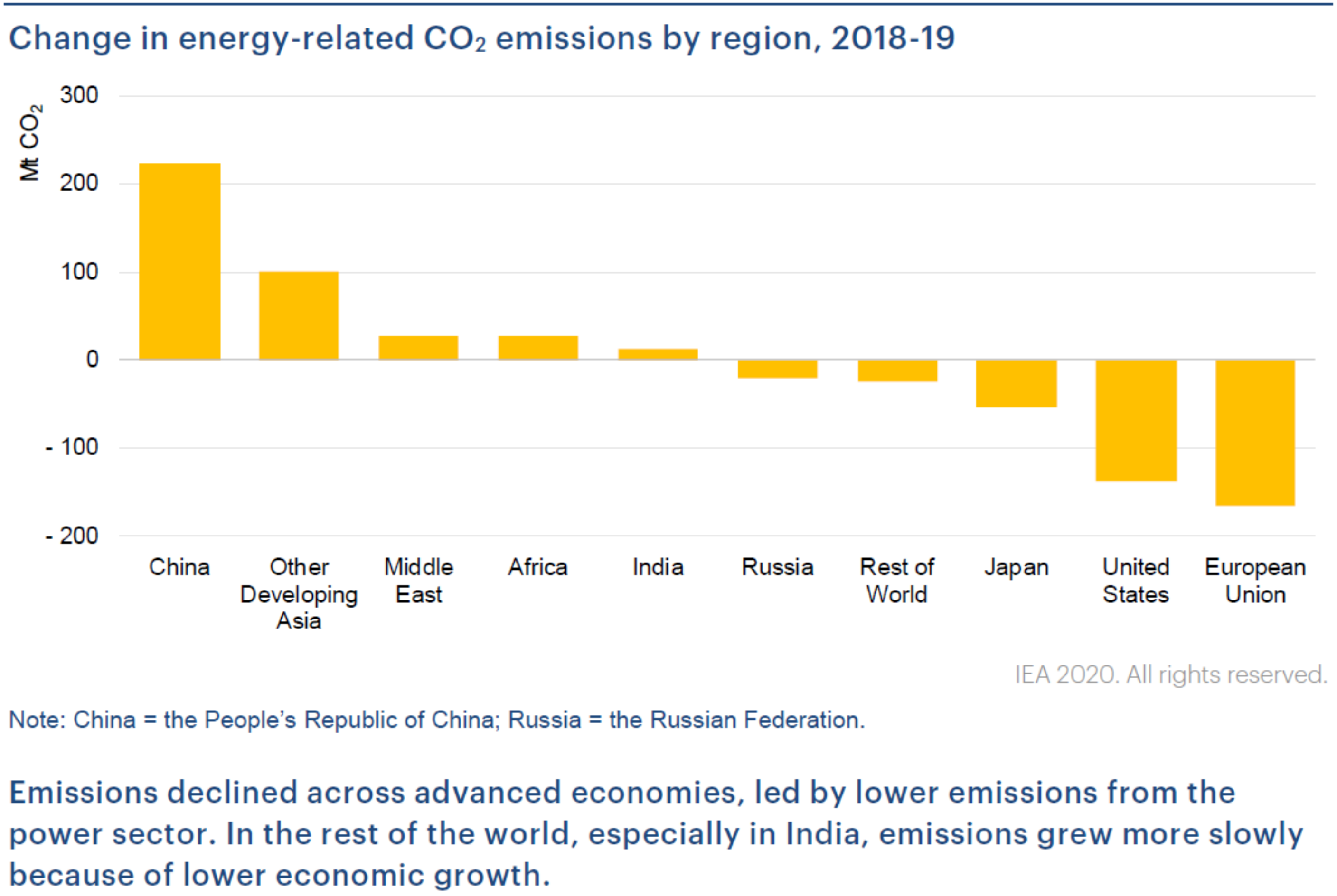


The share of natural gas in total primary energy demand continued to increase, reaching 23%, while modern renewables passed 10% in 2019.

Fonte: "Global Energy Review 2019", IEA (2019).

Energia e sustentabilidade

Emissões de CO_2 associadas à produção de energia

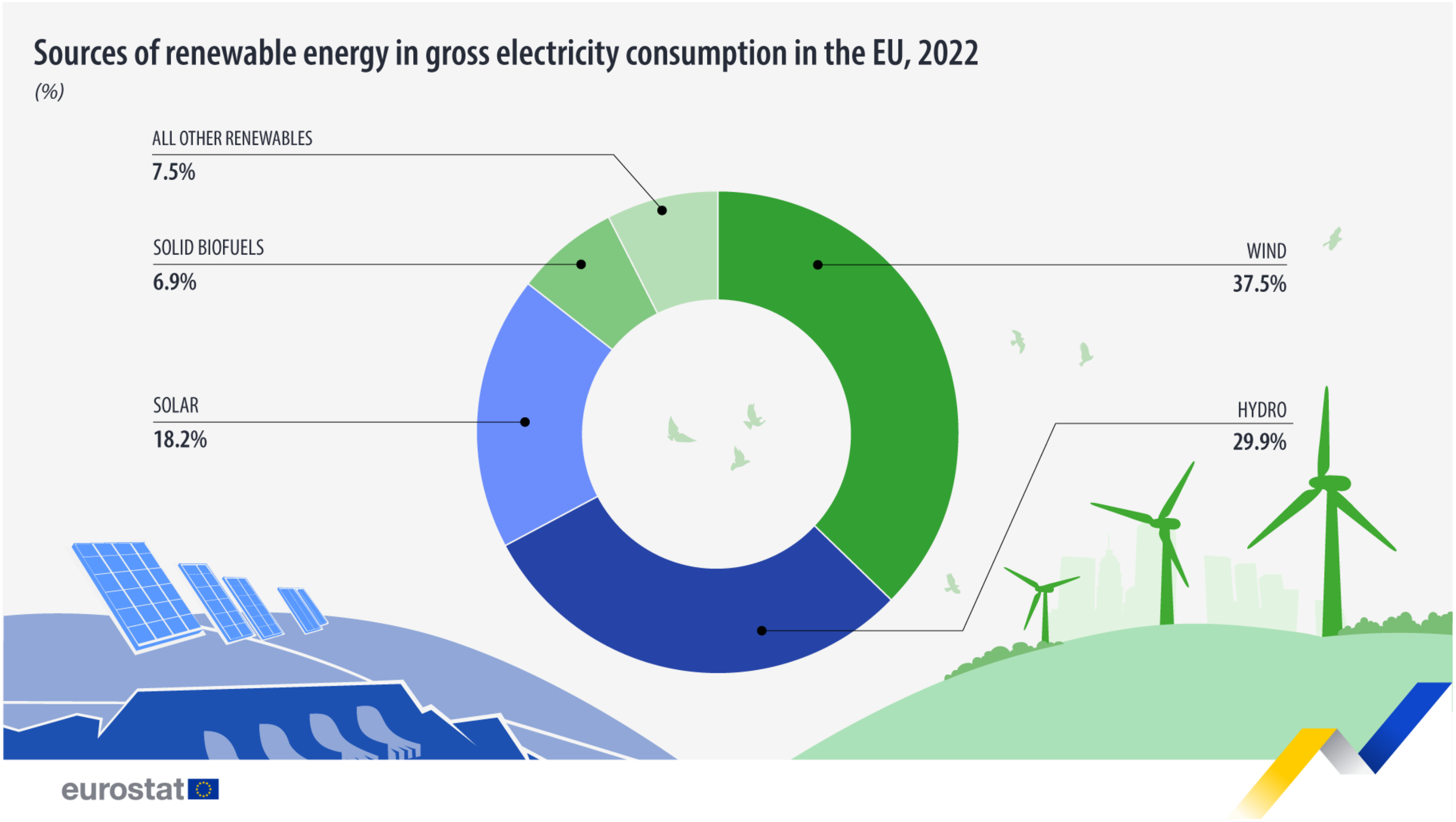


Fonte: "Global Energy Review 2019", IEA (2019).

Energia e sustentabilidade

Renewable sources generating eletricity in the EU

2022

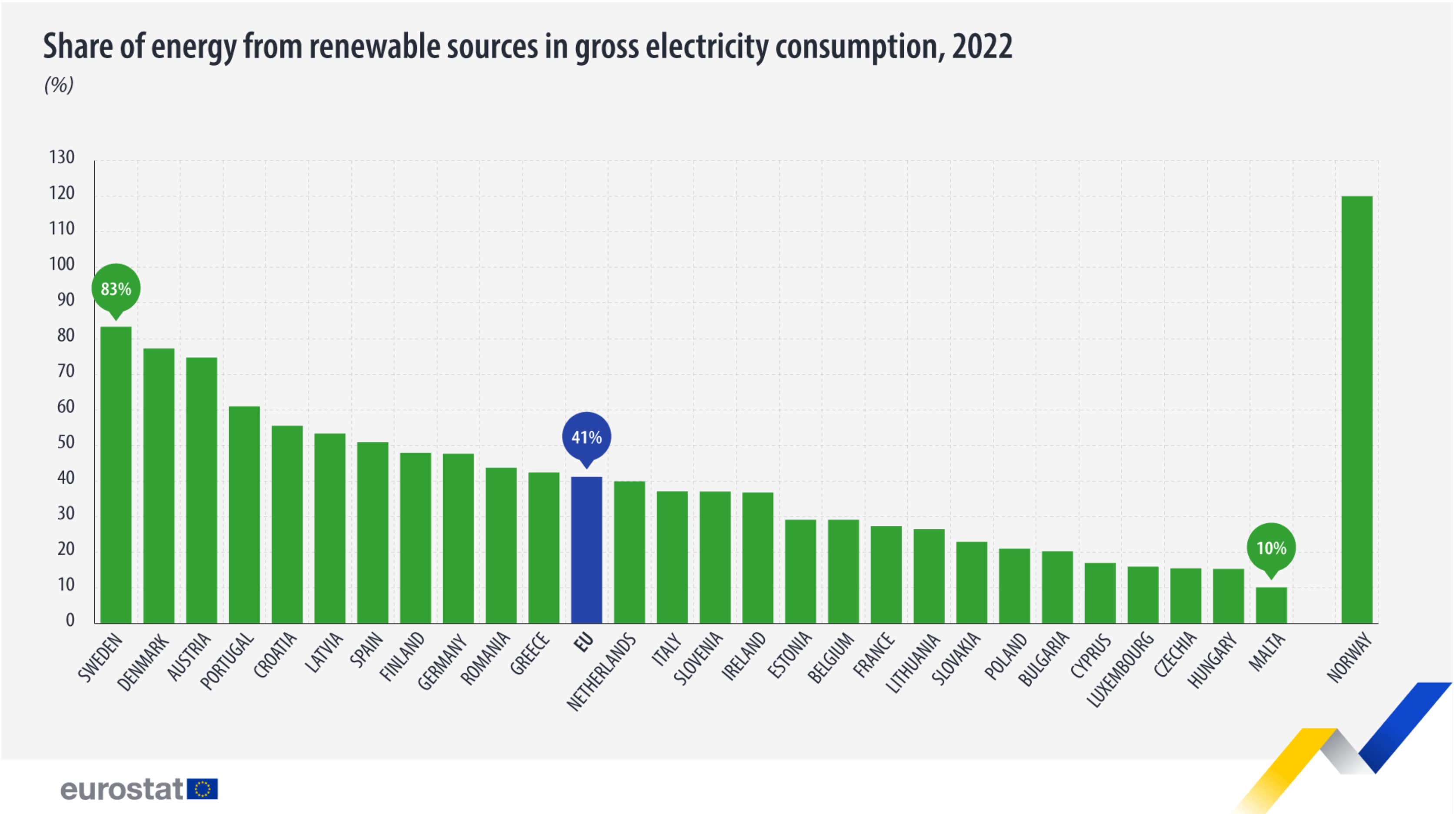


Fonte: https://ec.europa.eu/eurostat/en/web/products-eurostat-news/w/ddn-20240221-1

Energia e sustentabilidade

Electricity from renewable sources

2022



Fonte: https://ec.europa.eu/eurostat/en/web/products-eurostat-news/w/ddn-20240221-1

Context in Portugal

Key energy statistics, 2020

All statistics

Energy production
TJ

254.5574
↑ 79.35% from 1990

Total primary energy supply
Mtoe

20.14
↑ 20.02% from 1990

Electricity final consumption
TWh

50.03
↑ 98.45% from 1990

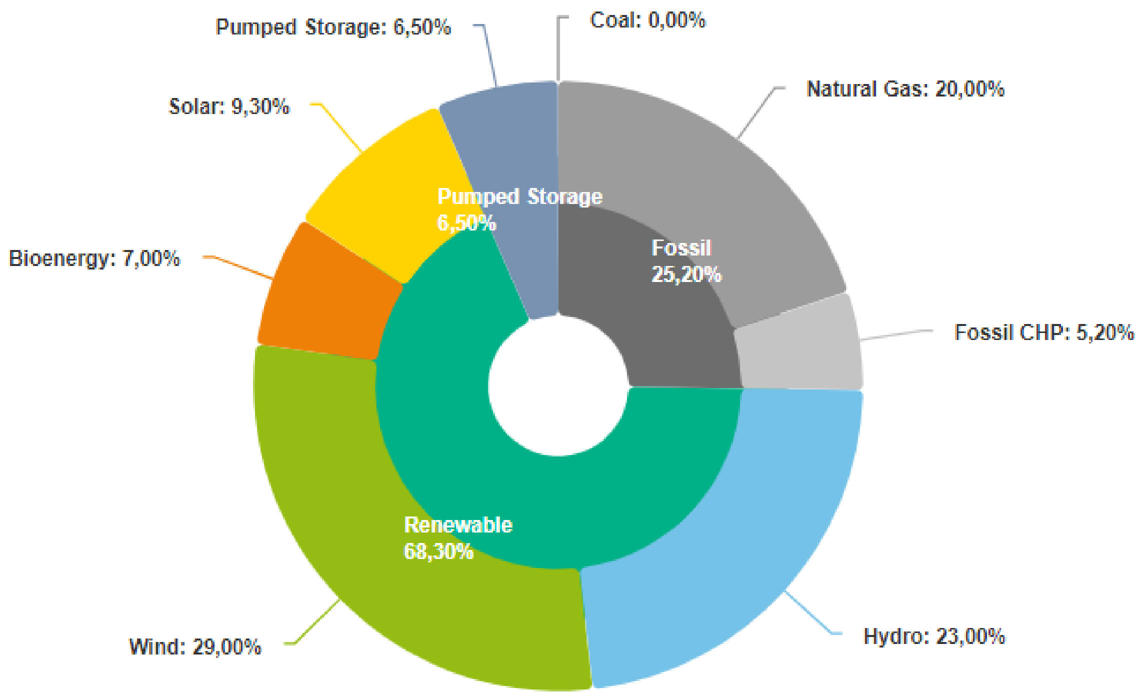
Total CO2 emissions
Mt of CO2

36.66
↓ -3.25% from 1990

Source: International Energy Agency (https://www.iea.org/countries/portugal)

Context in Portugal

Electricity Generation by Energy Sources in Mainland Portugal (in 2023)

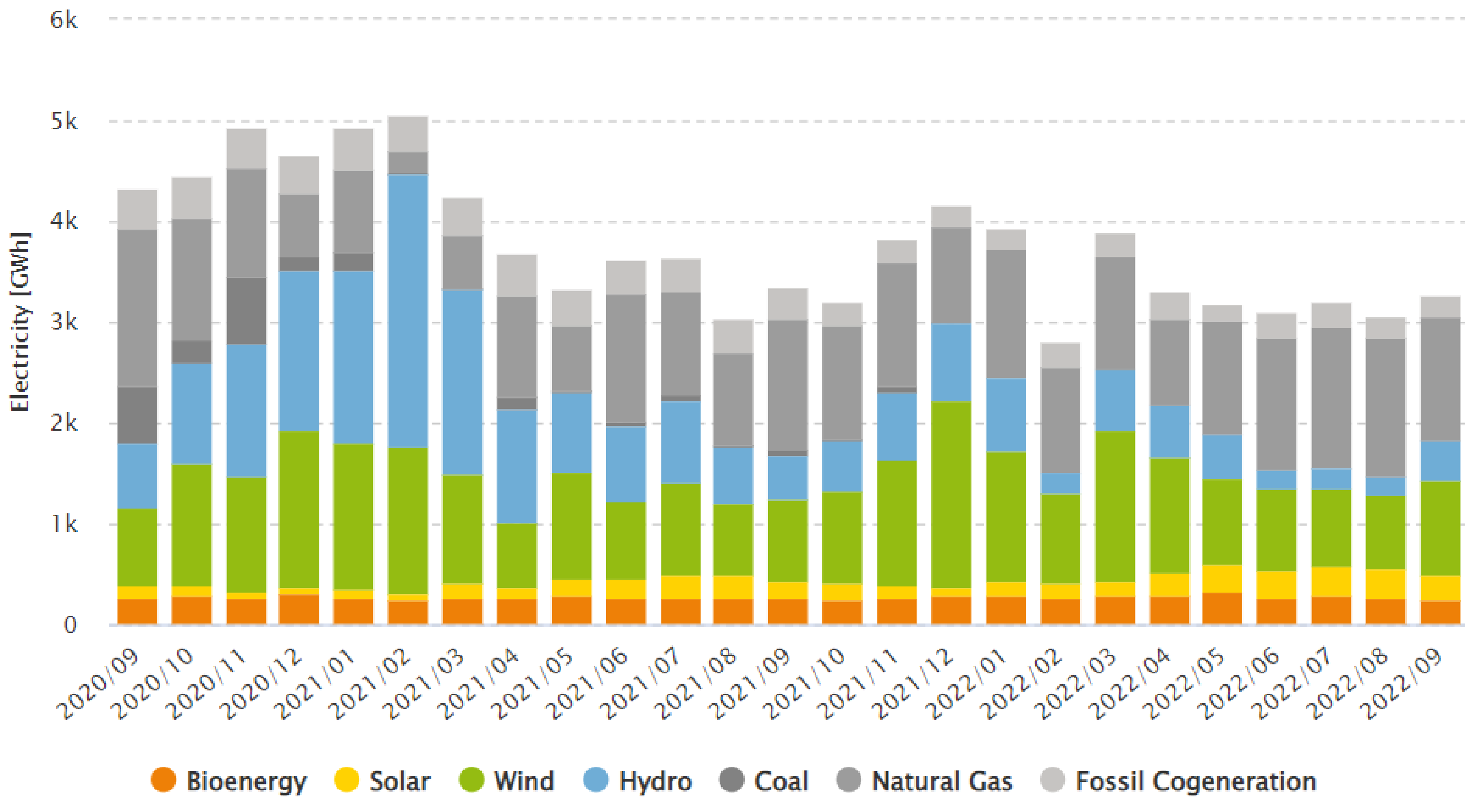


Between January 1 and August 31, 2023, **28,316 GWh of electricity** were generated in Continental Portugal, from which **68.2 % came from renewable sources**.

Source: APREN - Associação de energias renováveis (disponível em: https://www.apren.pt/en/renewable-energies/production))

Context in Portugal

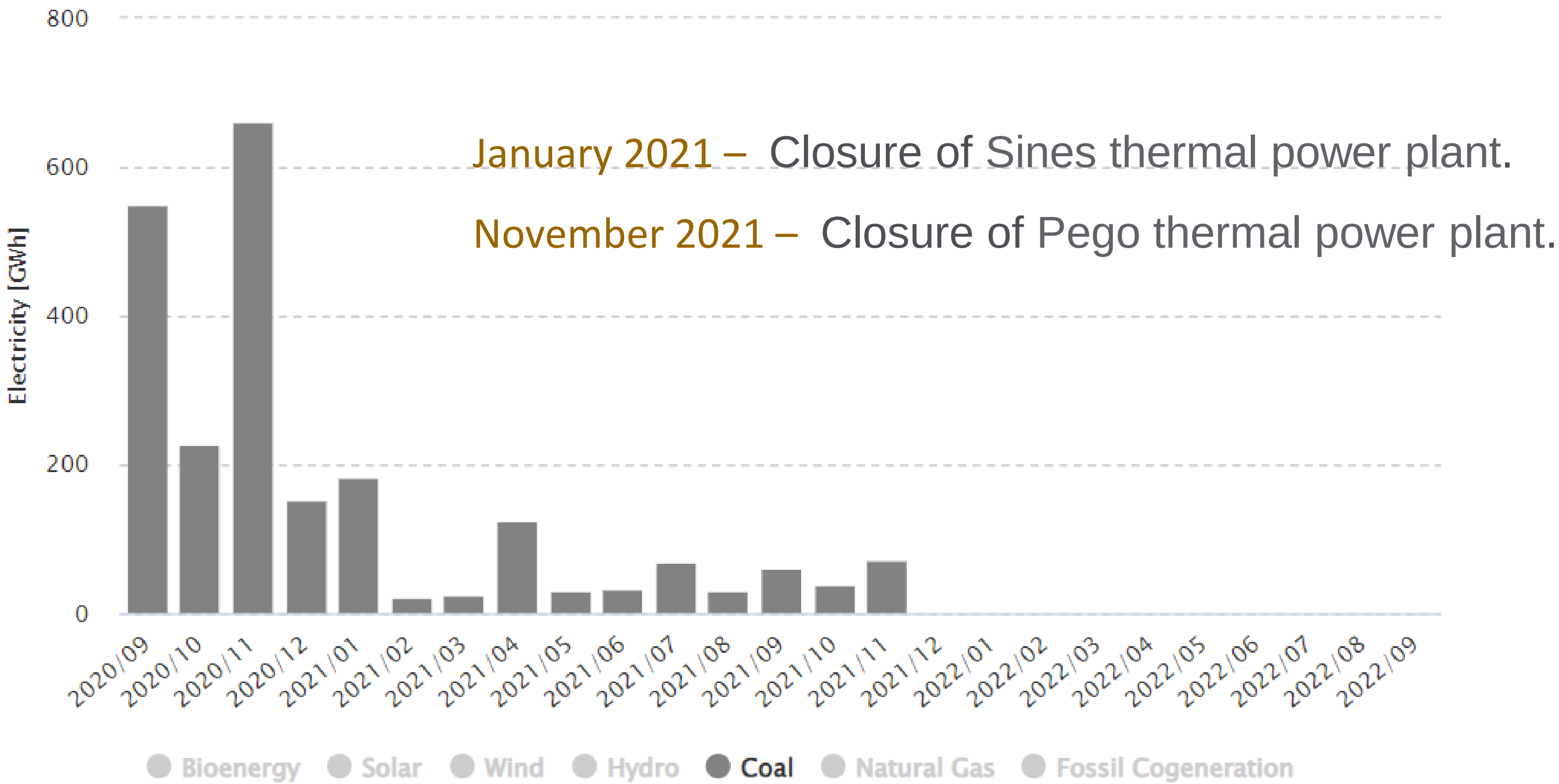
Distribution of the electricity generation by source
(September 2020 to September 2022)



Source: APREN - Associação de energias renováveis (disponível em: https://www.apren.pt/en/renewable-energies/production))

Context in Portugal

Distribution of the electricity generation – coal
(September 2020 to September 2022)



Source: APREN - Associação de energias renováveis (disponível em: https://www.apren.pt/en/renewable-energies/production))

Context in Portugal

Why did Portugal decided to shut down its coal plants?

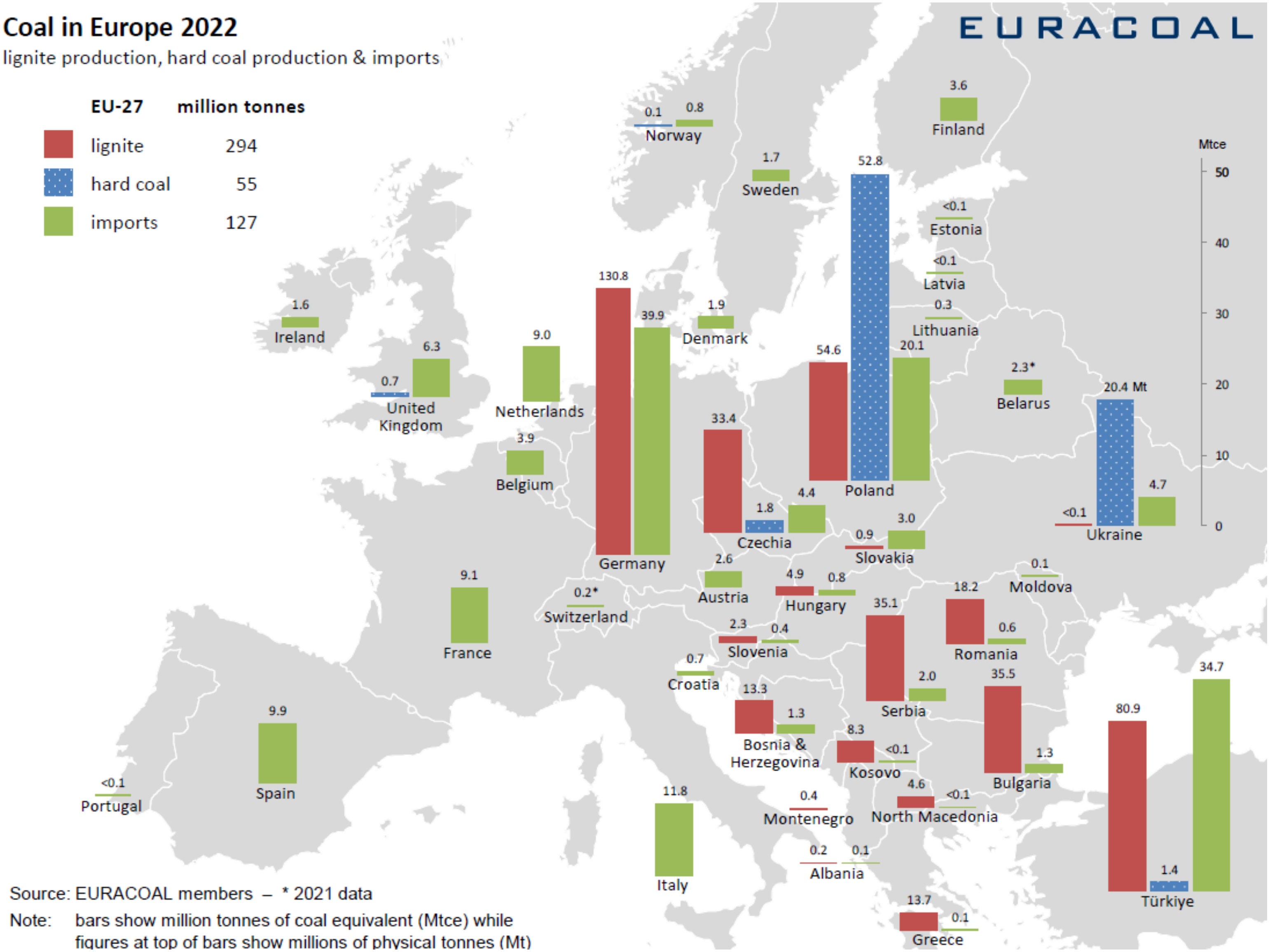
2017

Posição	Empresa	Instalação	Toneladas (CO2e)	% país
1	EDP – Gestão da Produção de Energia, S.A.	Central Termoeléctrica de Sines	7316936	12.2
2	Tejo Energia, S.A	Central Termoeléctrica do Pego	3260878	5.4
3	Petróleos de Portugal – Petrogal S.A	Refinaria de Sines	2516364	4.2
4	Turbogás – Produtora Energética, S.A	Central de Ciclo Combinado da Tapada do Outeiro	1004750	1.7
5	CIMPOR – Indústria de Cimentos, S.A.	Cimpor – Centro de Produção de Alhandra	976183	1.6

Source: https://zero.ong/zero-divulga-as-10-instalacoes-com-maiores-emissoes-em-portugal/

Context in EU

2022



Source: European Association for Coal and Lignite (https://euracoal.eu/info/euracoal-eu-statistics/)

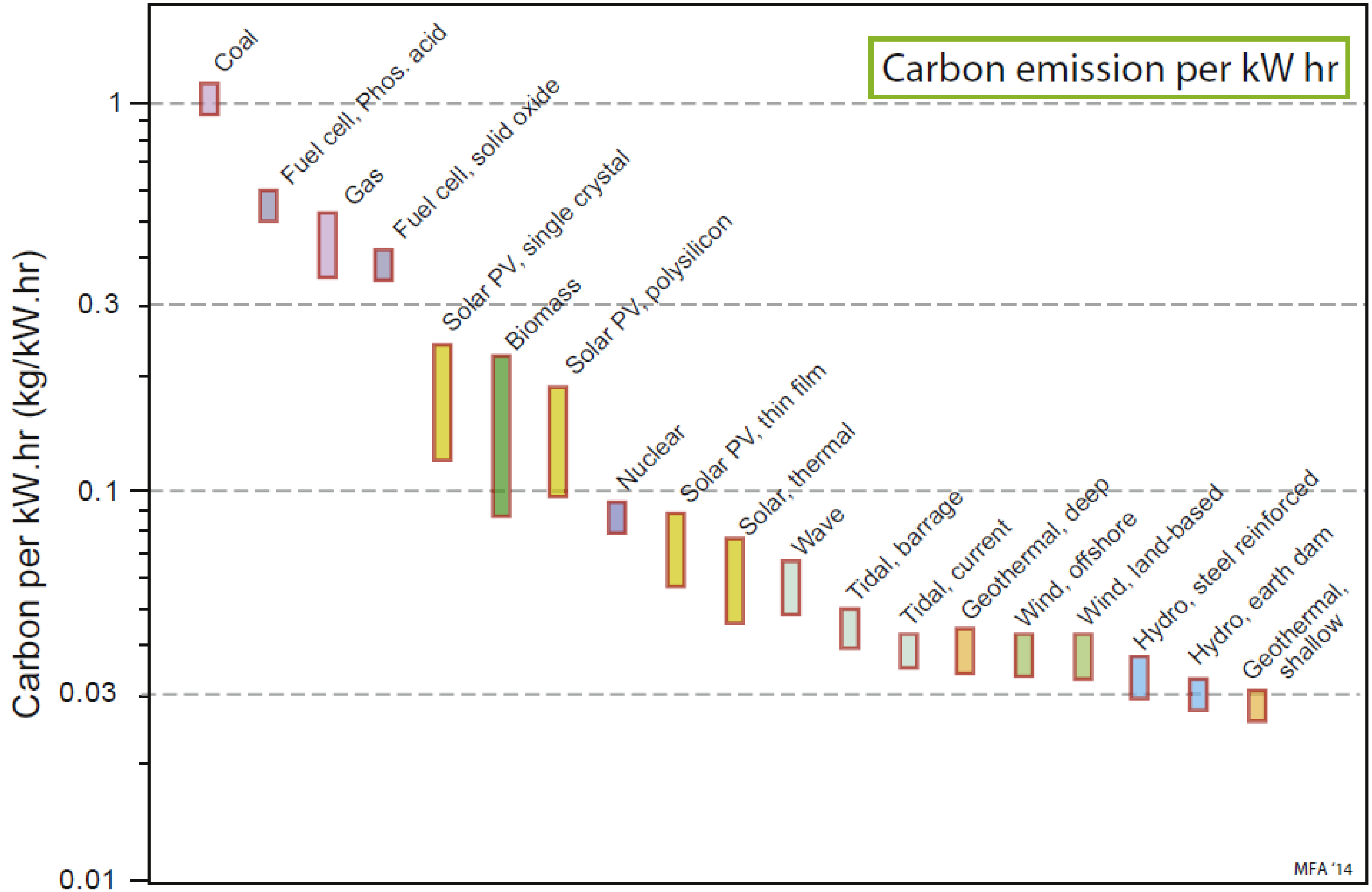
Coal in Europe’s energy mix

The graph below depicts the current state of play of national coal phase-out commitments in the EU.

Source: European Commission (https://energy.ec.europa.eu/topics/oil-gas-and-coal/eu-coal-regions/coal-regions-transition_en)

Energia e sustentabilidade

Pegada de carbono de sistemas de geração de energia



Energia e sustentabilidade

Intensidade energética e pegada de carbono de diferentes sistemas de geração de energia

Power System	Capital Intensity ($k\$/kW_p$)[a]	Area Intensity (m^2/kW_p)	Material Intensity (kg/kW_p)	Construction Energy Intensity (MJ/kW_p)	Construction Carbon Intensity (kg/kW_p)	Capacity Factor (%)
Conventional gas	0.6–1.5	1–4	605–1080	1,730–2,710	100–200	75–85
Conventional, coal	2.5–4.5	1.5–3.5	700–1600	3,580–9,570	100–700	75–85
Phosphoric acid fuel cell	3–4.5	0.1–0.5	80–120	5,000–10,000	600–1000	>95
Solid oxide fuel cell	7–8	0.3–1	50–100	2,000–6,000	200–400	>95
Nuclear - fission	3.5–6.4	1–3	170–625	2,000–4,300	105–330	75–95
Wind, land-based	1.0–2.4	150–400	500–2,000	3,500–6,000	240–600	17–25
Wind, off-shore	1.6–3	100–300	300–900	5,000–10,000	480–1,000	30–40
Solar PV, single crystal	4–12	30–70	800–1,700	30,000–60,000	2,000–4,000	8–12[b]
Solar PV, poly-silicon	3–6[b]	50–80[b]	1,000–2,000	20,000–40,000	1,500–3,000	8–12[b]
Solar PV, thin-film	2–5	50–100	1,500–3,000	10,000–20,000	550–1,000	8–12[b]
Solar thermal	3.9–8	20–100	650–3,500	19,000–40,000	1,500–3,500	20–35[c]
Hydro-earth dam	1–5	200–600	15,000–100,000	7260–15,000	630–1,200	45–65

(Continued)

Energia e sustentabilidade

Intensidade energética e pegada de carbono de diferentes sistemas de geração de energia

Power System	Capital Intensity ($k\$/kW_p$)[a]	Area Intensity (m^2/kW_p)	Material Intensity (kg/kW_p)	Construction Energy Intensity (MJ/kW_p)	Construction Carbon Intensity (kg/kW_p)	Capacity Factor (%)
Hydro- steel reinforced	1–5	120–500	8,000–40,000	30,000–66,000	1,000–4,000	50–70
Wave	1.2–4.4	42–100	1,000–2,000	22,950–31,540	1670–2070	25–40
Tidal-current	10–15	150–200	350–650	12,000–18,000	800-1130	35–50
Tidal-barrage	1.6–2.5	200–300	5,000–50,000	30,000–45,000	2,400–3,520	20–30
Geothermal-shallow	1.15–2	1–3	61–500	7,000–13,500	160–250	75–95
Geothermal-deep	2–3.9	1–3	400–1200	20,000–40,700	1,700–3,900	75–95
Biomass-dedicated	2.3–3.6	10,000–33,000	500–922	5,000–19,800	600–1800	75–95

Limites do desenvolvimento/crescimento de renováveis

Energia eólica

How much wind power could we plausibly generate?

power per person = wind power per unit area × area per person.

how to estimate the power per unit area of a wind farm in the UK. If the typical windspeed is 6 m/s (13 miles per hour, or 22 km/h), the power per unit area of wind farm is about $2\,W/m^2$.

$$250\ pessoas/km^2 = 4000\ m^2/pessoa$$

Limites do desenvolvimento/crescimento de renováveis

Energia eólica

How much wind power could we plausibly generate?

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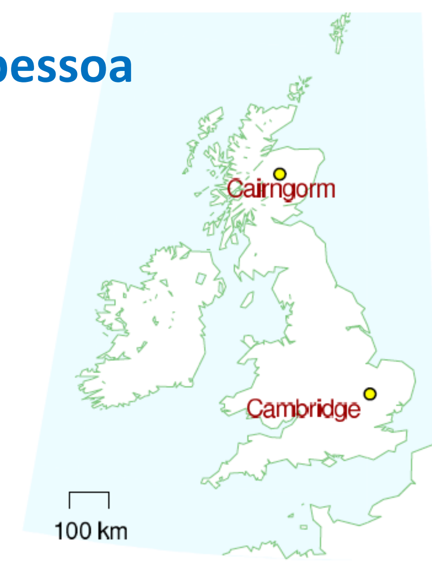
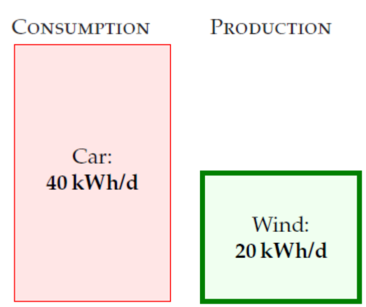
$$250\ pessoas/km^2 = 4000\ m^2/pessoa$$

$2\ W/m^2 \times 4000\ m^2/pessoa = 8000\ W/pessoa$ = 200 kWh/d . pessoa



Cenário:

utilizar 10% da área do país



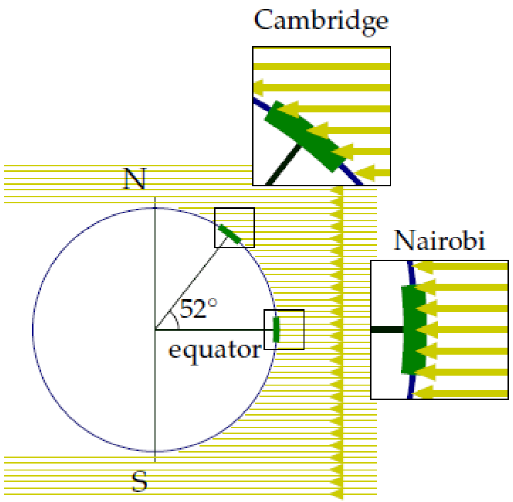
Limites do desenvolvimento/crescimento de renováveis

Energia solar

We are estimating how our consumption stacks up against conceivable sustainable production. In the last three chapters we found car-driving and plane-flying to be bigger than the plausible on-shore wind-power potential of the United Kingdom. Could solar power put production back in the lead?

The power of raw sunshine at midday on a cloudless day is 1000 W per square metre. That's 1000 W per m^2 of area oriented towards the sun, not per m^2 of land area. To get the power per m^2 of *land area* in Britain, we must make several corrections. We need to compensate for the tilt between the sun and the land, which reduces the intensity of midday sun to about 60% of its value at the equator (figure 6.1). We also lose out because it is not midday all the time. On a cloud-free day in March or September, the ratio of the *average* intensity to the midday intensity is about 32%. Finally, we lose power because of cloud cover. In a typical UK location the sun shines during just 34% of daylight hours.

The combined effect of these three factors and the additional complication of the wobble of the seasons is that the average raw power of sunshine per square metre of south-facing roof in Britain is roughly 110 W/m^2, and the average raw power of sunshine per square metre of flat ground is roughly 100 W/m^2.



Limites do desenvolvimento/crescimento de renováveis

Energia solar: painéis fotovoltaicos

Photovoltaic (PV) panels convert sunlight into electricity. Typical solar panels have an efficiency of about 10%; expensive ones perform at 20%. (Fundamental physical laws limit the efficiency of photovoltaic systems to at best 60% with perfect concentrating mirrors or lenses, and 45% without concentration. A mass-produced device with efficiency greater than 30% would be quite remarkable.) The average power delivered by south-facing 20%-efficient photovoltaic panels in Britain would be

$$20\% \times 110\,\mathrm{W/m^2} = 22\,\mathrm{W/m^2}.$$

Figure 6.5 shows data to back up this number. Let's give every person $10\,\mathrm{m^2}$ of expensive (20%-efficient) solar panels and cover all south-facing roofs. These will deliver

5 kWh per day per person.

22 x 10 x 24h = 5280 W/d.pessoa

Limites do desenvolvimento/crescimento de renováveis

Energia solar: painéis fotovoltaicos

Cenário:

utilizar 5% da área do país!

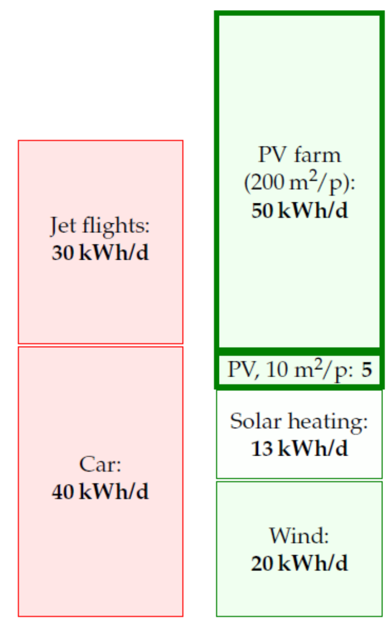
Fantasy time: solar farming

If a breakthrough of solar technology occurs and the cost of photovoltaics came down enough that we could deploy panels all over the countryside, what is the maximum conceivable production? Well, if we covered 5% of the UK with 10%-efficient panels, we'd have

$$\begin{aligned} & 10\% \times 100\,\mathrm{W/m^2} \times 200\,\mathrm{m^2} \text{ per person} \\ \simeq \quad & 50\,\mathrm{kWh/day/person}. \end{aligned}$$

I assumed only 10%-efficient panels, by the way, because I imagine that solar panels would be mass-produced on such a scale only if they were very cheap, and it's the lower-efficiency panels that will get cheap first. The power density (the power per unit area) of such a solar farm would be

$$10\% \times 100\,\mathrm{W/m^2} = 10\,\mathrm{W/m^2}.$$



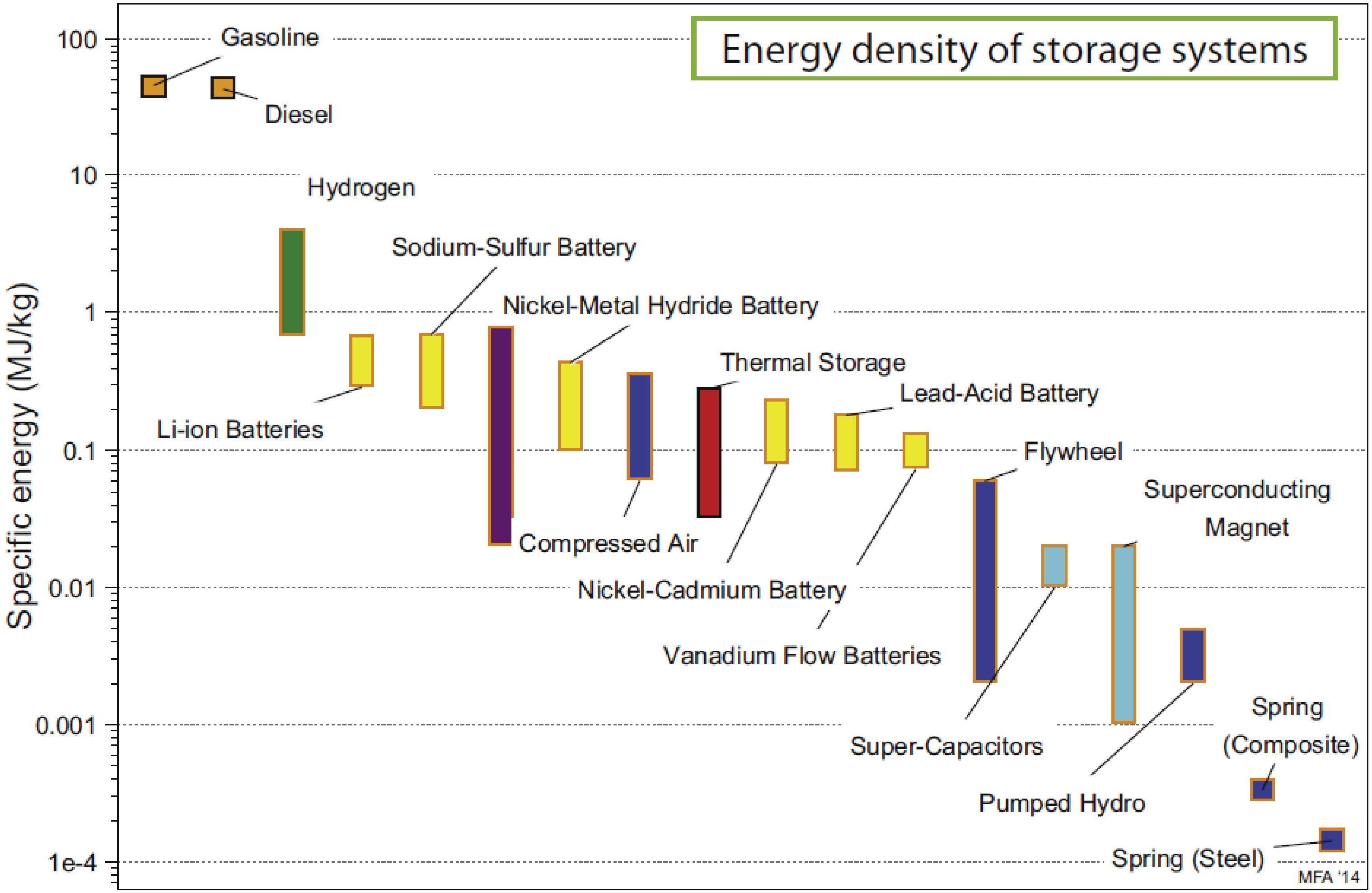
Energia e sustentabilidade

Sistemas de armazenamento de energia

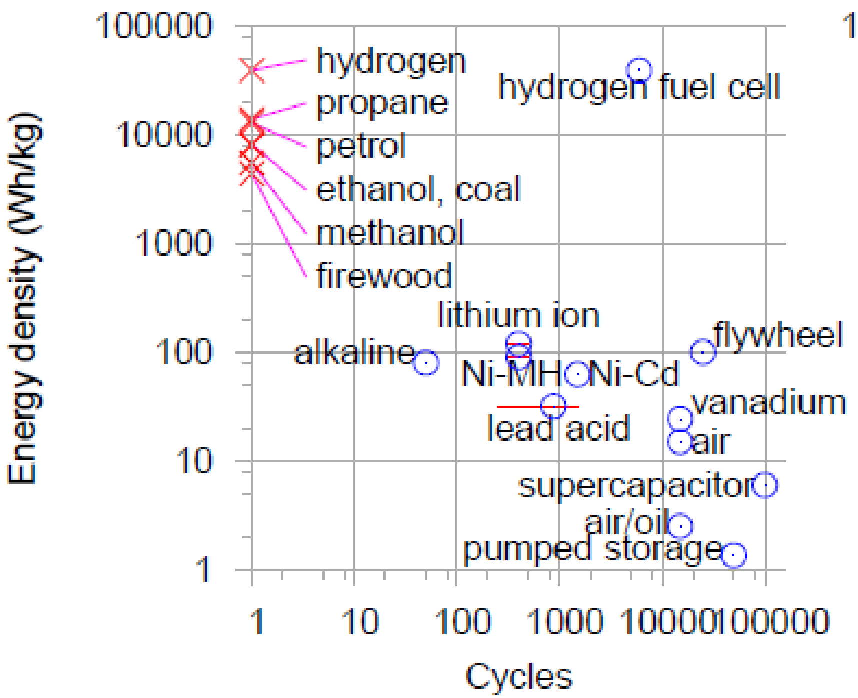
- Quando a energia é gerada de uma forma intermitente e não está sincronizada com o seu consumo, esta energia tem de ser armazenada até à sua utilização.
- E este processo é um grande desafio quando lidamos com energias renováveis, que são na sua maioria intermitentes.

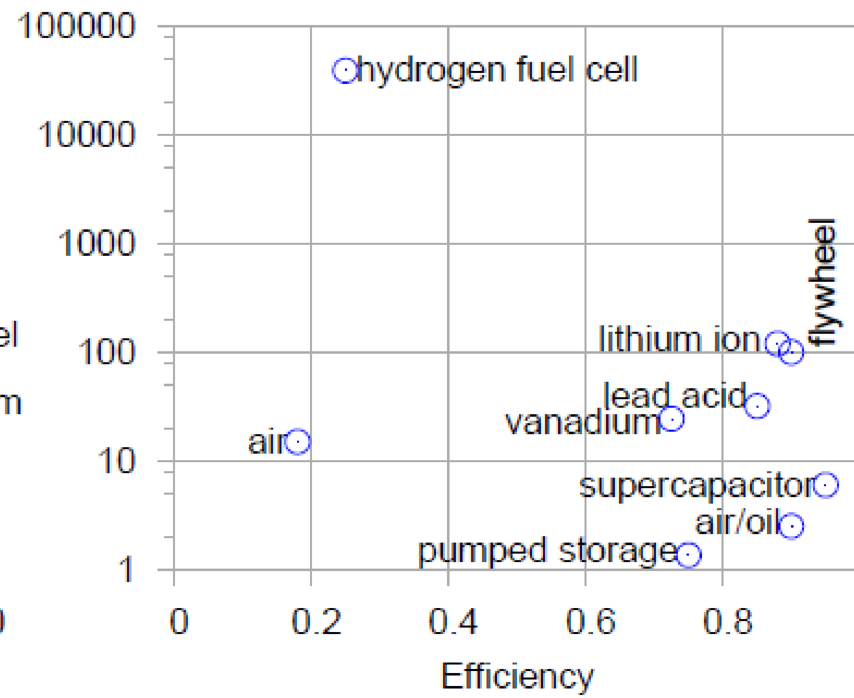
Energia e sustentabilidade

Sistemas de armazenamento de energia



Sistemas de armazenamento de energia e combustíveis





Energia e sustentabilidade

Sistemas de armazenamento de energia: comparação

Storage System	Specific Energy (MJ/kg)	Energy Density (MJ/m^3)	Operating Cost ($/MJ)	Specific Power (W/kg)	Efficiency (%)	Cycle Life (#-cycles)[b]
Conventional fuels	20–50	15,000–72,000	-	-	18–50	1
Pumped hydro	0.002–0.005	2–5	0.0006–0.0014	0.02–0.3	70–80	400,000
Compressed air energy storage	0.36	25	0.0001–0.0019	8	65–70	15,000
Springs	0.00014–0.00033	0.6–1.1	-	-	98–99.9	*Depends on loading*[1]
Flywheels	0.002–0.025	2.1	0.0008–0.0017	100–10,000	75–85	150,000
Thermal storage	0.032–0.036	160	0.0008–0.0019	1.5–1.7	72–85	10,000–15,000
Li-ion batteries	0.32–0.68	720–1,400	0.0019–0.0047	250–340	80–90	300–2,000
Sodium–sulfur batteries	0.2–0.7	140–540	0.0039	10–15	75–83	3600–4700
Lead-acid batteries	0.07–0.18	200–430	0.0008–0.0028	4–180	70–90	200–1500
Nickel cadmium batteries	0.08–0.23	72–310	0.0008–0.0055	30–150	60–85	800–1200
Nickel-metal hydride batteries	0.1–0.43	190–1300	0.0006–0.0028	4–140	65–85	300–1000
Vanadium flow batteries	0.07–0.13	110–170	0.0039	2.2–3.1	71–88	10000–16000
Hydrogen fuel cells	0.02–0.8	1–70	0.0006–0.0041	5–20	27–35	5,000–10,000
Super capacitors	0.010–0.020	10–25	0.0008–0.0019	1,000–20,000	90–95	1,000,000
Superconducting magnetic energy storage	0.001–0.02	2–10	0.0003–0.0083	500–20,000	85–92	50,000–200,000

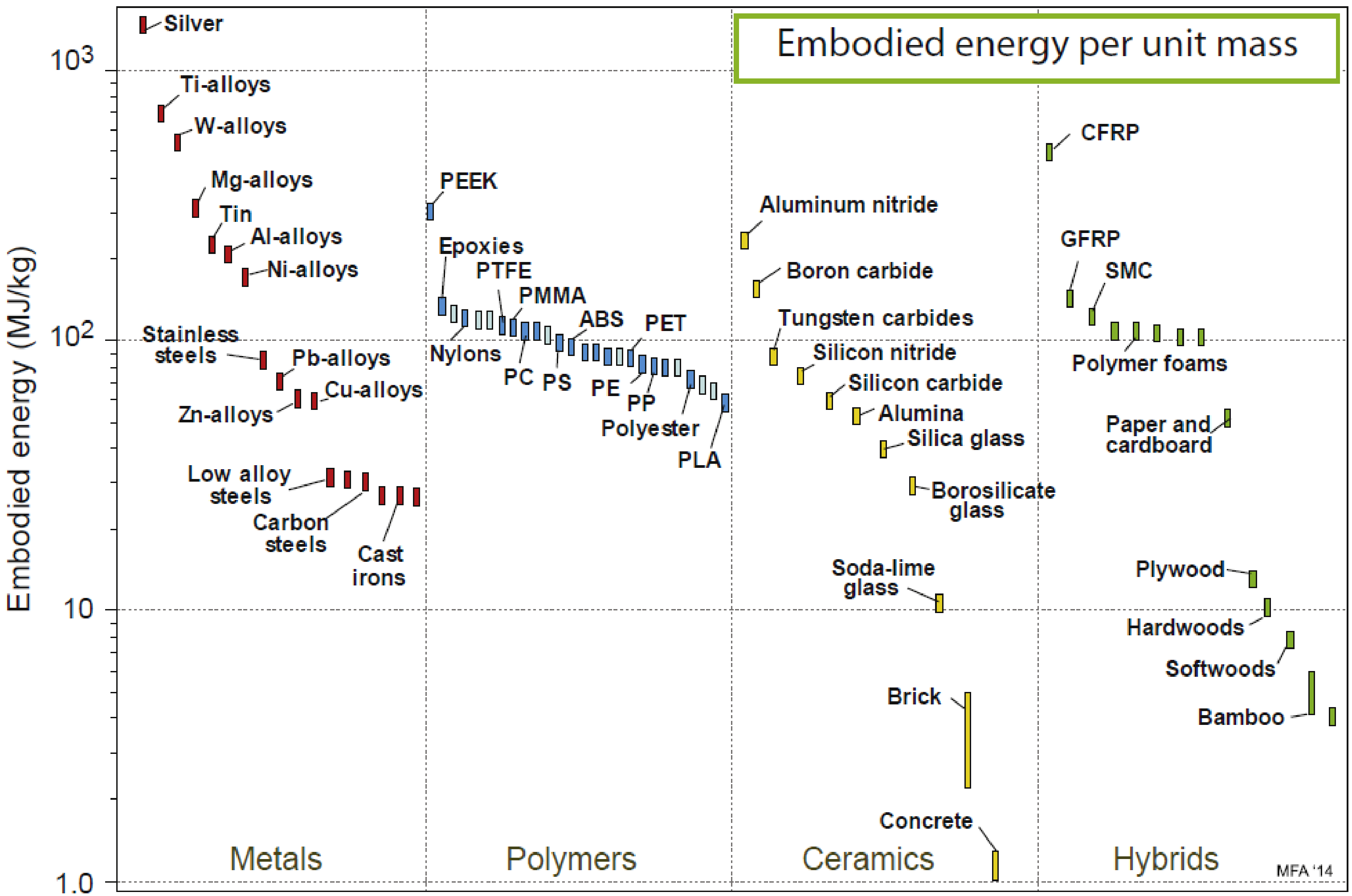
Energia e sustentabilidade

Energia incorporada na obtenção de materiais: indicador ambiental

- Todos os materiais contêm energia, usada na exploração e conformação, tratamento térmico ou químico, ou intrínseca (caso dos polímeros e elastómeros derivados do petróleo).
- Usar um material é usar a energia contida ou necessária à sua manipulação, com óbvia penalização ambiental: geração de CO_2, óxidos nitrosos (NOx), compostos sulfurosos, poeiras e calor perdido.
- Por isso a energia é um dos indicadores ambientais mais usados, também porque a sua contabilização é mais fácil de realizar.
- Estes índices ambientais (conteúdo energético) são derivados de forma análoga aos indicadores de desempenho (p.ex. peso mínimo) e de custo.

Energia e sustentabilidade

Energia incorporada na obtenção de materiais : indicador ambiental



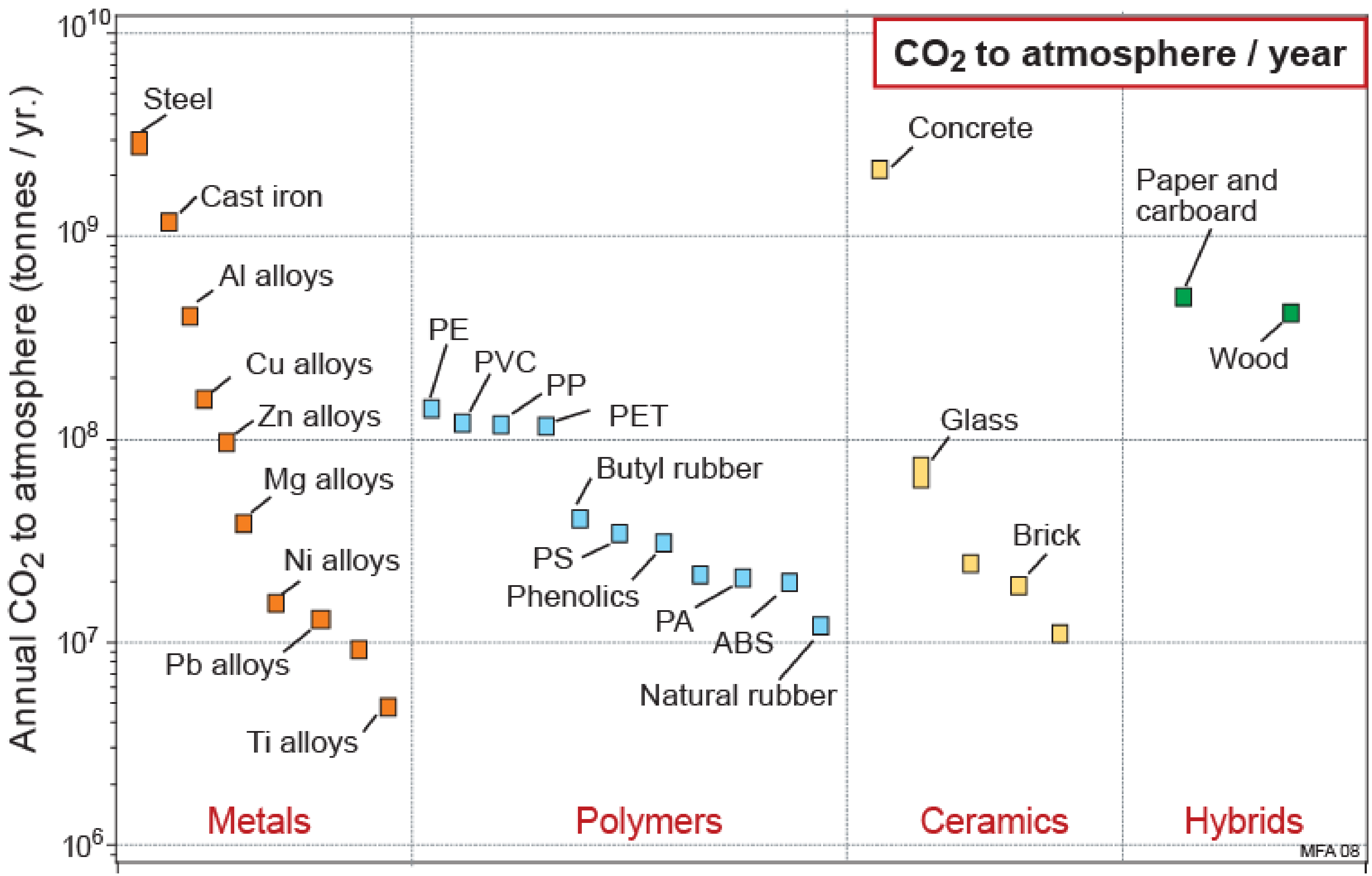
Energia incorporada: indicador ambiental

Element	Embodied Energy MJ/kg	$CO_{2,eq}$ (GWP) kg/kg	Water Usage l/kg
Aluminum	210	13	1.2e3
Antimony	140	13	3.4e3
Beryllium	6.4e3	400	360
Bismuth	150	9.3	2.9e3
Cadmium	13	0.68	820
Calcium	150	9.5	-
Cerium	510	33	55
Chromium	300	16	470
Cobalt	130	8.3	580
Copper	60	3.7	310
Dysprosium	1.4e3	90	55
Erbium	2.9e3	190	55
Europium	20e3	1.3e3	55
Gadolinium	1.3e3	86	55
Gallium	3.1e3	210	3.8e3
Gold	250e3	15e3	-
Hafnium	1.1e3	69	8.1e3
Holmium	1.9e3	120	55
Indium	2.9e3	180	1.3e3
Iridium	45e3	2.9e3	-
Iron	45	3	50
Lanthanum	290	19	55
Lead	27	1.9	340
Lithium	590	28	470
Lutetium	48e3	3e3	55
Magnesium	320	36	980

Element	Embodied Energy MJ/kg	$CO_{2,eq}$ (GWP) kg/kg	Water Usage l/kg
Manganese	65	4	240
Mercury	130	8.8	470
Molybdenum	380	34	360
Neodymium	85	5.5	55
Nickel	170	11	230
Niobium	1.7e3	110	150
Osmium	62e3	4e3	-
Palladium	160e3	8.5e3	-
Platinum	270e3	15e3	-
Praseodymium	650	42	55
Rhenium	12e3	770	3.8e3
Rhodium	560e3	30e3	-
Samarium	1.2e3	77	55
Scandium	59e3	3.8e3	55
Selenium	72	4.5	26
Silver	1.5e3	100	76e3
Tantalum	4.3e3	260	650
Tellurium	160	7.5	26
Terbium	9e3	580	55
Thallium	2.4e3	150	1.8e3
Thulium	26e3	1.7e3	55
Tin	230	13	11e3
Titanium	580	39	110
Tungsten	540	34	150
Uranium	1.3e3	81	3.5e3
Vanadium	3.7e3	250	650
Ytterbium	5.6e3	360	55
Yttrium	1.5e3	93	55

Energia e sustentabilidade

Emissões de CO_2/ano



Energia e sustentabilidade

Fontes antropogénicas de CO_2 por setor