ENERGY DATA SCIENCE

Introduction to the course: Part 2

Prof. Juri Belikov

Department of Software Science
Tallinn University of Technology
juri.belikov@taltech.ee

ENERGY & SCIENCE

Humans learn to use more energy ...

ENERGY AND POWER

Energy is the ability to do work.

Energy is measured in joule (J), but also in kilowatt hour, etc.:

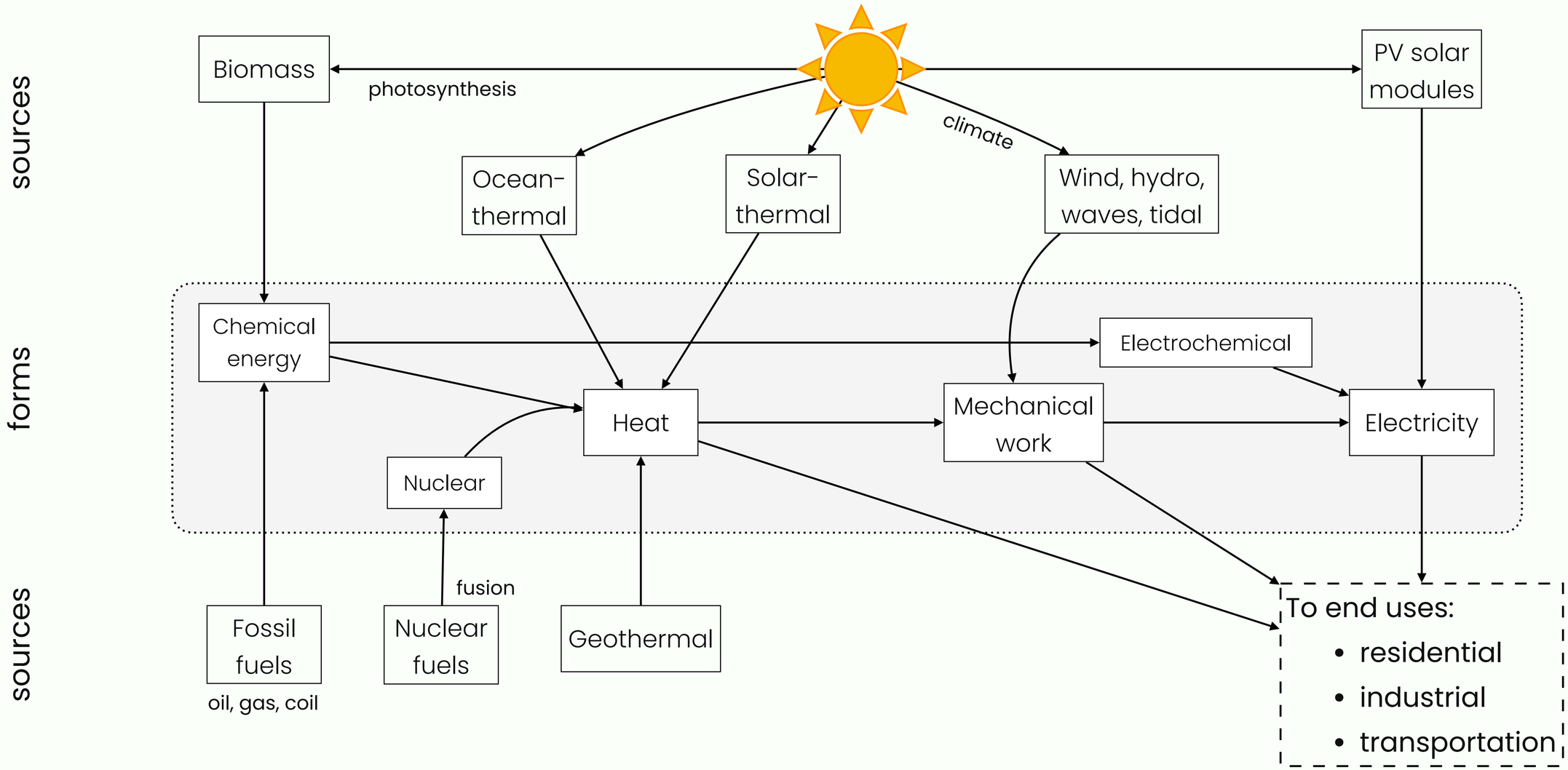
$$1 \text{ joule} = \frac{\text{kilogram} \cdot \text{meter}^2}{\text{second}^2}.$$

Power is the amount of energy transferred or converted per unit time; rate of energy use.

Power is measured in watt (W):

$$1 \text{ watt} = \frac{\text{joule}}{\text{second}}.$$

ENERGY SOURCES AND FORMS



Based on Fig. 1.2 from Tester, J. W., Drake, E. M., Driscoll, M. J., Golay, M. W., & Peters, W. A. (2012). Sustainable energy: choosing among options: MIT press.

Primary energy is the energy found in nature that has not been subjected to any human engineered conversion process.

Secondary energy is a carrier of energy, such as electricity, produced by conversion from a primary energy source.

NON-RENEWABLE ENERGY

coal

petroleum

natural gas

nuclear

NON-RENEWABLE ENERGY

coal

petroleum

natural gas

nuclear

Problems:

- Regenerate over hundreds of millions of years
- Environmental hazards: Greenhouse gas emissions, air and water pollution
- Price fluctuations
- Over-dependence

RENEWABLE ENERGY

wind

hydro

solar

geothermal

biomass

unlimited/sustainable sources

RENEWABLE ENERGY

wind

hydro

solar

geothermal

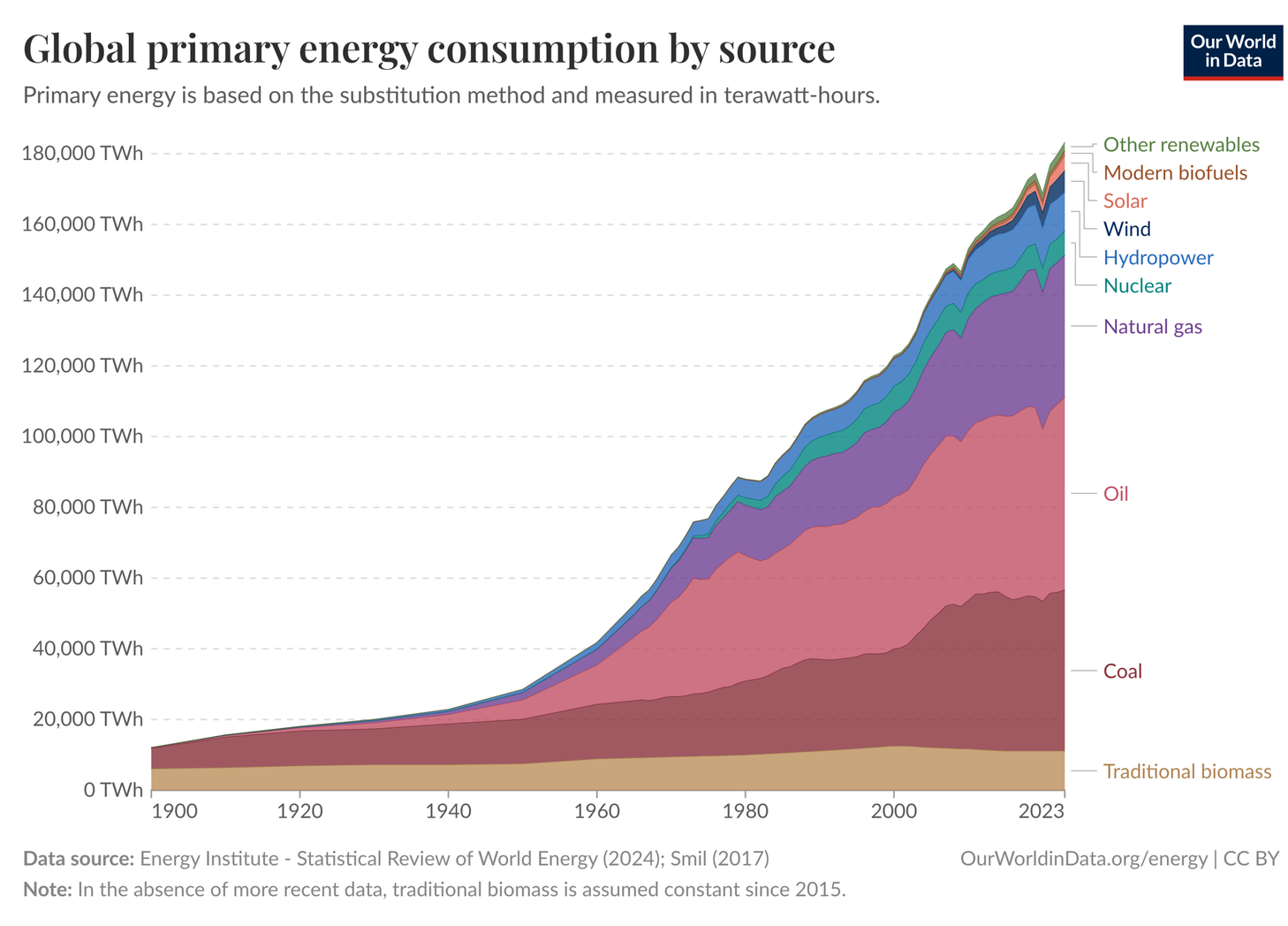
biomass

unlimited/sustainable sources

Problems:

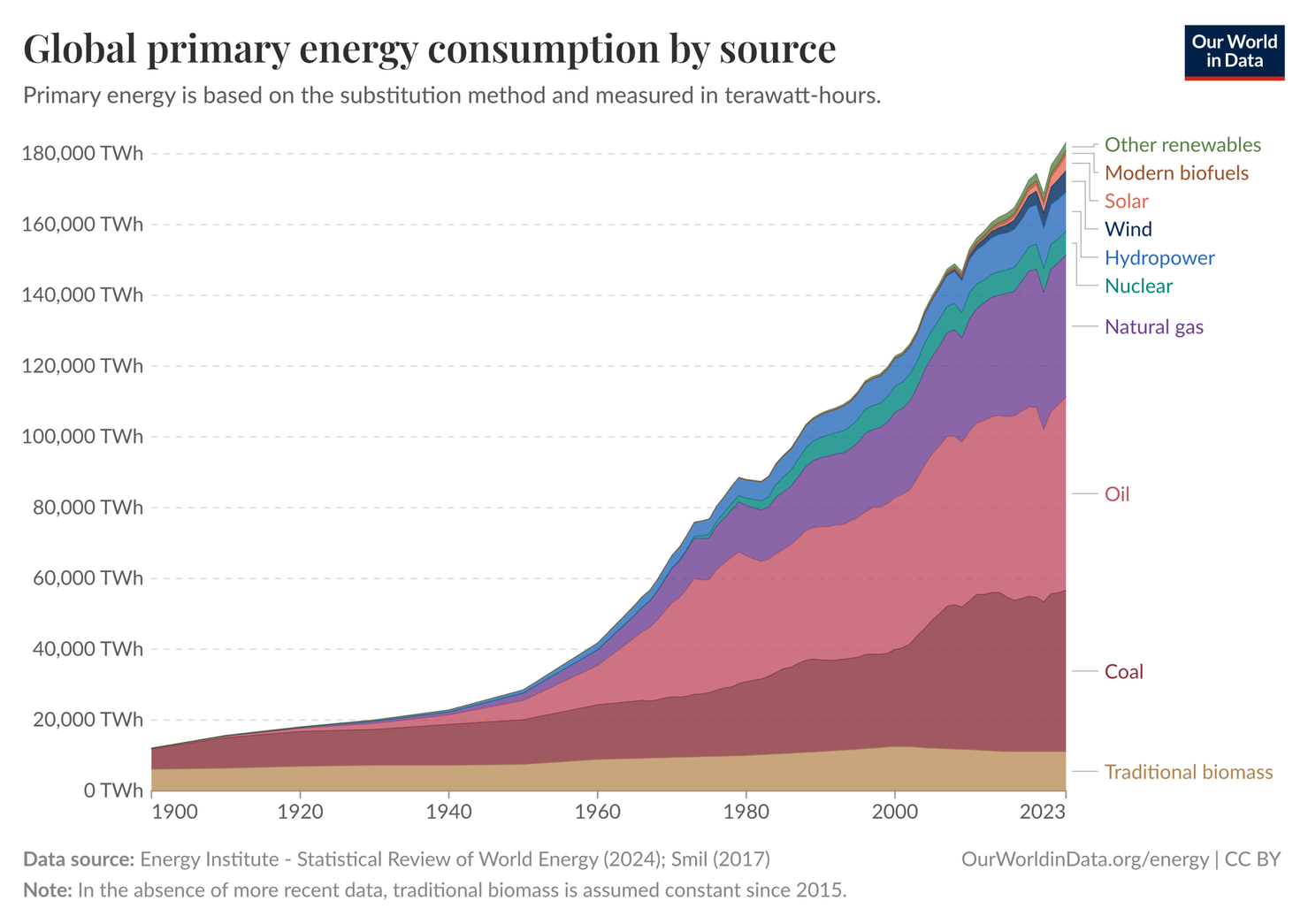
- Renewable energy is intermittent
- The efficiency of renewable technologies is low
- Initial cost is high
- Installations require a lot of space
- Utilisation concerns (recycling)

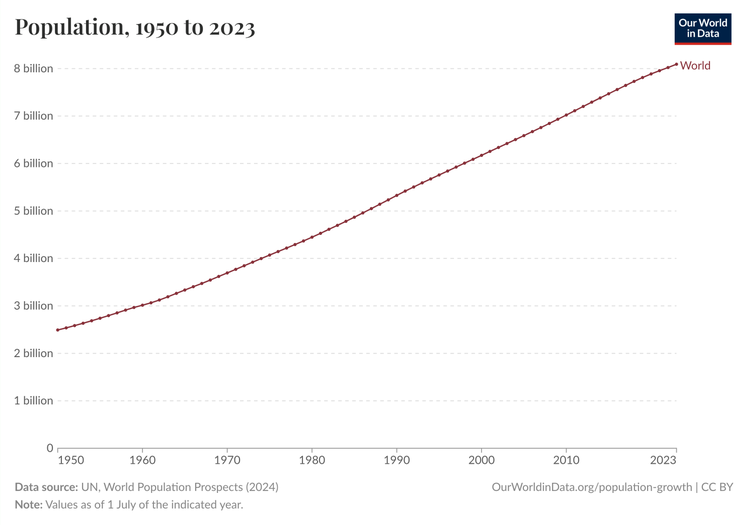
HISTORIC PERSPECTIVE



[Accessed May 5, 2025], https://ourworldindata.org/energy-mix

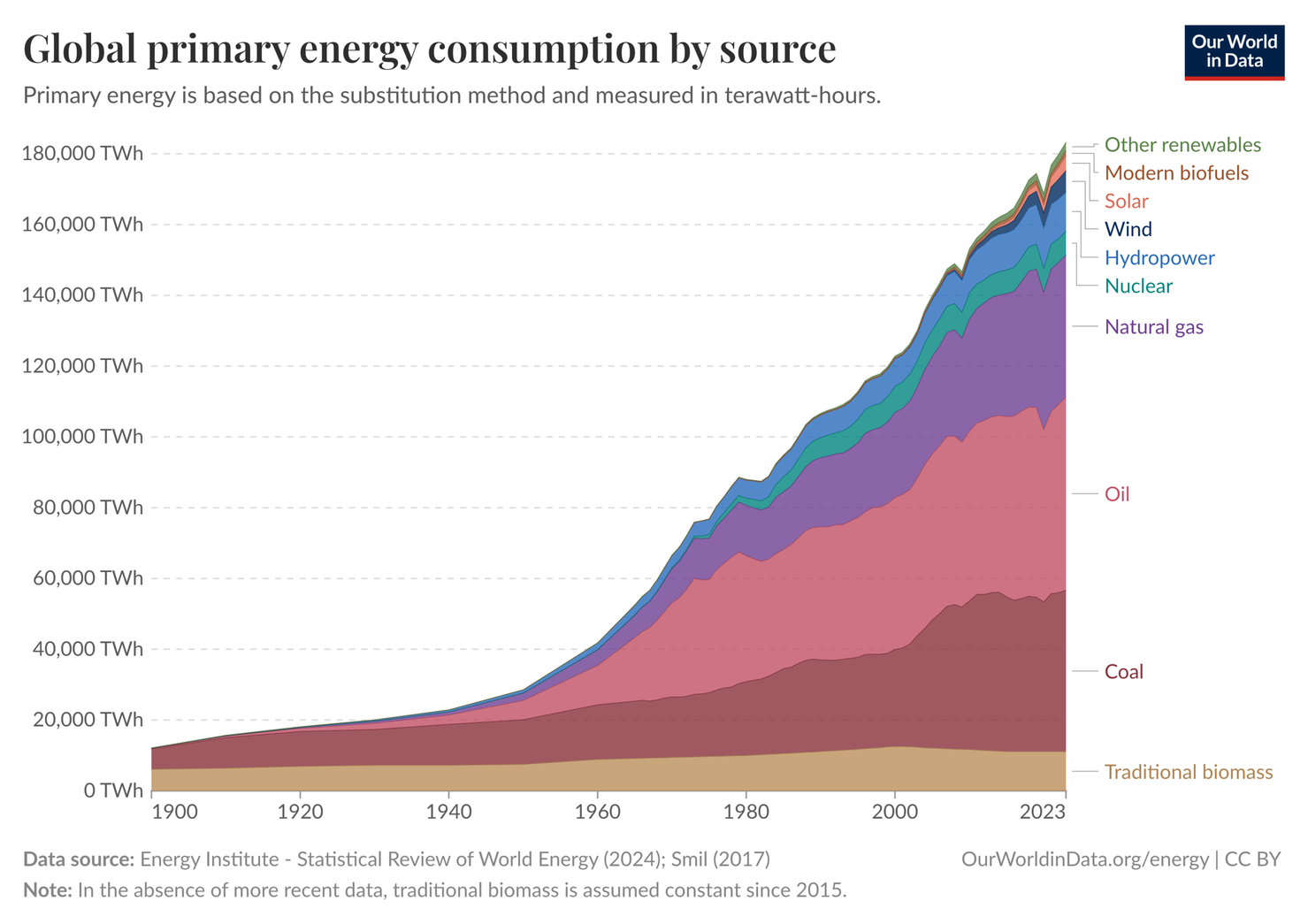
HISTORIC PERSPECTIVE

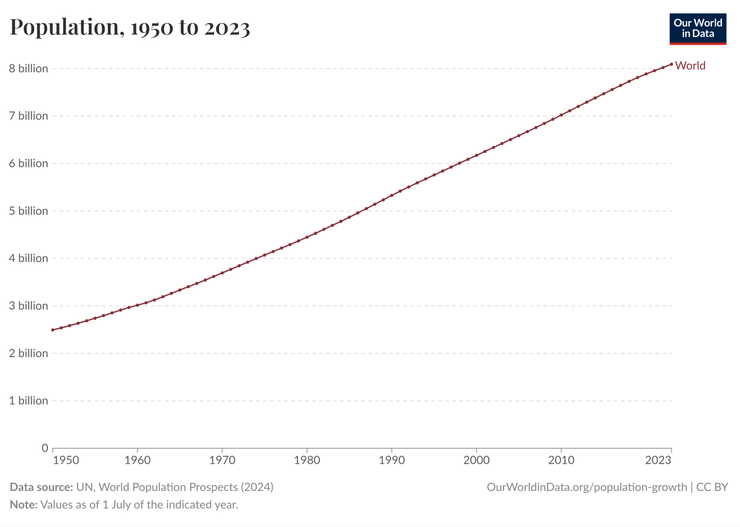


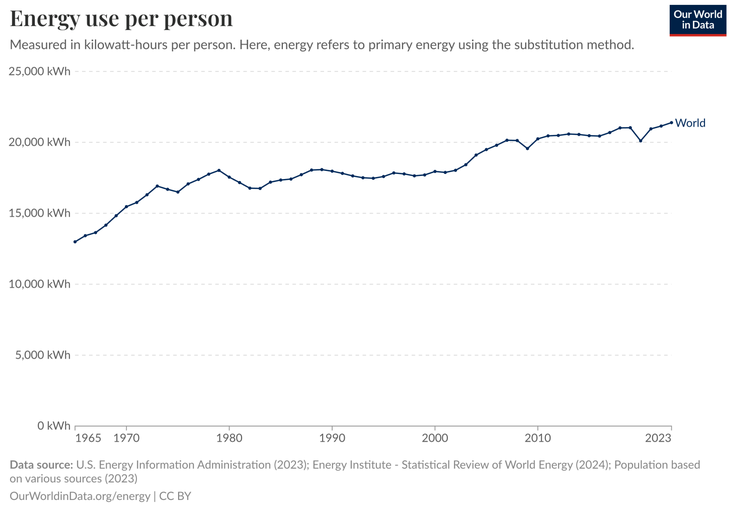


[Accessed May 5, 2025], https://ourworldindata.org/energy-mix

HISTORIC PERSPECTIVE

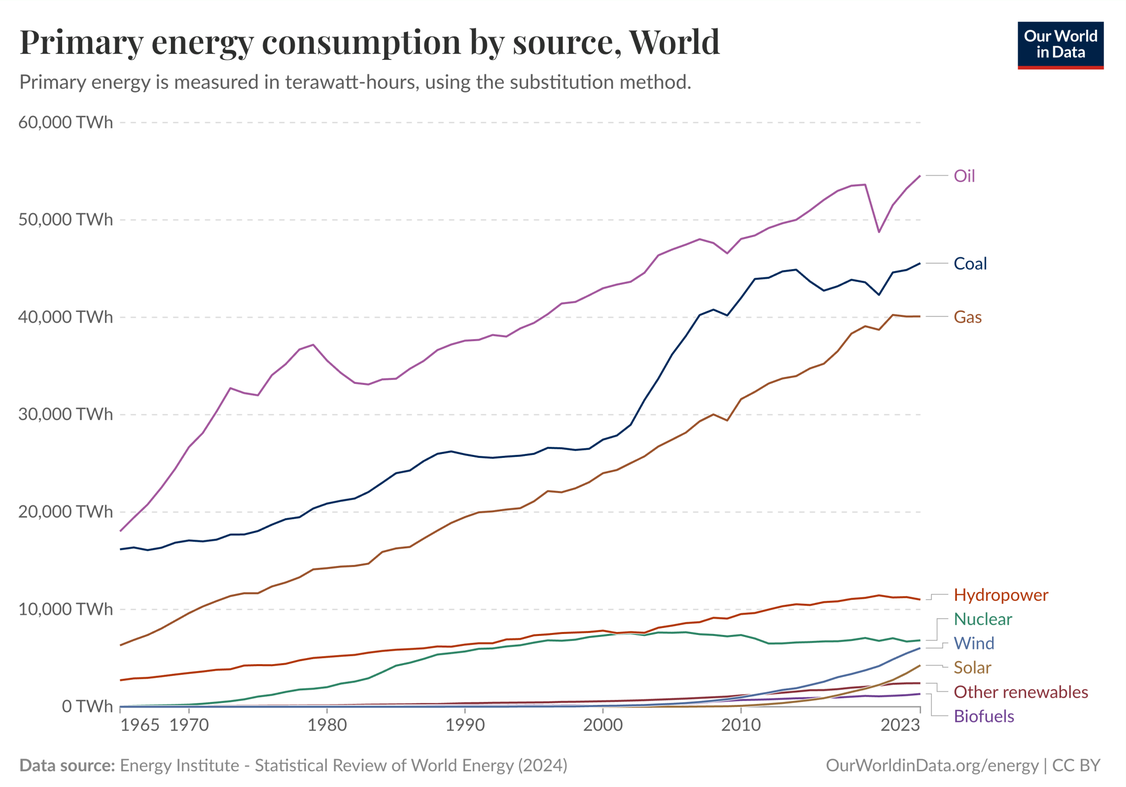


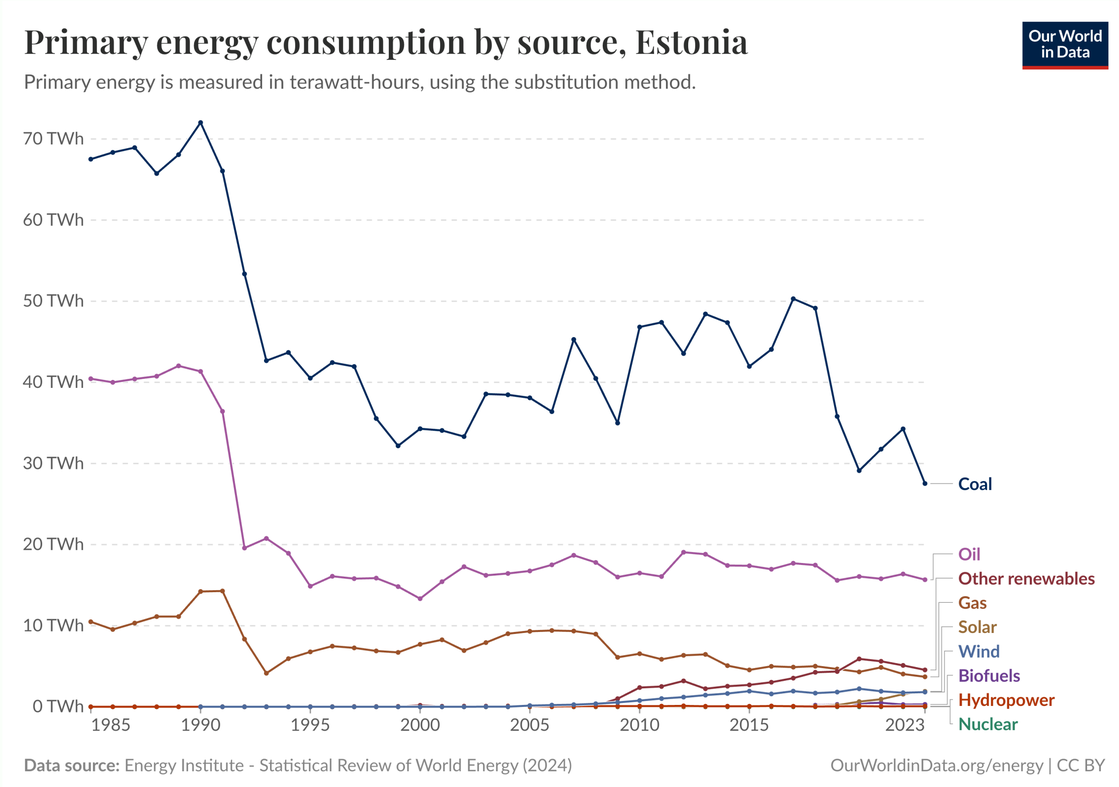




[Accessed May 5, 2025], https://ourworldindata.org/energy-mix

HISTORIC PERSPECTIVE (2)





https://ourworldindata.org/energy-mix

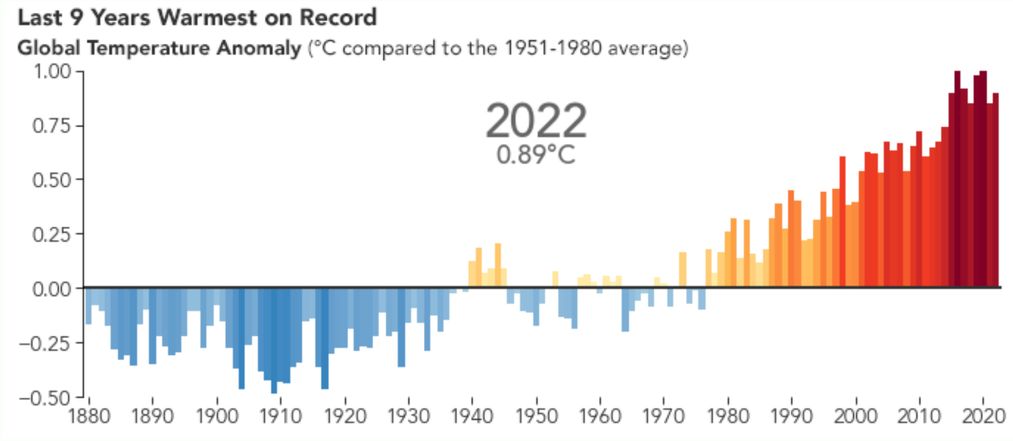
Global challenges in energy domain

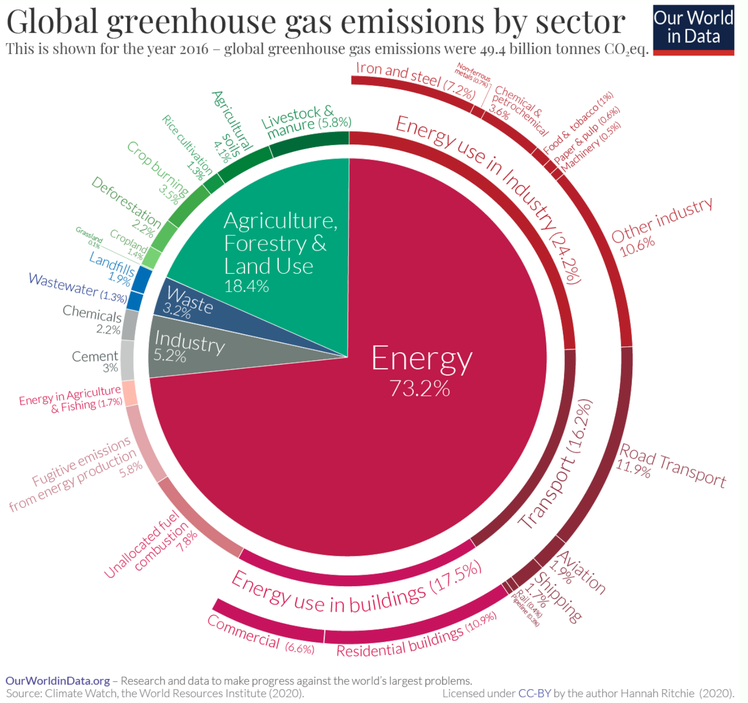
CLIMATE CHANGE

Problem **statement**: Climate change caused by carbon emissions

Brief **explanation**: Burning fossil fuels releases greenhouse gases, leading to global warming

Illustrative **example**: The melting of polar ice caps due to rising temperatures





[Accessed March 28, 2024], https://earthobservatory.nasa.gov/world-of-change/global-temperatures
https://ourworldindata.org/ghg-emissions-by-sector

(NON)RENEWABLE ENERGY

Problem **statement**: Overdependence on non-renewable energy sources

Brief **explanation**: Finite nature of non-renewable resources and their negative environmental impact

Illustrative **example**: Solar power plants as an alternative to coal power plants

ENERGY STORAGE

Problem **statement**: Limited energy storage capabilities

Brief **explanation**: Current energy storage technologies have limitations in terms of capacity, efficiency, and cost-effectiveness

Illustrative **example**: Lithium-ion batteries used in electric vehicles

GRID INTEGRATION

Problem **statement**: Integration of renewable energy into existing grids

Brief **explanation**: Renewable energy sources are intermittent and require storage and backup power

Illustrative **example**: The need for smart grids to manage the integration of renewable energy sources

ENERGY EFFICIENCY/PERFORMANCE

Problem **statement**: Inefficient use of energy resources

Brief **explanation**: Wasteful energy consumption practices lead to increased energy costs and carbon emissions

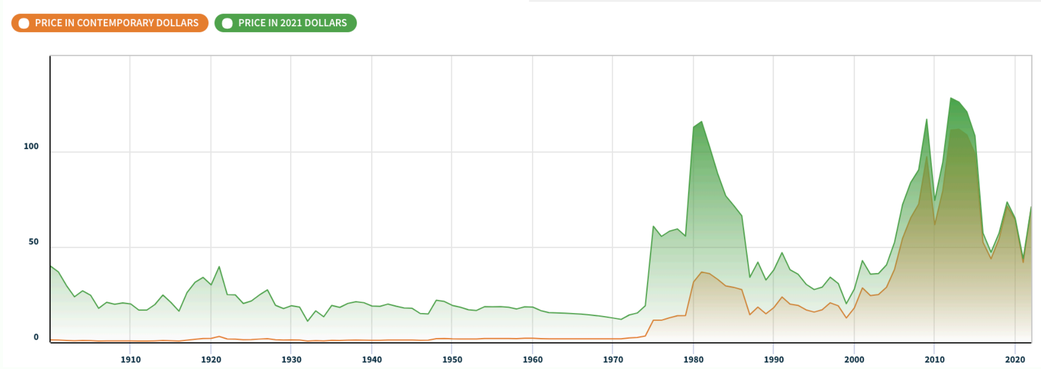
Illustrative **example**: Energy-efficient buildings that reduce energy usage and cost

ENERGY SECURITY

Problem **statement**: Dependence on foreign sources of energy

Brief **explanation**: Dependence on energy imports can lead to geopolitical tensions, supply disruptions, and economic instability

Illustrative **example**: The impact of oil price shocks (oil crisis) on the global economy



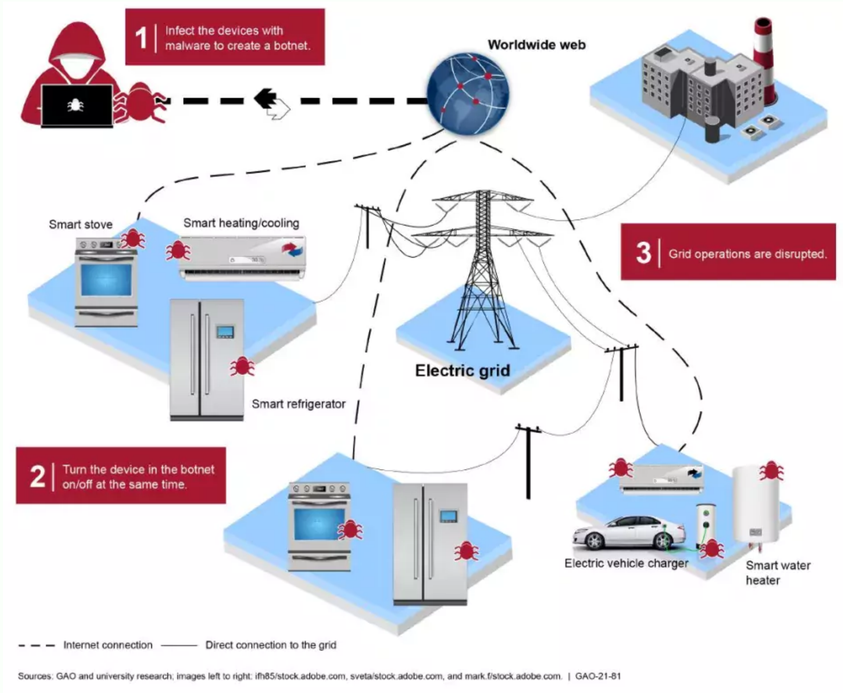
[Accessed May 5, 2025], https://safetyculture.com/topics/energy-security/
https://data.nasdaq.com/data/BP/CRUDE_OIL_PRICES-crude-oil-prices-from-1861

CYBER SECURITY

Problem **statement**: Increasing cyber security threats

Brief **explanation**: Cyber security threats in power grids pose significant risks to the reliability, stability, and security of electrical systems

Illustrative **example**: Cyber attackers may target operation centres to gain unauthorized access, disrupt operations, or manipulate data.



[Accessed May 5, 2025], https://www.gao.gov/blog/securing-u.s.-electricity-grid-cyberattacks

ENERGY POVERTY

Problem **statement**: Lack of access to energy resources

Brief **explanation**: Energy poverty affects millions of people around the world, leading to social, economic, and health problems

Illustrative **example**: Solar-powered lamps for communities without access to electricity

ENERGY POLICY

Problem **statement**: Lack of comprehensive energy policies

Brief **explanation**: Comprehensive energy policies are essential for addressing energy-related challenges

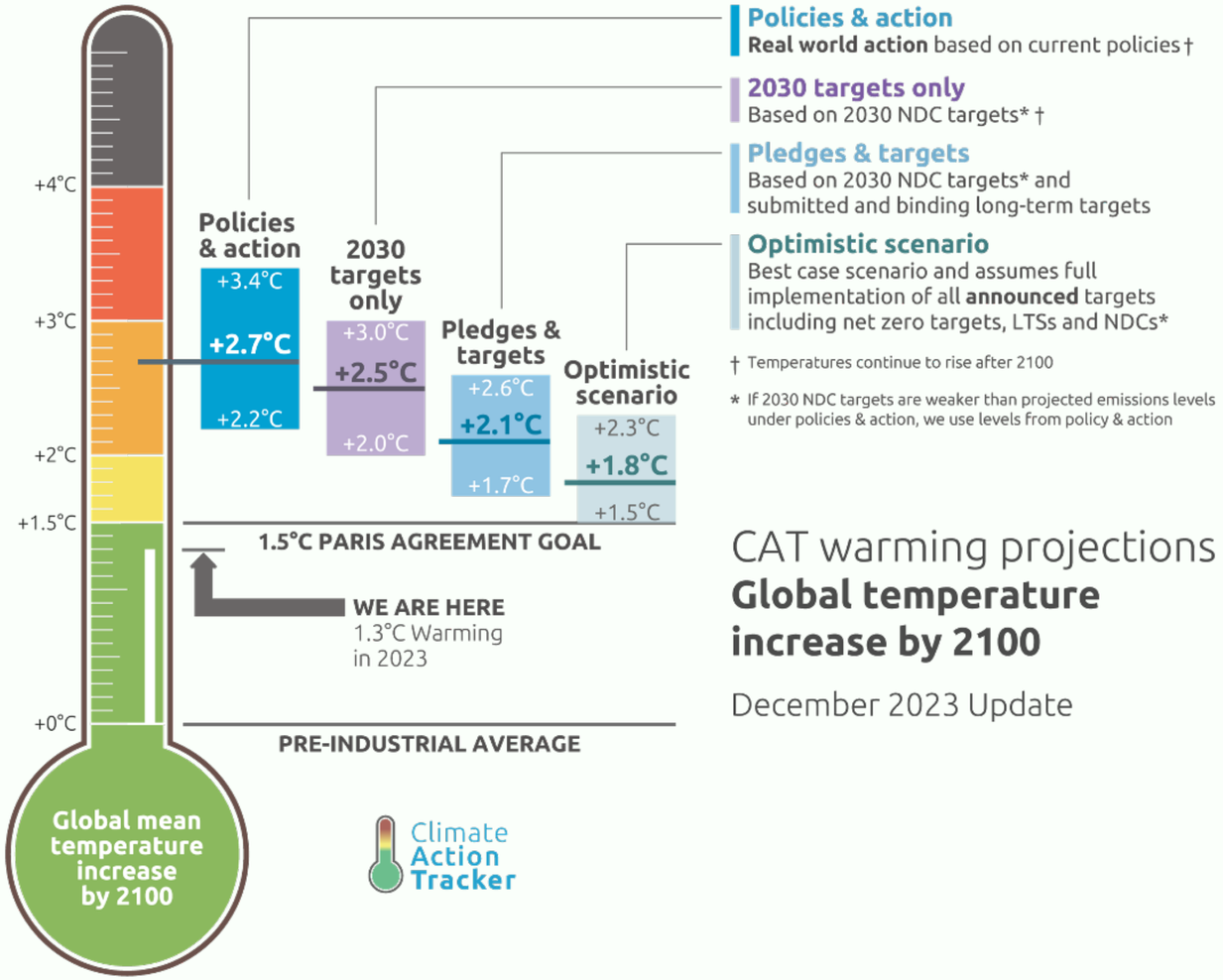
Illustrative **example**: The EU's Energy Union initiative

PARIS AGREEMENT, 2016

The goal is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5°C above pre-industrial levels.”

[Accessed May 5, 2025], https://unfccc.int/process-and-meetings/the-paris-agreement

HOW ARE WE DOING?



[Accessed May 5, 2025], https://climateactiontracker.org/

SUSTAINABLE DEVELOPMENT GOALS

[Accessed May 5, 2025], https://www.un.org/sustainabledevelopment/energy/

SUSTAINABLE DEVELOPMENT GOALS

SDG7

SDG11

SDG12

SDG13

[Accessed May 5, 2025], https://www.un.org/sustainabledevelopment/energy/

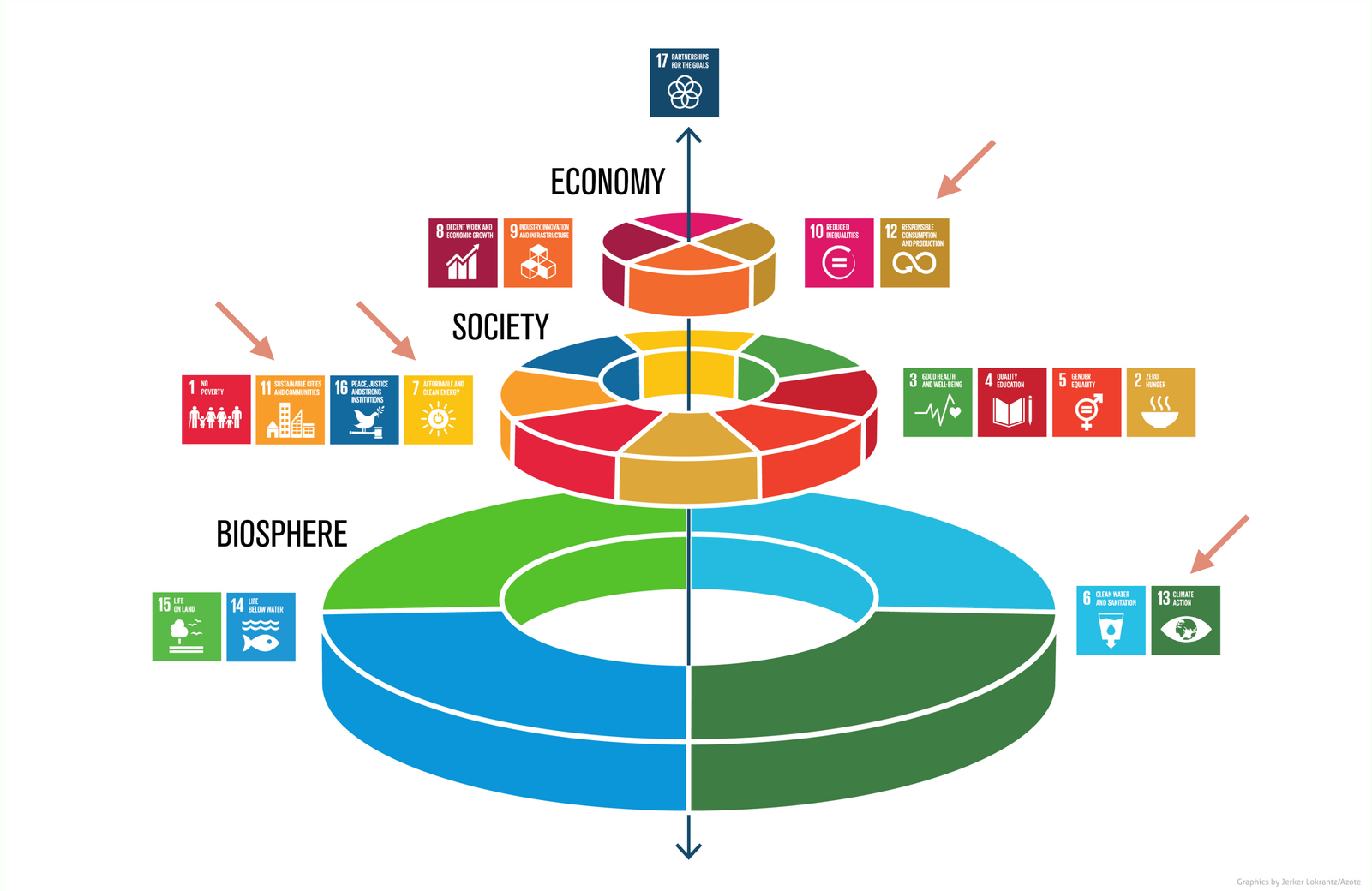
GLOBAL VISION (2)

SDG7

SDG11

SDG12

SDG13



[Accessed May 5, 2025], A. Obrecht *et al.* (2021). Achieving the SDGs with Biodiversity. In Achieving the SDGs with Biodiversity (Vol. 16, Number 1). Zenodo.

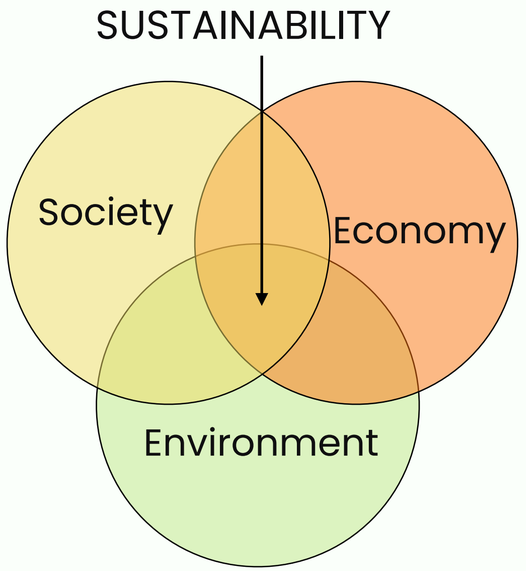
WHAT IS SUSTAINABILITY?

Sustainability is hard to define in a unique way.

[Accessed May 5, 2025], https://www.un.org/en/academic-impact/sustainability
https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf
Solow, R. (1995). An almost practical step toward sustainability. *Ekistics*, *62*(370/371/372), 15–20. http://www.jstor.org/stable/43623526
Tester J. W. (2005). Sustainable energy: Choosing among options. London: MIT Press.

WHAT IS SUSTAINABILITY?

Sustainability is hard to define in a unique way.

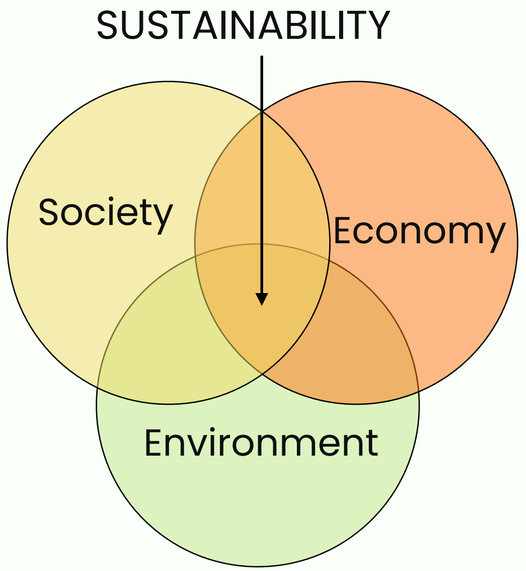


[Accessed May 5, 2025], https://www.un.org/en/academic-impact/sustainability
https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf
Solow, R. (1995). An almost practical step toward sustainability. *Ekistics*, *62*(370/371/372), 15–20. http://www.jstor.org/stable/43623526
Tester J. W. (2005). Sustainable energy: Choosing among options. London: MIT Press.

WHAT IS SUSTAINABILITY?

Sustainability is hard to define in a unique way.

- Meeting the needs of the present without compromising the ability of future generations to meet their own needs. UN report, Brundtland, 1987
- Preservation of productive capacity for the foreseeable future. Solow, 1992
- A dynamic harmony between the equitable availability of energy-intensive goods and services to all people and preservation of the earth for future generations. Tester, 2005

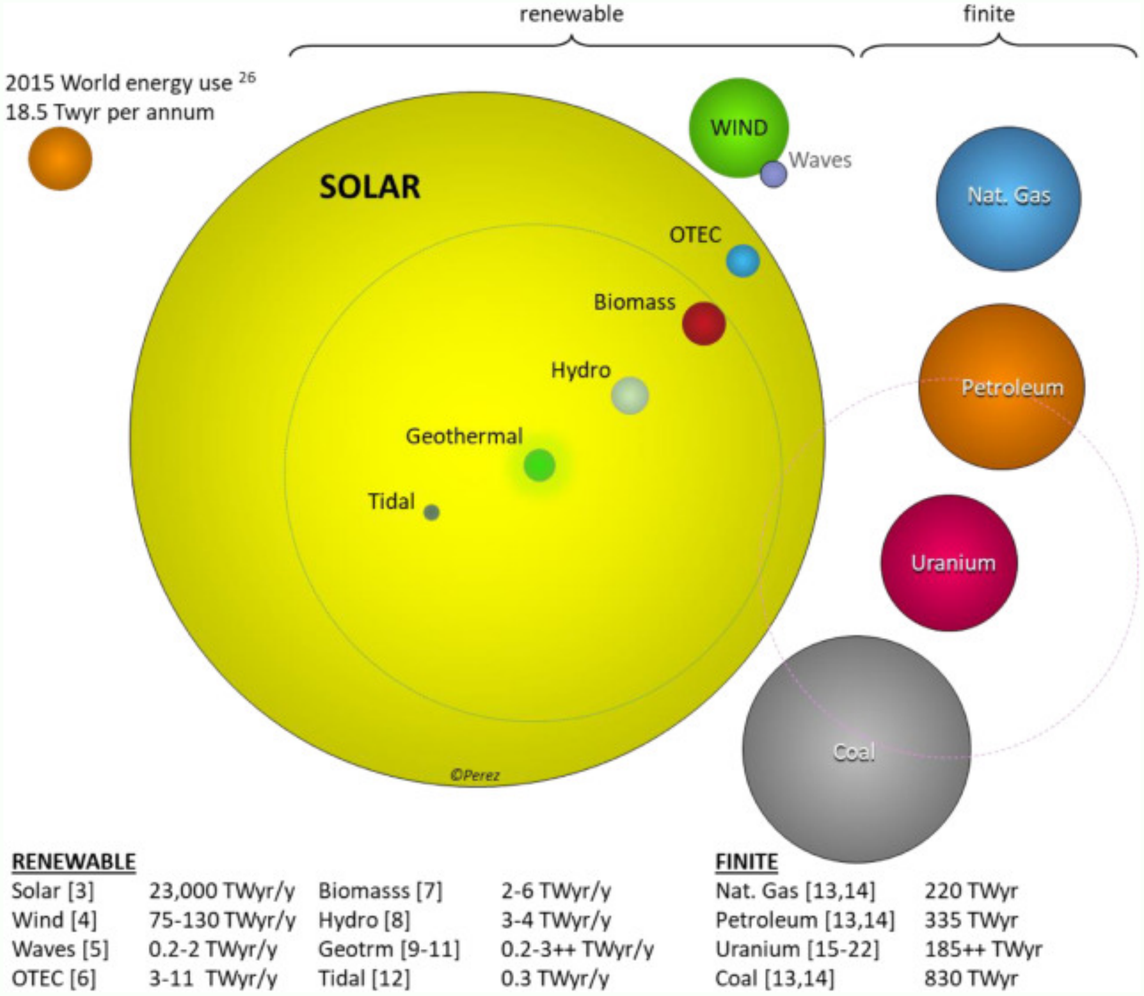


[Accessed May 5, 2025], https://www.un.org/en/academic-impact/sustainability
https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf
Solow, R. (1995). An almost practical step toward sustainability. *Ekistics*, *62*(370/371/372), 15–20. http://www.jstor.org/stable/43623526
Tester J. W. (2005). Sustainable energy: Choosing among options. London: MIT Press.

Shift energy production from fossil to renewable energy sources.

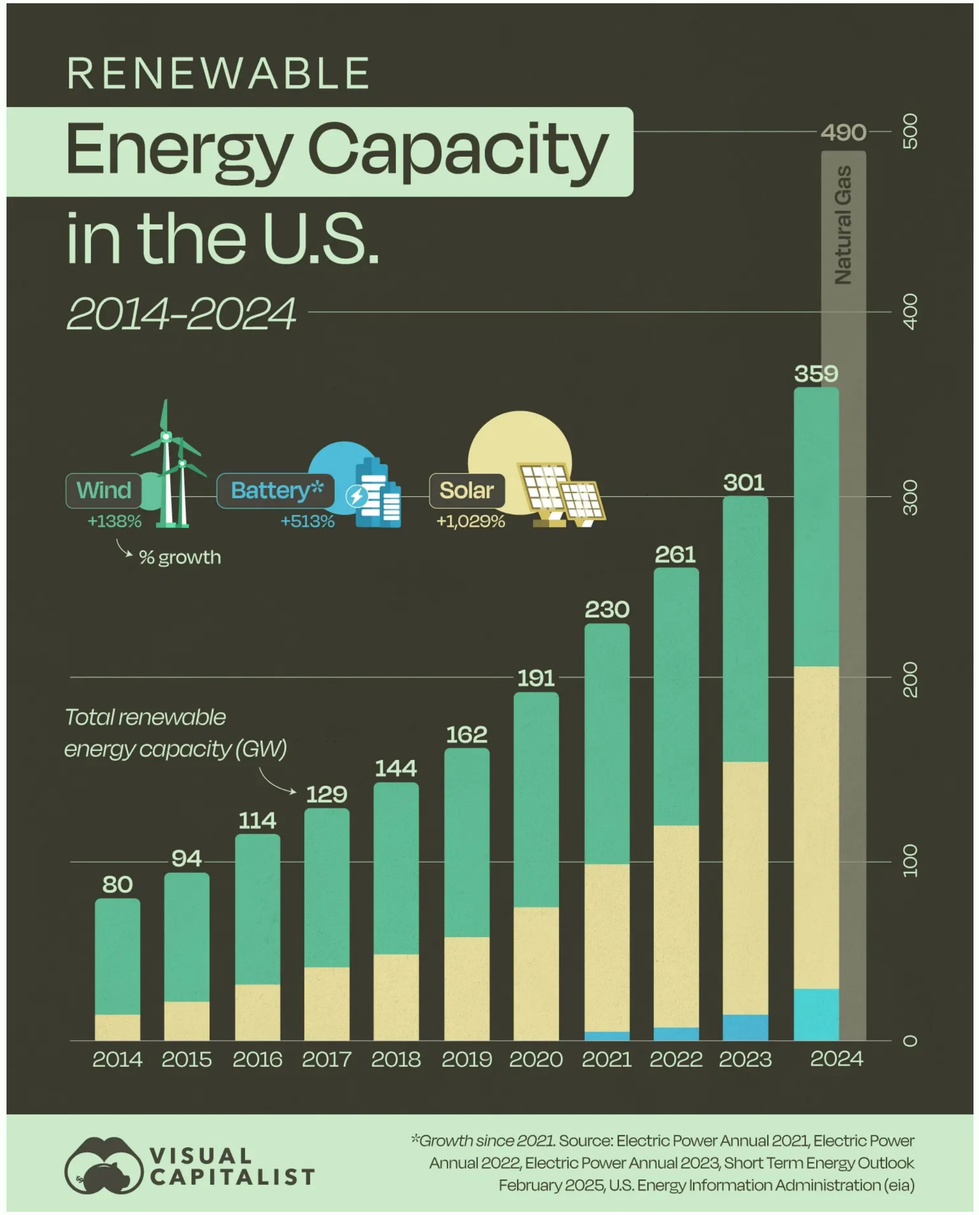
Is it the answer?

ENERGY POTENTIAL



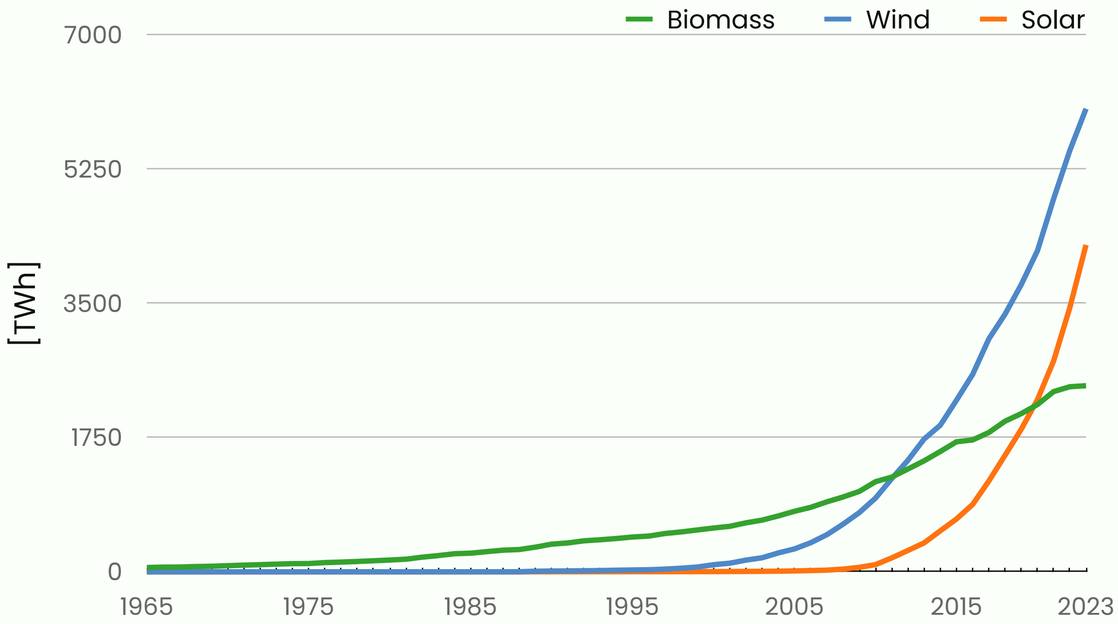
RENEWABLE				FINITE	
Solar [3]	23,000 TWyr/y	Biomasss [7]	2-6 TWyr/y	Nat. Gas [13,14]	220 TWyr
Wind [4]	75-130 TWyr/y	Hydro [8]	3-4 TWyr/y	Petroleum [13,14]	335 TWyr
Waves [5]	0.2-2 TWyr/y	Geotrm [9-11]	0.2-3++ TWyr/y	Uranium [15-22]	185++ TWyr
OTEC [6]	3-11 TWyr/y	Tidal [12]	0.3 TWyr/y	Coal [13,14]	830 TWyr

M. Perez and R. Perez (2022). Update 2022 – A fundamental look at supply side energy reserves for the planet. *Solar Energy Advances*, *2*, 100014.

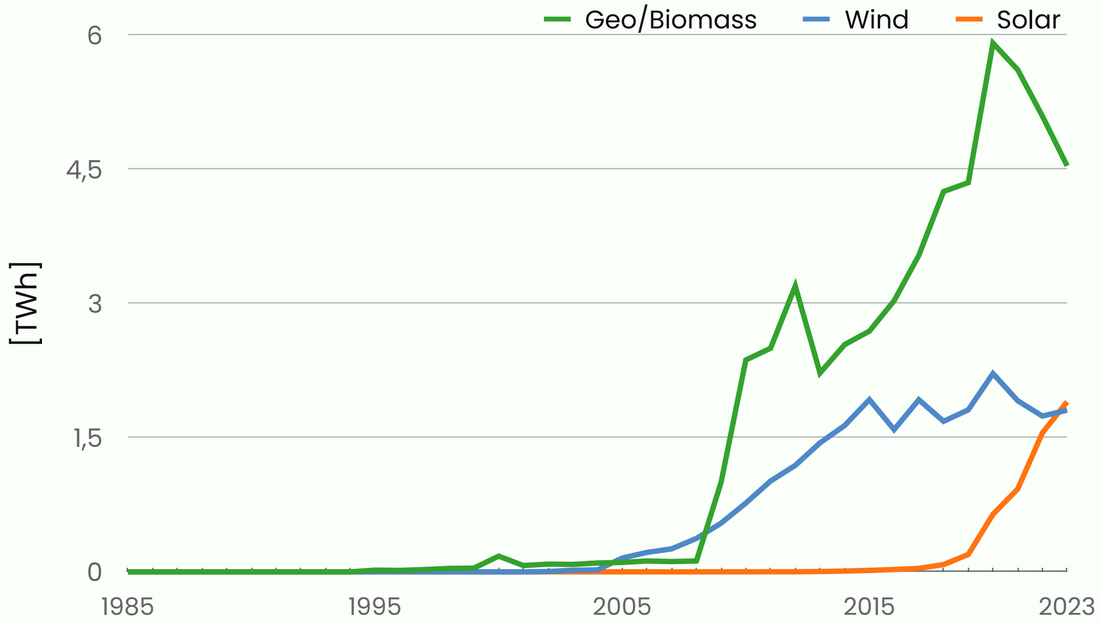

RENEWABLE
Energy Capacity in the U.S.
2014-2024
Wind
+138%
% growth
Battery*
+513%
Solar
+1,029%
Total renewable energy capacity (GW)
80
94
114
129
144
162
191
230
261
301
359
490
Natural Gas
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
0
100
200
300
400
500
VISUAL CAPITALIST
*Growth since 2021. Source: Electric Power Annual 2021, Electric Power Annual 2022, Electric Power Annual 2023, Short Term Energy Outlook February 2025, U.S. Energy Information Administration (eia)

RENEWABLE ENERGY

World



Estonia



RENEWABLE ENERGY IN SCOPE

Main directive COM(2016) 767/F2

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

EU Goals on renewable energy source (from COM(2016) 767/F2):

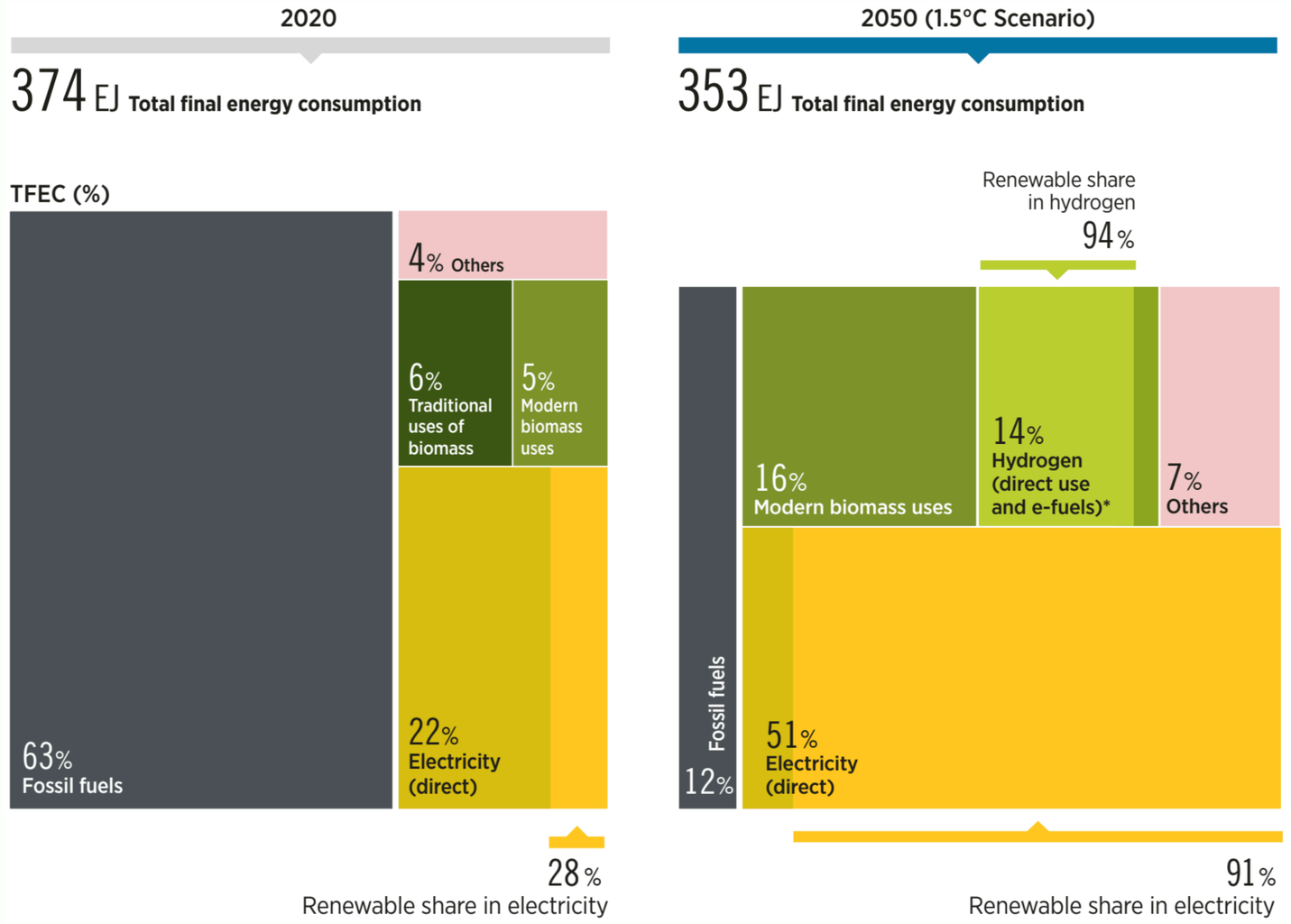
>32% by 2030 Reaching this threshold is in accordance with Paris agreement 2016

http://unfccc.int/paris_agreement/items/9485.php

Estonia is discussing possibility to reach **42%** by 2035

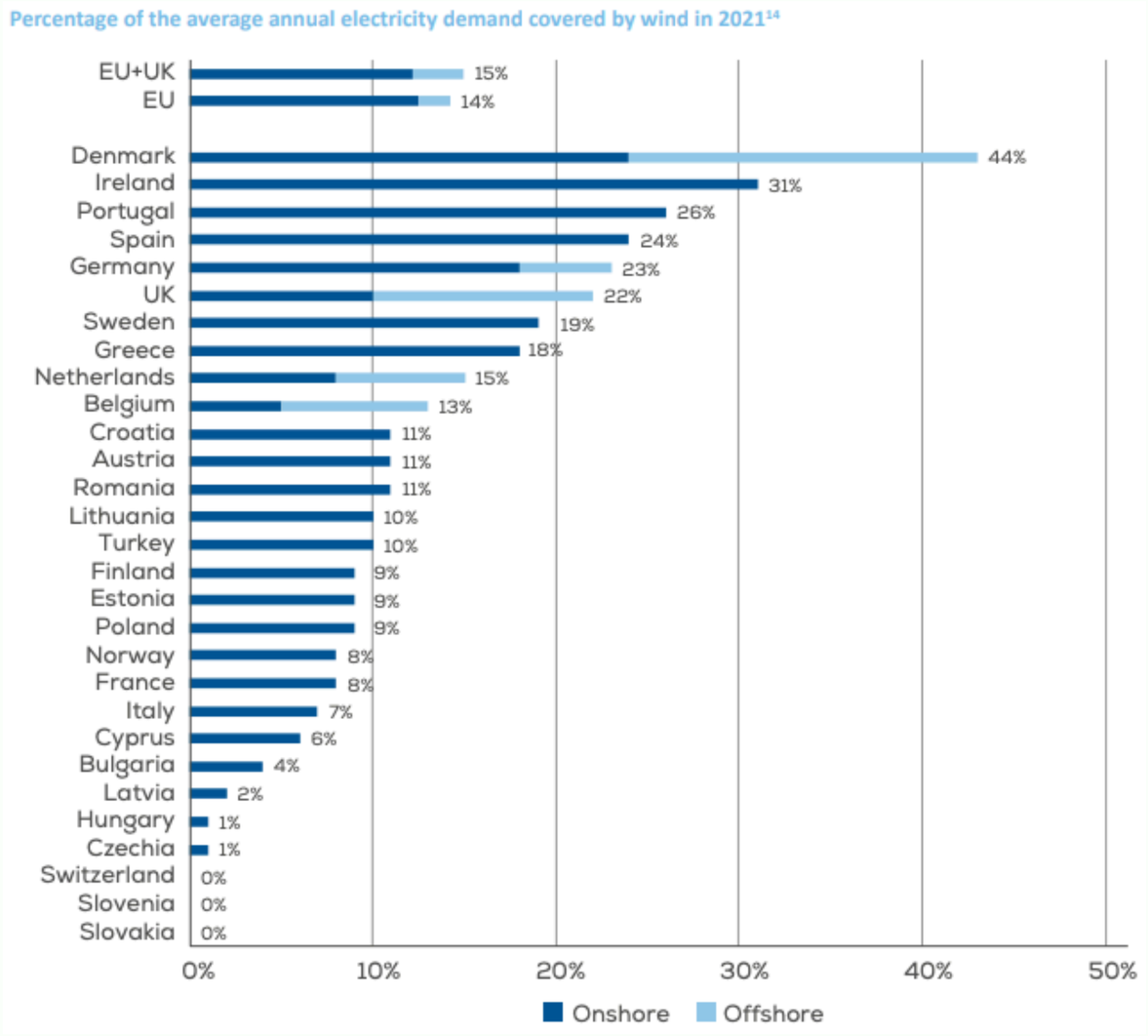
https://valitsus.ee/en/media/367/download

ENERGY CONSUMPTION BREAKDOWN



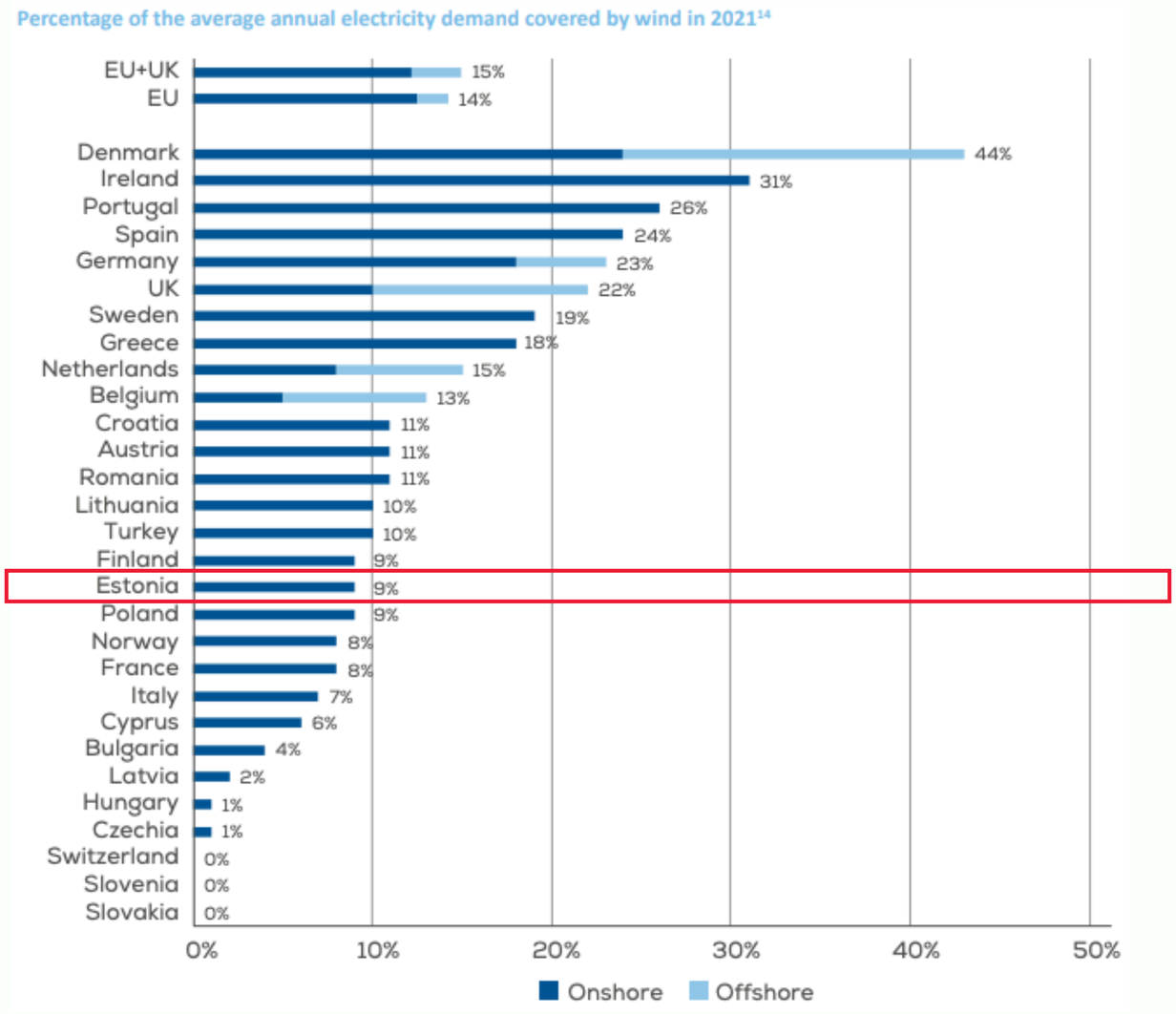
[Accessed May 5, 2025], https://www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023

WIND POWER IN EU



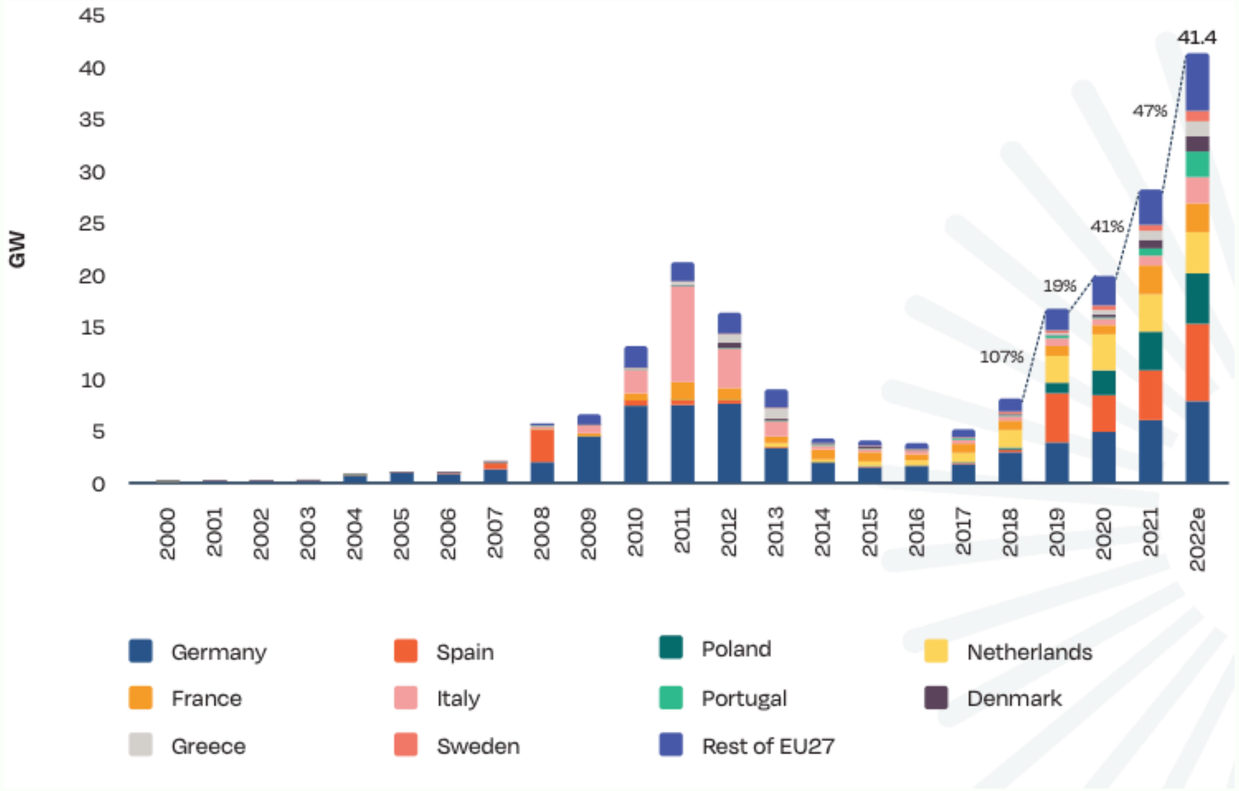
[Accessed May 5, 2025], https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2021-statistics-and-the-outlook-for-2022-2026/

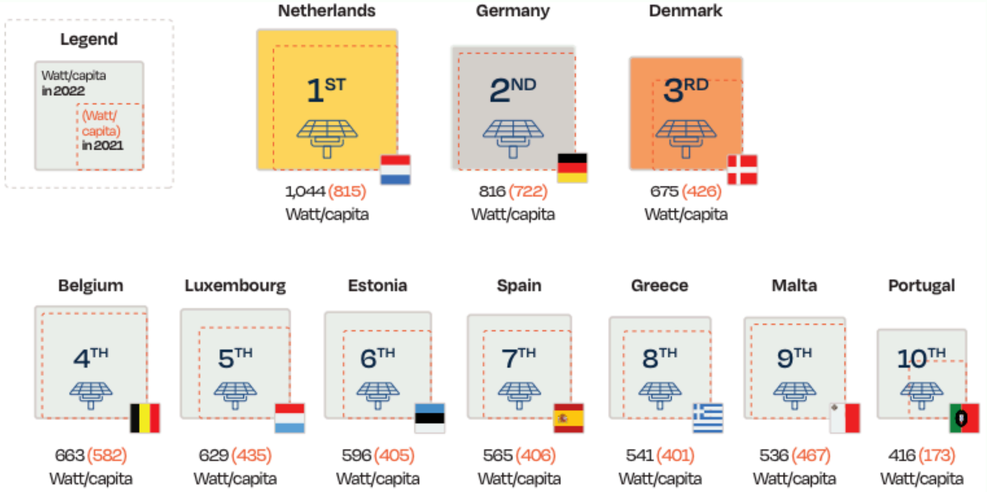
WIND POWER IN EU

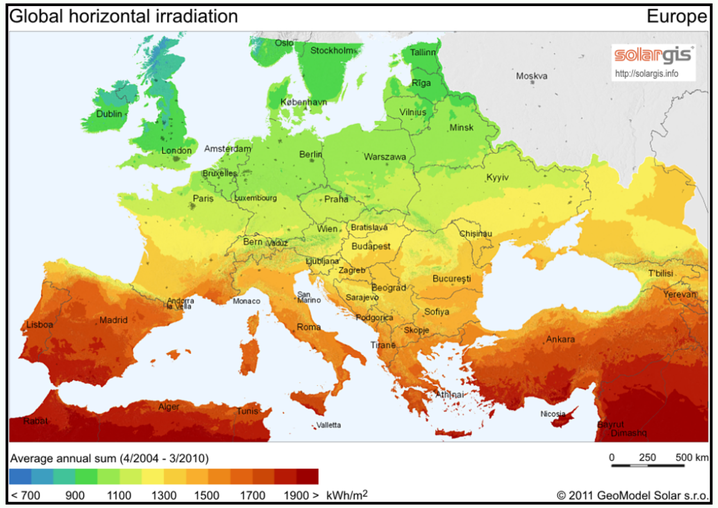


[Accessed May 5, 2025], https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2021-statistics-and-the-outlook-for-2022-2026/

SOLAR POWER IN EU

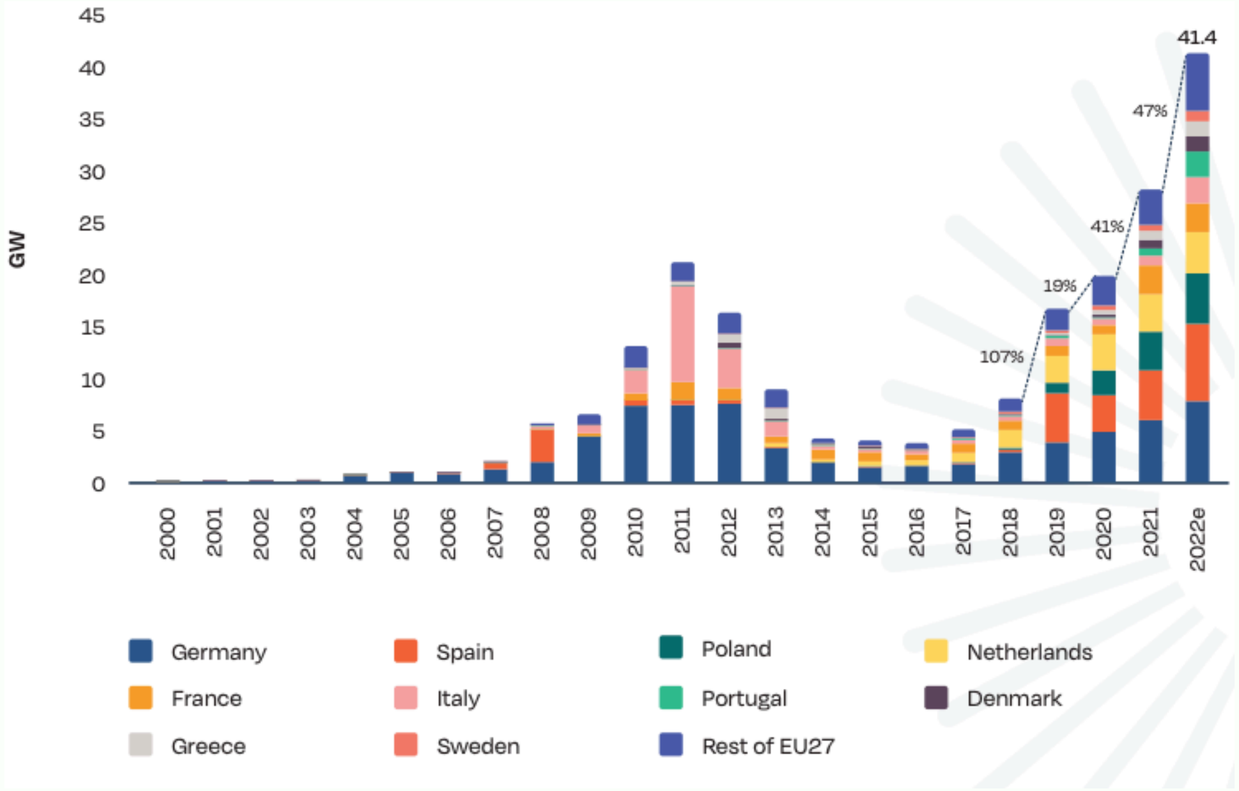


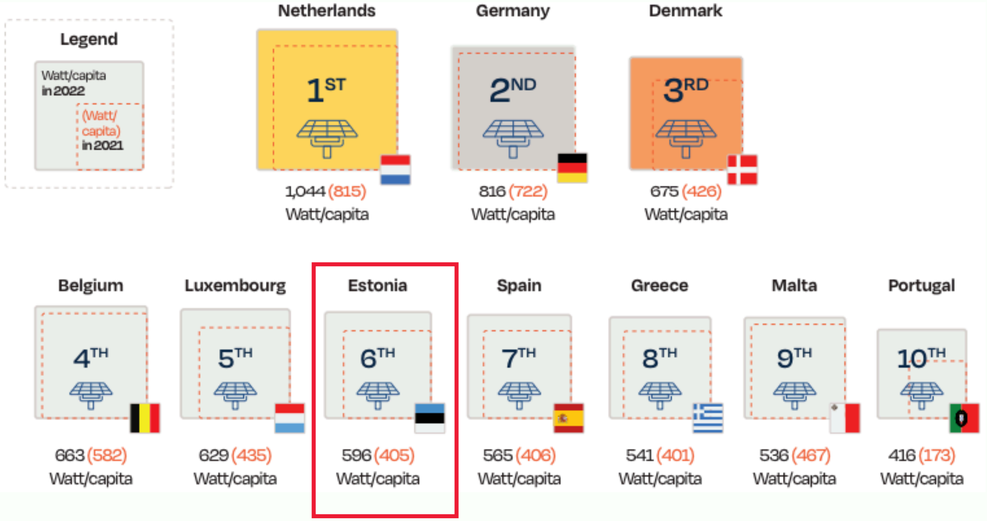


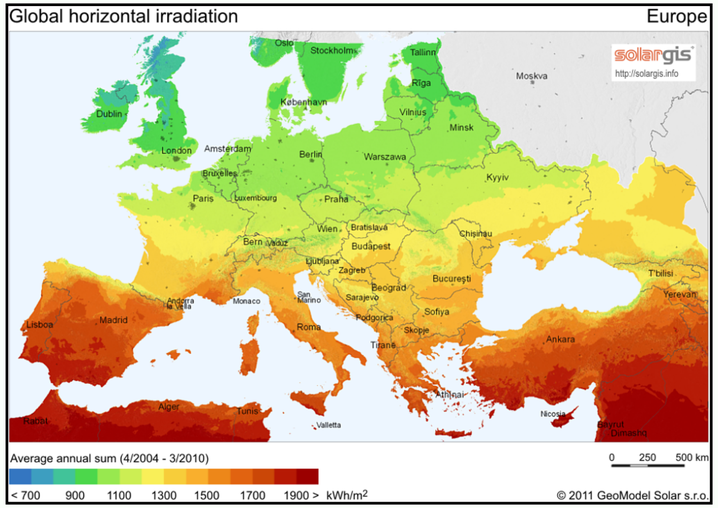


[Accessed May 5, 2025], https://www.solarpowereurope.org/press-releases/new-report-reveals-eu-solar-power-soars-by-almost-50-in-2022

SOLAR POWER IN EU







[Accessed May 5, 2025], https://www.solarpowereurope.org/press-releases/new-report-reveals-eu-solar-power-soars-by-almost-50-in-2022

SOLAR POWER WORLDWIDE PERSPECTIVE

1. Gonghe Talatan Solar Park (China): 15.6 GW
2. Hobq (China): 4 GW
3. Tog Front (China): 4 GW
4. Midong (China): 3.5 GW
5. Bhadla (India): 2.245 GW

[Accessed May 5, 2025], https://www.solarinsure.com/largest-solar-power-plants

SOLAR POWER WORLDWIDE PERSPECTIVE

1. Gonghe Talatan Solar Park (China): 15.6 GW
2. Hobq (China): 4 GW
3. Tog Front (China): 4 GW
4. Midong (China): 3.5 GW
5. Bhadla (India): 2.245 GW

Electricity consumption and generation

Estonia's all-time peak electricity consumption was 1,599 MW (4 January 2024).

[Accessed May 5, 2025], https://www.solarinsure.com/largest-solar-power-plants

Thank you!
Questions?