Energy Economics, Winter Semester 2024-5
Lecture 1: Organisation & Introduction

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Administration

Prof. Dr. Tom Brown

Department of 'Digital Transformation in Energy Systems', Institute of Energy Technology

I specialise in the modelling of energy systems to meet strict greenhouse gas emission targets. I work at the intersection of engineering, economics, informatics, mathematics & meteorology.

Philipp Glaum is a scientist in the group and will lead the tutorials; he can also answer any organisational questions (**p.glaum@tu-berlin.de**).

Group website: **https://www.tu.berlin/ensys**

Personal website: **https://nworbmot.org/**

Course Website

You can find lecture notes, exercise sheets and all other information on ISIS:

https://isis.tu-berlin.de/course/view.php?id=40267

Course ISIS name: [WiSe 2024/25] Energy Economics

Announcements will also be made there, and you can ask questions in the discussion forum.

Lecture slides will be available shortly before each lecture and online until after the exam.

Old video recordings of the lectures from 2022/3 will also be available.

Course Structure: 6 ECTS

The course has 6 ECTS.

Registration:

- via MTS (up to one week before the exam)
- Erasmus: try via MTS, if that fails, email Philipp Glaum

Written exam in presence

- 90-minute written exam in presence
- First exam on 04.03.2025, second exam/resit on 02.04.2025
- No materials may be used in exam except calculator
- Sample exam in the last week of lectures
- Content: as in lecture and tutorials
- Voluntary group project (six unsupervised study periods in Jan/Feb) can boost grade by 5 points (5% of total)

Course ‘Data Science for Energy System Modelling’

6 ECTS course starts Wednesday 16th October at 2pm, led by Dr. Fabian Neumann.

- Students get hands-on experience modelling and analysing future energy systems
- All coursework in programming language Python plus associated libraries
- Focus on renewable energy resources, storage and network infrastructures
- Working with real data on weather, land use, power plants, grids and demand
- Learn about the challenges and solutions for a successful transition towards climate-neutral energy systems across the globe

Course ISIS page

Seminar ‘New Developments in Energy Markets’ (3 ECTS)

- Students analyse a current topic in energy markets, prepare a presentation and present it for discussion
- Presentations as a block at the end of the lecture-free period
- Supervision and discussion led by Prof. Erdmann, Prof. Grübel and scientific employees of the department
- Students work on topic with a supervisor during semester
- Topics will be presented in November 2024, presentations in March 2025
- Example topics: market reform, EEG, European Green Deal, e-mobility, hydrogen economy, industrial decarbonisation, flexibility markets, etc.

Schedule for Lectures and Tutorials

Day	Time	Location	Event
Tuesday	1000-1200	MA 004	Lecture
Wednesday	1200-1400	BH-N 333	Tutorial
Thursday	1600-1800	H 0110	Lecture

First lecture: Tuesday 15th October 2024, last lecture: Thursday 13th February 2025

First tutorial: Wednesday 23rd October 2024, last tutorial: Wednesday 12th February 2025

Group work

- Voluntary group work (up to 5 students)
- 6 study periods instead of lectures and exercises
- Probably starting 06. or 13.01.2025
- Programming needed (can use Python/Matlab/R)
- Report and presentation
- Boost grade by up to 5 points (5%)
- Rewards: Deeper understanding of the topic, methodological competence and extra bonus points for the exam

There is no book which covers all aspects of this course; the world of energy markets is also changing fast. The following are at least concise:

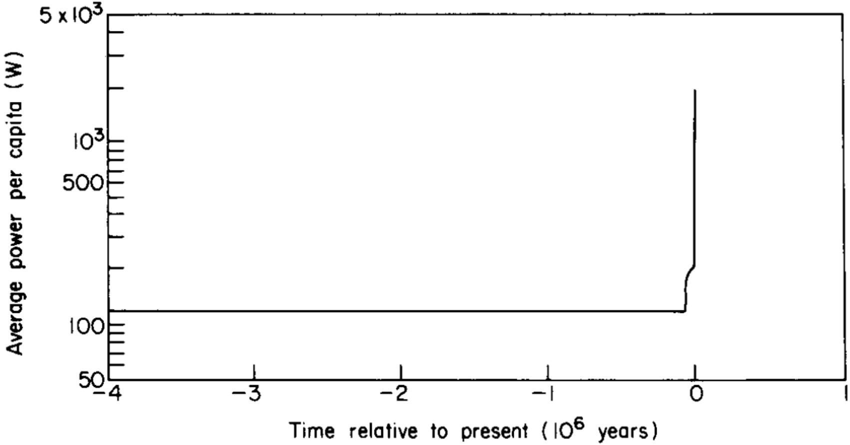
- G. Erdmann, A. Praktiknjo, P. Zweifel, “Energy Economics - Theory and Applications,” Springer, 2017
- M. Grubb et al, “Planetary Economics,” Routledge, 2013, **available online**
- S.C. Bhattacharyya, ”Energy Economics. Concepts, Issues, Markets and Governance,” Springer, 2011
- D.R. Biggar, M.R. Hesamzadeh, “The Economics of Electricity Markets,” Wiley, 2014
- C.A. Dahl, “International Energy Markets: Understanding Pricing, Policies, and Profits,” PennWell, 2004
- S. Stoft, “Power System Economics: Designing Markets for Electricity,” IEEE Press. 2002

Course outline

- Measuring energy, energy balances
- Basics of microeconomics
- Financial management
- Electricity markets
- Electricity grids
- Supporting renewables
- Emissions markets
- Resource management
- Oil markets
- Gas markets
- Learning curves and long-term dynamics
- Sector coupling
- Climate economics
- Current research topics

History and Definition of Energy Economics

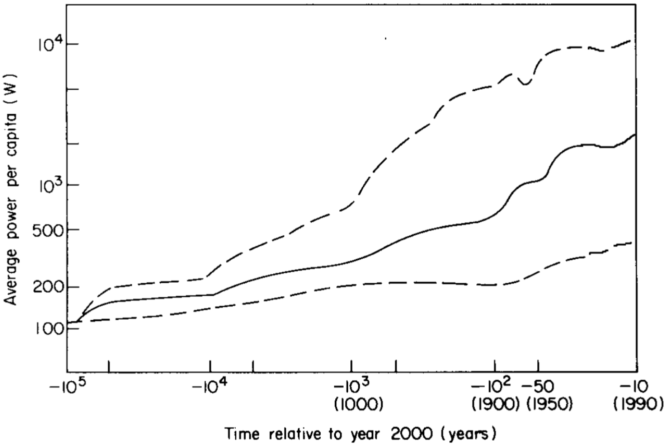
It is hard to exaggerate the historical discontinuity of modern energy consumption.



Source: Sørensen, "Renewable Energy", 1979

Average energy use over time

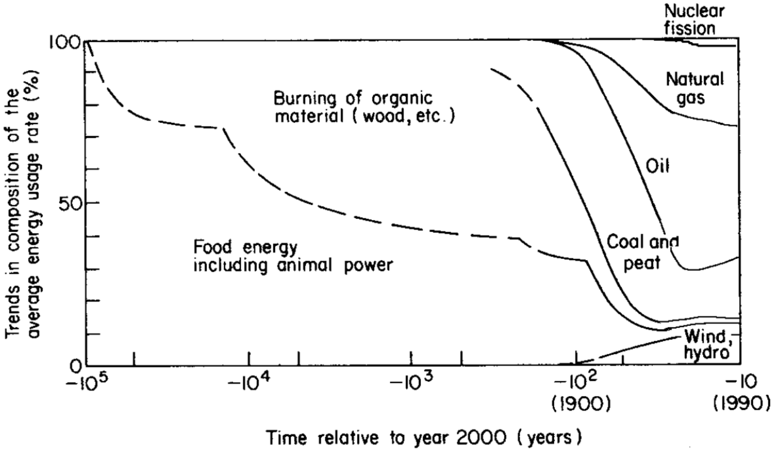
A logarithmic time axis is necessary. Solid line is world average, dashed lines show societies with highest and lowest energy use.



Source: Sørensen, "Renewable Energy", 1979

Several energy transitions

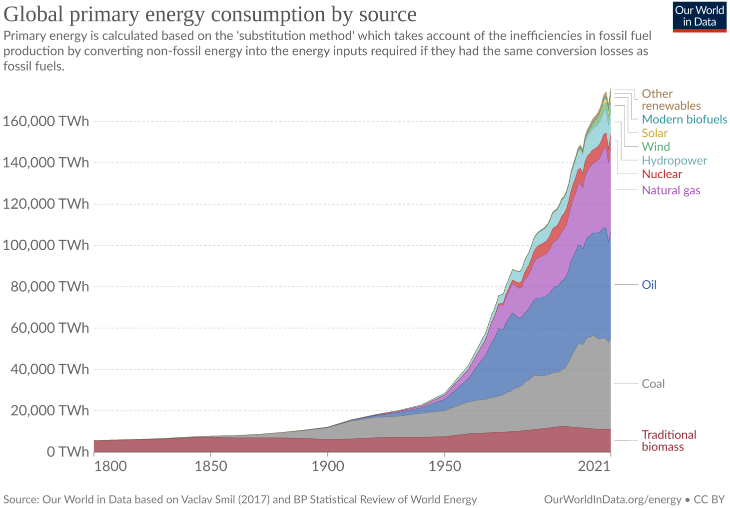
Energy transitions from muscle to biomass to coal to oil and gas, next: low-carbon electricity?



Source: Sørensen, "Renewable Energy", 1979

Primary energy growth

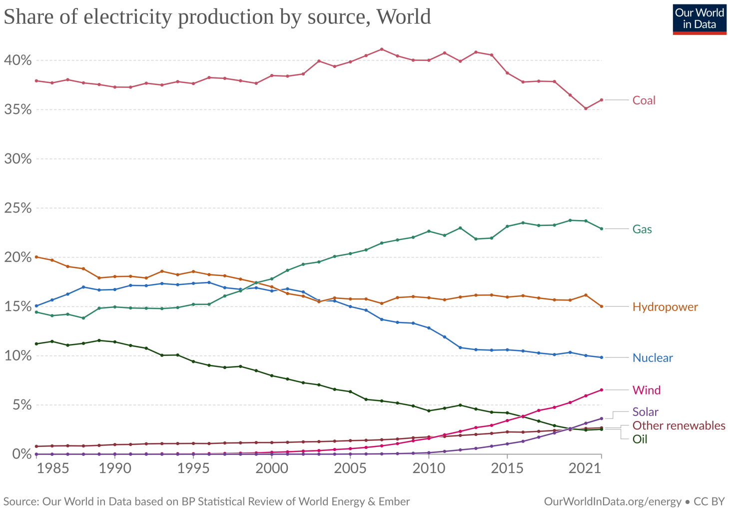
Extraordinary growth in primary energy consumption since 1950s, much in oil and gas.



Source: Our World in Data, 2022

Electricity: rate of change is important

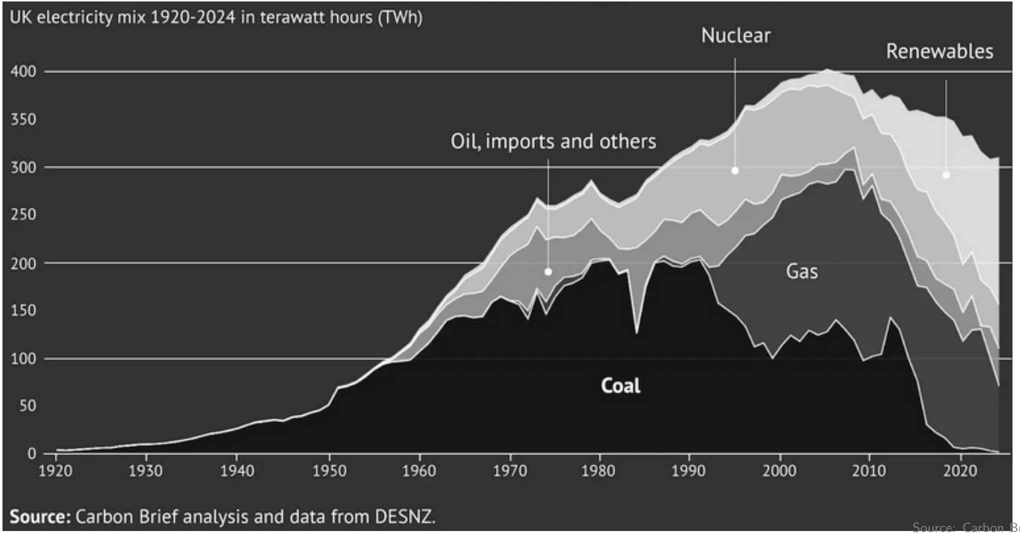
See growth of wind and solar. They surpassed 10% of world electricity in 2021.



Source: **Our World in Data, 2022**

Electricity: rate of change is important

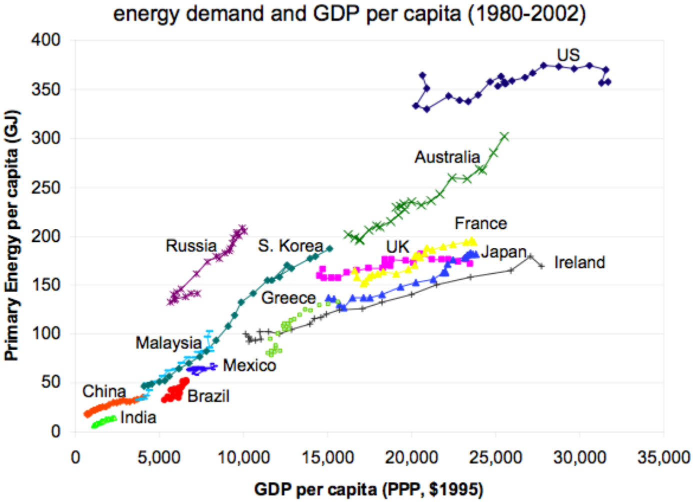
In OECD countries, coal is being pushed out by a combination of gas and renewables.



Source: Carbon Brief, 2024

Economic development and energy use go together

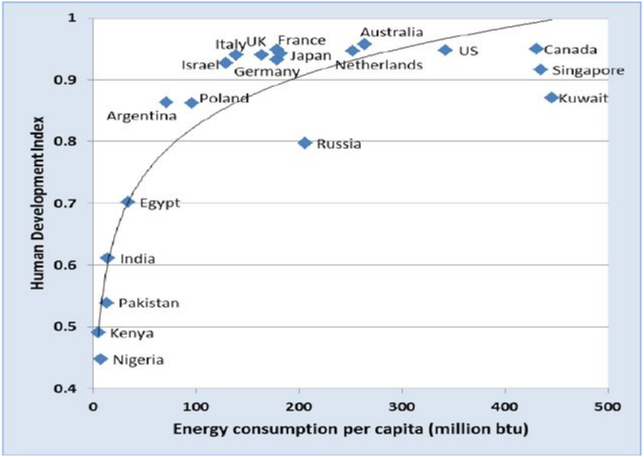
Energy demand versus GDP over time for selected countries.



Source: UN and DOE EIA

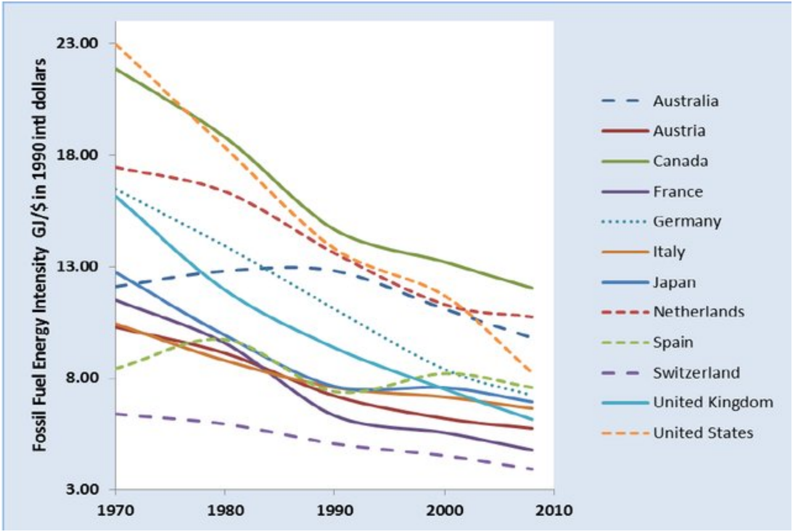
Economic development and energy use go together

Modern prosperity depends on a functioning energy supply for electricity, warmth/cooling, mobility and energy-intensive food and products.



Source: **Slaus & Jacobs**, 2011

Fossil-fuel intensity is decreasing



Source: **Slaus & Jacobs**, 2011

Why ‘energy economics’ ?

Like any area where there are diverse uses for a good with different value to consumers, as well as scarcity on the supply side leading to different supply costs, markets can play a role in allocating goods. Economics is the study of this allocation.

This raises further questions:

- What makes energy different to other goods?
- Why a whole subject ‘energy economics’ ?
- Why is energy politically so important?
- How does energy influence geopolitics?
- What questions does ‘energy economics’ try to answer?

What makes energy economics different from regular economics?

The unique features of energy are numerous:

- **Essential for modern life**: for farming, cooking, lighting, comfort in buildings (heating and cooling), communication, mobility, production of most goods. This makes it a **political concern**.
- **Essential to all economic activity**. Cf. negative economic consequences of electricity blackouts in South Africa, European gas crisis of 2021-2022.
- Reserves of fossil fuels and production capacity/minerals for renewables & storage are **concentrated in a few countries**. Geopolitics!
- **Large externalities**: most greenhouse gas emissions come from use of fossil fuels in energy, leads to climate breakdown; air pollution leads to widespread health impacts; for nuclear in meltdown and waste risk; for renewables in landscape impact.
- **High potential for innovation and cost reduction**: wind, solar, batteries, electrolysers.

What makes energy economics different from regular economics?

- Energy is **abundant** in nature, but mostly not immediately available for doing useful work.
- Infrastructure (transmission, generators) requires **long periods** of planning, investment and operation. Leads to slow change - inertia!
- In many markets there are **monopoly structures**, which are resistant to market solutions and need regulation (e.g. transmission networks, but also vertically-integrated utilities in some regions).
- Infrastructure **property rights** (e.g. underground, hydro) are sometimes with public rather than private sector.
- Some **risks are diffuse and widespread** (nuclear, hydro, landscape impact of wind).

Source: Zweifel et al, Energy Economics, 2017

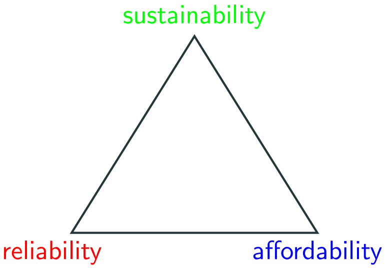
What questions does energy economics try to answer?

Here is a typical selection of energy economics questions:

- How do we allocate consumption and production of energy by existing assets (short run)?
- How should we investment in energy consumption and production assets in the long run?
- How can we most efficiently reduce greenhouse gas emissions and air pollution from the energy sector?
- Wind and solar power are low-cost, but how do we efficiently deal with their variability?
- How do we design markets for variable renewable energy?
- Is a decentral system design better than a centralised one?
- Can we protect vulnerable consumers from energy market volatility?

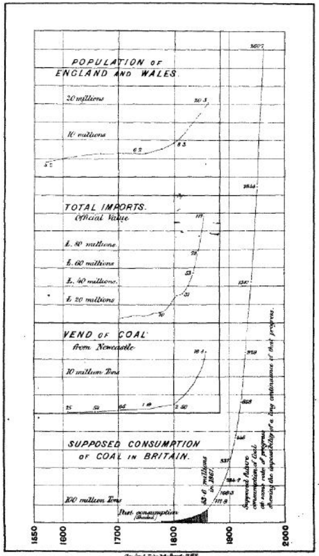
Guidelines for Energy Policy: Trilemma

What should a well-functioning energy system look like? We design with respect to three goals:



- **Sustainability**: Respect environmental constraints (greenhouse gases, air quality, preservation of wildlife), as well as social and political constraints (public acceptance of transmission lines, onshore wind, nuclear power)
- **Reliability**: Ensure energy services are delivered whenever needed, even when the wind isn't blowing and the sun isn't shining, and even when components fail
- **Affordability**: Deliver energy at a reasonable cost

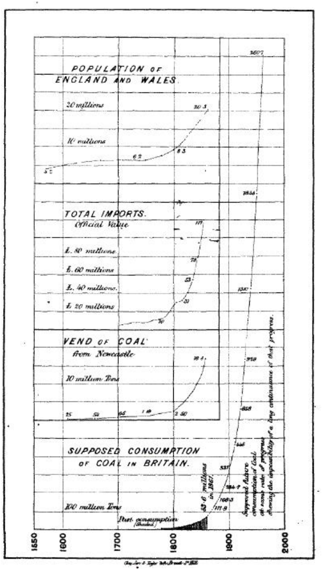
Some of these policy targets can come into **conflict** - an **energy trilemma**.



In 1865 William Stanley Jevons published **The Coal Question**, whose concern was the exhaustion of coal reserves in Britain given exponentially rising demand.

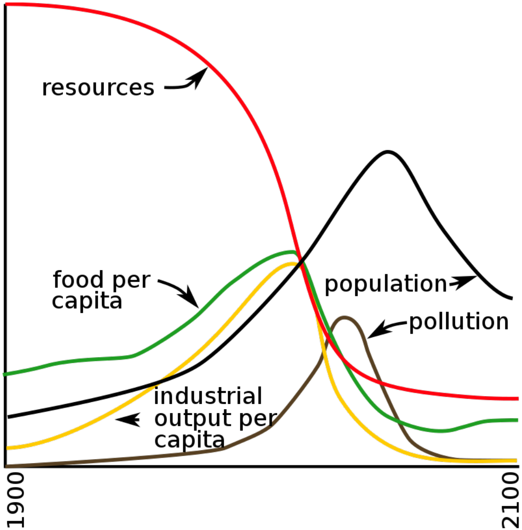
- "With coal almost any feat is possible or easy; without it we are thrown back into the laborious poverty of early times."
- "I must point out the painful fact that such a rate of growth will before long render our consumption of coal comparable with the total supply. In the increasing depth and difficulty of coal mining we shall meet that vague, but inevitable boundary that will stop our progress."
- He reviews renewables, including wind used to pump water up into reservoirs, and also green hydrogen, before dismissing them all.

Source: Jevons,1865



- **Jevons' Paradox**: "It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth...Whatever, therefore, conduces to increase the efficiency of coal, and to diminish the cost of its use, directly tends to augment the value of the steam-engine, and to enlarge the field of its operations."
- "If we lavishly and boldly push forward in the creation and distribution of our riches, it is hard to over-estimate the pitch of beneficial influence to which we may attain in the present. But the maintenance of such a position is physically impossible. We have to make the momentous **choice between brief greatness and longer continued mediocrity**."

Source: Jevons,1865



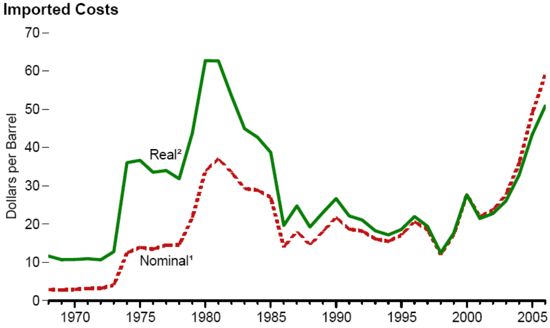
1972 report **The Limits to Growth**, commissioned by the Club of Rome, examined consequences of exponential economic and population growth with a finite supply of resources with a computer simulation.

- Conclusion: "the most probable result will be a rather **sudden and uncontrollable decline** in both population and industrial capacity".
- But ignores role of technological progress.
- Growth versus limits versus progress: debate continues today.

Source: [Limits to Growth]

In 1973 OPEC led by Saudi Arabia embargoed oil in response to the Yom Kippur War. Oil price jumps from 4 to 12 USD/barrel, before rising further in 1979 crisis following Iranian Revolution.

Fossil fuels are intimately tied to **geopolitics**. Triggered blooming of energy studies.



1973 oil crisis as a catalyst for change

In 1972, 92% of Denmark's energy consumption came from imported oil.

Catalyst for many people (mostly physicists - that's another story) to rethink energy supply: Amory Lovins ('Soft Energy Paths' 1976-7); Art Rosenfeld on Energy Efficiency; Union of Concerned Scientists report 'Energy Strategies: Toward a Solar Future' (1980); Bent Sørensen; Swedish Secretariat for Futures Studies; Le Groupe de Bellevue, ALTER: A Study of a Long-Term Energy Future for France based on 100% Renewable Energies (Paris, 1978); Wolf Häfele, Jeanne Anderer, A. McDonald and Nebojsa Nakicenoviç, Energy in a Finite World (Cambridge, MA: Ballinger, 1981), many others...

1975: Bent Sørensen: 1st consistent 100% RE scenario

In 1975 Bent Sørensen published a scenario for 100% renewable energy in Denmark. He dealt with the variability of wind (with hydrogen) & solar thermal (with TES).

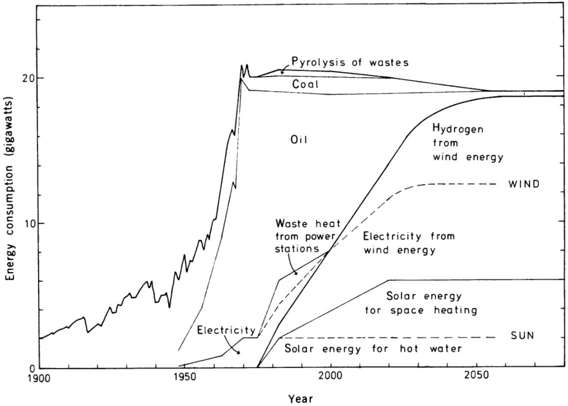


Fig. 4. Net energy consumption in Denmark, shown according to sources. Up to 1974, actual data are shown (*14*); data after 1974 indicate the proposed plan. The relative weighting between solar and wind energy shares might be altered, for example, if a major breakthrough occurred in the development of solar cells, making them competitive to wind-produced electricity under Danish conditions. The heavy, solid line indicates the proposed total share of solar and wind energy.

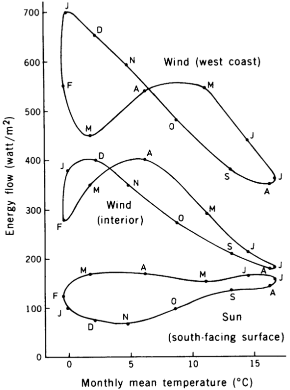


Fig. 2. Monthly average energy flow from continuous sources through a vertical square meter in Denmark, as function of the monthly mean temperature. The sun's height over the horizon at noon is 11° at winter's solstice. The wind data are taken 25 meters above smooth ground.

Source: Sørensen (1975) Science

Gas crisis of 2021-22

Russian re-invasion of Ukraine led to a geopolitical crisis, halt to almost all Russian gas imports and gas price peaks in 2022 of 17 times the previous equilibrium price.

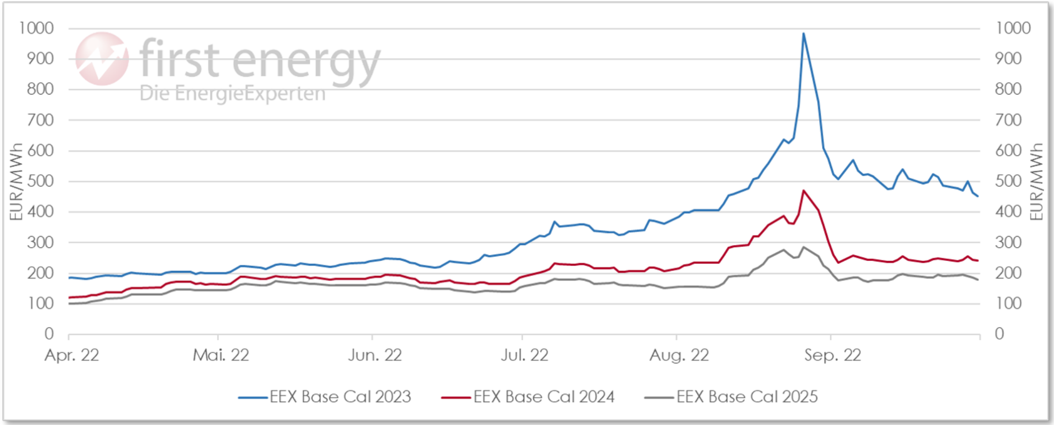
4.1 Gaspreise Großhandel

in EUR/MWh

Source: BNetzA, 2023

German 2022 electricity prices were six times higher than 2020

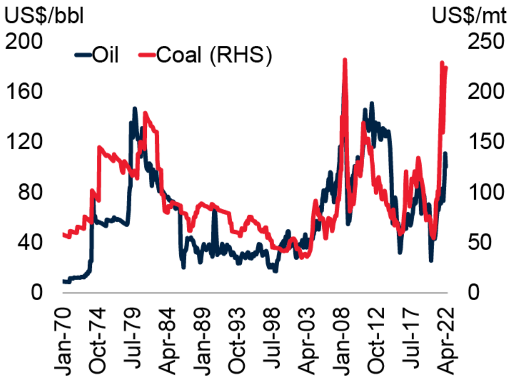
Gas powerplants often set the price in European electricity markets, leading to exploding prices.

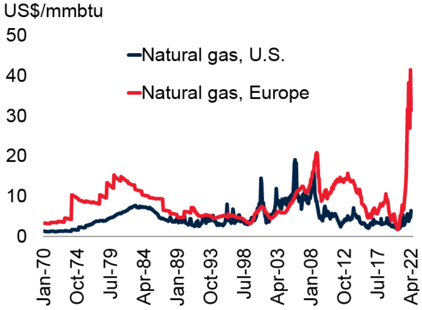


Source: [First Energy, 2022]

2022 was biggest energy market crisis since 1970s (or ever?)

All major energy carriers were hit in the 2022 crisis: oil, coal, gas and electricity. (‘Real prices’ means inflation-adjusted prices, as opposed to non-adjusted ‘nominal prices’.)





Source: World Bank, 2022

Impact of gas crisis is worldwide thanks to global LNG market

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Demand response to high LNG prices varied widely among the main importers in Asia

Gas demand impacts of high spot LNG prices across Asia

23 TWh

Pakistan
- Deep energy crisis with economy-wide implications
- Rolling blackouts of up to 12 hours
- LNG imports down 19% y-o-y in January-August 2022
- Spot LNG purchases down to a bare minimum
- Oil-fired generation up fivefold

7 TWh

Bangladesh
- No spot LNG purchases in July-August 2022
- Load shedding of up to 20% in mid-July
- Mandatory conservation measures

47 TWh

India
- Power sector gas burn down 28% y-o-y in January-August 2022 (partly replaced with coal)
- Reduced gas use in refining (down 29%) and chemicals (down 23%) mostly replaced with oil

>90 TWh

China
- Power sector gas use down by 9% y-o-y in January-August 2022
- Evidence of demand destruction in industry and transport

0 TWh

Japan
- Accelerated restart of 7 nuclear reactors from mid-2023
- Contingency plan for LNG supply cut scenario

10 TWh

Korea
- Voluntary coal restrictions suspended for summer 2022
- Accelerated start-up of new coal-fired and nuclear units

11 TWh

Thailand
- Power sector gas burn down by 6% y-o-y in January-July 2022, diesel generation up 16-fold
- Buy tenders cancelled or unawarded due to high price

Legend:

Primarily demand destruction | Primarily fuel-shift

Graph from IEA Gas Outlook 10/2022, preliminary numbers added

Source: IEA via Karsten Neuhoff, 2022

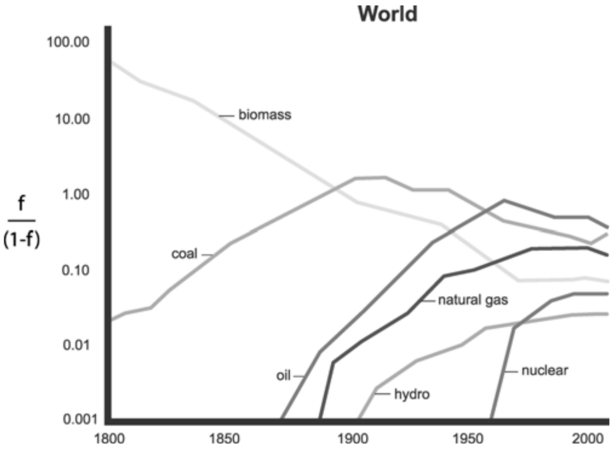
Today: urgent need for energy market reform

The list of necessary reforms is long and diverse:

- Current tax and subsidy structure: e.g. electricity heavily taxed compared to gas and oil for heating, hindering switch to heat pumps (solutions: reduce EEG-Umlage/Stromsteuer, raise CO_2 price on fossil fuels, subsidise heat pumps)
- Insufficient incentives for flexible demand and storage
- Expansion of wind and solar too slow in many regions
- More locational signals for demand and supply coordination
- Need more incentives for building renovations
- Further digitalisation of energy use and supply
- Investment incentives for decarbonisation of industry, hydrogen infrastructure

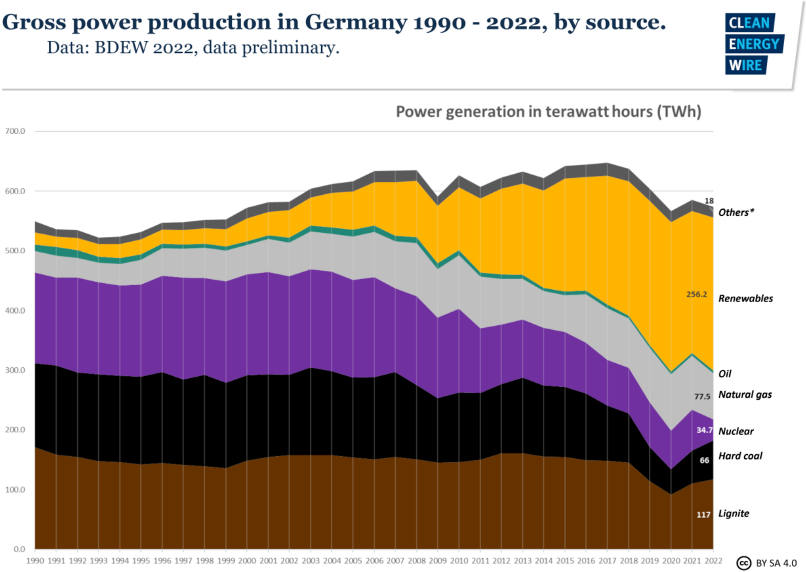
Introduction to Energy Transitions

From 1800 to 2010 biomass dominance replaced by hydrocarbons and electricity. Fossil fuel shares steady since 1970. f is fraction of primary energy supply.



Source: Vaclav Smil, "Energy Transitions", 2010

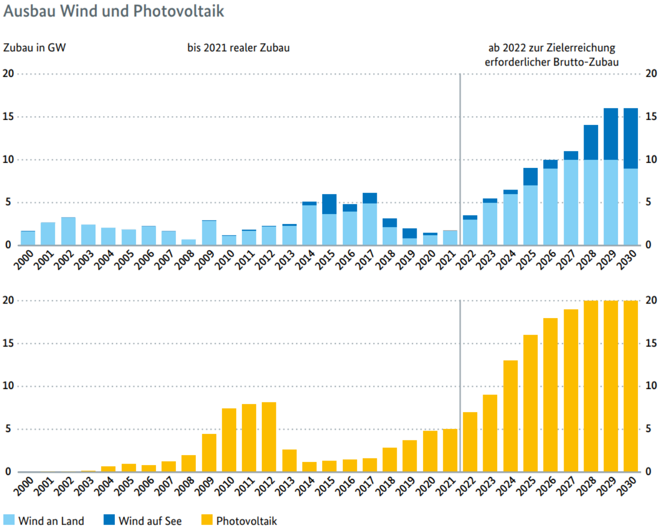
Renewables reached 44.6% of gross electricity in Germany in 2022



Source: Clean Energy Wire, 2023

Build-out rates for wind and solar need to increase rapidly

New traffic light coalition has target of 80% renewable electricity by 2030, 100% by 2035.



Source: BMWK, 2022

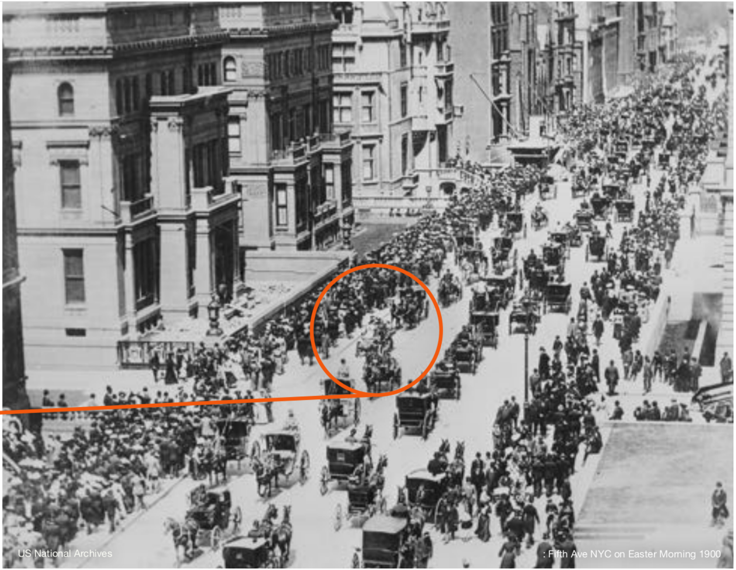
1900: Where's the car?

Technische Universität Berlin

5th AVE NYC

1900

Where is **the car?**



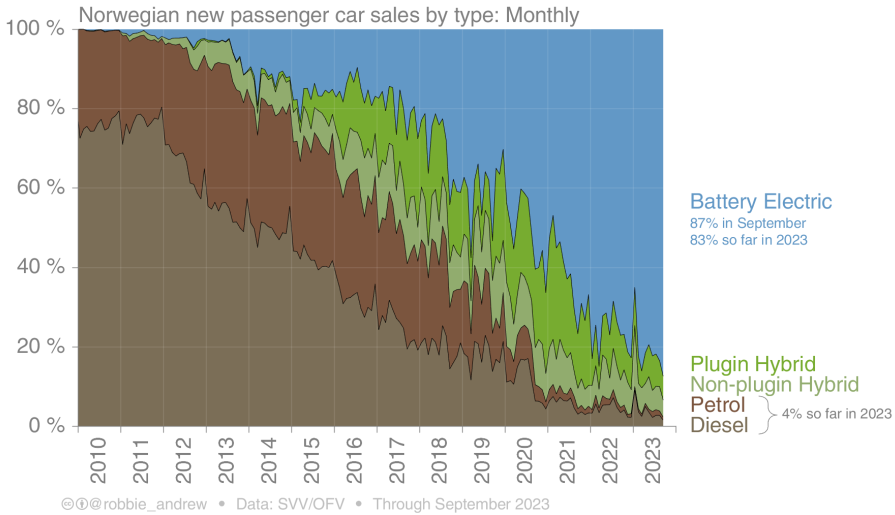
5th AVE NYC

1913

Where is the horse?

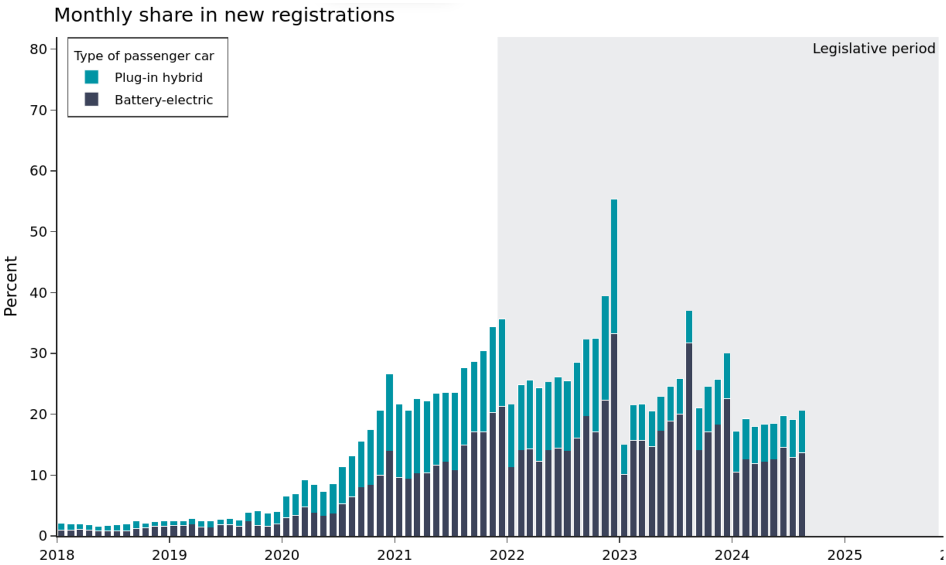
Photo: Easter 1913, New York. Fifth Avenue looking north.

Electric vehicles take off, first in Norway



Source: **Robbie Andrew, 2023**

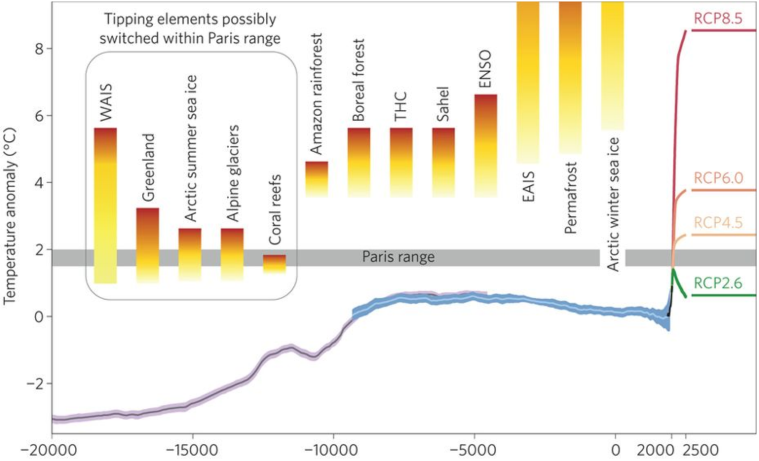
Electric vehicles: Germany catching up / stalling



Source: **Open Energy Tracker, 2024**

Climate Breakdown: 2015 Paris Agreement

The 2015 Paris Agreement pledged its signatories to 'pursue efforts to limit [global warming above pre-industrial levels] to **1.5°C**' and hold 'the increase...to **well below 2°C**'. These targets were chosen to avoid potentially irreversible **tipping points** in the Earth's systems.



WAIS: West Antarctic Ice Sheet ($\Rightarrow$ 5m sea level rise)

Greenland (7m)

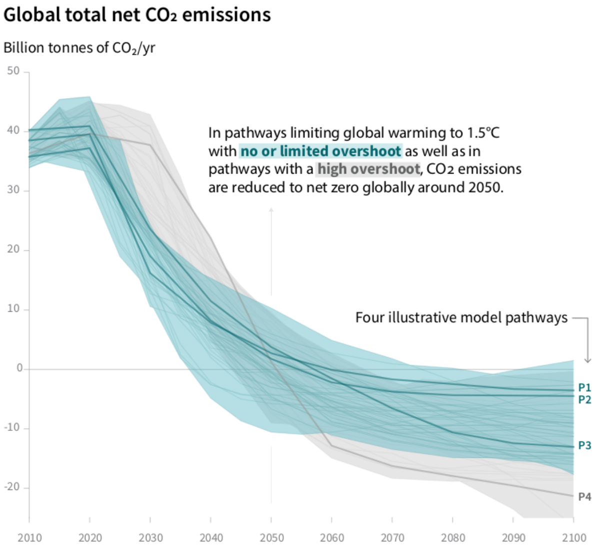
THC: thermohaline circulation (warms Europe)

ENSO: El Niño–Southern Oscillation (extreme weather)

EAIS: East Antarctic Ice Sheet ($>$ 50 m)

Source: **'Why the right climate target was agreed in Paris'**, Nature Climate Change, 2016

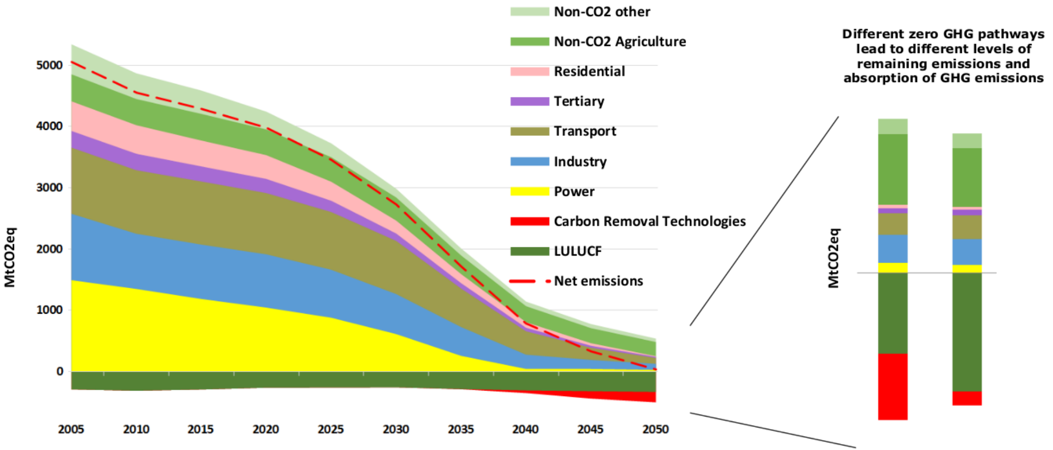
The Global Carbon Dioxide Challenge: Net-Zero Emissions by 2050



- Scenarios for global CO_2 emissions that limit warming to 1.5°C about industrial levels (**Paris agreement**)
- Today emissions **still rising**
- Level of use of negative emission technologies (NET) depends on rate of progress
- 2°C target without NET also needs rapid fall by 2050
- Common theme: **net-zero by 2050**

Source: IPCC SR15 on 1.5C, 2018

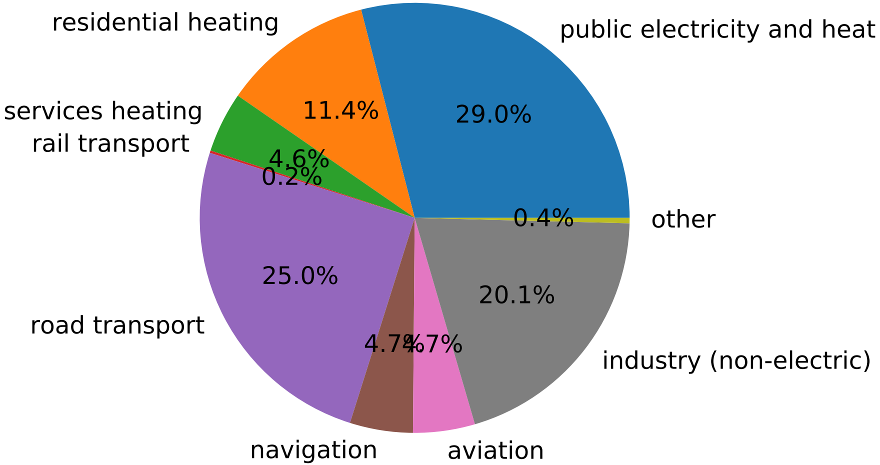
Paris-compliant 1.5° C scenarios from European Commission for **net-zero GHG in EU by 2050**. This target has been adopted by the EU and enshrined in the **European Green Deal**.



Source: European Commission 'Clean Planet for All', 2018

It's not just about electricity demand...

EU28 CO_2 emissions in 2016 (total 3.5 Gt CO_2, 9.7% of global):



Source: Brown, data from **EEA**

...but electrification of other sectors is critical for decarbonisation

Electrification is essential to decarbonise sectors such as transport, heating and industry, since we can use low-emission electricity from e.g. wind and solar to displace fossil-fuelled transport with electric vehicles, and fossil-fuelled heating with electric heat pumps.

Some scenarios show a **doubling or more of electricity demand**.

Source: Tesla; heat pump: Kristoferb at English Wikipedia

Efficiency of renewables and sector coupling

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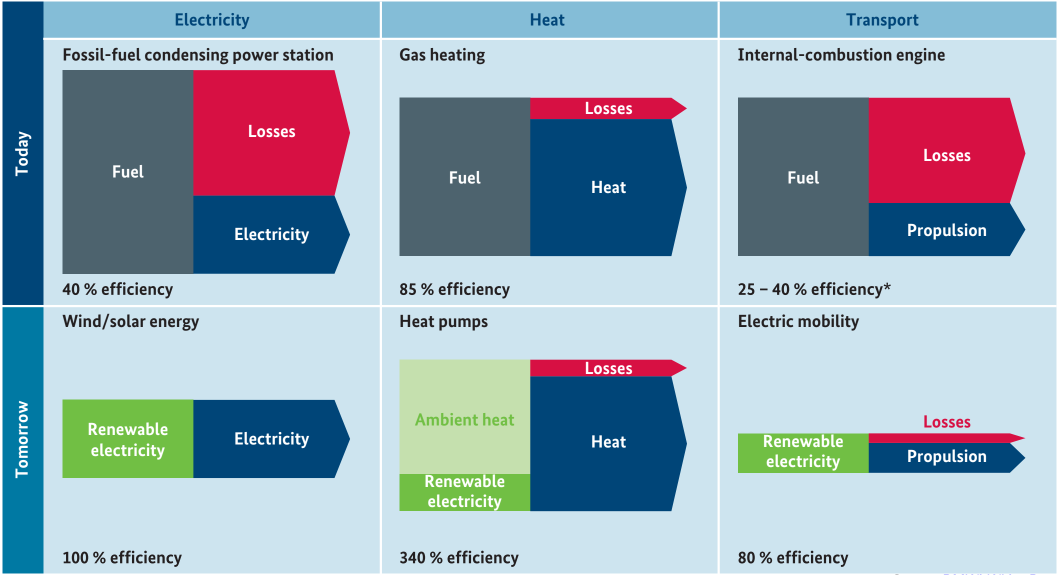

Source: BMWi White Paper 2015

Not just climate change: air pollution is a silent killer

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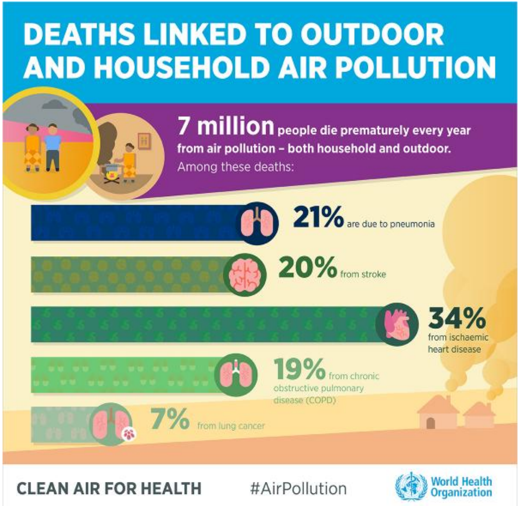
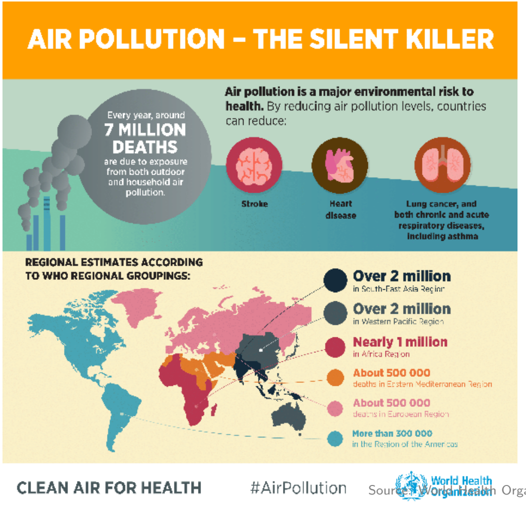
Air pollution from fossil fuel burning is linked to higher mortality (deaths) and morbidity (diseases, e.g. aggravation of asthma).

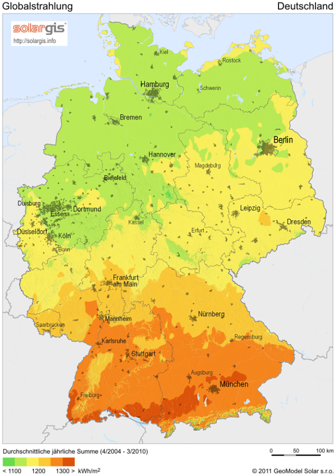


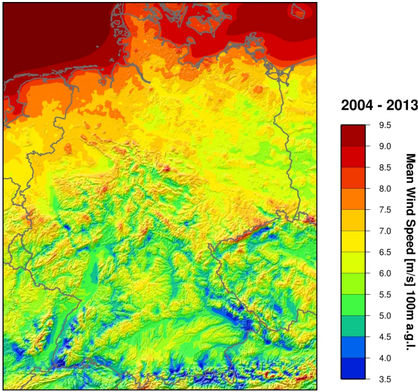


Source: World Health Organisation

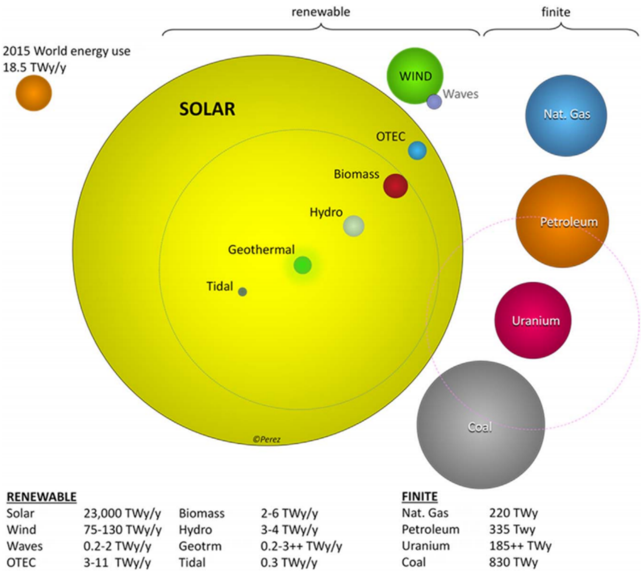
Why focus on wind and solar for electricity generation?

- construction and operation have low greenhouse gas emissions
- good wind and sun are available in many parts of the world
- worldwide potential that exceeds demand by many factors
- rapidly falling costs





Worldwide potentials



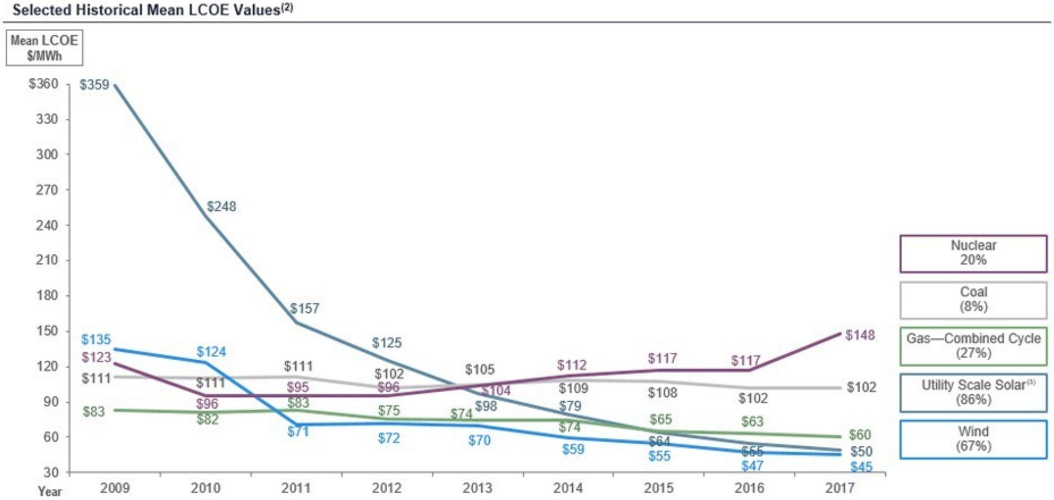
- Potentials for wind and solar exceed current demand by many factors (ignoring variability)
- Other renewable sources include wave, tidal, geothermal, biomass and hydroelectricity
- Uranium depends on the reactor: conventional thermal reactors can extract 50-70 times less than fast breeders

Source: **Perez et al, Applied Policy, 2016**

Low cost of wind & solar per MWh in 2017 (NB: ignores variability)

Technische Universität Berlin

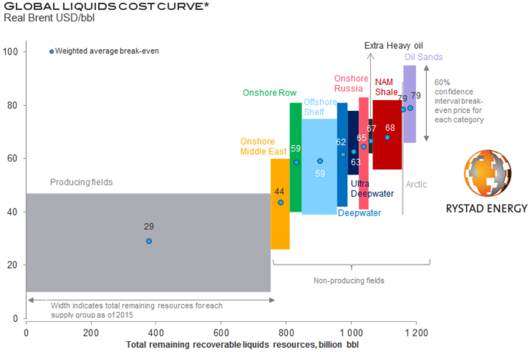
LCOE = **Levelised Cost of Energy** = Total Costs / Energy Output



Source: **Lazard's LCOE Analysis V11**

Fundamental shift from scarce exhaustible to renewable energy

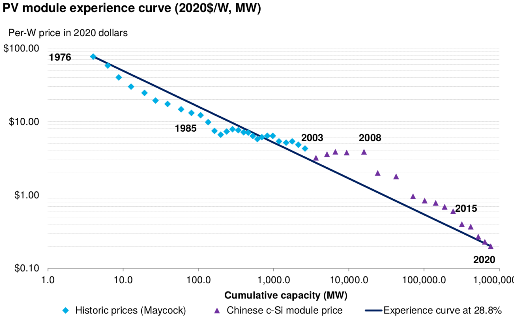
Fossil fuel costs rise with exploitation (can also drop with innovation)



*The break-even price is the Brent oil price at which NPV equals zero using a real discount rate of 7.5%. Resources are split into two life cycle categories: producing and non-producing (under development and discoveries). The latter is further split into several supply segment groups. The curve is made up of more than 20,000 unique assets based on each asset's break-even price and remaining liquids resources in 2015.
Source: Rystad Energy UCube September 2015

(2019 consumption was ∼37 billion barrels)

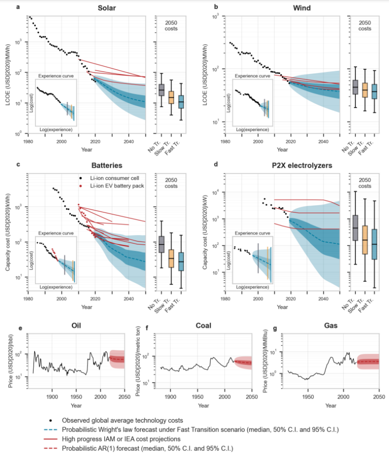
Solar and wind costs drop with innovation (can rise locally where land is scarce)



(1 TW of solar generates ∼1200 TWh/a compared to global electricity demand of ∼24,000 TWh/a)

Source: BNEF 2021

4 critical technologies: wind, solar, batteries, electrolyzers



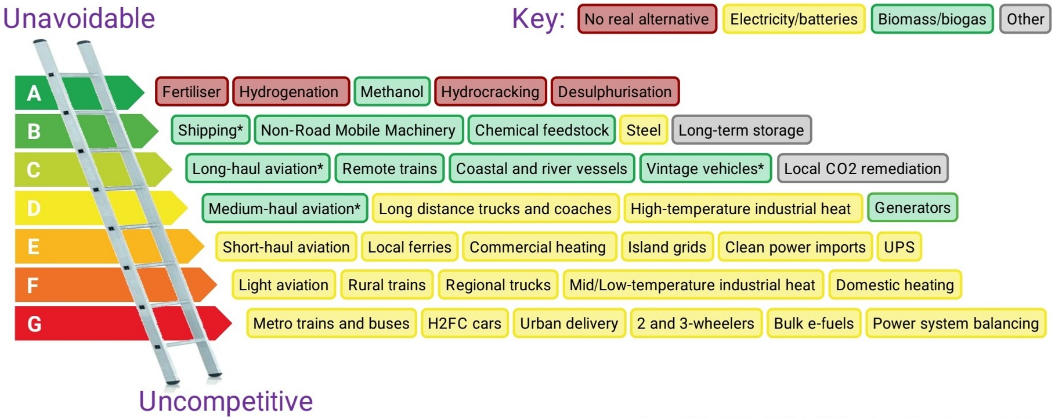
All the critical technologies for the energy transition share a small unit size, enabling fast production and installation, economies of scale in manufacturing and learning-by-doing.

- **Low-cost electricity** from wind and solar.
- **Batteries** for mobility and balancing applications.
- **Electrolytic hydrogen** (splitting water) for everything else: long-duration storage, aviation, shipping, industry.
- **Heat pumps** (missing from graphic) for building comfort and some low-temperature industry applications.

Source: Way et al, 2021

Hydrogen: the backstop of the energy transition

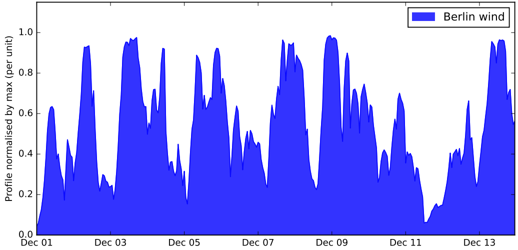
Clean hydrogen can do almost everything, but competes with direct electrification. Some say **champagne of energy transition**; could also say **backstop** for what efficiency and electrification don't reach.

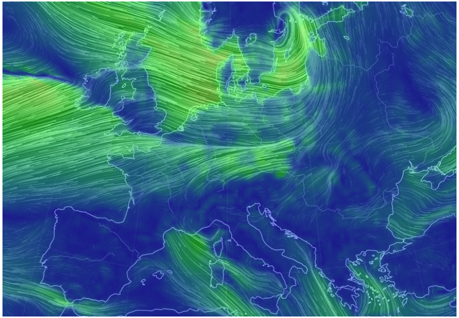


** Most likely via ammonia or e-fuel rather than H2 gas or liquid*

Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 4.1, 2021. Concept credit: Adrian Hiel, Energy Cities. CC-BY 3.0

But must take account of variability...





...and social & political constraints

Sustainability doesn't just mean taking account of environmental constraints.

There are also **social and political constraints**, particularly for transmission grid and onshore wind development.

Energy Transition: Several changes happening simultaneously

Energiewende: The Energy Transition, consists of several parts:

- Transition to an energy system with low greenhouse gas emissions
- Renewables replace fossil-fuelled generation (and nuclear in some countries)
- Increasing integration of international electricity markets
- Better integration of transmission constraints in electricity markets
- Sector coupling: heating, transport and industry electrify
- More decentralised location and ownership in the power sector