INTERNATIONAL ASSOCIATION *for* ENERGY ECONOMICS
WWW.IAEE.ORG

The Unpopular Truth… about Electricity and The Future of Energy

Energy and material input to „produce“ energy

IAEE Energy Policy

Switzerland, 17 April 2023
Dr. Lars Schernikau, energy economist, commodity trader
shareholder HMS Bergbau AG

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**Recommendation:
Check everything yourself**

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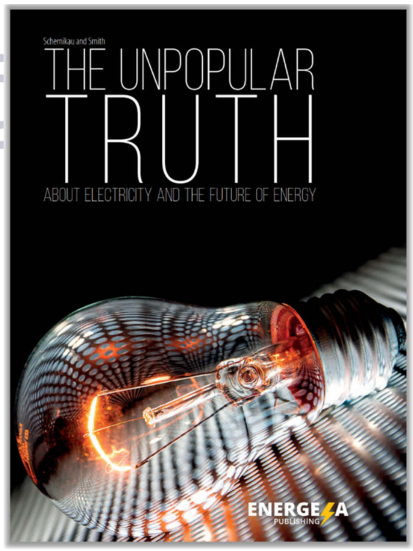
About Lars

Dr. Lars Schernikau

HMS BERGBAU AG
commodities for the future

- Lives in Switzerland & Singapore, shareholder www.hms-ag.com
- Studied in US (Finance @NYU), France (MBA @INSEAD) and Germany (Economics @TU-Berlin)
- 6+ years at The Boston Consulting Group: M&A, start-ups
- Joined raw materials business 20 years ago, today focusing on strategy and marketing HMS group's products in Asia, Africa, Americas, and Middle East
- Wrote „The Renaissance of Steam Coal" 2010 (Springer), "Why Coal Continues to Power the World" 2017 (Springer), "Unpopular Truth…about Electricity and the Future of Energy" 2022 (Energeia), several articles, and scientific papers, book- and peer-reviews
- Serves and served on the board of several energy raw material producers and marketing companies in (Eastern-)Europe, Americas, Africa, and Asia
- Regular speaker at international conferences. Has advised governments, banks and multinationals on energy policy and sustainability



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What are Key "Earthly" Challenges Today?

Humanity's key challenges

1. Food & Water

Main problems:

Pollution and overuse of water
Pollution of Soil

2. Energy

Main problem:

Pollution of air

3. Health (bodily, mental, spiritual)

Main Issue:
(Inner-) Peace

4. Human Waste = Pollution

Energy => Food/Water and Waste treatment… & cool or heat our planet

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Content

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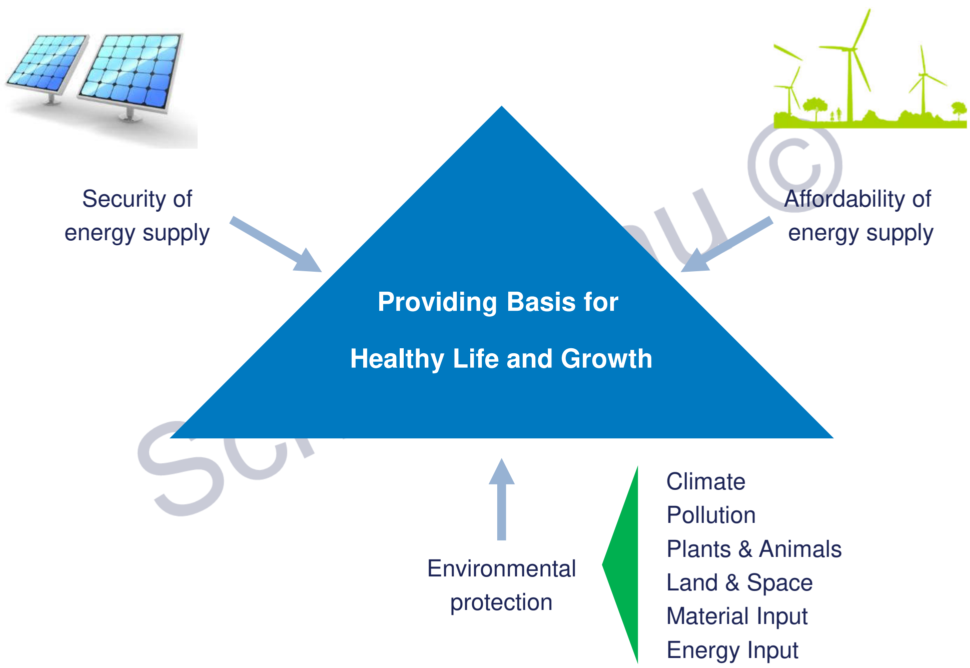
Triangle of Objectives in Energy Policy



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Source: Schernikau research; i343

Electricity: About 40% of Global Primary Energy

Fossil Fuels: About 60% of Electricity and 80% of Global Primary Energy

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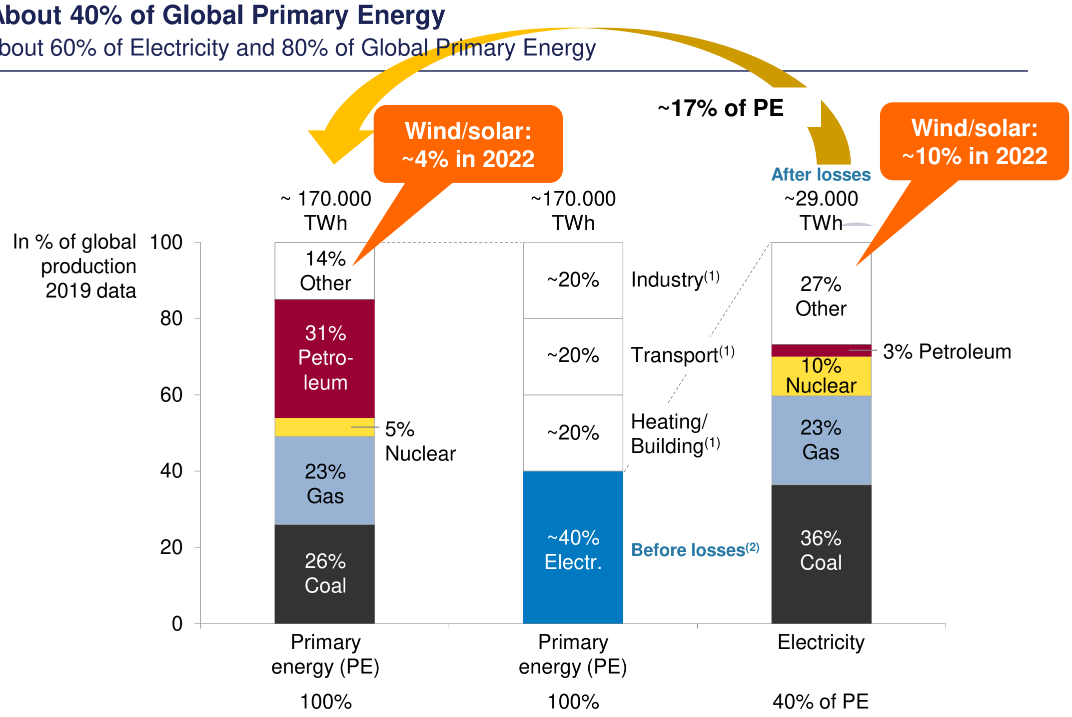

(1) Only the portion of Industry/Transport/Building that is not included under electricity; (2) assumed worldwide net efficiency of about 33% for nuclear, 37% for coal, 42% for gas, assume avg. ~40% efficiency => 27.000TWh becomes 68.000 TWh or 40% of 170.000TWh
Sources: Schernikau analysis based on IEA Energy Technology Perspectives 2020 (link), BP Statistical Review of World Energy 2020 (link), see also World in Data

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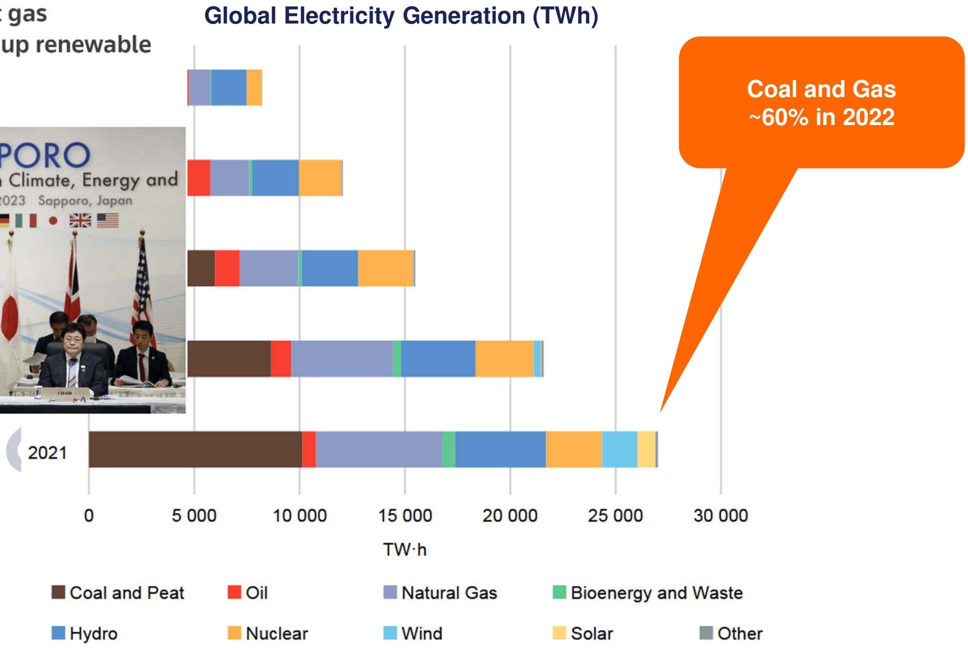
REUTERS®
World Business Markets Legal Breakingviews Technology Investigations

Environment

3 minute read · April 15, 2023 11:12 AM GMT+2 · Last Updated 2 days ago

G7 ministers agree to cut gas consumption and speed-up renewable energy

By Katya Golubkova and Yuka Obayashi



Source "IAEA: Energy, Electricity and Nuclear Power Estimates for the Period up to 2050." *Fuel and Energy Abstracts*, September 2022. https://doi.org/10.1016/0140-6701(95)95132-6.

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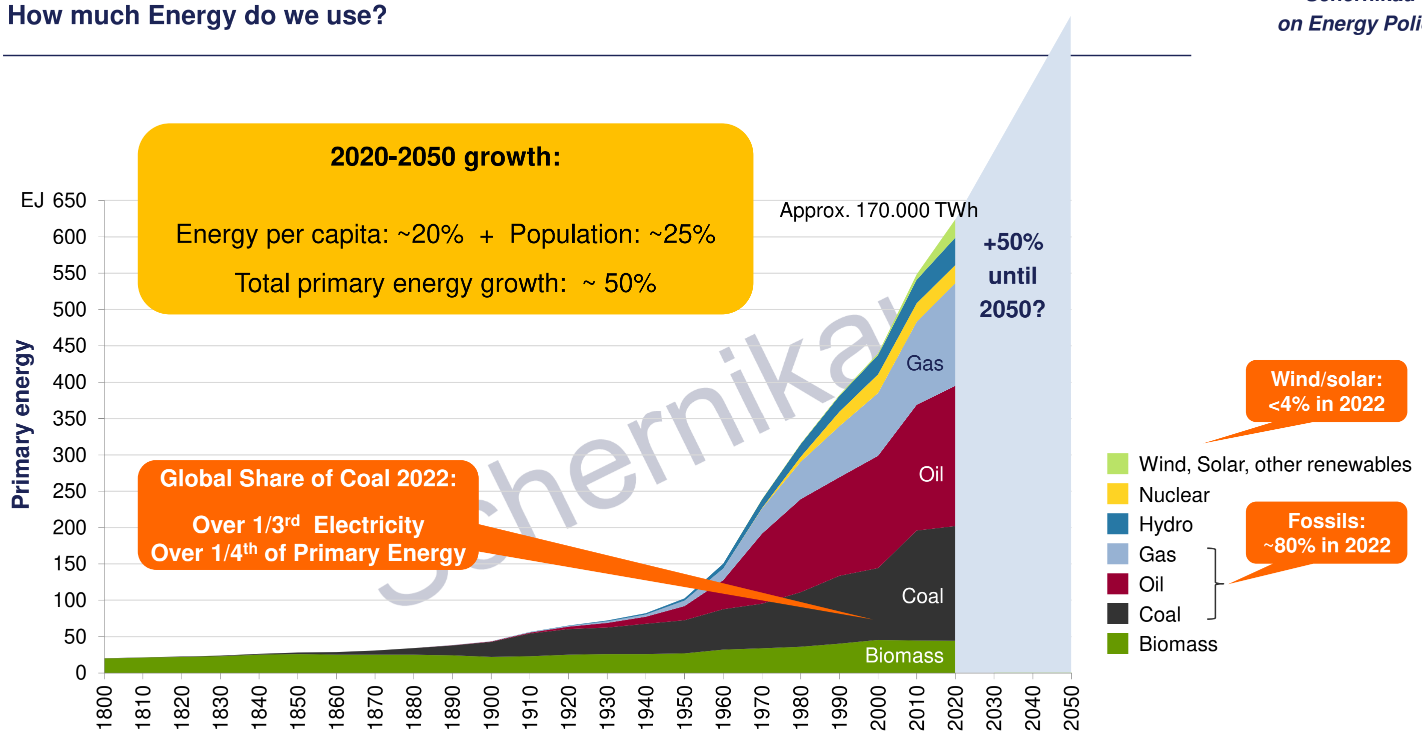
How much Energy do we use?



Note: Original values in TWh, converted to EJ using a factor of 278; Indonesia consumed about 2,8 TWh in 2021
Source: Our World in Data based on Vaclav Smil 2017 and BP Review of World Energy (link)

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IEA 2021 Net-Zero Pathway: Total Energy Down by 2050, About 20% from Coal, Oil & Gas

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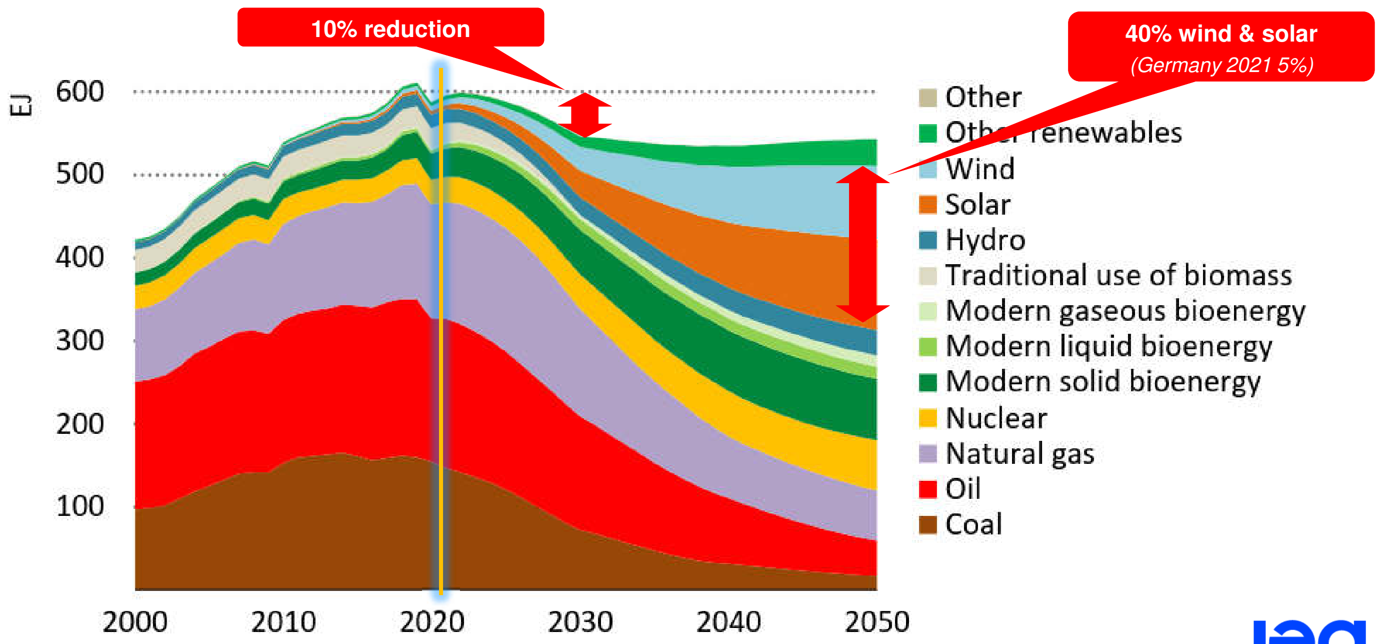

Source: "IEA: Net Zero by 2050 – Analysis," May 2021. https://www.iea.org/reports/net-zero-by-2050, p57.

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IRENA: Shares of renewables versus electrification in 2050 across various scenarios

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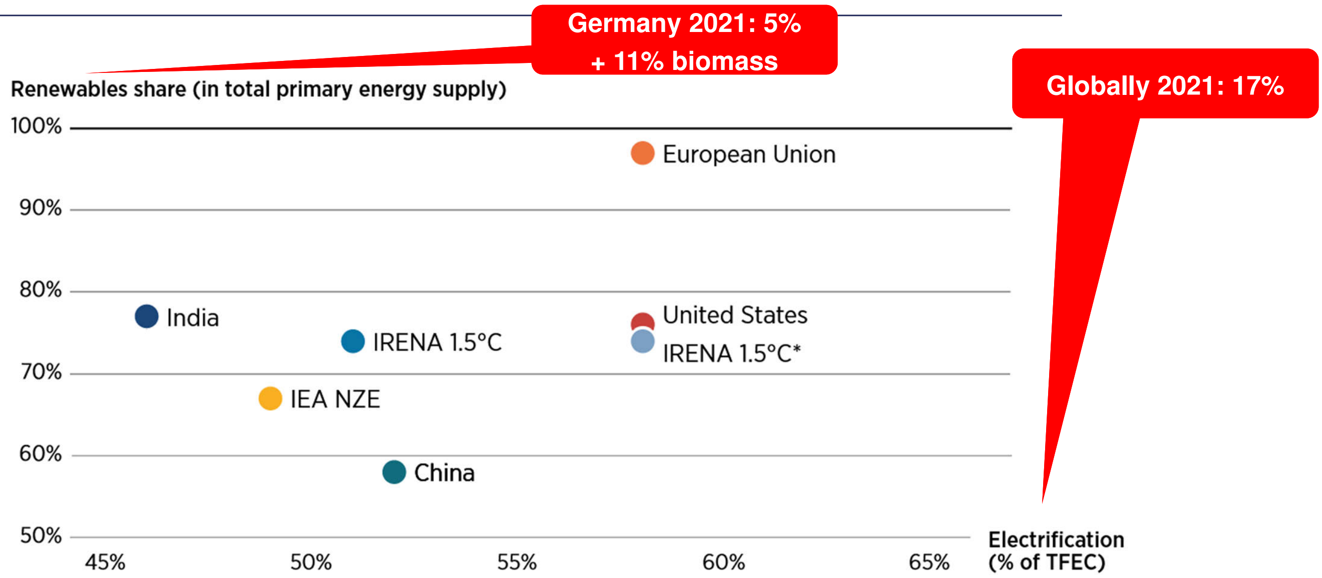

Source: India: NZE with reforestation and CCS Scenario - Transforming to a Net Zero Emissions Energy System [The Energy Resources Institute (TERI), SHELL, 2021]; European Union: Vision Scenario - Vision Scenario for the European Union [Greens/ European Free Alliance and Öko-Institut e.V., 2018]; China: 1.5°C Scenario -Transition of the Chinese Economy in the Face of Deep Greenhouse Gas Emissions Cuts in the Future [Kejun et al., 2021]; United States: Central Scenario - America's Zero Carbon Action Plan, 2020 [SDSN, 2020]; IEA NZE: NZE Scenario - IEA's Net Zero by 2050 [IEA, 2021a]; IRENA 1.5°C: 1.5°C Scenario - World Energy Transitions Outlook: 1.5°C Pathway [IRENA, 2021a]. Note: IRENA 1.5°C* represents the additional electrification share required to produce green hydrogen; TFEC: Total Final Energy Consumption
Source: IRENA: World Energy Transitions Outlook: 1.5°C Pathway, March 2022. https://www.irena.org/publications/2022/Mar/World-Energy-Transitions-Outlook-2022, p38

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The Green Quadrant

Energy Consumption vs. Fossil Fuel Consumption Annual Change, Global, 1965-2021

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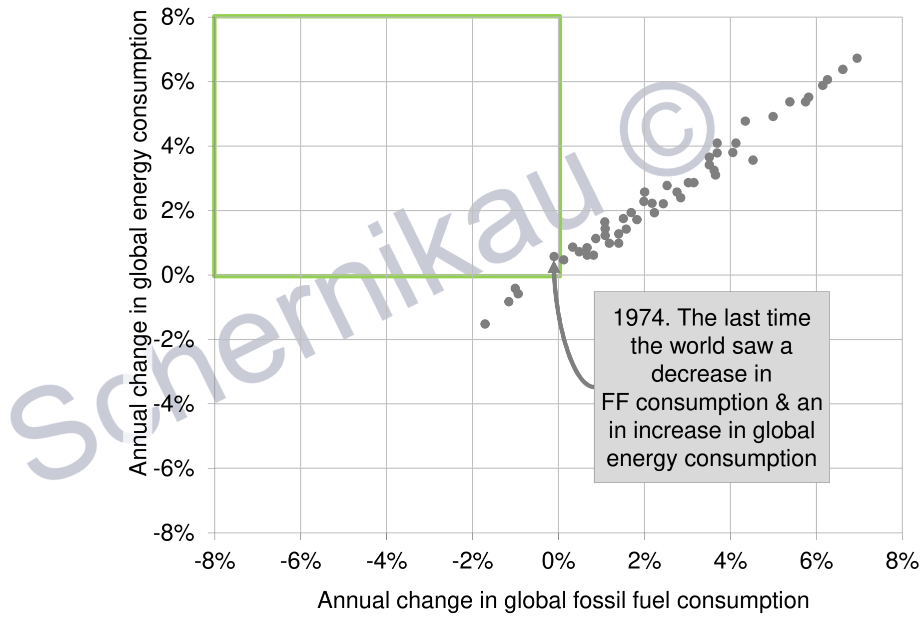

Source: The Honest Broker, by Roger Pielke Jr., 25 Oct 2022 (https://rogerpielkejr.substack.com/p/the-green-quadrant?utm_source=substack&utm_medium=email)

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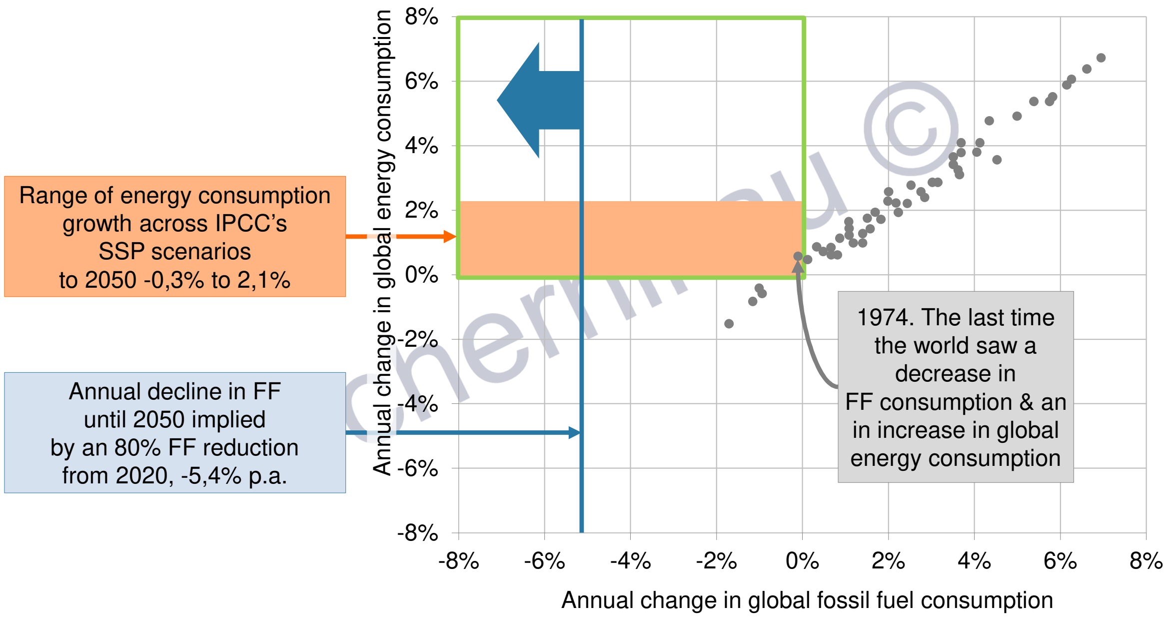

Note: FF = Fossil Fuel, IPCC = Intergovernmental Panel on Climate Change; SSP = Shared Socio-Economic Pathways, are scenarios defined by the IPCC about future development
Source: The Honest Broker, by Roger Pielke Jr., 25 Oct 2022 (https://rogerpielkejr.substack.com/p/the-green-quadrant?utm_source=substack&utm_medium=email)

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Investments in Coal Less than Half of Wind/Solar

… While Coal Provides 4x More Energy

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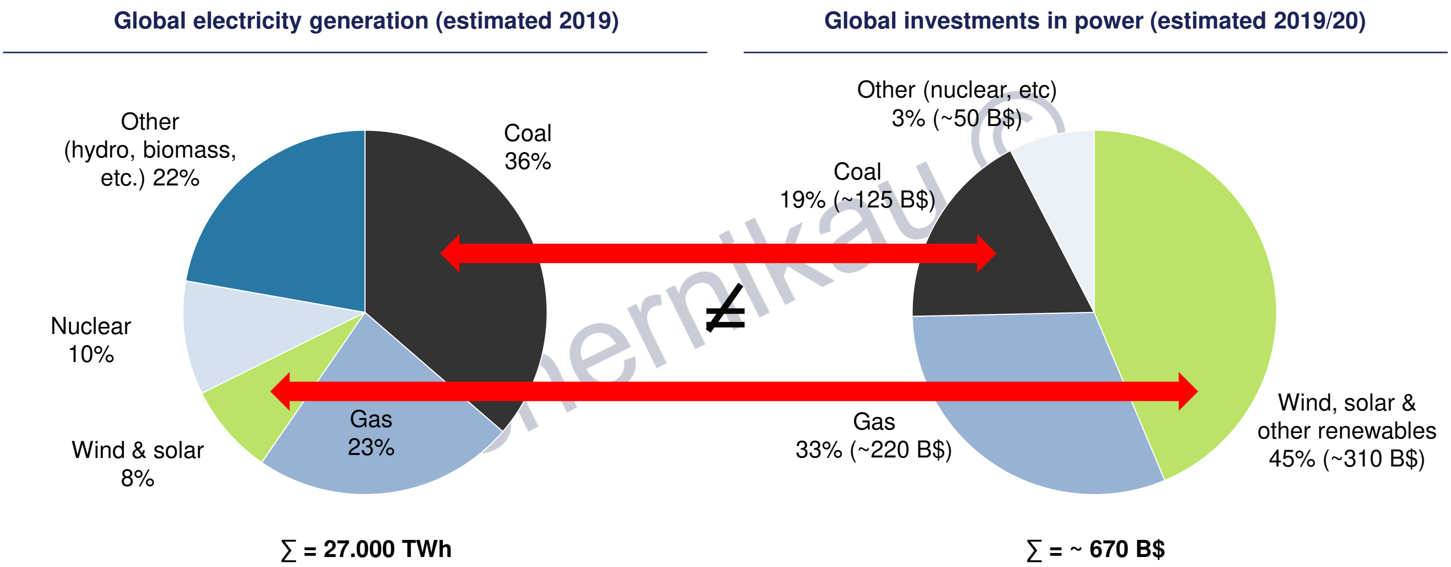

Note: Right side includes investments in fuel supply and power; for Gas it is assumed that 50% of total "oil & gas" fuel supply investments went into gas (511 B$ x 0,5 = 255 B$)
Sources: Schernikau Research & Analysis based no IEA and BNEF Data; Fuel supply – World Energy Investment 2020 – Analysis - IEA

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Germany 2021: Renewable Installed Capacity vs. Power Generation and Primary Energy

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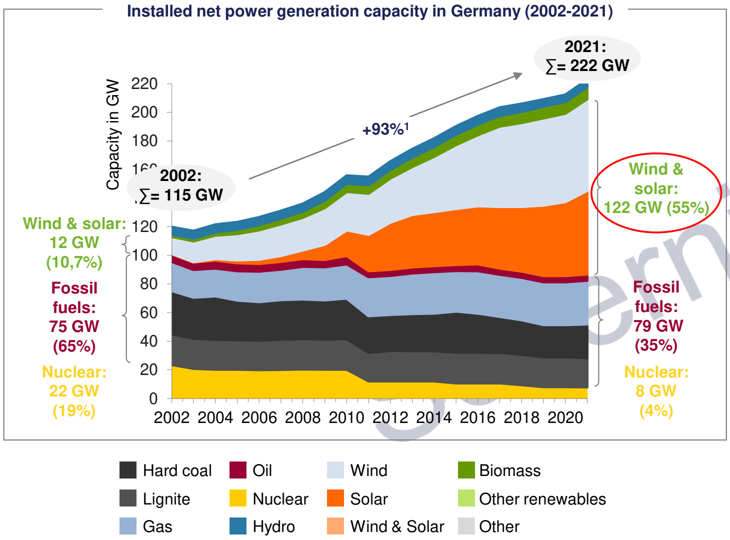

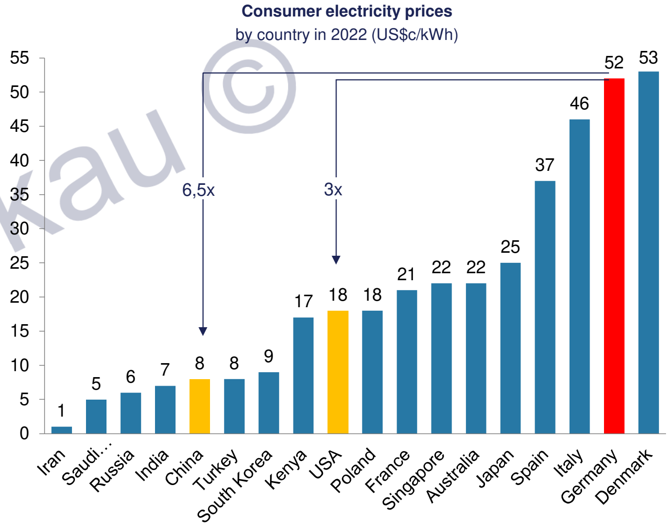

(1) CAGR: +3,5%; (2) CAGR: +0,1%; (3) CAGR -0,9%; (4) Including hydro & biomass
Sources: Schernikau Research and Analysis based on Frauenhofer Institute (link), Agora Energiewende (https://static.agora-energiewende.de/fileadmin/Projekte/2022/2022_01_DE-JAW2021/A-EW_247_Energiewende-Deutschland-Stand-2021_WEB.pdf), AG Energiebilanzen (https://ag-energiebilanzen.de/daten-und-fakten/primaerenergieverbrauch/ and https://ag-energiebilanzen.de/daten-und-fakten/zusatzinformationen/)

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Germany 2021: Renewable Installed Capacity vs. Power Generation and Primary Energy

Wind & Solar: 55% Capacity Gave Germany 28% Electricity and 5% Primary Energy

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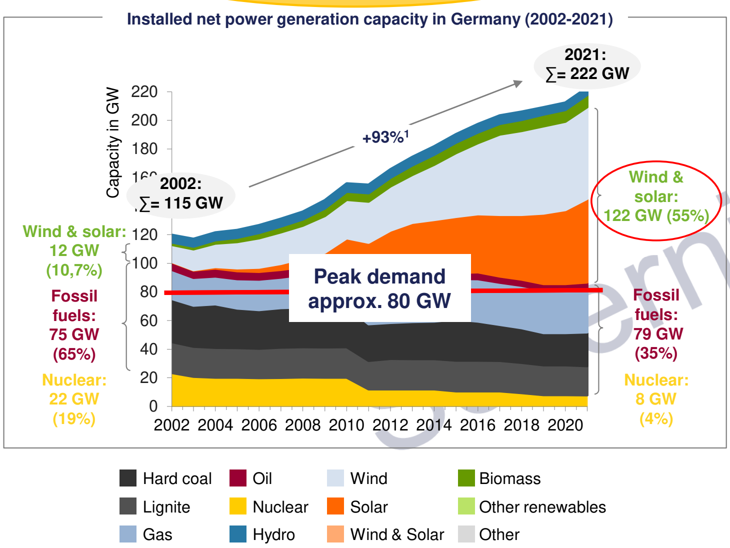
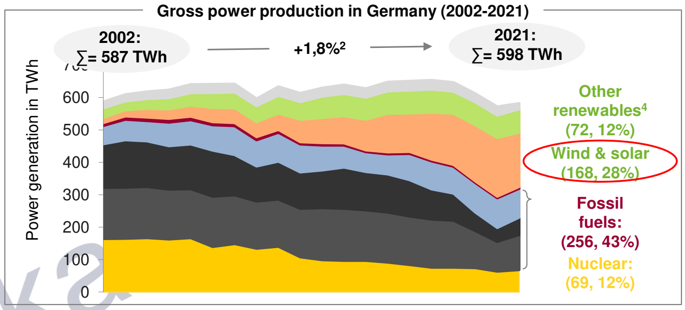
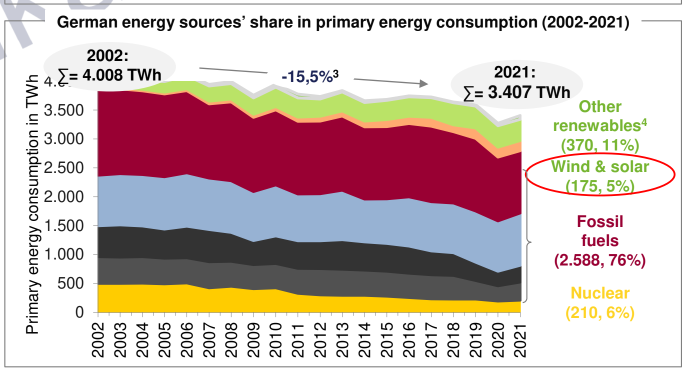
∑ = ~8.000 GW = 8 TW in 2020
Total global installed capacity







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Sources: Schernikau Research and Analysis based on Frauenhofer Institute (link), Agora Energiewende (https://static.agora-energiewende.de/fileadmin/Projekte/2022/2022_01_DE-JAW2021/A-EW_247_Energiewende-Deutschland-Stand-2021_WEB.pdf), AG Energiebilanzen (https://ag-energiebilanzen.de/daten-und-fakten/primaerenergieverbrauch/ and https://ag-energiebilanzen.de/daten-und-fakten/zusatzinformationen/)

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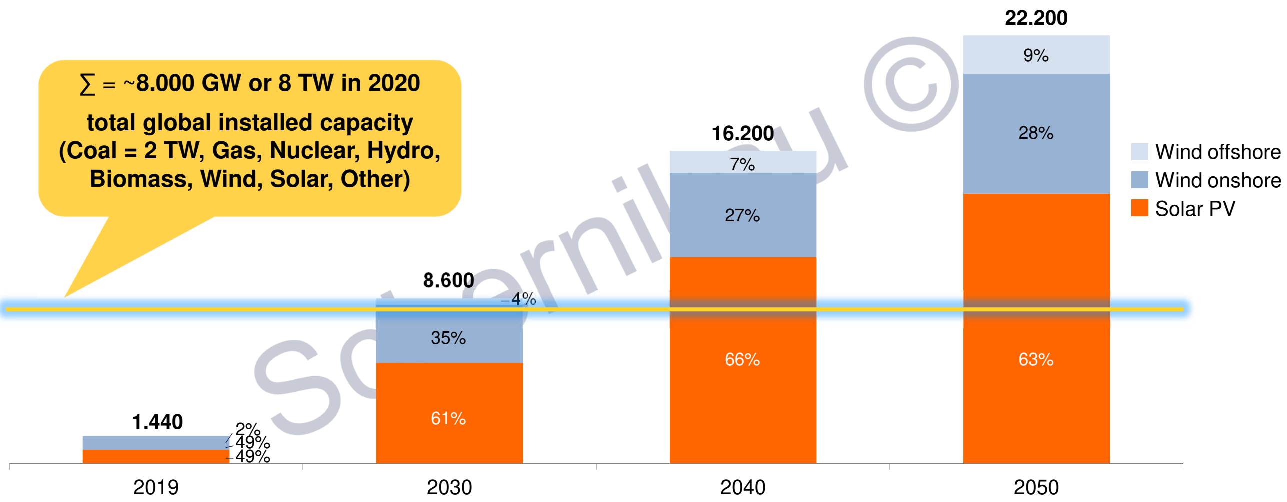
Global: Wind/Solar Capacity Forecast for 2050 to Be Almost 4x Total (Fossil/Ren) Today …

… Demonstrates Dramatic Misconception about Energy-Densities and -Efficiencies

Global Installed Wind/Solar Capacity Forecast (GW)



Note: PV = photovoltaics.
(1) The range of the compound annual growth rate is based on the planned energy scenario vs. the 1.5OC scenario.
Source: 2021 IRENA World Energy Transitions Outlook; BCG analysis: "BCG: Mastering Scale in Renewables," June 2021. https://www.bcg.com/publications/2021/maximizing-value-from-scale-renewable-energy.

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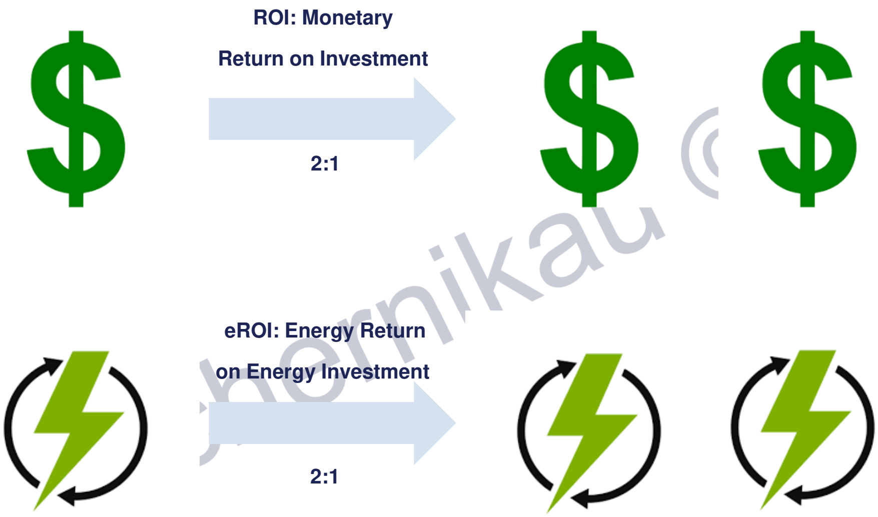
What is eROI?



eROI (energy returns) measures net energy efficiency

Source: Schernikau research

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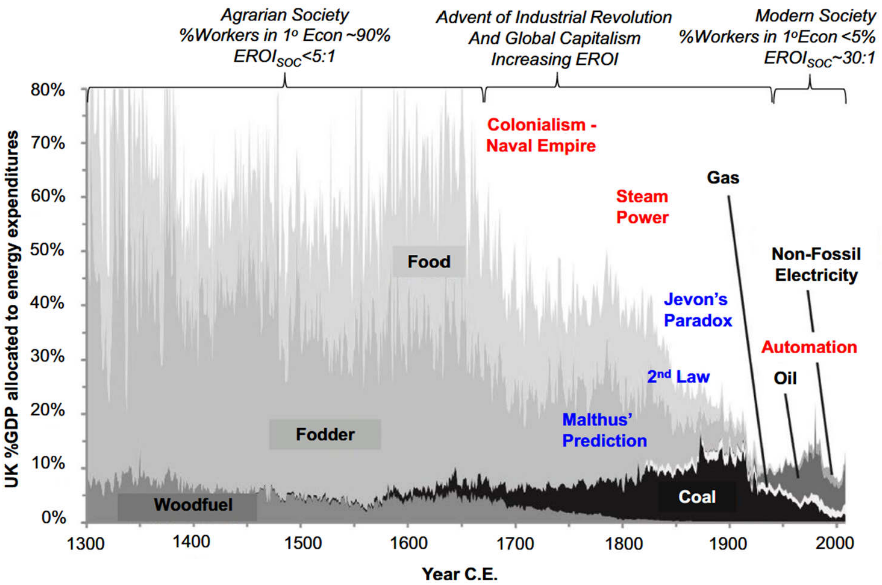
GDP Spent on Energy Generation – in UK

Share of GDP spent on Energy in UK (Economic share of acquiring food and fuel)



Key: **Energy Source, Intellectual Paradigm, Net Energy Keystones**

Note;: fooder = food, especially dried hay or feed, for cattle and other livestock.; Percent of GDP allocated to energy expenditure in the United Kingdom from 1300 to 2008. Energy sources are labeled in black; keystone innovations are labeled in red, and intellectual paradigms are in blue (Reproduced with permission from Fizaine and Court 2016). (Color figure online)
Source: Day et al 2018 "The Energy Pillars of Society: Perverse Interactions of Human Resource Use, the Economy, and Environmental Degradation." *BioPhysical Economics and Resource Quality* 3, no. 1 (February 2018, https://doi.org/10.1007/s41247-018-0035-6

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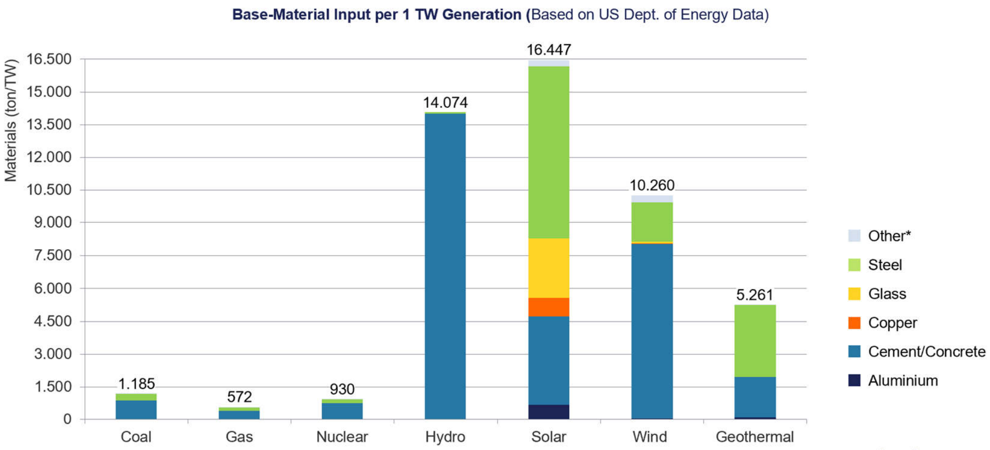

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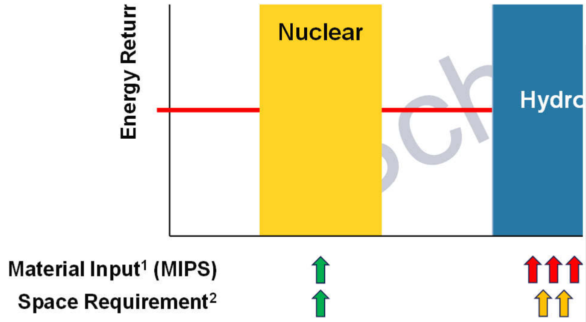

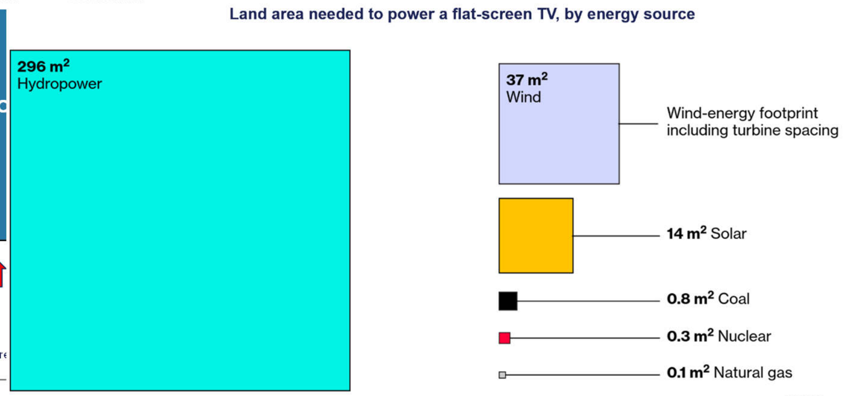

(1) Tonnage of material input per energy output, such as cement, steel, aluminum, lithium, rare earth, etc; (2) land area re
Source: Schernikau research and analysis

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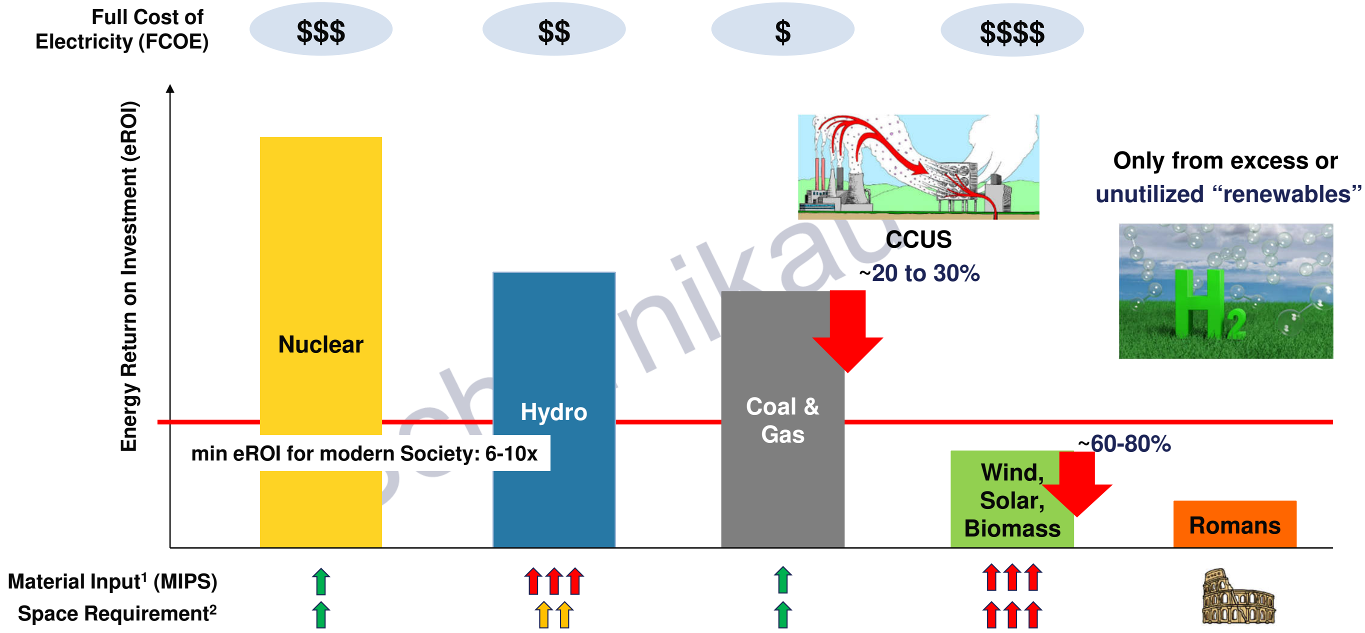
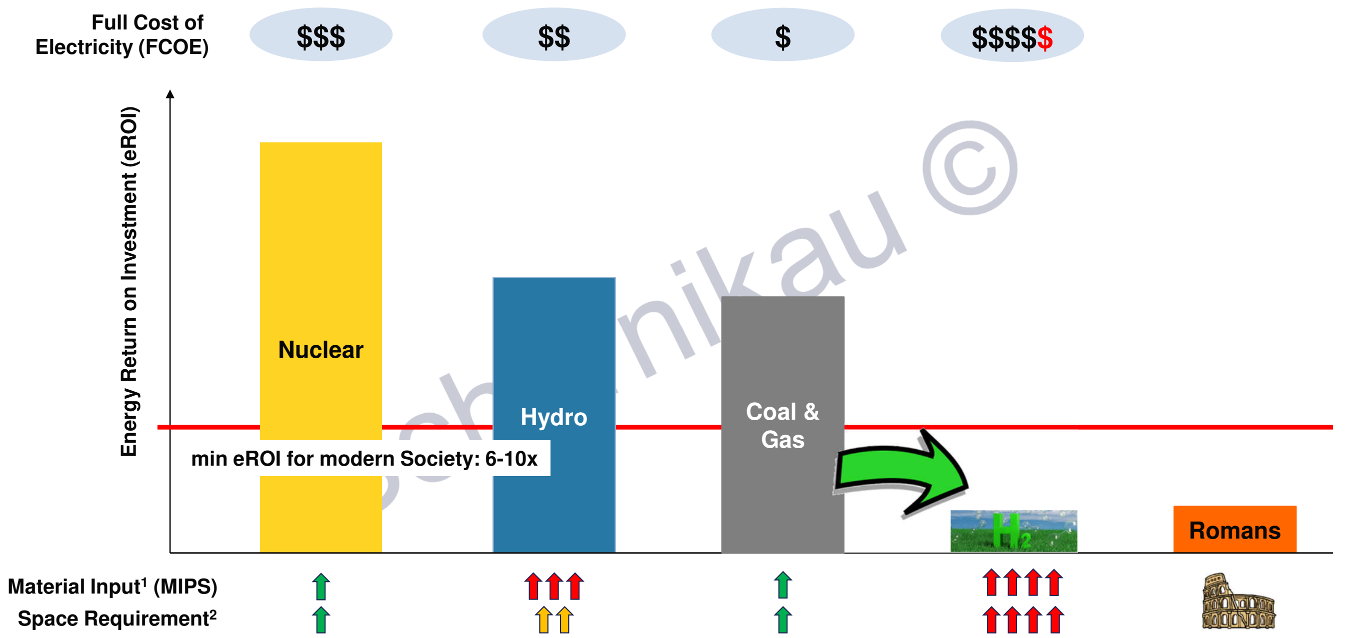
Comparing eROI – illustrative (here focus electricity)



(1) Tonnage of material input per energy output, such as cement, steel, aluminum, lithium, rare earth, etc; (2) land area required per unit of energy output per annum… part of Room Cost which includes all costs of occupying large areas of land
Source: Schernikau research and analysis

Comparing eROI – Illustrative (Here Focus Electricity)



(1) Tonnage of material input per energy output, such as cement, steel, aluminum, lithium, rare earth, etc; (2) land area required per unit of energy output per annum… part of Room Cost which includes all costs of occupying large areas of land
Source: Schernikau research and analysis; Energiekosten: 200.000 Jobs in Gefahr – Stahlindustrie im Klima-Dilemma - WELT

Global Wind and Solar Resources are not sufficient

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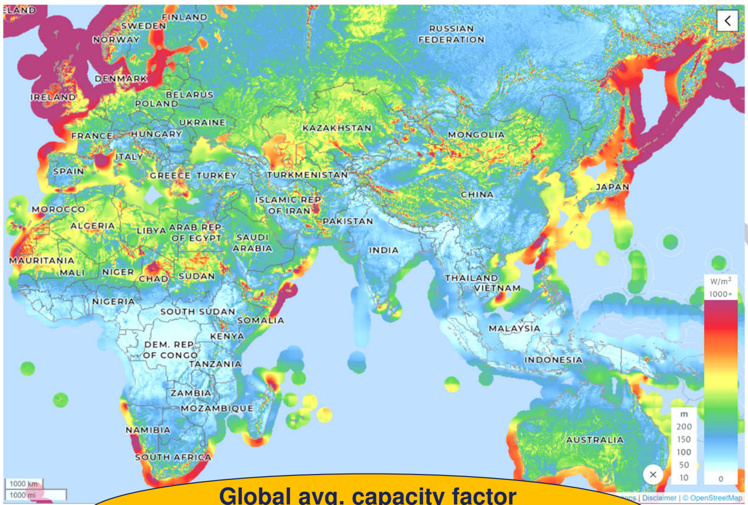
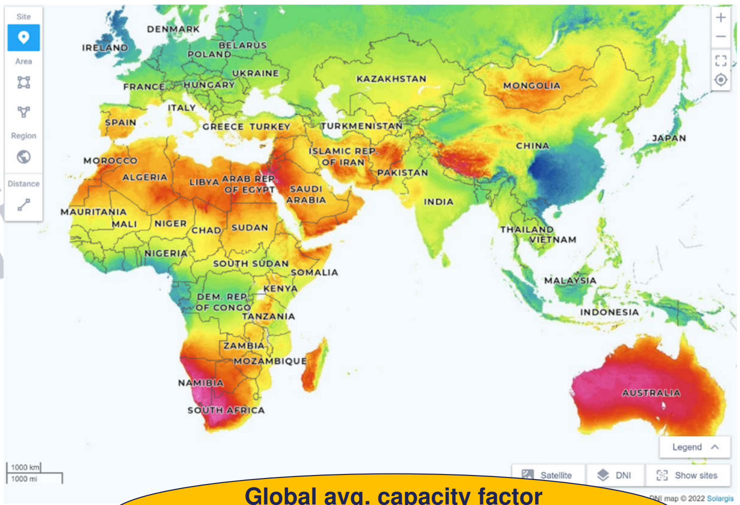
Wind Map (Europe, Africa, Asia)



Global avg. capacity factor 21-24% for wind

Solar Irradiance Map (Europe, Africa, Asia)



Global avg. capacity factor 11-13% for solar PV

(1) Global average capacity factors according to Carbajales-Dale et al. 2014
Source accessed 11 Feb 2022 : Global Wind Atlas (setting Mean Power Density - for the 10% windiest in the selection region at 100m height), www.globalwindatlas.info; Global Solar Atlas, www.globalsolaratlas.info (setting Direct normal irradiance, DNI)

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Typical Electricity Demand Curve and PV Production – a Sunny Day around the Equator

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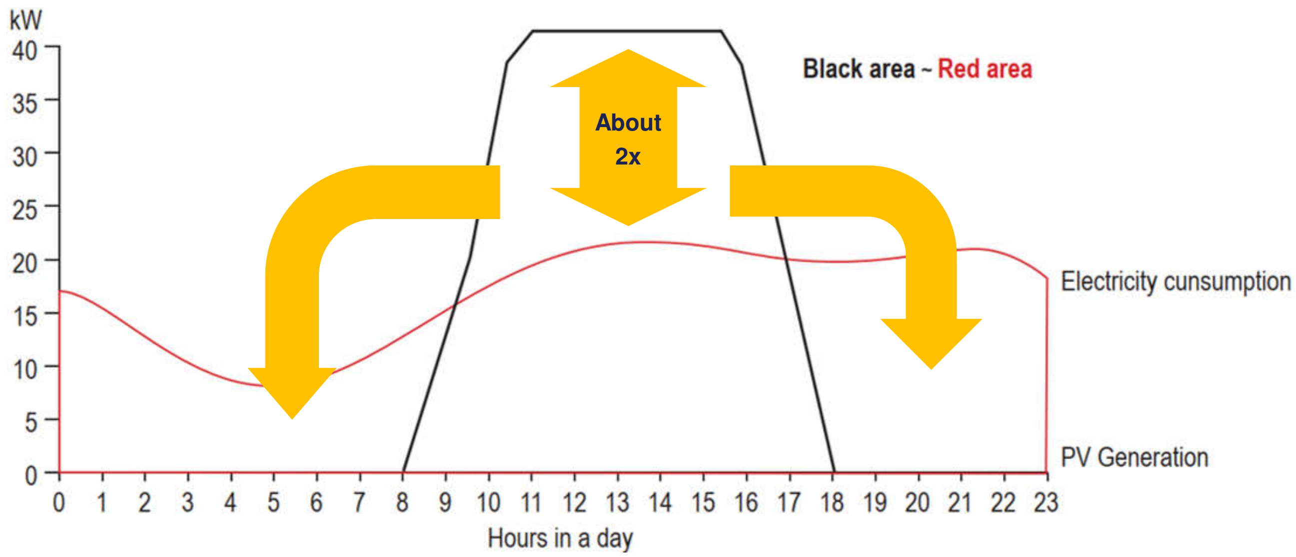
Electricity demand curve with required PV production



Note: The photovoltaic peak must be approximately twice the demand peak.
Source: Nominal electricity demand curve with photovoltaic production schematic by the author, adapted from EnergyMag accessed 4 Sep 2020 at this link.

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Typical Electricity Demand Curve an… d… Day around the Equator

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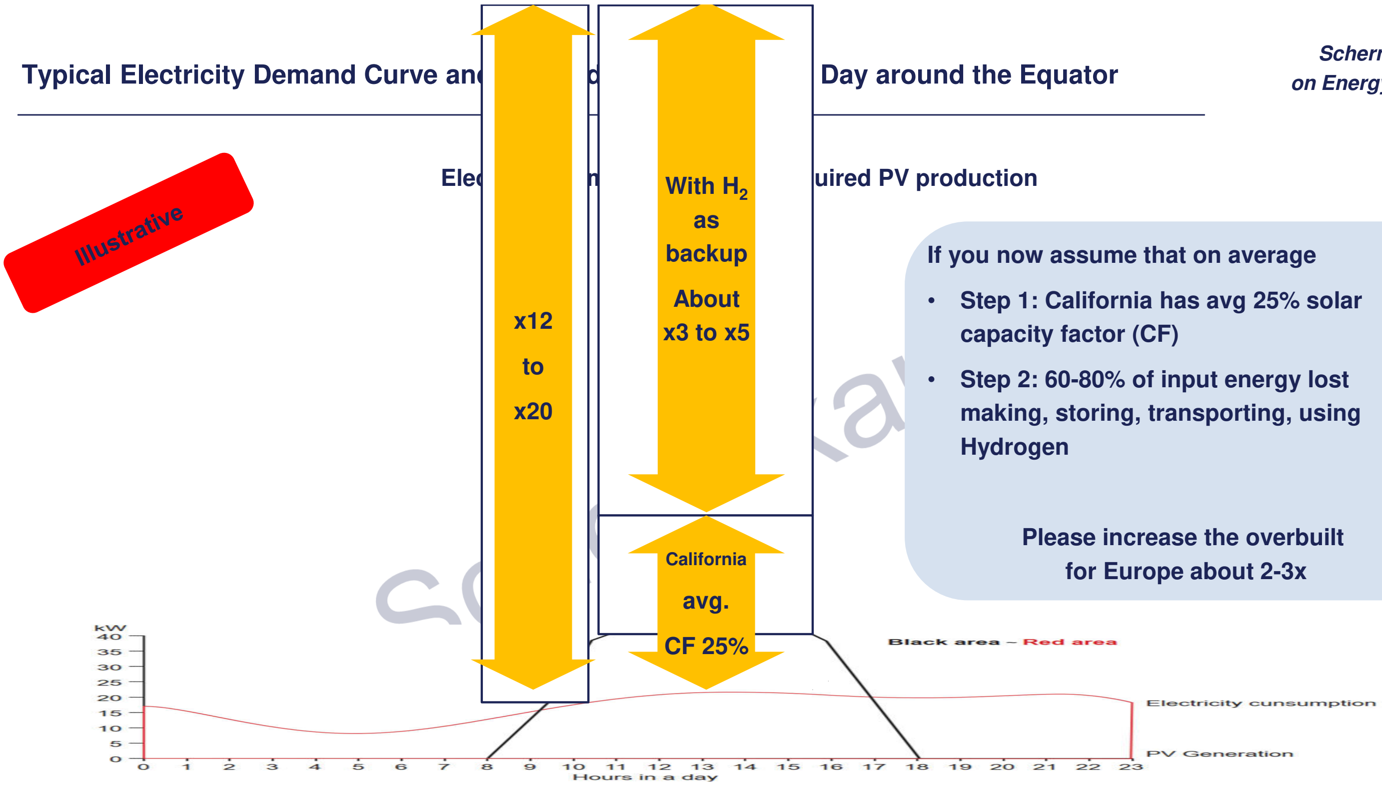

If you now assume that on average

- **Step 1: California has avg 25% solar capacity factor (CF)**
- **Step 2: 60-80% of input energy lost making, storing, transporting, using Hydrogen**

Please increase the overbuilt for Europe about 2-3x

Note: The photovoltaic peak must be approximately twice the demand peak.
Source: Nominal electricity demand curve with photovoltaic production schematic by the author, adapted from EnergyMag accessed 4 Sep 2020 at this link.

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Lazard April 2023: Levelized Cost of Energy Comparison—Unsubsidized Analysis

Lazard: “selected renewables are cost-competitive with conventionals under certain circumstances”

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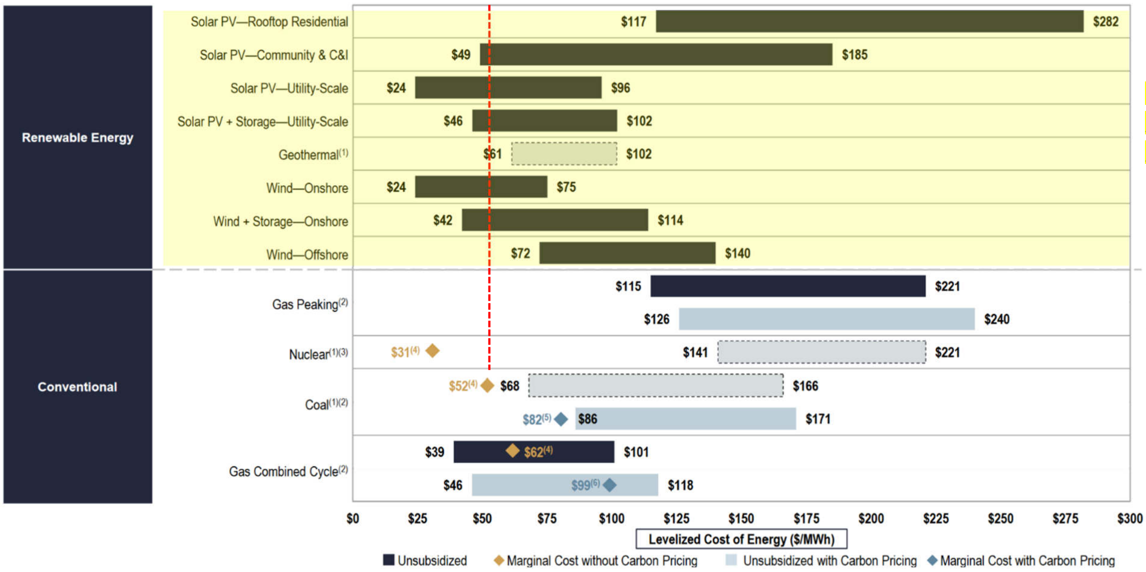

Key Assumptions

*no differentiation between „**natural capacity factor**“ and „**utilization**“*

- *Solar 15-30% <= Global: 11-13%*
- *Wind 30-55% <= Global: 21-24%*
- ***Coal 35-85%***
- *Gas CCG 30-90%*
- *No consideration of network integration*
- *No long duration energy storage*

***Disclaimer**: Other factors would also have a potentially significant effect on the results contained herein, but have not been examined in the scope of this current analysis. These additional factors, among others, could include: implementation and interpretation of the full scope of the Inflation Reduction Act (“IRA”); network upgrades, transmission, congestion or other integration-related costs; permitting or other development costs, unless otherwise noted; and costs of complying with various environmental regulations (e.g., carbon emissions offsets or emissions control systems). This analysis also does not address potential social and environmental externalities, including, e.g., the social costs and rate consequences for those who cannot afford distributed generation solutions, as well as the long-term residual and societal consequences of various conventional generation technologies that are difficult to measure (e.g., nuclear waste disposal, airborne pollutants, GHGs, etc.)*

Source: Lazard April 2023, https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/

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OECD confirms higher costs of wind and solar

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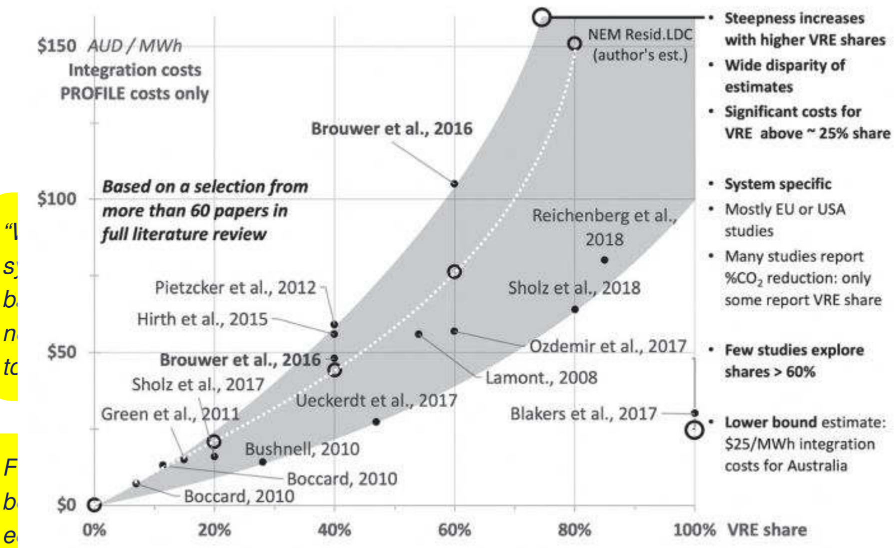

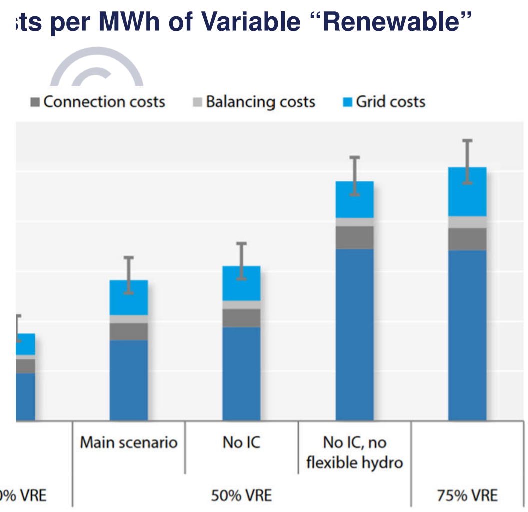

Note on profile cost Profile Costs of Wind Energy: Why are Utilities Overpaying? - Master Resource, profile cost measures the relative value of energy based on the time of day and how reliable it is to the electrical grid.
Source: OECD: The Full Costs of Electricity Provision | En | OECD,” June 2018. https://www.oecd.org/publications/the-full-costs-of-electricity-provision-9789264303119-en.htm, p48, Nuclear Energy Agency. “OECD: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables.” OECD, January 2019. https://doi.org/10.1787/9789264312180-en, p19

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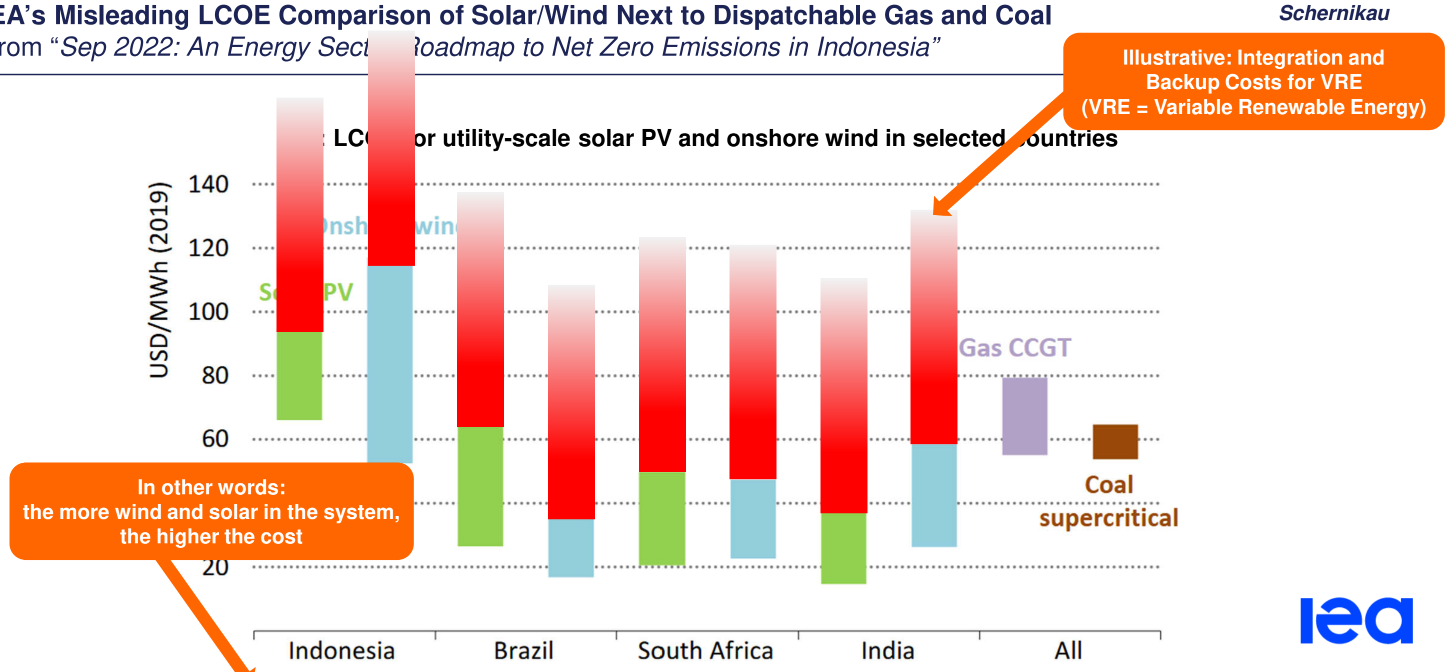
IEA's Misleading LCOE Comparison of Solar/Wind Next to Dispatchable Gas and Coal

From "*Sep 2022: An Energy Sector Roadmap to Net Zero Emissions in Indonesia*"



IEA Dec 2020: „ … *the system value of variable renewables such as wind and solar decreases as their share in the power supply increases*"

Notes: IEA note: LCOE = levelised cost of electricity; CCGT = combined-cycle gas turbine. LCOEs are based on projects with final investment decisions in 2020, Source: IEA (2021b).
Source: Schernikau based on "IEA: An Energy Sector Roadmap to Net Zero Emissions in Indonesia," September 2022. https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia/executive-summary., p195, fig 5.26

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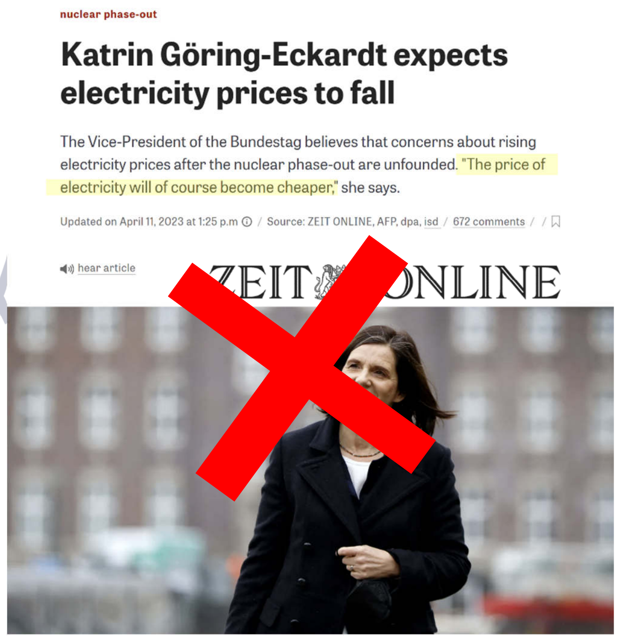
Media and Politicians continue to Mislead (or be mislead?)


Switching to renewable energy could save trillions - study

By Jonah Fisher
BBC Environment Correspondent

2 days ago

The cost of green energy like wind and solar has been falling for decades


nuclear phase-out

Katrin Göring-Eckardt expects electricity prices to fall

The Vice-President of the Bundestag believes that concerns about rising electricity prices after the nuclear phase-out are unfounded. "The price of electricity will of course become cheaper," she says.

Updated on April 11, 2023 at 1:25 p.m / Source: ZEIT ONLINE, AFP, dpa, isd / 672 comments

hear article

Source: BBC Sep 2022 and Die Zeit Apr 2023

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What Is the Cost of Energy? = NOT Levelized Cost of Electricity (LCOE)

… but Full Cost of Electricity (FCOE) … to Society or a Country

LCOE is incomplete

1. Cost of Building
2. Cost of Fuel
3. Cost of Operating

LCOE

4. Cost of Transmission/ & Conditioning/Balancing

5. Cost of Storage

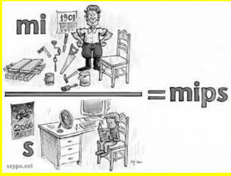
6. Cost of Backup

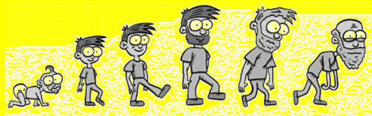
7. Cost to Environment

8. Cost of Recycling

9. Room Costs

Non-USD Metrics

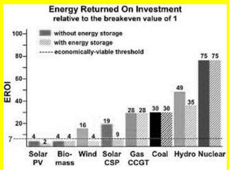


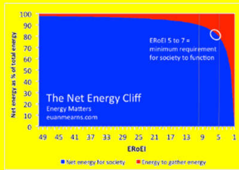


10a: MIPS – Material Input Per Unit of Service

10b: Lifetime

10c: eROI – energy Return On energy Invested





Full Cost of Electricity (FCOE)

Source: Schernikau et al 2022, Energy Primer, to be published

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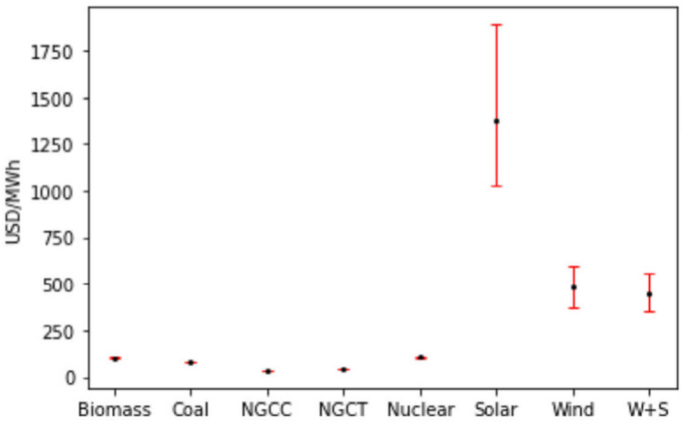
For Germany and Texas: Full Cost of Electricity is over 10x higher than LCOE at 100% VRE

Idel 2022: Levelized Full System Costs of Electricity - LFSCOE

[only]

Idel 2022: "the function of supply in electricity markets is not to generate electricity… … but to provide a specified amount of electricity to a specific place at a particular time."

LFSCOE Germany ($/MWh)



LFSCOE with 100% share each ($/MWh)
VRE cost drop by more than half if 95% is assumed

Comparison of LCOE and LFSCOE.

Technology	LCOE [USD/MWh]	LFSCOE Germany [USD/MWh]	LFSCOE Texas [USD/MWh]
Biomass	95	103	117
Coal (USC)	76	78	90
Natural Gas CC	38	35	40
Natural Gas CT	67	39	42
Nuclear	82	105	122
Solar PV	36	1380	413
Wind	40	483	291

Source: Idel, Robert. "Idel 2022: Levelized Full System Costs of Electricity." Energy 259 (November 2022): 124905. https://doi.org/10.1016/j.energy.2022.124905

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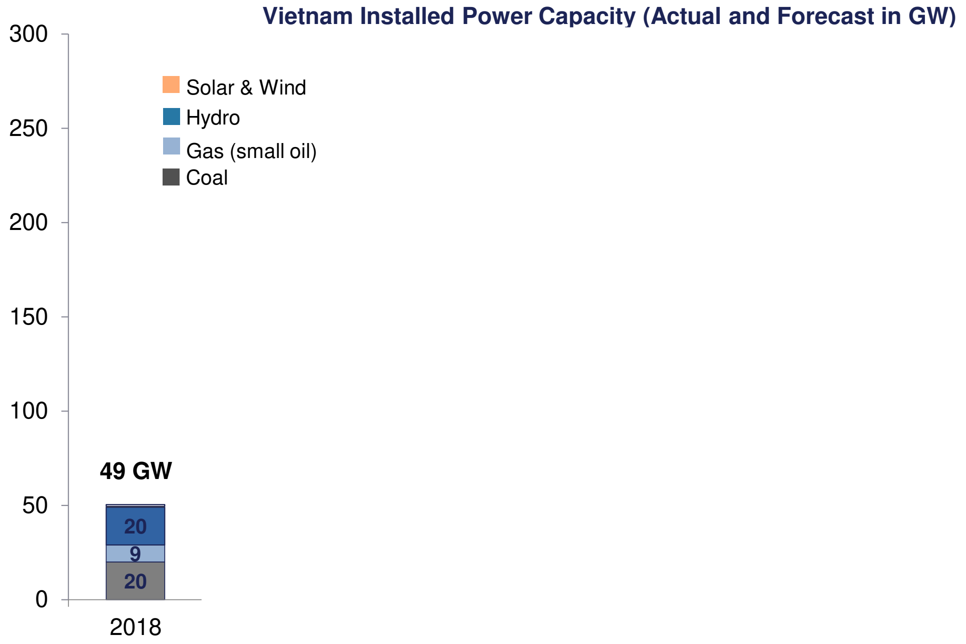
Example: Vietnam and Electricity production – realistic forecast?

Schernikau
on Energy Policy



Note: Chart shows forecast capacity by energy type, Renewable energy sources does NOT include hydro
Source: Schernikau, based on Vietnam Energy Outlook Report 2021, Reuters, 23 Nov 2022, Kripa Jayaram, Vietnam boosts coal use plan for 2030, based on Power Development Plan VIII ("PDP VIII")

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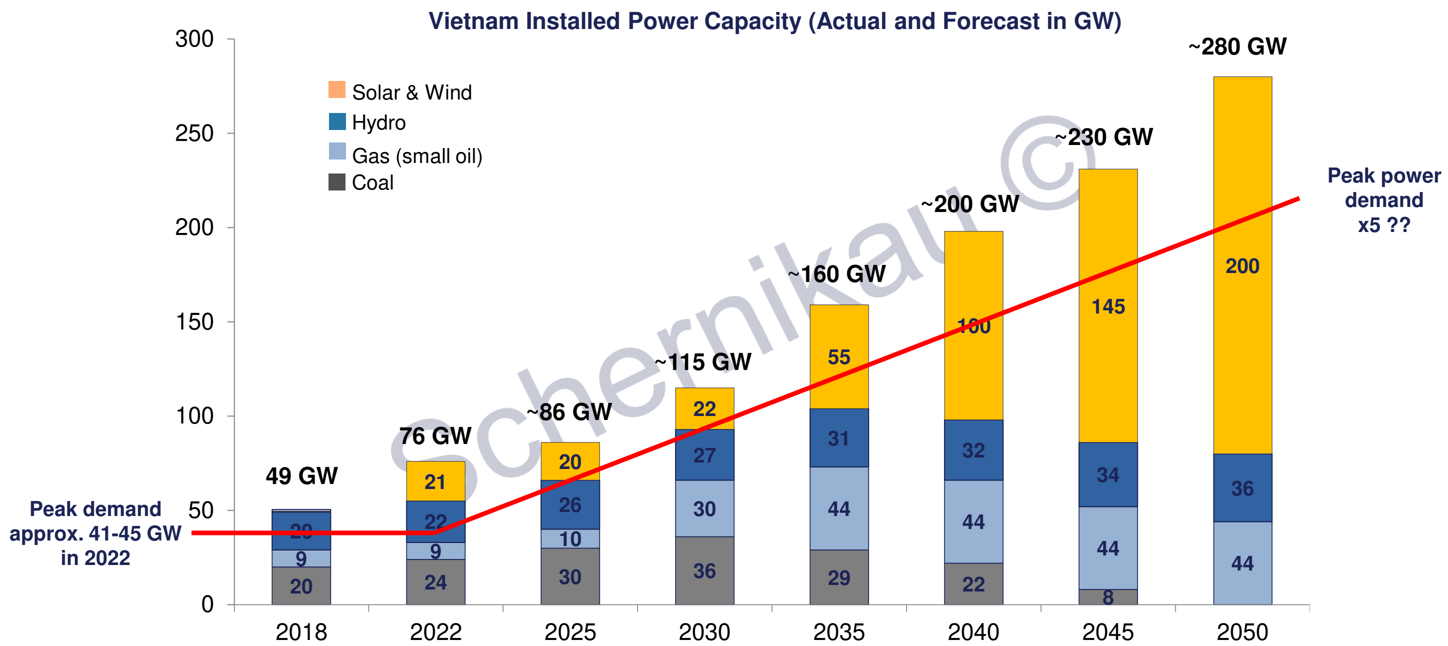
Vietnam and Electricity production – realistic forecast?

Schernikau
on Energy Policy



Note: Chart shows forecast capacity by energy type, Renewable energy sources does NOT include hydro
Source: Schernikau, based on Vietnam Energy Outlook Report 2021, Reuters, 23 Nov 2022, Kripa Jayaram, Vietnam boosts coal use plan for 2030, based on Power Development Plan VIII ("PDP VIII")

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Content

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The Economist Wakes Up?

The Economist | Subscribe | Menu

Briefing
Jun 12th 2021 edition ›

1. Low capacity factors (especially in Asia) & low energy density (E/m²)
2. True cost of intermittency, conditioning, conversion, transmission, balancing plus 100+% backup/storage
3. Supply is located far from demand & wind and solar are highly correlated across continents
4. Material inefficiency of wind and solar + backup
5. Short lifetime, climate/enviromental impacts of wind/solar, recycling challenges
6. **Low net energy returns «eROI»** (energy returns on energy invested)

Missing ingredients

The bottlenecks which could constrain emission cuts

and Energy!

The green revolution risks running short of minerals, money and places to build

Jun 12th 2021

Externalities of Energy Systems

Production/ Mining	Processing	Transportation	Manufacturing	Operations	Recycling
▪ Includes raw materials extraction	▪ Includes upgrading, refining of raw materials	▪ Transportation of products along entire value chain	▪ Manufacturing of equipment	▪ Includudes combustion for energy generation	▪ Incldues waste handling processing, disposal

Externalitiies (Human & Environment)

Emissions
- CO_2
- CH_4
- SO_x
- NO_x
- Mercury
- Chlorine
- Particulate matter
- etc., etc., etc.

CO_2 = Sole Focus of "Carbon" Taxation

Current Focus of Energy Policy

Other environmental
- Energy input
- Raw Materials
- Space
- Animals/Plants
- Waste
- etc., etc., etc.

Human
- Health/Safety
- Energy Poverty
- Financial Poverty
- Industrial development
- etc., etc., etc.

Carbon taxation leads to distortions and undesired consequences
Because it dismisses other emissions, non-emissions, and human impacts

Source: Schernikau/Smith 2021, Climate Impacts of Fossil Fuels, SSRN Electronic Journal, Nov 2021, (link, DOI 10.2139/ssrn.3968359)

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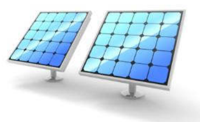
Triangle of Objectives in Energy Policy

Examining Wind & Solar



✗ Security of energy supply

Affordability of energy supply ✗

Providing Basis for Healthy Life and Growth

Environmental protection

- Climate ?
- Pollution ✓
- Plants & Animals ✗
- Land & Space ✗
- Material Input ✗
- Energy Input ✗

Source: Schernikau research; i343

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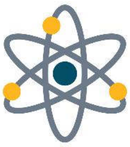
What is the Future of Energy?

The New Energy Revolution

1. Invest in base research

to sustainably wean off fossil fuels

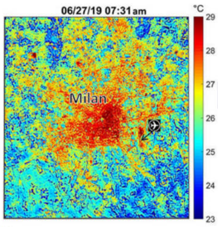
energy generation, material extraction & processing, storage, superconductors, recycling, etc.



nuclear force

"power" of our planetary system (i.e., sun)

energy from within our planet



"Such new energy system may be completely new, … a presently unknown energy source?"

2. Invest in existing energy infrastructure

to reduce environmental burden and increase energy efficiencies

✓ *Reduce the waste we generate (e.g., WtP)*
Reduce poverty to weather climatic changes

"If investments in fossil fuels will not increase substantially, a prolonged global energy crisis is difficult to avoid this decade"

Source: Schernikau et al. 2022

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Content

Introduction

eROI

LCOE vs. FCOE (Full Cost of Electricity)

What Next?

Discussion

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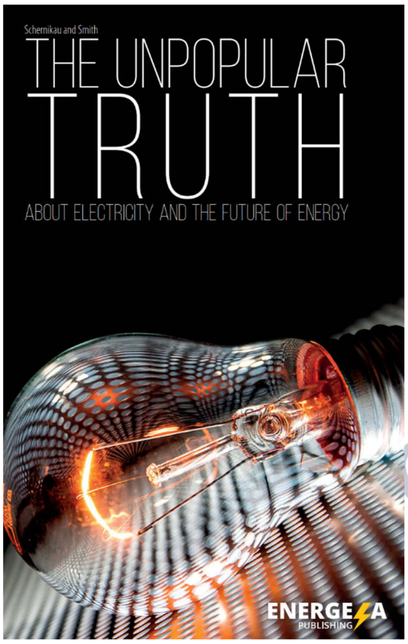
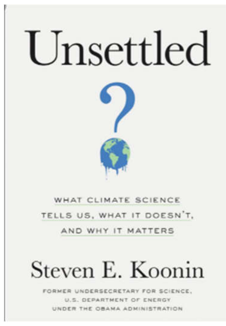
Recommended Papers and Books (www.unpopular-truth.com)



Available on Amazon now
https://amzn.to/3togypC

https://youtu.be/k_uBiHoIZIw/



https://papers.ssrn.com/sol3/cf_dev/AbsByAuth.cfm?per_id=4356382

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commodities for the future

THANK YOU

Please contact me for clarification where needed

I am available selectively for presentations/workshops

- **Energy economics and policy**
- **Science of climate change**
- **„Renewable“ vs. conventional energy**

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Appendix

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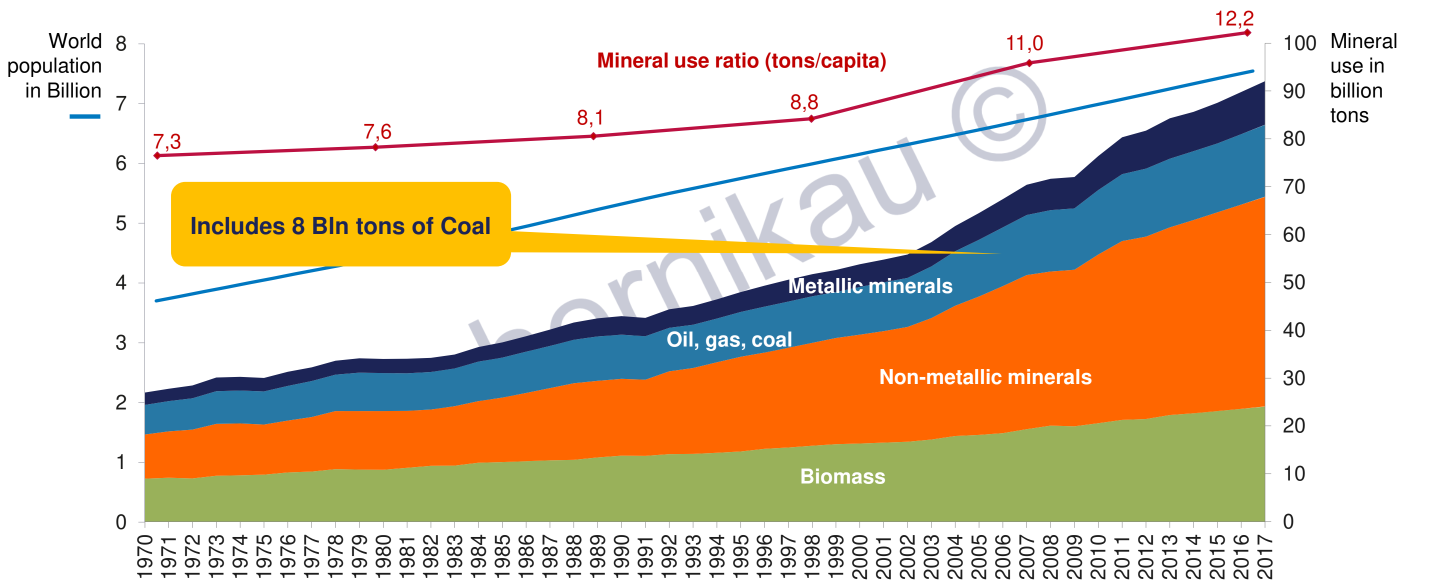
Global Material/Mineral Extraction Reaches Close to 100 Billion Tons p.a.

Schernikau on Energy Policy

Domestic extraction worldwide from 1970-2017



Note: WU Vienna (2020): Material flows by material group, 1970-2017. Visualisation based upon the UN IRP Global Material Flows Database. Vienna University of Economics and Business
Source: Autthors Research and Analysis based on http://www.materialflows.net/visualisation-centre/data-visualisations/?_inputs_&sidebar=%22bar_chart_1%22; Population division, UN, 2019 (https://population.un.org/wpp)

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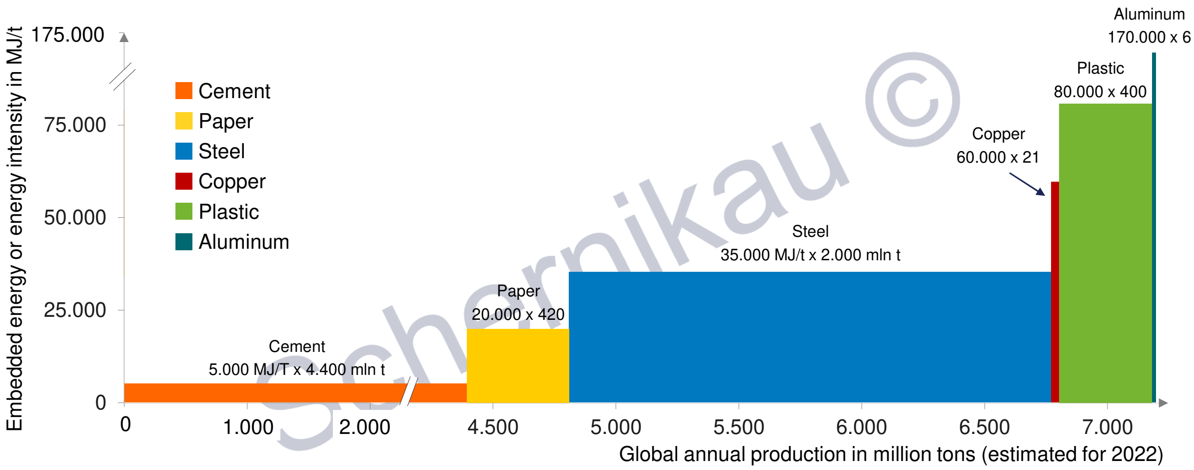
Embedded Energy: Energy Intensity of Key Industrial Materials
Material Intensity is Entirely Different

Embodied energy for selected industrial materials, or better "base products"



The average life expectancy for a steel product is 34 years, and for aluminum is 21 year

Note: copper embodied energy estimated from https://www.princeton.edu/~ota/disk2/1988/8808/880809.PDF and from https://publications.csiro.au/rpr/download?pid=csiro:EP12183&dsid=DS3,
Note: 1 kWh = 860 kcal = 0,086 kg oe = 3.600 kj; 1 kcal = 4,186 kj; 1 Gj = 278 kWh = 23,9 kg oe = 43,5 kg of coal
Source: Schernikau research and analysis based on Sustainable materials, Allwood/Cullen/Carruth et al., annual production for 2022 based on worldsteel.org, statista.com, international-aluminium.org

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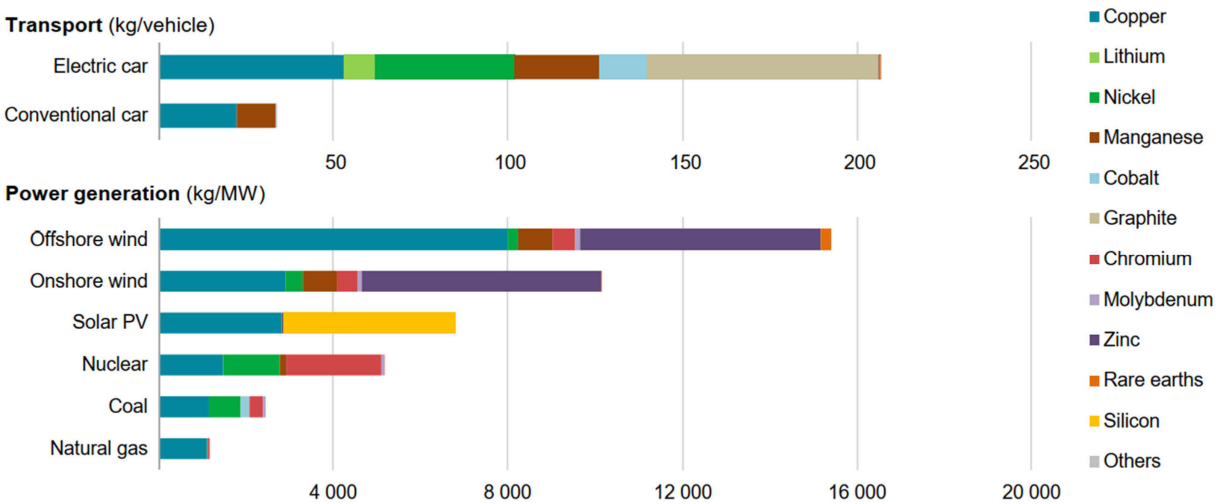
Comparing Mineral Needs for Renewable Technology

Minerals used in selected "clean" energy technologies



Source: "IEA: The Role of Critical Minerals in Clean Energy Transitions – Analysis," May 2021, page 6. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.

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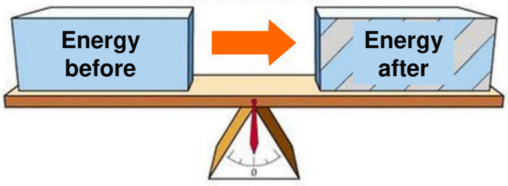
Two Important Laws of Thermodynamics

«Laws of Energy» do NOT follow the «Laws of Computing»

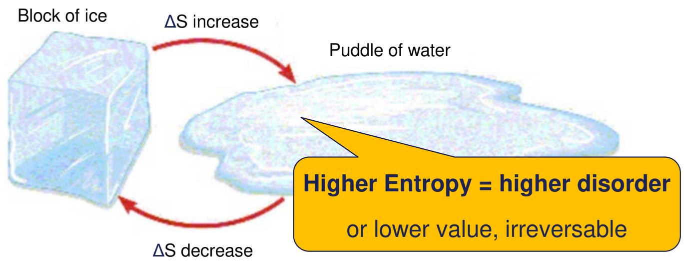
1st Law of Thermodynamics
(energy is never lost)

2nd Law of Thermodynamics
«Entropy always increases» or energy loses 'value' with conversion



Internal Energy

Entropy increases when melting



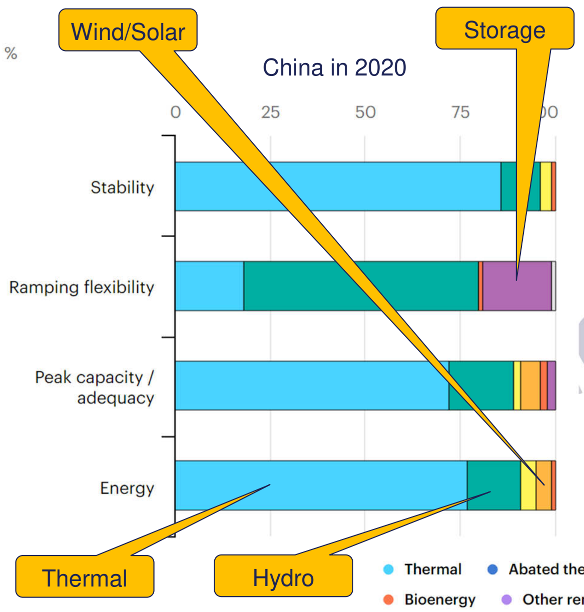
Entropy decreases when freezing

Conversion or storage of energy always means loosing useful energy

Note: Planck: Every process occurring in nature always increases the sum of the entropies of all bodies taking part in the process, at best the sum remains unchanged.
Source: Scherrnikau research and analysis, graphs from 10.3 - Entropy and the 2nd law (slideshare.net) and https://i.ytimg.com/vi/IyNNzOT4jO0/maxresdefault.jpg

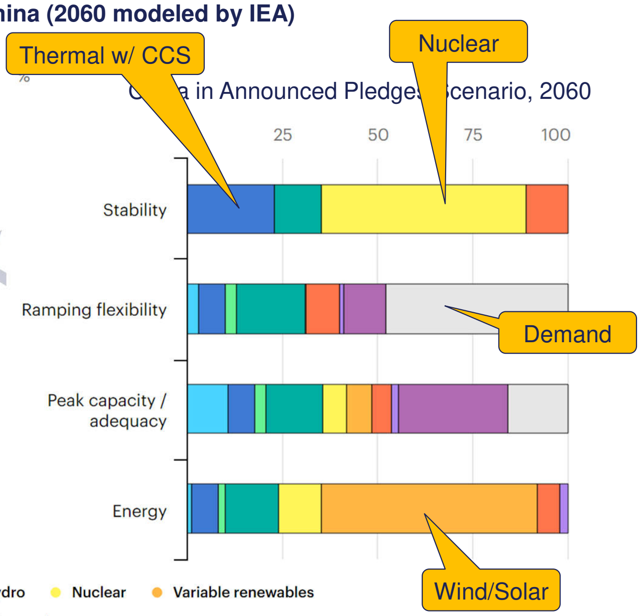
Current and Future Electricity Systems – Example China

Energy and service contributions of different technologies to maintain electricity security in China (2060 modeled by IEA)



"Shifting away from centralized thermal power plants as the main providers of electricity makes power systems more complex.

Multiple services are needed to maintain secure electricity supply."



Thermal · Abated thermal · Clean fuels · Hydro · Nuclear · Variable renewables · Bioenergy · Other renewables · Storage · Demand response

Source: IEA: Energy Transitions Require Innovation in Power System Planning – Analysis, January 2022. https://www.iea.org/articles/energy-transitions-require-innovation-in-power-system-planning.

Carrying Energy over DC Lines is Energy Inefficient

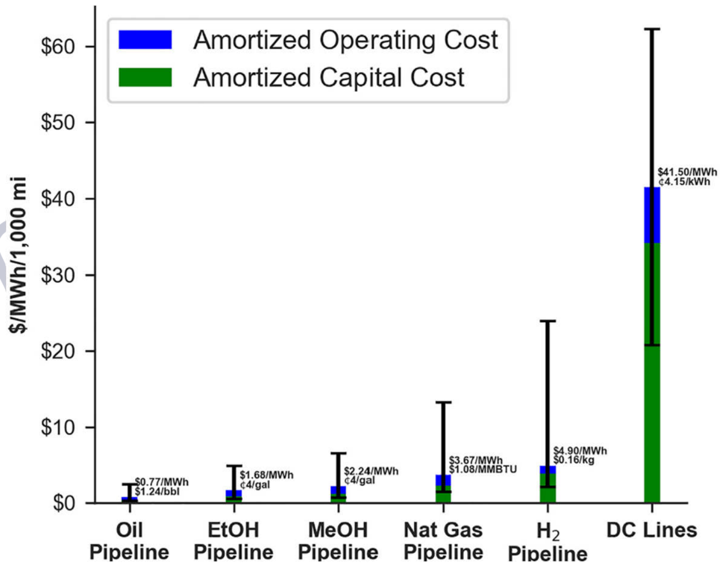
Amortized Transmission Costs per 1.000 miles (1.600 km)

DeSantis et al. 2022 (iScience, peer-reviewed)

… cost of electricity transmission per MWh can be

- Up to 8x higher than for H_2 pipelines
- About 11x higher than for natural gas pipelines
- About 20-50x higher than for liquid fuels pipelines
- These differences are also true for shorter distances

Higher transmission costs is primarily caused by lower carrying capacity (MW per line) of transmission lines



Source: DeSantis et al 2021, iScience. 2021 Dec 17; 24(12): 103495, Published online 2021 Nov 22. doi: 10.1016/j.isci.2021.103495; https://www.sciencedirect.com/science/article/pii/S2589004221014668

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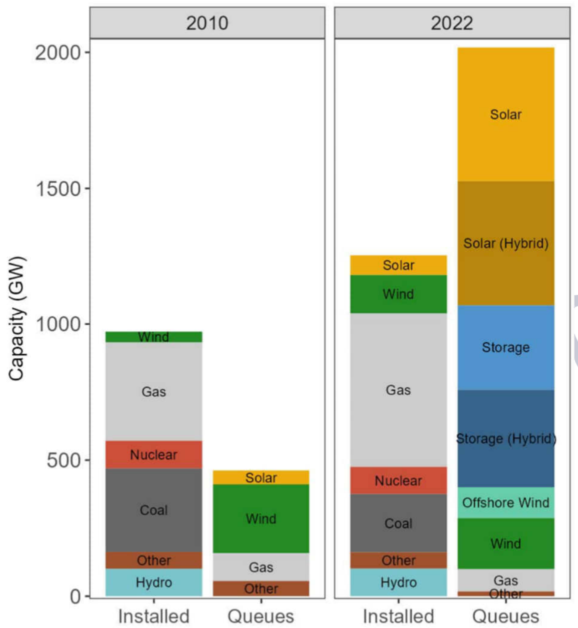
US: 2 TWs of generation and storage capacity sits in interconnection queues

US Installed Capacity vs. Active Queues



Ggrowing backlog has become major bottleneck for project development:

- **Projects are taking longer to complete the interconnection study and to come online, and most of interconnection requests are ultimately canceled.**

Despatchable Capacity Growth hardly present

What are interconnection queues?

Utilities and regional grid operators require projects seeking to connect to the grid to undergo a series of studies before they can be built.

This process establishes what new grid system upgrades may be needed before a project can connect to the system and then estimates and assigns the costs of that equipment.

The lists of projects that have applied to connect to the grid and initiated this study process are known as "interconnection queues".

Source: Rand, Joseph, Mark Bolinger, Ryan Wiser, Seongeun Jeong, and Bentham Paulos. "Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection As of the End of 2020," April 2023. https://doi.org/10.2172/1784303.

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Miller Keith 2018: Harvard Article on „down side“ of Wind

Schernikau on Energy Policy


SCIENCE & TECHNOLOGY

The down side to wind power

Wind farms will cause more environmental impact than previously thought

This research was funded by the Fund for Innovative Climate and Energy Research

The key messages in the Harvard article are

- the transition to wind or solar power in the U.S. would require five to 20 times more land than previously thought
- real-world wind power generation had been overestimated because they neglected to accurately account for interactions between turbines and atmosphere
- We found that average wind power density — meaning rate of energy generation divided by encompassing area of the wind plant — was up to 100 times lower than estimates by some leading energy experts
- If your perspective is next 10 years, wind power actually has — in some respects — more climate impact than coal or gas…If your perspective is the next thousand years, ***then wind power has enormously less climatic impact than coal or gas***
  - The Harvard researchers found that the warming effect of wind turbines in the continental U.S. was actually larger than the effect of reduced emissions for the first century of its operation.

“The direct climate impacts of wind power are instant, while the benefits of reduced emissions accumulate slowly”

Sources: Miller, Lee, and David Keith. “Miller Keith 2018 - Climatic Impacts of Wind Power.” *Joule* 2 (2018). https://doi.org/10.1016/j.joule.2018.09.009.

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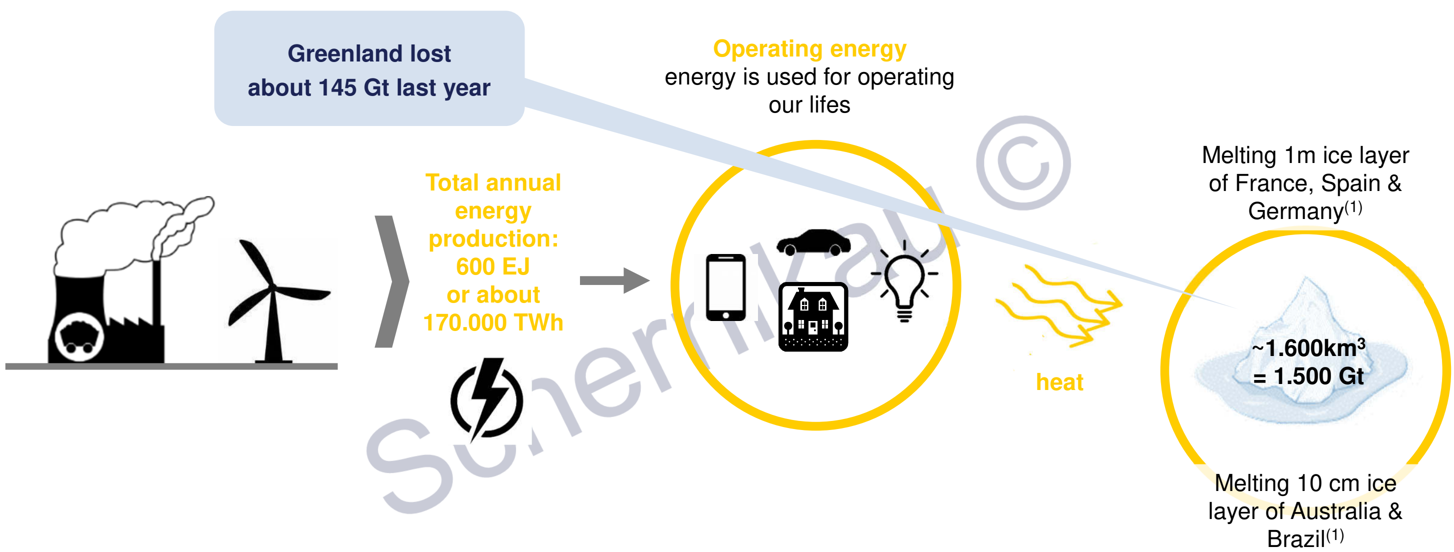
Humans Cause Warming

Melting Ice Causes Warming (Reduced Albedo/Reflection of Sun Rays)

Schernikau on Energy Policy

illustrative



The sun is much much stronger and above is miniscule compared to solar changes
… on a sunny day temperature can be 5-10 °C higher[2]

(1) ~550 EJ (~ 160.000 TWh p.a.) = has the capacity of melting 1.500 km³ ice, or 1m ice layer of 1.530.000 km² which translates to an approx. area size of France, Spain & Germany and b) melting 10 cm of ice layer of 15.300.000 km² which translates to an approx. area size of Australia & Brazil; (2) assuming one sunny day increased temps by 5 °C, this would translate to 5/365 = 1,4 °C in 100 years
Source: Schernikau research and analysis based on Dr. Bodo Wolf 2020 „Eine Expertise über die Energetik der Biosphäre“; book Sustainable Materials Without the Hot Air (2015 by Jonathan M. Cullen, Julian M. Allwood)

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Power Consumption and GDP per Capita for Coal Import/Export Countries

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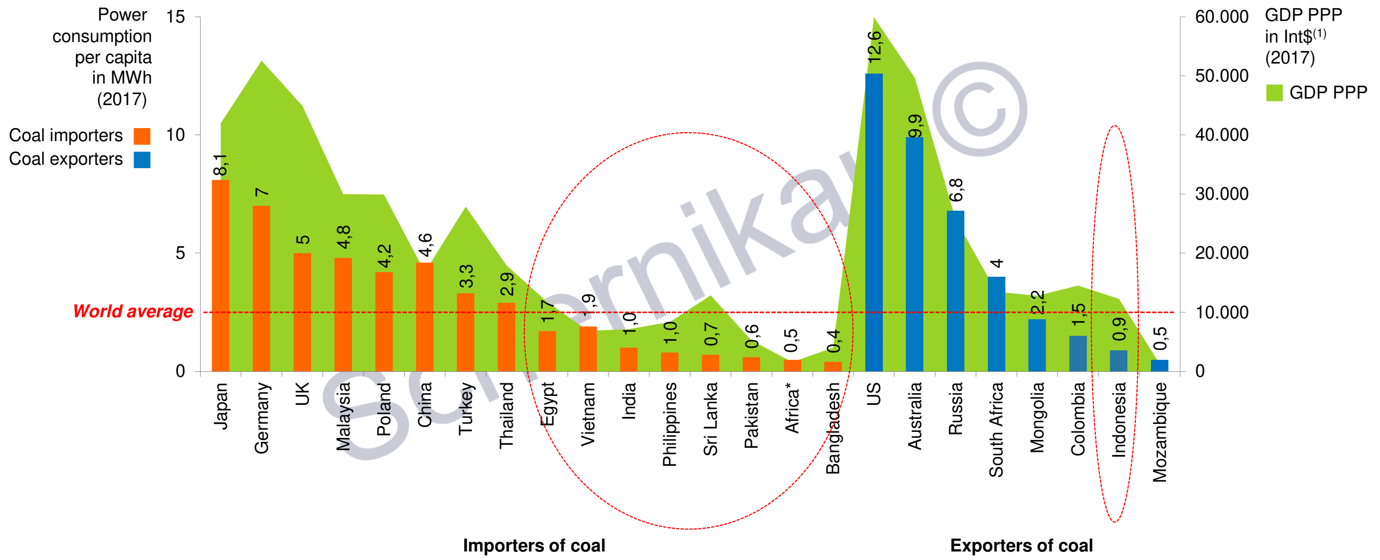
on Energy Policy

no dispute



(1) Figures are in current Geary-Khamis dollars, more commonly known as international dollars (Int$)
* Sub-Saharan Africa without South Africa; GPD PPP rounded to Int$ 1.500 based on World Bank
Sources: Schernikau analysis based on The World Bank (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD) and IEA Atlas of Energy (http://energyatlas.iea.org/#!/tellmap/-1118783123/1)

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Lazard 16.0: Levelized Cost of Energy – First Rise in 2023

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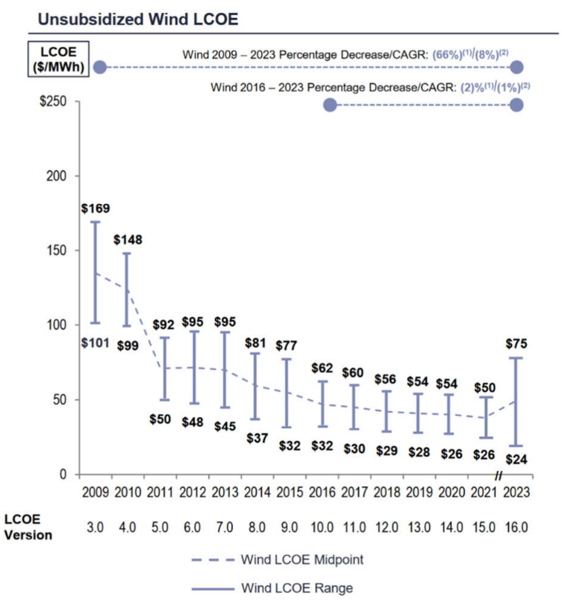

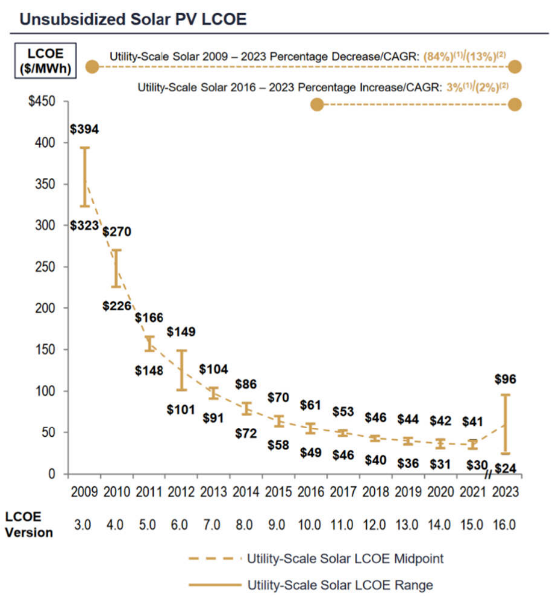

Key Assumptions

„Capacity Factors"

- *Solar 15-30%*
- *Wind 30-55%*
- *Coal 35-85%*
- *Gas CCG 30-90%*
- *no differentiation between „natural capacity factor" and „utilization"*
- *No consideration of network integration*
- *No long duration energy storage*

Source: Lazard April 2023, https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/

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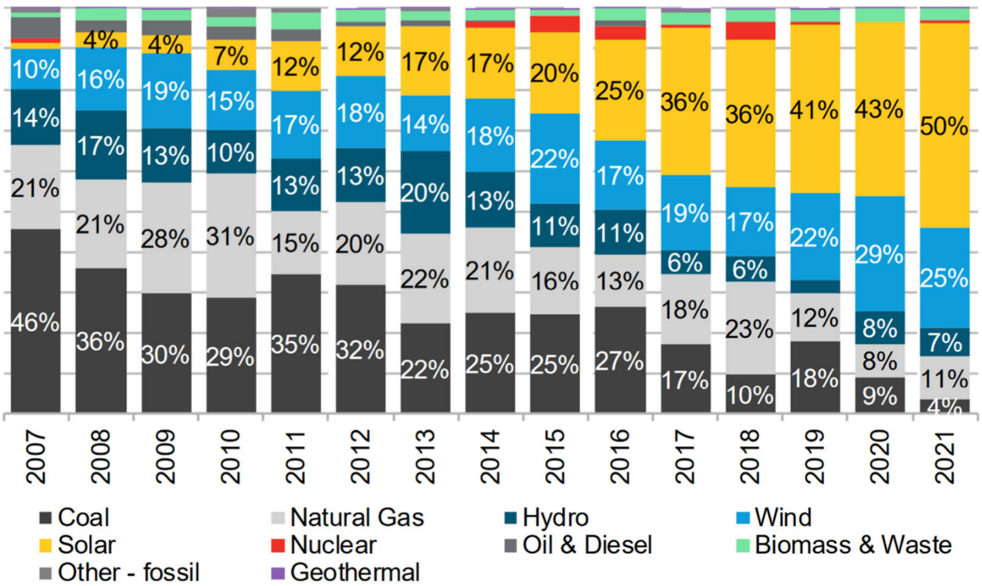
Bloomberg NEF on Electricity: Solar was half of all capacity installed in 2021

Share of Global Capacity Additions by Technology



Source: Bloomberg NEF, Nov 2022, https://global-climatescope.org//, excluding capacity retirements

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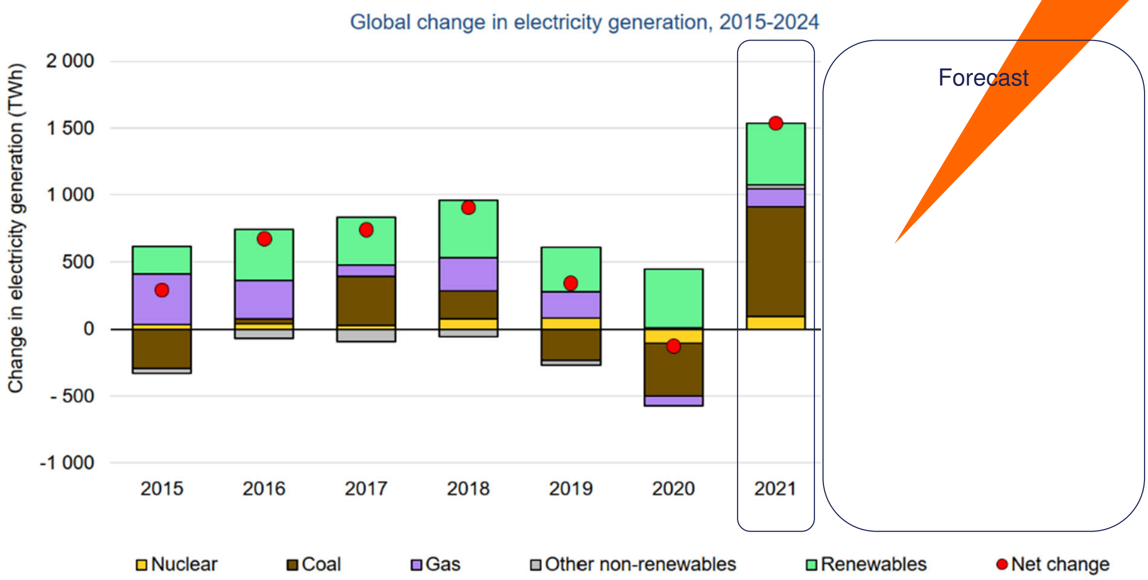
IEA Jan 2022: Coal Largest Contributor to Growth

Includes all forms of renewables such as hydro, geothermal, biomass, solar & wind



Note: Other non-renewables includes oil, waste and other non-renewable energy sources.
Source: IEA analysis based on data from IEA (2022), Data and statistics.: IEA: Electricity Market Report - January 2022 – Analysis, January 2022. https://www.iea.org/reports/electricity-market-report-january-2022.

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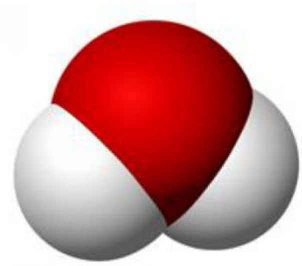
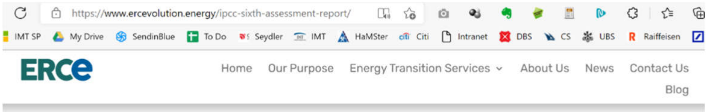
What is Global Warming Potential – GWP?

Note: The authors have reservations about IPCC's GWP metric

H_2O



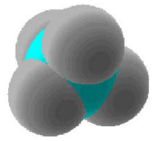
Water Vapor (Major)



IPCC Sixth Assessment Report Global Warming Potentials

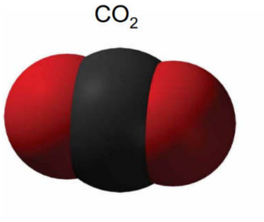
Greenhouse Gas	100 Year Time Period			20 Year Time Period		
	AR4 2007	AR5 2014	AR6 2021	AR4 2007	AR5 2014	AR6 2021
CO_2	1	1	1	1	1	1
CH_4 fossil origin	25	28	29.8	72	84	82.5
CH_4 non fossil origin			27.2			80.8
N_2O	298	265	273	289	264	273

CH_4



Methane (Very Minor)

CO_2

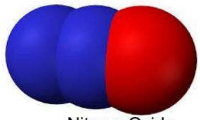


Carbon Dioxide (Minor)

Global Warming Potential (IPCC):

CH_4 84x higher than CO_2 over 20 years

(28x over 100 years)



Nitrous Oxide (Very Minor)

Schernikau

Airborne: Comparing CO_2^{eq} Coal vs. Gas (2019 data)

	Global CO_2 from combustion only	CO_2^{eq} @GWP_{20} from measured methane emissions only	Global total CO_2^{eq} emissions @ GWP_{20}
Coal	14.360 Mt CO_2 less 54% = 7.600 Mt CO_2 airborne ▪ 43.850 TWh PES ▪ **Ratio = 0,15 Mt CO_2/TWh**	3.530 Mt CO_2^{eq} (primarily from underground mining) ▪ 43.850 TWh PES ▪ Ratio = 0,08 Mt/TWh	10.000 Mt CO_2^{eq} airborne ▪ 43.850 TWh PES ▪ Ratio = 0,23 Mt/TWh
Natural Gas	7.620 Mt CO_2 less 45% 3.500 Mt CO_2 airborne ▪ 39.290 TWh PES ▪ Ratio 0,09 Mt/TWh	3,440 Mt CO_2^{eq} ▪ 39.290 TWh PES ▪ Ratio 0,09 Mt/TWh	7.130 Mt CO_2^{eq} airborne ▪ 39.290 TWh PES ▪ **Ratio 0,18 CO_2^{eq} Mt/TWh**
Global Sum (inc. natural, oil, agriculture, other)	**16,5 Bt CO_2 airborne (total emissions 36 Bt CO_2)** ▪ **Coal share = 40 %** ▪ **Gas share = 21 %**	**49,5 Bt CO_2^{eq} (590 Mt CH_4)** ▪ **Coal share = 7,1 %** ▪ **Gas share = 6,9 %**	**66 Bt CO_2^{eq} airborne** ▪ **Coal share = 15 %** ▪ **Gas share = 11 %**
	Gas better Coal/Gas = 1,7x	**Coal better Coal/Gas = 0,9x**	**Gas better Coal/Gas = 1,3x**

Surface-mined coal ~15% "better for climate" than average natural gas

Coal has lower CH_4 emissions @GWP_{20}: Gas/Coal "climate" breakeven if ~2% or more CH_4 is lost along the value chain

Note: PES = Primary Energy Supply 2019:; Note 2: Airborne = After 50% natural ocean and plant uptake of CO2 as per IPCC AR6 p89 it is actually 54%
Source: Schernikau/Smith 2021, Climate Impacts of Fossil Fuels, SSRN Electronic Journal, Nov 2021, (link, DOI 10.2139/ssrn.3968359)

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… How Move from Coal to LNG Effect Developing Nations?

Schernikau

Bangladesh scraps 10 coal-based power plants over environmental worries

Staff Correspondent, bdnews24.com
Published: 2021-06-27 14:05:55 BdST

June 2021

File Photo

The Bangladesh government has cancelled 10 planned coal-based power plar impact into consideration.

The Integrated Energy and Power Masterplan needs to set the coal-based power generation targ overall situation into consideration, said State Minister for Power and Energy Nasrul Hamid at a p Sunday.

Global Gas Crunch Leaves Ba Facing Blackouts Until 2026

- Bangladesh to buy less spot LNG on high prices, r
- South Asia seeing severe LNG shortages as price

A protest against the recent electricity crisis in Dhaka on July 25. *Photographer: Rehmar Asad/NurPhoto/Getty Images*

By Ann Koh

Aug 2022

August 1, 2022 at 6:21 AM GMT+2

Bangladesh faces another three years of rolling power cuts as th developing nation struggles to secure long-term supplies of natu gas and is priced out of spot markets.

3 minute read · October 5, 2022 12:30 AM GMT+2 · Last Updated 9 days ago

Bangladesh plunged into darkness by national grid failure

REUTERS®

By Ruma Paul and Sudarshan Varadhan

A pharmaceutical shop uses candle lights to serve customers during countrywide blackout in Dhaka, Bangladesh, October 4, 2022. REUTERS/Mohammad Ponir Hossain

Summary Companies

Oct 2022

- Power grid collapse leads to blackouts in 75-80% Bangladesh
- Authorities working to restore power, investigating cause
- Government had rationed some gas due to high global prices

Sources: https://bdnews24.com/detail/economy/1907104, Global Gas Crunch Leaves Bangladesh Facing Blackouts Until 2026 – Bloomberg, Bangladesh plunged into darkness by national grid failure | Reuters

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"Human" Impact on GDP

Reported Jan 2023

Schernikau
on Energy Policy

bp Energy Outlook
2023 edition

Impact of Russia-Ukraine war on global GDP (change relative to Energy Outlook 2022)

Impact of Covid on GDP

"During 2020, the world's collective GDP fell by 3,4 percent"

Covid19 may have caused a permanent 5-6% drop in global GDP

statista

Source: "BP Energy Outlook 2023," January 2023. BP2023, p24; Impact of the coronavirus pandemic on the global economy - Statistics & Facts | Statista, Jan 2023

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IPCC and UNFCCC language on GDP impact of Climate Change

Impact of Climate Change as per IPCC

UN globally government funded body studying climate change

„Intergovernmental Panel on Climate Change“

Oct 2018

2,6% GDP loss
from 3,7 °C temperature rise
in year 2100

al. (2018c) of 15 trillion USD. Under the no-policy baseline scenario, temperature rises by 3.66°C by 2100, resulting in a global gross domestic product (GDP) loss of 2.6% (5–95% percentile range 0.5–8.2%), compared with 0.3% (0.1–0.5%) by 2100 under the 1.5°C

"… GDP loss of 1,2% per degree of warming…"

Of course, not linear, so very approximate

United Nations Climate Change

Oct 2022

"…combined climate pledges of 193 Parties under the Paris Agreement could put the world on track for around 2.5 degrees Celsius of warming by the end of the century."

Thus, about 1,2% GDP loss from 2,5 °C warming

(5-95% percentile range 0,25-3,8% GDP loss)

Note: IPCC names several studies in the Chapter 3.5.2.4 "Global Aggregate Impacts": including Warren et al 2018, Pretis et al 2018, Burke et al 2018, Shindell et al 2018
Note: UNFCCC = UN Climate Change or United Nations Framework Convention on Climate Change
Source: "1,5 Deg Special Report," 2018; http://www.ipcc.ch/report/sr15/. p256 in Chapter 3; "UN Climate Change: Climate Plans Remain Insufficient: More Ambitious Action Needed Now | UNFCCC," October 2022, unfccc.

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Cost of the Energy "Transition"…

McKinsey & Company

Global capital spending in the transition could rise in the short term before falling back

- Cumulative spending of around **$275 trillion or about 7.6% of global GDP** across 2021-2050
- Poorer countries and those reliant on fossils are most exposed to the shifts in a net-zero transition

The cost of "Net-Zero": US$75 trillion economic loss by 2050

- Less developed and low-income economies will bear a disproportionally high burden.
- keeping warming to 1.5 °C would shave 2% off our basecase GDP forecast for 2050

This translates to 10% per capita GDP loss by 2050

Source: The Net-Zero Transition: Its Cost and Benefits | Sustainability | McKinsey & Company," January 2022. link; WoodMac: No Pain, No Gain – the Economic Consequences of Accelerating the Energy Transition, January 2022. link.

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