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

The opinions expressed in this presentation and on the following slides are solely those of the presenter and not necessarily those of HMS Bergbau AG, or any company/organization. The presenter does not guarantee the accuracy or reliability of the information provided herein.

Recommendation:
Check everything yourself

Please do NOT quote me or make public any slides without my consent
What are Key “Earthly” Challenges Today?

Humanity's key challenges

1. Food & Water
2. Energy
3. Health (bodily, mental, spiritual)
4. Human Waste = Pollution

Main problems:
- Pollution and overuse of water
- Pollution of Soil
- Pollution of air

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

Introduction

eROI

LCOE vs. FCOE (Full Cost of Electricity)

What Next?

Discussion

Triangle of Objectives in Energy Policy

Providing Basis for Healthy Life and Growth

Security of energy supply

Affordability of energy supply

Environmental protection

Climate

Pollution

Plants & Animals

Land & Space

Material Input

Energy Input

Source: Schernikau research, i343

© Dr. Lars Schernikau

not to be copied or distributed without written consent

Page 4
Electricity: About 40% of Global Primary Energy
Fossil Fuels: About 60% of Electricity and 80% of Global Primary Energy

Global Electricity Generation (TWh)

- Coal and Gas ~60% in 2022

Wind/solar: ~4% in 2022
Wind/solar: ~10% in 2022

In % of global production 2019 data

Primary energy (PE) 100%
~ 170.000 TWh
Industry(1) ~20%
Transport(1) ~20%
Heating/Building(1) ~20%
Before losses(2) ~40% Electr.
Electricity 40% of PE
~29.000 TWh
~17% of PE
3% Petroleum
27% Gas
26% Coal
~14% Other
5% Nuclear

Sources: Schernikau analysis based on IEA Energy Technology Perspectives 2020, IEA Statistical Review of World Energy 2020, see also World in Data

Notes:
(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

Global Electricity Generation
https://doi.org/10.1016/0140-6701(95)95132-6

Sernikau on Energy Policy

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

By Kate Gubinski and Yuki Obata

Source: “G7: Ministers’ Meeting on Climate, Energy and April 15 and 16, 2023, Sapporo, Japan.” Sapporo

Sernikau on Energy Policy
How much Energy do we use?

2020-2050 growth:
Energy per capita: ~20% + Population: ~25%
Total primary energy growth: ~ 50%

Global Share of Coal 2022:
Over 1/3rd Electricity
Over 1/4th of Primary Energy

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

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

- **Germany 2021:** 5% + 11% biomass
- **Globally 2021:** 17%


---

The **Green Quadrant**

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

- **1974:** The last time the world saw a decrease in FF consumption & an increase in global energy consumption

The Green Quadrant

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

Range of energy consumption growth across IPCC’s SSP scenarios to 2050 -0.3% to 2.1%

1974. The last time the world saw a decrease in FF consumption & an increase in global energy consumption

Annual change in global fossil fuel consumption

Note: FF = Fossil Fuel, IPCC = Intergovernmental Panel on Climate Change; SSP = Shared Socio-Economic Pathways, are scenarios defined by the IPCC about future development

Annual decline in FF until 2050 implied by an 80% FF reduction from 2020, -5.4% p.a.

Annual change in global energy consumption

Investments in Coal Less than Half of Wind/Solar
… While Coal Provides 4x More Energy

Global electricity generation (estimated 2019)

Global investments in power (estimated 2019/20)

Note: Right side includes investments in fuel supply and power; for Gas it is assumed that 52% of total “oil & gas” fuel supply investments went into gas (511 B$ x 0.52 = 265 B$)
Sources: Schernikau Research & Analysis based on IEA and BNEF Data; Fuel supply – World Energy Investment 2020 – Analysis – IEA

© Dr. Lars Schernikau not to be copied or distributed without written consent
Germany 2021: Renewable Installed Capacity vs. Power Generation and Primary Energy

Installed net power generation capacity in Germany (2002-2021)

Wind & solar: 122 GW (55%)
Fossil fuels: 75 GW (33%)
Nuclear: 8 GW (4%)

2002: 115 GW
2021: 222 GW

+93%

Wind & solar: 122 GW (55%)

2021: ∑ = 222 GW

2002: ∑ = 115 GW

Primary energy consumption in TWh

2002: ∑ = 587 TWh
2021: ∑ = 598 TWh

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

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

Σ = ~8.000 GW or 8 TW in 2020
total global installed capacity
(Coal = 2 TW, Gas, Nuclear, Hydro, Biomass, Wind, Solar, Other)

Note: PV = photovoltaics.
[1] The range of the compound annual growth rate is based on the planned energy scenario vs. the 1.5°C scenario.

Introduction
eROI
LCOE vs. FCOE (Full Cost of Electricity)
What Next?
Discussion
What is eROI?

ROI: Monetary Return on Investment

2:1

eROI: Energy Return on Energy Investment

2:1

eROI (energy returns) measures net energy efficiency

Source: Schernikau research

GDP Spent on Energy Generation – in UK

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

Note: Fodder = 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)

Energy Return

Material Input\(^1\) (MIPS)
Space Requirement\(^2\)

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Material Input (MIPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1.185</td>
</tr>
<tr>
<td>Gas</td>
<td>0.572</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.920</td>
</tr>
<tr>
<td>Hydro</td>
<td>14.074</td>
</tr>
<tr>
<td>Solar</td>
<td>16.447</td>
</tr>
<tr>
<td>Wind</td>
<td>10.260</td>
</tr>
<tr>
<td>Geothermal</td>
<td>5.261</td>
</tr>
</tbody>
</table>

Source: Schernikau research and analysis

1. Tonnage of material input per energy output, such as cement, steel, aluminium, lithium, rare earth, etc.
2. Land area in square meters per unit of energy output per annum

Full Cost of Electricity (FCOE)

(1) Tonnage of material input per energy output, such as cement, steel, aluminium, lithium, rare earth, etc.
(2) Land area in square meters per unit of energy output per annum

Part of Room Cost which includes all costs of occupying large areas of land

Land area needed to power a flat-screen TV, by energy source:

- **Wind**:
  - 37 m\(^2\) Wind energy footprint including turbine spacing
- **Solar**:
  - 14 m\(^2\) Solar
- **Coal**:
  - 0.8 m\(^2\) Coal
- **Nuclear**:
  - 0.3 m\(^2\) Nuclear
- **Natural Gas**:
  - 0.1 m\(^2\) Natural gas
Comparing eROI – illustrative (here focus electricity)

Energy Return on Investment (eROI)

Full Cost of Electricity (FCOE)

$$$

$$

$

$$$$

Nuclear

Hydro

Coal & Gas

Wind,

Solar,

Biomass

Romans

~60-80%

~20 to 30%

min eROI for modern Society: 6-10x

Material Input¹ (MIPS)

Space Requirement²

(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.

~60-80%

~20 to 30%

min eROI for modern Society: 6-10x

Coal & Gas

Hydro

Nuclear

Wind,

Solar,

Biomass

Romans

(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.
Global Wind and Solar Resources are not sufficient

Wind Map (Europe, Africa, Asia)

Solar Irradiance Map (Europe, Africa, Asia)

Global average capacity factor

- 21-24% for wind
- 11-13% for solar PV

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

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 EnergyMap accessed 4 Sep 2020 at this link.
Typical Electricity Demand Curve and PV Production — a Sunny Day around the Equator

Illustrative

With H₂ as backup
About x3 to x5
California avg.
CF 25%

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

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

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: Levelized Cost of Energy Comparison—Unsubsidized Analysis

OECD confirms higher costs of wind and solar

Note on profile cost: "Profile Costs of Wind Energy: Why are Utilities Overpaying?" - Master Resource. 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.

IEA Dec 2020: “... the system value of variable renewables such as wind and solar decreases as their share in the power supply increases.”


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”

Illustrative: Integration and Backup Costs for VRE (VRE = Variable Renewable Energy)

In other words: the more wind and solar in the system, the higher the cost

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

Switching to renewable energy could save trillions - study

Katrin Göring-Eckardt expects electricity prices to fall

nuclear phase-out

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.

Source: BBC Sep 2022 and Die Zeit Apr 2023
What Is the Cost of Energy? = NOT Levelized Cost of Electricity (LCOE)

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

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

LCOE is Incomplete

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)

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

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.”

Comparison of LCOE and LFSCOE.

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

Example: Vietnam and Electricity production – realistic forecast?

Vietnam Installed Power Capacity (Actual and Forecast in GW)

- Solar & Wind
- Hydro
- Gas (small oil)
- Coal

49 GW

2018

Note: Chart shows forecast capacity by energy type. Renewable energy sources does NOT include hydro

Vietnam and Electricity production – realistic forecast?

Vietnam Installed Power Capacity (Actual and Forecast in GW)

- Solar & Wind
- Hydro
- Gas (small oil)
- Coal

Peak power demand x5 ??

Note: Chart shows forecast capacity by energy type. Renewable energy sources does NOT include hydro
The Economist Wakes Up?

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/environmental impacts of wind/solar, recycling challenges
6. Low net energy returns «eROI» (energy returns on energy invested)
**Externality of Energy Systems**

- **Production/Mining**
  - Includes raw materials extraction

- **Processing**
  - Includes upgrading, refining of raw materials

- **Transportation**
  - Transportation of products along entire value chain

- **Manufacturing**
  - Manufacturing of equipment

- **Operations**
  - Includes combustion for energy generation

- **Recycling**
  - Includes waste handling, processing, disposal

**Emissions**

- CO₂
- CH₄
- SO₂
- NOₓ
- Mercury
- Chlorine
- Particulate matter etc., etc., etc.

**Other environmental**

- Energy input
- Animals/Plants
- Space
- Waste etc., etc., etc.

**Human**

- Health/Safety
- Energy Poverty
- Financial Poverty
- Industrial development

**Current Focus of Energy Policy**

- CO₂ = Sole Focus of “Carbon” Taxation

**Carbon taxation leads to distortions and undesired consequences**

- Because it dismisses other emissions, non-emissions, and human impacts

**Externalities (Human & Environment)**

- **Human**
  - Health/Safety
  - Energy Poverty
  - Financial Poverty
  - Industrial development

- **Emissions**
  - CO₂
  - CH₄
  - SO₂
  - NOₓ
  - Mercury
  - Chlorine
  - Particulate matter etc., etc., etc.

**Triangle of Objectives in Energy Policy**

- Providing Basis for Healthy Life and Growth
  - Examining Wind & Solar
  - Security of energy supply
  - Affordability of energy supply

- Environmental protection
  - Climate Pollution
  - Plants & Animals
  - Land & Space
  - Material Input
  - Energy Input

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

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

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

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

Content

Introduction

eROI

LCOE vs. FCOE (Full Cost of Electricity)

What Next?

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

Available on Amazon now
https://amzn.to/3t9qy5C

Lars Schernikau

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

Source: Authors 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)
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 years.

Comparing Mineral Needs for Renewable Technology

Minerals used in selected “clean” energy technologies

Two Important Laws of Thermodynamics

1st Law of Thermodynamics
(energy is never lost)

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

Conversion or storage of energy always means losing 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: Schernikau research and analysis, graphs from 10.3 - Entropy and the 2nd law (slideshare.net) and https://i.ytimg.com/vi/IyNNzOT4jO0/maxresdefault.jpg

Conversion or storage of energy always means losing useful energy

Higher Entropy = higher disorder or lower value, irreversible

Entropy decreases when freezing

Current and Future Electricity Systems – Example China

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

China in 2020

China in Announced Pledges Scenario, 2060

“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.”

Carrying Energy over DC Lines is Energy Inefficient

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

… cost of electricity transmission per MWh can be

- Up to 8x higher than for H₂ 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


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

Growing 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”.
**Miller Keith 2018: Harvard Article on „down side“ of Wind**

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".

---

**Humans Cause Warming**

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

Human activities cause warming in the planet:

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

Greenland lost about 145 Gt last year.

Operating energy is used for operating our lives.

The sun is much much stronger and above is miniscule compared to solar changes.

Illustrative Image:

- Total annual energy production: 600 EJ or about 170,000 TWh
- Melting 1m ice layer of France, Spain & Germany (1)
- Melting 10 cm ice layer of Australia & Brazil (1)

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

Importers of coal
Exporters of coal

World average

Power consumption per capita in MWh (2017)

Coal importers
Coal exporters

Japan
Germany
UK
Malaysia
Poland
Turkey
Thailand
Egypt
India
Philippines
Africa
Bangladesh
US
Australia
Russia
South Africa
Mongolia
Colombia
Indonesia
Mozambique

GDP PPP
(1) in Int$ (2017)

0
5
10
15
20.000
30.000
40.000
50.000
60.000

12.6
9.9
6.8
4.0
2.2
1.5
0.9
0.5
0

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

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

Unsubsidized Wind LCOE

Unsubsidized Solar PV LCOE

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


© Dr. Lars Schernikau
not to be copied or distributed without written consent
Bloomberg NEF on Electricity: Solar was half of all capacity installed in 2021

Share of Global Capacity Additions by Technology

IEA Jan 2022: Coal Largest Contributor to Growth

Includes all forms of renewables such as hydro, geothermal, biomass, solar & wind
What is Global Warming Potential – GWP?
Note: The authors have reservations about IPCC's GWP metric

Global Warming Potential (IPCC):
\[ \text{CH}_4 \] 84x higher than \( \text{CO}_2 \) over 20 years
(28x over 100 years)

Airborne: Comparing \( \text{CO}_2^{eq} \) Coal vs. Gas (2019 data)

<table>
<thead>
<tr>
<th>Source</th>
<th>Global ( \text{CO}_2 ) from combustion only</th>
<th>( \text{CO}_2^{eq} ) from measured methane emissions only</th>
<th>Global total ( \text{CO}<em>2^{eq} ) emissions @ GWP(</em>{20})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>14.360 Mt ( \text{CO}_2 ), less 54% = 7.600 Mt ( \text{CO}_2 ) airborne</td>
<td>3.530 Mt ( \text{CO}_2^{eq} ), primarily from underground mining</td>
<td>10.000 Mt ( \text{CO}_2^{eq} ) airborne</td>
</tr>
<tr>
<td></td>
<td>( 43.850 \text{TWh PES} )</td>
<td>( 43.850 \text{TWh PES} )</td>
<td>( 43.850 \text{TWh PES} )</td>
</tr>
<tr>
<td></td>
<td>( \text{Ratio} = 0.15 \text{Mt CO}_2/\text{TWh} )</td>
<td>( \text{Ratio} = 0.08 \text{Mt CO}_2/\text{TWh} )</td>
<td>( \text{Ratio} = 0.18 \text{Mt CO}_2/\text{TWh} )</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>7.620 Mt ( \text{CO}_2 ), less 45% = 3.500 Mt ( \text{CO}_2 ) airborne</td>
<td>3.440 Mt ( \text{CO}_2^{eq} ), ( 39.290 \text{TWh PES} )</td>
<td>7.130 Mt ( \text{CO}_2^{eq} ) airborne</td>
</tr>
<tr>
<td></td>
<td>( 39.290 \text{TWh PES} )</td>
<td>( 39.290 \text{TWh PES} )</td>
<td>( 39.290 \text{TWh PES} )</td>
</tr>
<tr>
<td></td>
<td>( \text{Ratio} = 0.09 \text{Mt CO}_2/\text{TWh} )</td>
<td>( \text{Ratio} = 0.09 \text{Mt CO}_2/\text{TWh} )</td>
<td>( \text{Ratio} = 0.18 \text{CO}_2^{eq} \text{Mt CO}_2/\text{TWh} )</td>
</tr>
<tr>
<td>Global Sum</td>
<td>16.5 Bt ( \text{CO}_2 ) airborne (total emissions 36 Bt ( \text{CO}_2 ) )</td>
<td>49.5 Bt ( \text{CO}_2^{eq} ) ( (590 \text{ Mt CH}_4) )</td>
<td>66 Bt ( \text{CO}_2^{eq} ) airborne</td>
</tr>
<tr>
<td></td>
<td>( \text{Coal share} = 40 % )</td>
<td>( \text{Coal share} = 7.1 % )</td>
<td>( \text{Coal share} = 15 % )</td>
</tr>
<tr>
<td></td>
<td>( \text{Gas share} = 21.1 % )</td>
<td>( \text{Gas share} = 6.8 % )</td>
<td>( \text{Gas share} = 11 % )</td>
</tr>
</tbody>
</table>

Coal has lower \( \text{CH}_4 \) emissions @GWP\(_{20}\): Gas/Coal “climate” breakeven if ~2% or more \( \text{CH}_4 \) is lost along the value chain

Note: PES = Primary Energy Supply 2019; Note 2: Airborne = After 50% natural ocean and plant uptake of \( \text{CO}_2 \) as per IPCC AR6 p89 it is actually 54% Source: Schernikau/Smith 2021, Climate Impacts of Fossil Fuels, SSRN Electronic Journal, Nov 2021, [link](http://doi.org/10.2139/ssrn.3968359)
**Human** Impact on GDP

Reported Jan 2023

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
IPCC and UNFCCC language on GDP impact of Climate Change

Impact of Climate Change as per IPCC

<table>
<thead>
<tr>
<th>Year</th>
<th>GDP Loss</th>
<th>Temperature Rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct 2018</td>
<td>2.6%</td>
<td>3.7 °C</td>
</tr>
</tbody>
</table>

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 scenario.

"... GDP loss of 1.2% per degree of warming..."

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"

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.