Climate Change Calculated 4

Prof. Dr.-Ing. G. Schuller
Technical University Ilmenau
Institute for Media Technology

I find it fascinating that many, sometimes controversial questions about climate change can be answered independently with 10th grade **physics of** and **Open Data**. I spent a lot of time and effort last summer and autumn in calculating key issues of climate change, and it worked. Physics has the advantage that everything **can be checked independently** using data and mathematics.

This time we answer the question:what can we do?

- **In Part 1** we answered the question: Does **mankind** cause the observed increase in atmospheric **CO2 concentration** through the the use of **fossil fuels**? Physics says: yes.

- We saw that if fossil CO2 emissions were **stopped** today, it would still take around **150 years** before pre-industrial CO2 concentrations were reached again. Only then would the global temperature stop rising.

- In **part 2** we answered the question: Does the increased CO2 concentration cause an **increase in the global temperature**?
  Physics says: yes.

- If the CO2 emissions remain the same, the CO2 concentration will continue to rise and the **temperature rise will be correspondingly faster**.

- In part 2 we also saw that the global temperature is now already over 1 degree above the pre-industrial value.

- In **part 3**, we answered the question: Does the increased CO2 concentration cause the poles to melt and cause a significant **rise in sea level**?
  Physics says: yes.

- In part 3 we saw that the **global economy is very sensitive** even to local disasters such as floods.
- In the context: There were civilizations that caused or intensified (regional) climate change, and vanished as consequence:
  https://en.wikipedia.org/wiki/Nazca_culture
  https://de.wikipedia.org/wiki/Indus-Kultur
  (through deforestation and unsustainable irrigation)

- The goal of keeping global warming to below 2 degrees Celsius (or even 1.5 C) is **still realistic and**

technically feasible, but requires global measures, as shown in the Paris climate agreement, and should be done quickly because we could be close to “tipping points”.

- All this can be **calculated with school physics**!

- Interestingly enough, this physical observation has become a **political issue**, much like the physical observation in the 17th century that the **earth revolves around the sun** (and not the other way around, which the Church insisted, for fear of losing power and influence).

- I will show the feasibility of limiting global warming in the following.

Fossil CO2 is actually just a form of **air pollution**, and this can be solved in a similar way as previous pollution problems, not with restrictions, but with **technical solutions**.

Examples:

- **Garbage cans in Paris in 1700**: even there, in the beginning there was resistance, because of the effort and cost involved, (https://en.wikipedia.org/wiki/Eug%C3%A8ne_Poubelle)
- **catalytic converters in cars in the 1980s**, with it and unleaded gasoline, the air in cities was successfully improved and forest health improved.

(https://en.wikipedia.org/wiki/Catalytic_converter)

- The catalytic converter demanded **new cars**, which were also a bit more expensive (a few 1000 $), similar to electric cars today, and against which the industry at that time also resisted.
- The catalytic converter is now standard, **prices fell** with production volume.
- **Worldwide ban on CFCs as coolants and propellants, and their replacement with alternatives** in the 1990s: it successfully reduced hole in the ozone layer.
- **Ban on low-power light bulbs in Australia, Europe (and the USA),** which was not strictly enforced, but which promoted the switch to LED lamps. As a result, the number of units rose and **the prices for LED lamps fell**.

Principle of getting away from fossil CO2:

- We just have to **avoid fossil energy**, it's that simple! Oil, coal, and gas must **remain in the earth**.

- **Nuclear energy** does not produce fossil CO2, but **is not practical or economical** in the long term because it is not renewable (therefore it only lasts for a limited time) and in principle generates unlimited costs for storage spent nuclear fuel.
- Energy from **renewable sources** is now **cheaper**.

- **Strengthening nature** to reduce fossil CO2, e.g. avoid large-scale deforestation of forests.
- We can switch to **technologies** that do **not use fossil energy**, that is, use **electricity as a form of energy** .
- It is not important that the electricity is already completely from renewable sources, but that our technology is **ready to use electricity from renewable sources in the future**.
- This means that **CO2 balances** should not be based on today's electricity mix, but on the **future electricity mix**, which hopefully will do without fossil CO2, in order to see how **suitable technologies are for the future**.

What proportion of electricity is from fossil sources?

Origin of electrical energy in Germany in 2019:
https://strom-report.de/strom/

- Renewables: 236 TWh (46%)
- Lignite 102 TWh (19.8%)
- Nuclear energy: 71 TWh, (13.7%)
- Natural gas: 54 TWh (10.5%)
- Hard coal: 49 TWh (9.5%)

(TWh: Terawatt hours, Tera: 10^{12})

Note: **Almost half** (46%) of the electrical energy already comes from **renewable** sources.

The remaining fossil share is:
(102 + 49 + 54) TWh = 205 TWh per year

The fossil share plus nuclear power is:
(205 + 71) TWh = **276 TWh**

-> This is comparable to the renewable energy that we already generate, hence **doable**!

Can we replace this with renewable energies?
Is it affordable?

Generation costs per KWh:

Total costs for construction, operation, dismantling, repair of a plant, **divided** by thein its lifetime **energy generated** in KWh.

Price comparison:
https://www.ise.fraunhofer.de/de/presse-und-medien/presseinformationen/2018/studie-zu-stromgesthungskosten-photovoltaik-und-onshore-wind-sind-guenstigste-technologies-in-deutschland. html

nuclear energy:
http://npolicy.org/article_file/New_Nuclear-The_Economics_Say_No.pdf (2009)
https://en.wikipedia.org/wiki/Cost_of_electricity_by_source
This results in the electricity generation costs per KWh to:

- Solar: **free standing 3.8-6.5 c / KWh**, **falling**
- wind onshore: **4-8 c / KWh**, **falling**

- gas: **10-22 c / KWh**
- lignite: **4.5-8 c / KWh**, **increasing**, if the **damage caused** by climate change and the “eternity costs” would be included **considerably more**
- Nuclear energy: at least **6.5 c / KWh, increasing** (2009)
  Hinkley Point, new reactor in Great Britain: feed-in tariff: **11 c / kWh** (2013)
  if the **costs** for **final storage** and **accidents** (similar to liability insurance) would be included, considerably more. These costs are mainly borne by the taxpayer.

Conclusion: Renewable energy is already the **cheapest**. Gas can replace nuclear power and fossil energy for the transition.

What can an individual do?

*** Book a green electricity tariff, from renewable energy:**

- The costs are essentially the same as for conventional energy, sometimes even cheaper!
- With CO2 pricing, the renewable tariffs will become comparably cheaper
- Demand will generate a corresponding supply.

*** Use only electrical energy for transport if possible:**

- electric trains, trams, electric buses, electric cars, car sharing with electric cars.
- If possible, do not use cars with combustion engines with fossil fuels, trains with diesel engines or diesel buses.
- Wherever possible use a bike or walk.

- Buy CO2 offsets when traveling by air. Although this is not perfect, it creates demand for climate-friendly projects (e.g. afforestation).

*** Use only renewable energy for the household if possible: Use**

- heat pumps as heating.
- If possible, set up solar energy and possibly a small wind turbine on the house.

Developments in key technologies over time:

***Price drop of lithium-ion batteries:**

- https://de.statista.com/infografik/20280/preisentwicklung-von-lithium-ionen-batterien/
- 2013: 400 eur / kWh,
- 2020: approx. 84 EUR / kWh.
- That means the prices have **dropped to less than ¼** in just 7 years!
- This will make renewable energy base load capable.

*** Wind power, development of the average nominal power:**

- https://de.wikipedia.org/wiki/Windkraftanlage
- 1990: 164 kW
- 2011: over 2.2 MW,
- so more than a **factor of 10** in 20 years!

*** Solar cell efficiency:**

- https://en.wikipedia.org/wiki/Solar_cell
- 1980s: approx. 5%

- 2020: commercially available approx. 20%, research cells over 30%, comparable to the efficiency of chlorophyll in plant leaves.
- Hence in about 40 years we have an **efficiency increase by a factor of 4!**
- **10 square meters of solar cells** deliver about 2 KW peak power in our latitudes, which gives us about 2000 kWh energy over the year. With battery **storage enough for a 1 person household**. (https://strom-report.de/stromverbrauch/, https://www.solaranlage-ratgeber.de/photovoltaik/photovoltaik-leistung/photovoltaik-ertrag-in-sommer-und-winter)
- The installation costs fell by more than half the last 10 years: https://www.solaranlagen-portal.com/photovoltaik/kosten
  -> Cheaper than regular electricity!

- These increases in efficiency make it realistic to generate the electricity required.
- These technologies are also an important driver of current and future economic growth.
- They are also more environmentally friendly to build and dismantle than coal or nuclear power.

More on this and on calculating how the switch to 100% renewable electricity is possible in the next episode.