A Personal View on a Zero Carbon Future

Axel Winter

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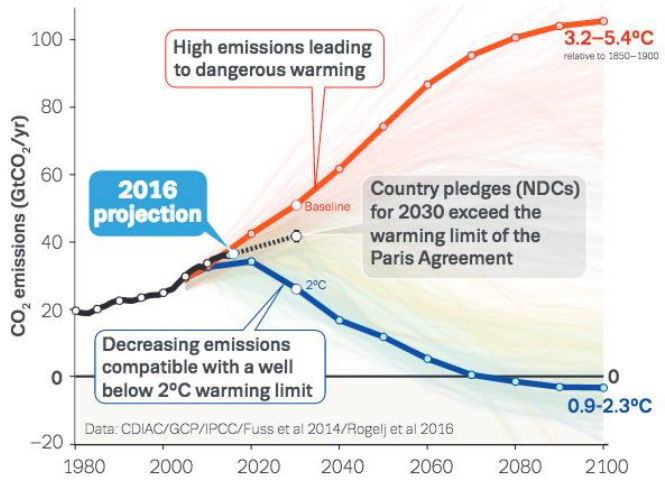
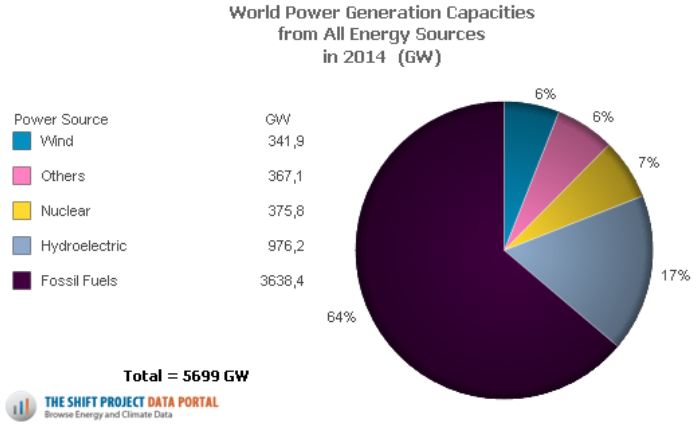
The Paris Climate Accord – Consequences





- Paris accord excellent starting point, but pledges insufficient to meet 1.5°C goal
- Total greenhouse emission budget at 92% in 2016 for 1.5°C goal
- Across all energy sources, 64% generated from fossil fuels which must be phased out by 2050 to achieve goal

Key assumptions

- Do we wish to predominantly maintain current lifestyle in the first world?
- Do we wish to enable developing countries to catch up?
- Do we –generally- wish to maintain the society/economic model the world runs on?

Let’s assume the answer to all the above is yes…

Consequences

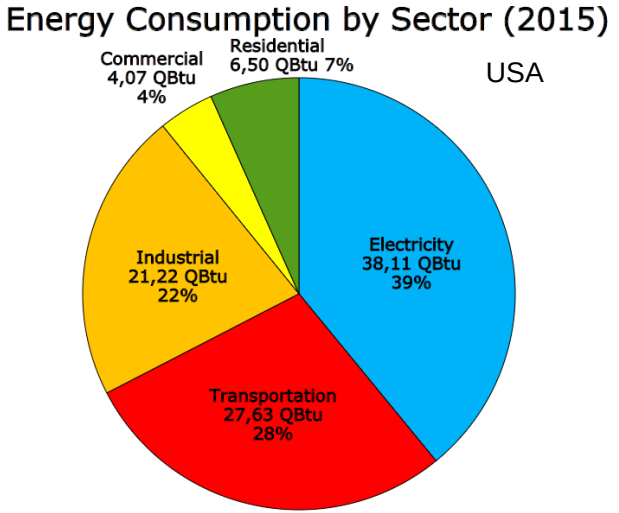
- Primary energy demand in first world countries will remain constant but significant shift to carbon-neutral production necessary – this already assumes a reduction of GHG/$ GDP
- Primary energy demand in developing countries will continue to grow but must grow carbon-neutral

How to get to a carbon-neutral scenario from here?

1. Supply
2. Transport
3. Demand

What's a way forward – supply

- Enable zero-carbon electricity generation of present consumption AND migrate demand from other primary energy consumers to electricity (e.g. transport, industry) → demand will rise sharply (more than double)
- For industrialized nations → almost impossible to see path forward without zero-carbon baseload capability (nuclear fission and eventually nuclear fusion) with 30-60% renewables, based on storage availability → huge effort
- Need game changer in supply → nuclear fusion to replace coal and fission by 2050 may be a viable option



What's a way forward – storage and distribution

- Enough storage to bridge low production periods essential for renewables to significantly exceed 30% of primary energy mix
- Example for a 100% renewable electricity generation
  - Germany: 1.5 TWh per day electricity consumption → 3 day buffer requires 4.5 TWh storage (total primary energy consumption is about 6.5 times that)
- 2017 projections are around 200 MWh: around 23.000 times less than required
- Need a game changer for electricity storage → none on the horizon as far as I can see…

Numbers can be found on Wikipedia…

Transport

- De-centralized production and distribution for developing countries and rural areas, centralized grid for industrial areas with high demand → Targeted solution for each case, no “one shoe fits all”
- For massive carbon neutral energy transport → think hydrogen economy: liquid hydrogen made by electrolysis using tankers for long distance transport and pipelines for land-based transport and converted back to electricity (or used in transport) by fuel cells.
- BUT: This requires a carbon-neutral electricity source
- Fuel cells: 85 % efficiency with use of excess heat, high reliability and zero-carbon → hydrogen economy with nuclear fusion as electricity source may be a viable path.

ex: fuel cell driven submarine in 2016

What's a way forward – demand

- Make every effort in energy efficiency and demand side management to reduce and balance loads (conservation, efficiency, IoT, AI, smart grid, etc.)
- Good news: technology exists → but needs to be implemented
- Political vision and commitment is essential

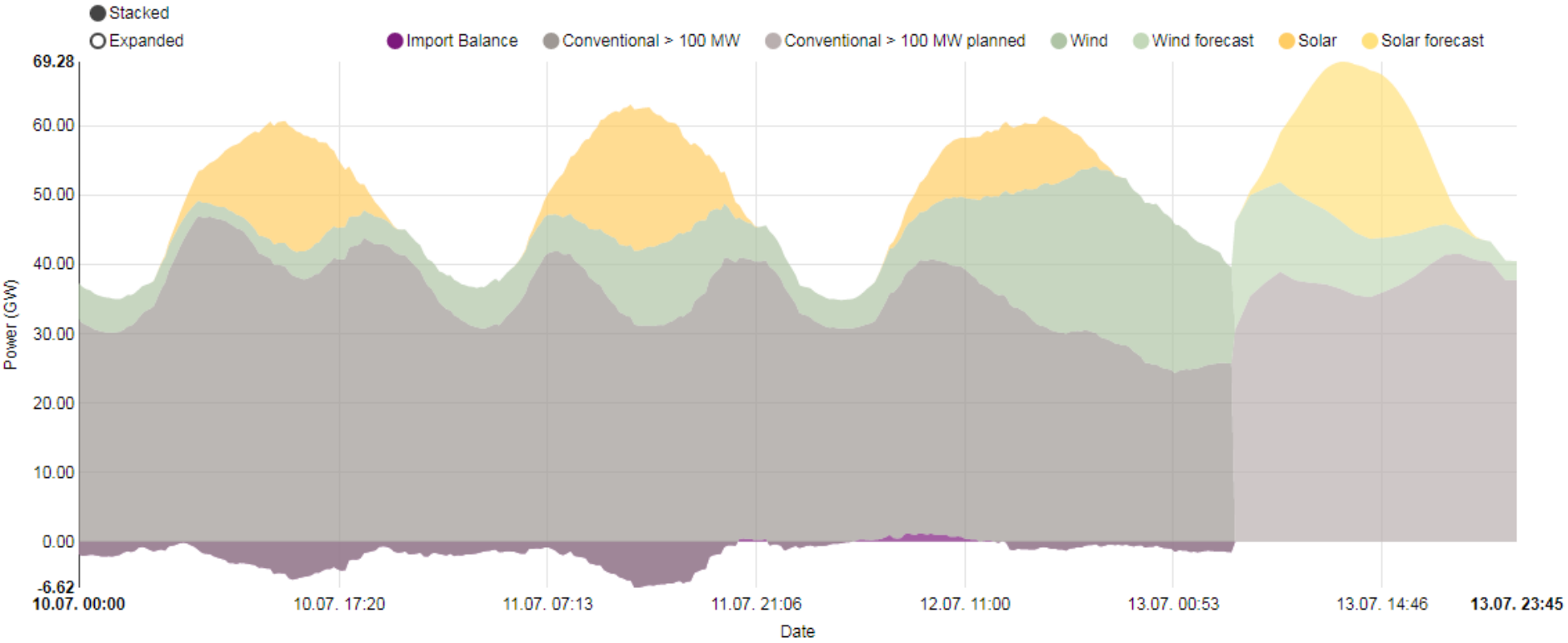
Conclusion

- Shift of primary energy use to carbon-free electricity essential with significant grow in demand
- Game changers needed for storage/transport and electricity supply
- Short-term solution → nuclear fission for baseload to be replaced by fusion
- Transport → re-invent grids and use alternatives, e.g. hydrogen from electrolysis and fuel cells
- Demand-side management crucial
- Political vision and wise steering through policy is essential

Difficult, but not impossible. Mankind has proven innovation power and game changers have been developed in the past.

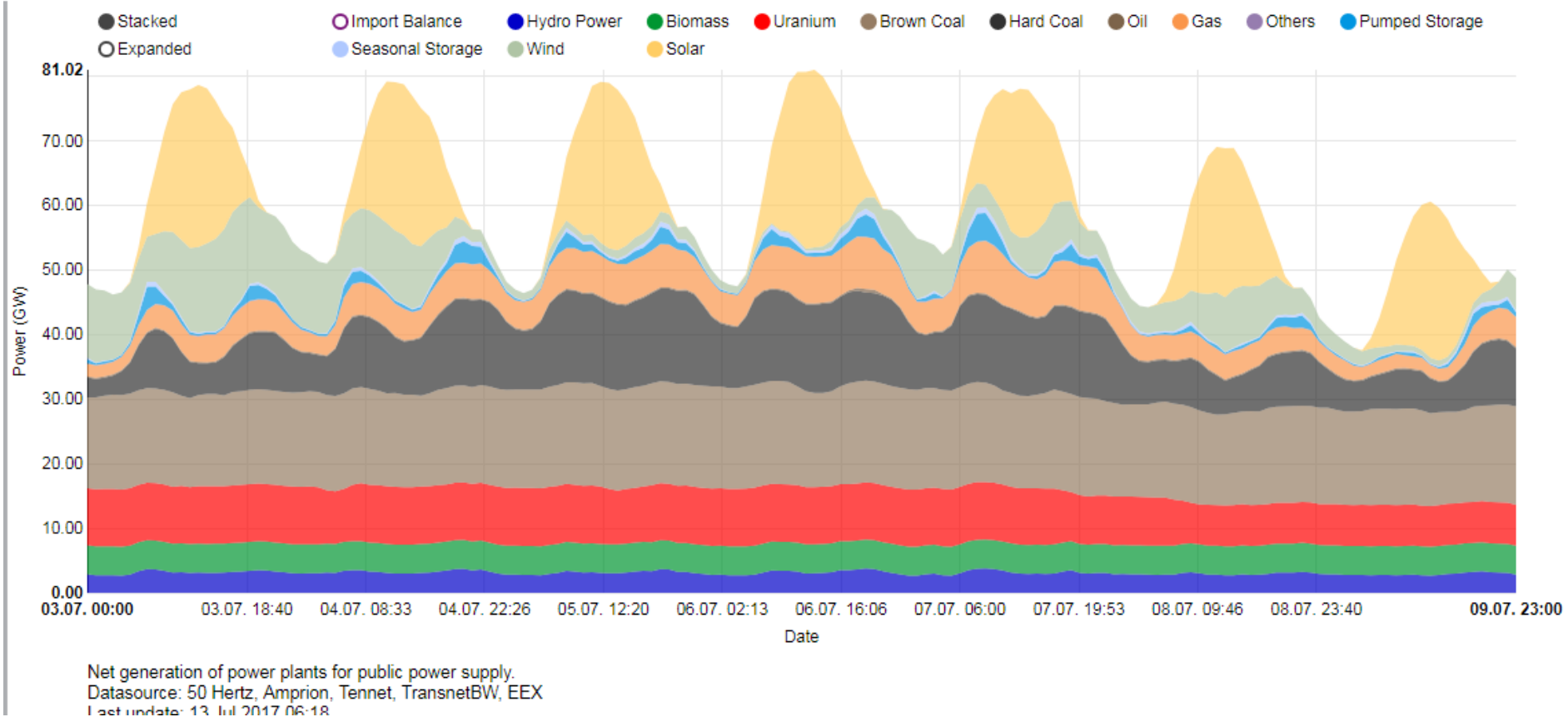
So let's get to work!

Real energy mix today (ex. Germany)



Net generation of power plants for public power supply.
Datasource: 50 Hertz, Amprion, Tennet, TransnetBW, EEX
Last update: 13 Jul 2017 06:18

https://www.energy-charts.de/power.htm



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