Why and how 100% Renewables

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Energy Transition: Towards 100% Emission Free Energy System
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Key diagrams why there will be massive change

Key insights:
- massive continued cost decline for solar PV, wind, battery, electrolysers, CO₂ DAC
- massive pressure to eliminate all fossil fuels
- massive direct and indirect electrification of all energy sectors and non-energetic fossil fuel demand

References:
PV, battery: Vartiainen et al., Progress in PV
Electrolysers: LUT model assumptions, Nature
CO₂ DAC: Fasihi et al., J of Cleaner Prod
CO₂eq decline: IPCC SR1.5

In pathways limiting global warming to 1.5°C with no or limited overshoot as well as in pathways with a high overshoot, CO2 emissions are reduced to net zero globally around 2050.
Power-to-X – covering hydrocarbon demand

Key insights:

- PtX enables sustainable production of hydrocarbons
- Ingredients: electricity, water, air
- w/o PtX Paris Agreement would be wishful thinking
- Profitability from 2030 onwards
- Flexible seasonal storage option
- Global hydrocarbon downstream infrastructure usable
- Most difficult sectors to decarbonise can be managed with PtX (aviation, chemistry, agriculture, metals, etc.)
- CO₂ direct air capture is part of PtX
Nov 2016, COP-22, Marrakech: 48 countries (Climate Vulnerable Forum) decided for a 100% RE target

More Countries and States set 100% targets, e.g.: Denmark, Sweden, California, Spain, Hawaii, …

Some Countries are already around 100%, e.g.: Norway, Costa Rica, Uruguay, Iceland, Tokelau, …

Cities with 100% RE targets, e.g.: Barcelona, Masdar City, Munich, Masheireb, Downtown, Doha, Vancouver, San Francisco, Copenhagen, Sydney, …

Companies with 100% RE targets, e.g.: Google, Microsoft, Coca-Cola, IKEA, Wärtsilä, Walmart, …
Major milestones on 100% RE research


Bogdanov et al. 2019
## Key rationale for electrification: Efficiency

<table>
<thead>
<tr>
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<th>Electricity</th>
<th>Heat</th>
<th>Transport</th>
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<tbody>
<tr>
<td><strong>Today</strong></td>
<td>Fossil-fuel condensing power station</td>
<td>Gas heating</td>
<td>Internal-combustion engine</td>
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<td>Fuel</td>
<td>Heat</td>
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<td></td>
<td>Electricity</td>
<td>Losses</td>
<td>Losses</td>
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<td>40 % efficiency</td>
<td>85 % efficiency</td>
<td>25 – 40 % efficiency*</td>
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<td><strong>Tomorrow</strong></td>
<td>Wind/solar energy</td>
<td>Heat pumps</td>
<td>Electric mobility</td>
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<td></td>
<td>Renewable electricity</td>
<td>Ambient heat</td>
<td>Losses</td>
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<td></td>
<td>Electricity</td>
<td>Heat</td>
<td>Propulsion</td>
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<td>100 % efficiency</td>
<td>340 % efficiency</td>
<td>80 % efficiency</td>
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*The efficiency of internal-combustion engines in other applications (e.g. maritime transport, engine-driven power plants) can exceed 50%.*

source: Brown et al., 2018., Renewable and Sustainable Energy Reviews, 92, 834-847
100% RE for Power Sector

Radical transformation pathway towards sustainable electricity via evolutionary steps

Dmitrii Bogdanov, Javier Farant, Kristina Sadovskaja, Arman Aghahosseini, Michael Child, Ashish Gulati, Ayoami Solomon Oyewo, Larissa de Souza Noel Simas Barbosa & Christian Breyer

A transition towards long-term sustainability in global energy systems based on renewable energy resources can mitigate several growing threats to human society simultaneously: greenhouse gas emissions, human-induced climate deviations, and the exceeding of critical planetary boundaries. However, the optimal structure of future systems and potential transition pathways are still open questions. This research describes a global, 100% renewable electricity system, which can be achieved by 2050, and the steps required to enable a realistic transition that prevents societal disruption. Modelling results show that a carbon neutral electricity system can be built in all regions of the world in an economically feasible manner. This radical transformation will require steady but evolutionary changes for the next 35 years, and will lead to sustainable and affordable power supply globally.

Area demand:
- Wind: 4% max per region; 0.3% of land area used
- Solar PV rooftop is zero impact area; ground-mounted is 0.14% of total global land area

source: Breyer et al., 2018., Progress in Photovoltaics, 26, 505-523; Bogdanov et al., 2019. Nature Communications, 10, 1077
Global Overview

- The world is structured into 9 major regions, which are further divided to 145 sub-regions
- Some sub-regions represent more than one country, others parts of a larger country
- The sub-regions are interconnected by power lines within the same country
- The results shown are for the Power, Heat, Transport, Desalination sectors
- The energy transition scenario is carried out in full hourly resolution for all energy sectors
- In total 106 different technologies are applied
Key insights:
- TPED shifts from being dominated by coal, oil and gas in 2015 towards solar PV and wind energy by 2050.
- Renewable sources of energy contribute just 22% of TPED in 2015, while in 2050 they supply 100% of TPED.
- Solar PV drastically shifts from less than 1% in 2015 to around 69% of primary energy supply by 2050, as it becomes the least cost energy supply source.
Energy System Cost

Key insights:

- The total annual costs are in the range of 5100-7200 b€ through the transition period and well distributed across the 3 major sectors of Power, Heat and Transport.
- LCOE remains around 50-57 €/MWh and is increasingly dominated by capital costs as fuel costs lose importance through the transition period, which could mean increased self-reliance by 2050.
- Costs are well spread across a range of technologies with major investments for PV, wind, batteries, heat pumps and synthetic fuel conversion up to 2050.
- The cumulative investment costs are about 67,200 b€.
Regional Variation in 2050

Key insights:
- Solar PV dominates most of regions around the world and particularly in the Sun Belt
- Wind energy drives systems in the Northern and Southern hemispheres with excellent wind conditions and lacking seasonal solar energy
- Some regions are further complemented with hydropower to form a mixed system

www.energywatchgroup.org
Why we do not yet hear more about 100% RE?

Key insights:

- practically ALL global scenarios dramatically fail in the right role of solar PV
- fast cost decline of the last 10 years is ignored by IEA, IPCC (based on IAMs), and others
- climate change mitigation could be more powerful, if major institutions would perform better
- massive and fundamental re-thinking on solar PV plus batteries is needed

articles based on real PV cost

Vartiainen et al., 2019. PIP
Bogdanov et al., 2019. Nature Comms, 10, 1077
IPCC cost for PV
Krey et al., 2019. Energy, 172, 1254-1267
Desertec Reloaded

Key insights:
- power line based Desertec is most likely limited due to lack of relative cost benefits
- excellent solar and very good wind resources enable new opportunities in entire MENA
- Power-to-X for fuels, chemicals, material refining and NETs opens a new door
- sustainable fuels (Fischer-Tropsch) and chemicals (Methanol, Ammonia) are key
- negative CO₂ emissions (DACCS) may be a new business opportunity on the horizon
Role of Sector Coupling

Key insights:

• **Power-to-X** is the central element of a future energy system, since electricity is the universal platform

• Electricity-based hydrogen emerges to the 2nd relevant energy carrier (for fuels, chemicals)

• Flexibility in the energy system is key:
  • Supply response (hydro reservoirs, bioenergy) for indirect balancing of solar and wind
  • Grid interconnections, in particular for balancing wind energy
  • Smart demand response: BEV (smart charging, V2G), heat pumps, electrolysers
  • Storage (hours, days, weeks, seasons; electricity, heat, fuels)

• **Cross-border integration may be less important than cross-sectoral cost reduction**

• **Efficient sector coupling substantially reduces curtailment**

• Low-capex batteries and low-capex electrolysers are key for the energy transition

• No flexibility from CO₂ direct air capture units, H₂-to-X synthesis and desalination
Thank you for your attention …
… and to the team!

all publications at:  www.researchgate.net/profile/Christian_Breyer
new publications also announced via Twitter: @ChristianOnRE
100% RE articles in recent years

Key insights:
- Research field exists since about 10 years
- Most publications are in hourly resolution
- More multisector publications
- Europe (FI, DK, DE) is hot spot of 100% RE research
- Gaps are in regional coverage and sectoral coverage (industry, NETs), temporal range (21st century)
- Community starts to get impact on neighbouring fields (e.g. IAMs, IPCC), but still ignored for major reports (IEA, IRENA, most governments)