We witness the start of the Solar Age

Global solar investment to be higher than coal, gas and nuclear combined in 2017

Wednesday, 17 May 2017

Robin Whitlock

Declining project costs are driving investment towards renewables as the industry continues to transition to more decentralised and intelligent energy systems, finds a report by Frost & Sullivan.

The report, by Frost & Sullivan’s Energy & Environment team, examines the continued rise of renewable energy systems around the world. Global Power Industry Outlook, 2017, a new analysis from Frost & Sullivan’s Power Generation Growth Partnership Service programme, examines power market trends, including installed capacity, investment, and regional growth across coal-fired, gas-fired, nuclear, hydro, solar PV, wind and biomass power.

Prices for both solar and wind continue to decline enabling a boom in investment in renewable energy at the expense of traditional power generation. Lower project costs and continued regulatory support for renewable energy in key markets will see global renewable power investment reach $243.1 billion in 2017, with solar photovoltaic (PV) the fastest growing segment, followed by wind power. By 2020, non-hydro renewables will account for 65 percent of global power investment.

Comments:
- Most global energy scenarios do not yet see that reality
- LUT results clearly indicate a solar century and PV as the key energy technology
Global Energy Scenarios: Selected Overview

Key insights:
- **100% RE**: Greenpeace, WWF, Jacobson et al.: demand strongly deviates, PV and wind dominated, no hourly resolution
- **IEA, WEC, Shell**: not COP21 compatible, high nuclear shares, low solar shares, no hourly resolution

Source: Ram M. et al., 2017. Comparing electricity production costs of renewables to fossil and nuclear power plants in G20 countries, study commissioned by Greenpeace
Current status of the power plant mix

Source:
Farfan J. and Breyer Ch., 2017. Structural changes of global power generation capacity towards sustainability and the risk of stranded investments supported by a sustainability indicator; J of Cleaner Production, 141, 370-384
LUT Energy System Model

Full system

Renewable energy sources
- PV rooftop (RES, COM, IND)
- PV ground-mounted
- PV single-axis tracking
- Wind onshore/offshore
- Hydro run-of-river
- Hydro dam
- Geothermal energy
- CSP
- Waste-to-energy
- Biogas
- Biomass

Electricity transmission
- node-internal AC transmission
- interconnected by HVDC lines

Storage options
- Batteries
- Pumped hydro storage
- Adiabatic compressed air storage
- Thermal energy storage, Power-to-Heat
- Gas storage based on Power-to-Gas
  - Water electrolysis
  - Methanation
  - CO₂ from air
  - Gas storage

Energy Demand
- Electricity
- Water Desalination
- Industrial Gas
LUT Energy System Model

Key Objectives

Definition of an optimally structured energy system based on 100% RE supply

- optimal set of technologies, best adapted to the availability of the regions’ resources,
- optimal mix of capacities for all technologies and world structured into 145 sub-regions globally,
- optimal operation modes for every element of the energy system,
- least cost energy supply for the given constraints.

Input data

- historical weather data for: solar irradiation, wind speed and hydro precipitation
- available sustainable resources for biomass and geothermal energy
- synthesized power load data
- non-energetic industrial gas and water desalination demand
- efficiency/ yield characteristics of RE plants
- efficiency of energy conversion processes
- capex, opex, lifetime for all energy resources
- min and max capacity limits for all RE resources
- nodes and interconnections configuration

LUT Energy System model, key features

- linear optimization model
- hourly resolution
- multi-node approach
- flexibility and expandability
- enables energy transition modeling
- overnight scenarios
- energy transition scenarios in 5-year steps
LUT Energy System Model
publications peer-reviewed

- Examples of research with LUT energy model published in peer-reviewed journals (13 in total)

Broyer et al., 2017
Bogdanov and Broyer, 2016
Gulagi et al., 2017

Role of PV in Global Energy Transition
Christian Breyer ⏪ christian.breyer@lut.fi

7
capex variation based on learning curves, market growth
PV capex has been continuously too high in own work during the last 10 years
PV most important in energy transition scenarios, hence very good capex understanding required
now split into 5 types of PV segments (rooftop RES/ COM/ IND, ground-mounted fixed, tracking)

source: ETIP-PV, 2017. The True Competitiveness of Solar PV – A European Case Study
LUT Energy System Model

Model improvements in recent months

- PV prosumer segments split capex-wise into residential, commercial, industrial, now reaching 5 segments in total (PV prosumer plus optimally fixed-tiled and single-axis tracking)
- PV capex referenced to ETIP-PV report
- Batteries for prosumers split capex-wise into residential, commercial, industrial
- Storage capex split in power and energy component for improved energy-to-power modeling
- CSP capex based on leading DLR research project
- Wind energy yield of the past adjusted to less favourable designs (turbines, hub height) and future options checked repeatedly
- Waste-to-energy plants inventory better integrated in model
- OCGT and CCGT plants inventory better integrated in model
- 2015 real production with existing power plant fleet reproduced in an improved way in the model
- PV system inventory (rooftop, ground-mounted) better integrated in model
- Biomass/waste resource data improved for Europe
- Hydro (RoR, reservoir, PHS) refurbishment investments better integrated in results
- Maximum growth limits for new RE capacity adjusted according to empiric data
- Transmission and distribution grid losses within regions well projected
- Code optimization for modeling algorithm
- Automatised results structuring in xls and diagrams for 145 regions in different aggregation levels
Energy Transition Modeling: Global

Key insights:
- energy system transition model for 145 regions forming 92 countries
- LCOE decline on energy system level driven by PV + battery
- beyond 2030 solar PV becomes more competitive than wind energy
- solar PV + battery finally runs the system more and more
- solar PV supply share in 2050 at about 70% (!!) as least cost
Energy Transition Modeling: Global

- Role of PV in Global Energy Transition
- Christian Breyer
  - Christian.Breyer@lut.fi

![Graph showing installed capacity for different energy sources from 2020 to 2050]

- Energy sources include Steam Turbine, CCGT, OCGT, Int Combust Generator, Biomass Solid, MSW incinerator, CHP biogas, Geothermal, CSP solar field, PV fixed tilted, PV single-axis, PV prosumers, Wind onshore, Wind offshore, Hydro Run-of-River, Hydro Dam, Methanation, Coal PP Hard Coal, Nuclear PP.

![Graph showing newly installed capacity for 5 years intervals from 2020 to 2050]

- Y-axis: newly installed capacity (GW)

![Graph showing Capex for 5 years intervals from 2020 to 2050]

- Y-axis: Capex for 5 years intervals [€]

![Graph showing CO₂ emissions and ratio of CO₂ to generated electricity from 2020 to 2050]

- Y-axis: CO₂ [Mt/annum]
- X-axis: years [2020, 2030, 2040, 2050]
- Ratio of CO₂ to generated electricity [KWh/€]
Role of PV in Energy Transition
Christian Breyer – Christian.Breyer@lut.fi

Key insights:
- 1.0% electricity share by 2015
- Strong growth till 2030 would be possible
- By 2050 solar PV could be the dominating source of electricity
- Canada is still in progress for simulations
- Countries in the Sun Belt would be almost fully dominated by solar PV, e.g., Africa, India, Southeast Asia, Central America
- Regions of strong seasons and excellent wind show lower PV values, as well as the few hydro power and geothermal regions
- Solar PV supply share in 2050 at about 70% (!!) as least cost
Role of PV in Global Energy Transition

Christian Breyer

Christian.Breyer@lut.fi

Key insights:

- Total LCOE by 2050 around 50 €/MWh (incl. generation, storage, curtailment, some grid cost)
- 60% ratio of primary generation cost to total LCOE
- Total PV installed capacity around 22 TWp (ONLY for today's power sector)
# Examples of representative countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Seasonality</th>
<th>Resources</th>
<th>Demand growth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>solar</td>
<td>wind</td>
</tr>
<tr>
<td>Poland</td>
<td>strong</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Britain and Ireland</td>
<td>strong</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Turkey</td>
<td>moderate</td>
<td>++</td>
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<td>Saudi Arabia</td>
<td>weak</td>
<td>+++</td>
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<tr>
<td>Brazil</td>
<td>equatorial</td>
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<tr>
<td>Ethiopia</td>
<td>equatorial</td>
<td>+++</td>
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</tr>
<tr>
<td>Indonesia</td>
<td>equatorial</td>
<td>+++</td>
<td>-</td>
</tr>
</tbody>
</table>
Examples: Poland (top) / UK & Ireland (bottom)
Examples: Turkey (top) / Saudi Arabia (bottom)
Examples: Brazil (top) / Ethiopia (bottom)
Key insights:

- Solar PV growth for all constraints
- PV and battery go hand in hand and cost decline during the energy transition for all constraints
- PV prosumer are relevant all over the world and they shift the energy system design to a more distributed one
- Strong seasonality (Poland, UK & Ireland) forces wind energy continuously to the energy system
- Sun Belt countries cover from 2030 onwards almost all additional energy demand by solar PV
- Wind stagnates from 2030s onwards on a global level in absolute numbers, declines in relative numbers
Impact: Energy Globe Award

Global Internet of Energy: http://neocarbonenergy.fi/internetofenergy/#
Impact: Renewable Transformation Challenge

Top 10 entries to the Renewable Transformation Challenge award

The following entries were selected as the top 10 (in alphabetical order):

Shreya Agarwal, Boond Engineering and Development Pvt Ltd, India
Smart Metering Technology for Microgrids

Christian Breyer, Lappeenranta University of Technology, Finland
Global-local 100% RE Modeling in High Resolution

Ajay Chandak, PRINCE (Promoters, Researchers & Innovators in New & Clean Energy), Suman Foundation, India
Virtual Rooftop Solar Power with Retail Exchange

Andy Cloud, Cirrostratus, USA
Pumped Storage Hydropower with Floating PV Power

Sebastian Groh, SOLshare, Bangladesh
The Energiewende 3.0 - Smart PaP Solar Grids

Jemma Green, Curtin University, Australia
Citizen Utilities

Kate Greenwood, Alternative Technology Association (ATA), Australia
Light Up East Timor

Venkat Rajaraman, Cygni Energy Private Limited, India
Solar DC Micro-grid

Brian Somers, Standard Microgrid, South Africa
Re-imagining the African Utility

Varun Vohra, University of Electro-communications, Japan
Eco-friendly Low-cost Energy Devices for Everyone

• more than 200 submissions
• we had been the only short-listed contributor from Europe
• only 3 academic short-listed applications
Abstracts of 25 Peer-Reviewed Published Journal Articles Supporting the Result That the Electric Grid can Stay Stable with Electricity Provided by 100% or Near-100% Renewable Energy

August 19, 2017

- 7 articles by LUT (all NCE)
- 5 articles by Aalborg
- 4 articles by Stanford
- 3 articles by UNSW
- 2 articles by ANU
- 4 articles by others

compiled by Mark Jacobson, Stanford University
Impact: NGOs (Greenpeace/ Energy Watch Group)

source: Ram M. et al., 2017. Comparing electricity production costs of renewables to fossil and nuclear power plants in G20 countries, study commissioned by Greenpeace

- contract for a global leading energy transition scenario
- sectors: power, heat, mobility, industry
- duration: now to 12/2018
- first milestone: results on power sector in 11/2017
- financed by Stiftung Mercator and German Federal Environmental Foundation and lion share transferred to LUT
Energiewende weltweit – nur ein Traum?

In the abridged article, it states that the article was published in the German edition of pv magazine, featuring Christian Breyer's results on the 100% RE global power system. The leading PV industry magazine has now put NCE on the radar screen.
Role of PV in Global Energy Transition
Christian Breyer ➤ christian.breyer@lut.fi

Impact: Media - Round the Globe

Forum energii budowaniego: od счетчика тепла до атомной станции
Международные эксперты рекомендуют, как нам реануть с 1% энергии солнца и ветра

Impact: Media - Round the Globe

Forum energii budowania, stworzony w ramach międzynarodowej wysokiej EECGP w Atenach, obejmuje stałe, odmienne i najnowsze technologie energetyczne w świecie wodopożbimiento i alternatywne źródła energii. Odbiorcy i gazety odnoszą się do skomplikowanej sytuacji w kwestii problemów. Wszystko jest zgodne z obowiązującym prawem państwowym w zakresie oraz wzmocnieniem, jakie przekazują wiedza i zrozumienie. Poniżej przedstawiamy listę źródeł energetycznych, które użytkownikom nie są dostępne, ale praktycznie przekazują wiedzę w zakresie bezpieczeństwa i zdrowia.

Agromechanika energii w krainie w sosnowej

Jednym z najbardziej ważnych jest wybor stacji elektrycznych w Obiektach elektrycznych. Christian Breyer w swoim odmienieniu duży kontynuator错误的，do czasu przekroczenia węglowego systemu w 2050 roku. Ponadto, wynik 2050- 4049. Potem, aby w zakresie wodopożbimiento energii, nie można szacować, na którą datę, ani po razy kiedy najlepiej. To wskazuje w naszej grupie, że była przewidziana w poprzedniej pisma, dziennikarz Christian Breyer. O tych pozwoleniach, które przekazuje wiedza w zakresie zdrowia i bezpieczeństwa, jakie przekazują wiedza w zakresie bezpieczeństwa i zdrowia.

Pomimo, że w wiedzę profesorowi na Forum energetyczne, jesteśmy nasza dalsza. Obiektów, aby omówić, nawet, jak to zrozumieć w konkretnej sytuacji w zakresie bezpieczeństwa i zdrowia, a także w zakresie wodopożbimiento energii, nie można szacować, na którą datę, ani po razy kiedy najlepiej. To wskazuje w naszej grupie, że była przewidziana w poprzedniej pisma, dziennikarz Christian Breyer. O tych pozwoleniach, które przekazuje wiedza w zakresie zdrowia i bezpieczeństwa, jakie przekazują wiedza w zakresie bezpieczeństwa i zdrowia.

Cheaper Renewables
Renewable energy will be cheapest form of electricity in 2030: Greenpeace
**Impact: European Parliament**

**EUFORES 17th Inter-Parliamentary Meeting on Renewable Energy and Energy Efficiency – Chapter II**

"Baltic Sea energy cooperation – stronger together on the way to a 100% RES energy system"

29 September 2017, Parliament of Estonia, Lossi plats 1a

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**Friday 29 September 2017; Parliament of Estonia, Lossi plats 1a, 15:365 Tallinn**

08:00 IPM17 Registration in the Estonian Parliament (please bring ID)
Conference Chair: Jan Geiss, Secretary General, EUFORES

09:00 Welcome
Chair: Theresa Griffin, MEP UK, Vice-President of EUFORES
- Welcome by Rainer Volka, Member of the Estonian Parliament and Host of IPM17
- Welcome by Kadri Simson, Estonian Minister of Economic Affairs and Infrastructure

09:30 Session 1: Opening
Chair: Jesper Knudsen, MEP Denmark, Vice-President of EUFORES
- "The importance of regional cooperation in the EU Energy Union", Claude Turmes, MEP and President of EUFORES
- "The Baltic Sea Study on grid and offshore", Maros Sefcovic, Vice-President Energy Union of the European Commission*
- "Sweden’s role in a Baltic regional cooperation", Isabella Lövin, Minister for International Development Cooperation and Climate, and Deputy Prime Minister, Sweden*
- "An integrated Baltic Sea power market", Pekka Lundmark, President and CEO of FORTUM
- "Nordic Energy Cooperation: strong today - stronger tomorrow", Jorma Ollila, Advisor to the Nordic Council of Ministers*
- "Integrated infrastructure planning as a driver for the Baltic Sea market integration", Peder Andreassen, DK EnergieNet

Discussion with MEPs and MPs

11:00 Coffee Break

11:30 Session 2: Renewable Energy Sources in the Baltics
Chair: Emma Hult, MP Sweden* & Linas Balys, MP Lithuania
- "The Baltic Region - the first region in EU to be 100% RES", Christian Breyer, Professor of Solar Economy at Lappeenranta University of Technology (LUT)*
- "Successes in Estonia and a vision for the region", Rene Tammsaar, Estonian Renewable Energy Association
- "The Baltic Region - off-shore wind success stories", Hans-Dieter Kettwig, CEO, ENERCON
- "Offshore Wind in the Baltic Region", Martin Neubert, Chief Strategy Officer for Wind Power, DONG Energy*

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- Invitation by EUFORES to speak on 100% RE in the Baltic region
- Very high level of EU decision makers
  - Claude Turmes, MEP
  - Maros Sefcovic, VP Energy Union of EC
  - Isaella Lövin, Deputy PM Sweden
  - Pekka Lundmark, CEO Fortum
  - Jorma Ollila
  - Hans-Dieter Kettwig, CEO Enercon
  - Martin Neubert, CSO DONG Energy
  - many MEPs and MPs
- Outstanding chance to push the 100% RE vision, now shared by a fast increasing number of political and business leaders
Summary

• Existing RE technologies can generate sufficient energy to cover all electricity demand globally for the year 2050
• Total LCOE in global average are around 50 €/MWh for 100% RE in 2050 (incl. curtailment, storage and some grid cost) – lower than today
• Share of solar PV for total electricity supply can reach 70% in global average by 2050
• Wind energy may not grow anymore much after 2030
• Seasonal variations are the key reason for keeping wind energy in the system
• Almost all Sun Belt countries will have very high solar PV shares
• Solar PV and batteries are the most relevant energy technologies for the transition
• Next steps: RE-based mobility, heat, fuels, chemicals, clean water
• Energy system models have to be drastically improved in methodology and quality
• Impact generation by NCE in science, media, interested public, policy
• High level decision makers are increasingly interested in the details
Thank you for your attention …
… and to the team!

The authors gratefully acknowledge the public financing of Tekes, the Finnish Funding Agency for Innovation, for the ‘Neo-Carbon Energy’ project under the number 40101/14.

all publications at: www.researchgate.net/profile/Christian_Breyer
new publications also announced via Twitter: @ChristianOnRE