Sustainable Power Generation MJ2405

An objective view to sustainability for the present and the future power sector

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Sustainable ≠ Renewable

SUSTAINABLE is not equal to RENEWABLE!!
Sustainability is not linked only to energy. It is a much broader term, involving also food, water, raw materials, habitats, economy, etc..

Actually, energy and fuels are not the most looming global sustainability issue, but rather the availability of fresh water resources and… phosphorus!!

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- How can we be more **sustainable?**

(Should we move back to the stone age in order to have lower environmental impact?)

- **Which type of energy would be most sustainable?**

Sustainable Energy

- **Which energy is most sustainable?**
  (actually it's the one we save, the one we don't need to use, therefore we don't need to produce and deliver it!!)

- We should divert humanity towards a more sustainable development path without losing our modern lifestyles.

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Major "goals" of sustainability

- Nearly zero impact on environment by any human activity!
- Less energy used ➔ Less energy produced ➔ Less pollution
- Less materials used ➔ Less extraction of minerals from the earth ➔ more active recycling
- Higher efficiency for any energy conversion process!
- Cleaner fuels or renewable sources alone do not help much unless efficiency and utilization practices are improved
- And what else?… you name it…

…but please don't overuse the sustainability terminology!

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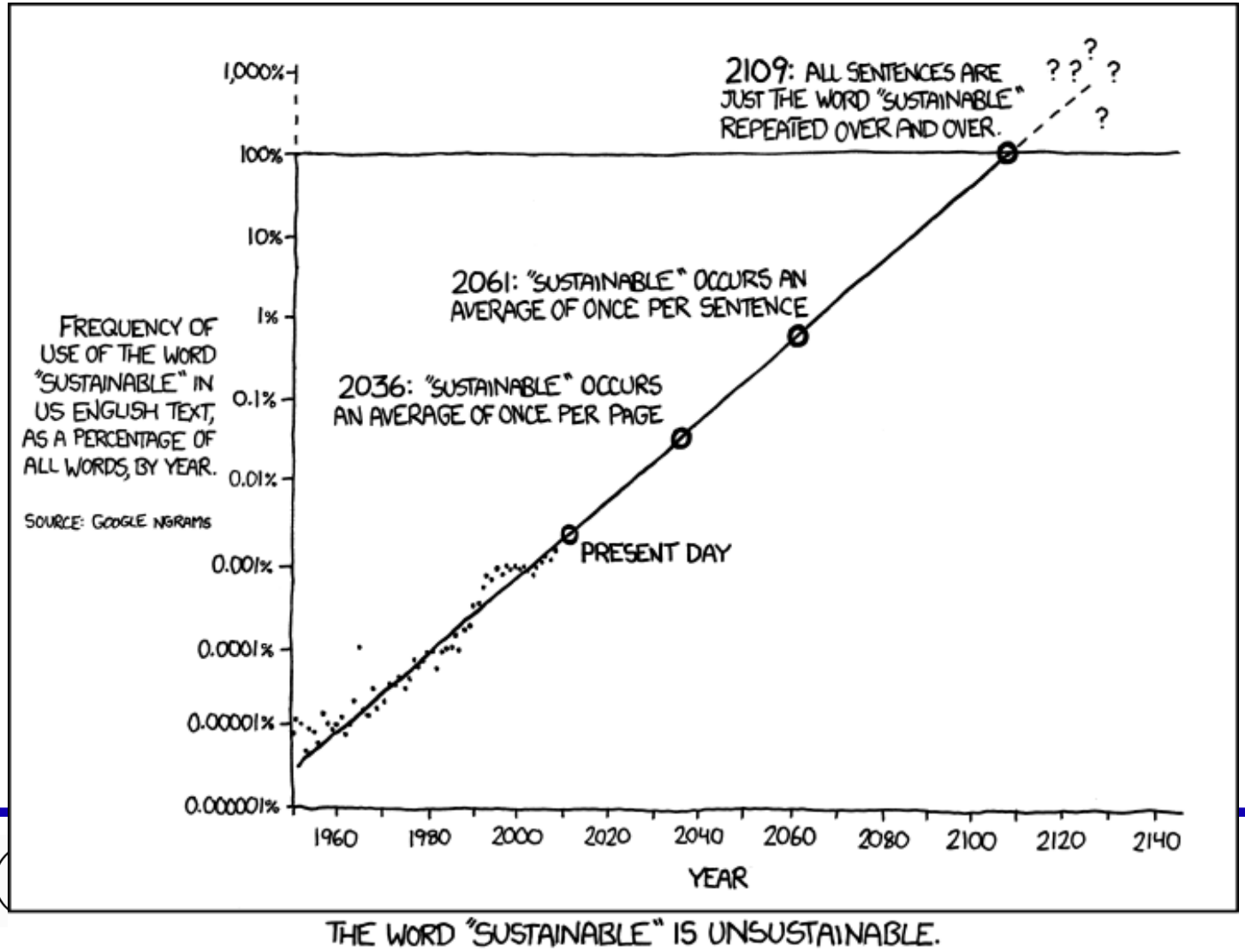

Source: http://xkcd.com

Growing Environmental Awareness: pollution by power generation

- **Local pollution** (dust, soot, ash, bad odour, toxics, smog). *Solution:* higher chimney - better spreading the gases high up in the atmosphere. Recognized already in the 1800's.

- **Regional pollution** (SOx, NOx, acid rain across borders). Raised up international awareness in the 1970-s. *Solution:* DeSOx and DeNOx systems introduced in the 1980-s and 1990-s.

- **Global pollution** – CO_2! Recognized recently. *Solution?? Carbon capture & storage? New technology & improved efficiency? Or simply switching to clean fuels?* There is no easy quick-fix option! A range of combined solutions are needed for dealing with the CO_2 problem.

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Definition of a “clean” fuel?

- **Natural Gas is believed to be cleaner than coal.**

  Indeed, an immediate reduction of all pollutant emissions can be achieved if we quickly replace all coal-fired plants with NG-fired such: ~100% less SOx & UHC, ~50% less NOx, ~50% less CO_2…

- **Biomass is always cleaner than fossil fuels? Actually, NOT always!**

  Poor combustion of solid biomass produces lots of toxic pollutants!

- **Biomass is perfectly CO_2-neutral. Actually, NOT always!**

  Cutting off a 100-year old forest and burning it within a week to replace coal, will not help decreasing today’s CO_2 emissions.
  Biomass as a carbon-sink should be reproduced in short cycles in order to be CO2-neutral in the near term!

Pitfalls for "clean" energy

- **Non-fossil fuels still involve fossil-based energy in their production/upgrading/distribution, etc.**
  A proper LCA evaluation should be done for any biofuel!
- **Methane (natural gas) is a much more potent greenhouse gas than CO2**
  At >2.7% leakage rate, methane is worse than coal!
  Average leakage from today's NG or biogas production ~1.5%
- **Energy spent to produce fossil fuels is also growing.**
  There is no shortage of fossil fuels yet. But their exploration and extraction becomes more and more difficult and costly.
- **This applies also to exotic materials being used for renewable energy development, whose production is costly and polluting!**

Energy spent to produce fuels

Producing and refining fossil or renewable fuels demands a lot in terms of invested energy and materials.

Sustainable fuels should have low ”energy investment” for their production and utilization.

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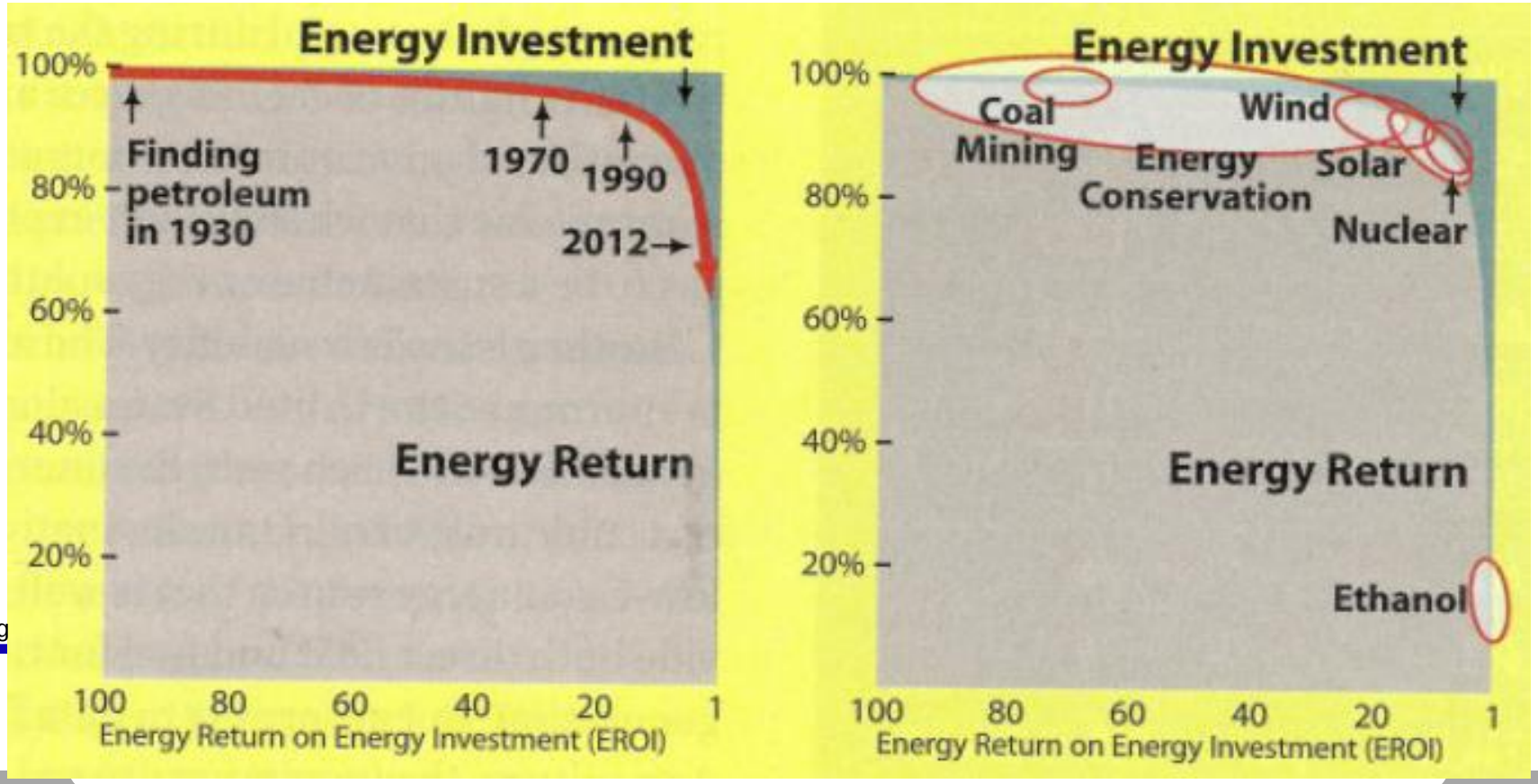

Figure by Frank Kreith, in Mechanical Engineering magazine, Vol.134/5, May 2012

Raw materials for renewable energy

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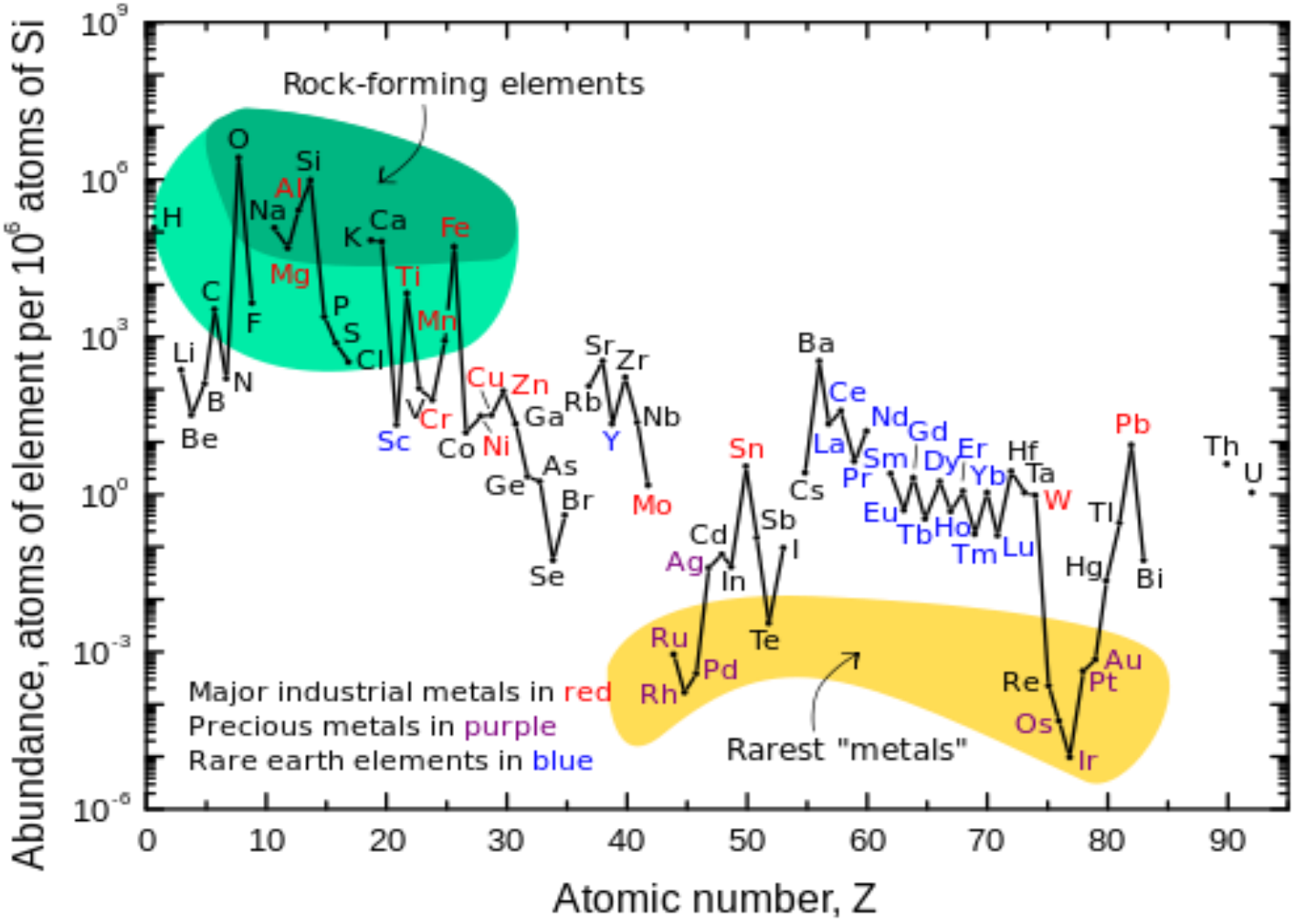
- The strain on the environment by extraction of exotic raw materials (other than fossil fuels) is not yet fully understood and quickly grows in importance…
- These are mostly the **rare-earth metals** used in advanced technology, such as in superconductors, magnets, batteries, PV cells, high-temperature alloys, etc.
- The limited availability of these materials and the pollution that their production process is causing might soon become **more troublesome than the greenhouse gas issue…**

Availability of raw materials



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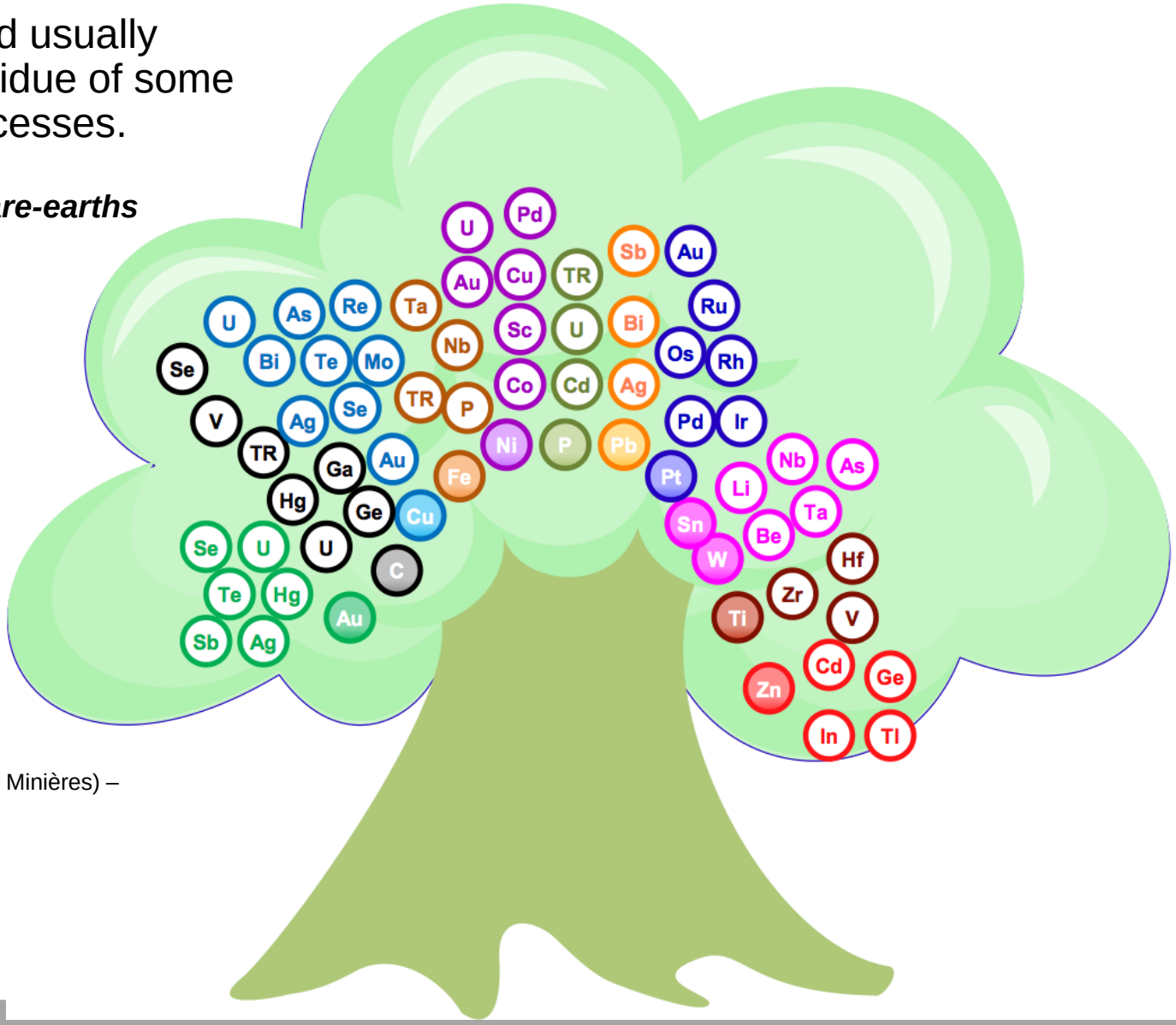
Extraction of exotic materials

They are difficult to find and usually produced only as a residue of some main metal mining processes.

in the graph: "TR" stands for Rare-earths



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Source: BRGM (Bureau de Recherches Géologiques et Minières) – the French Geological Survey Bureau

Market hypocrisy: Fossil vs. Renewable

Renewables:

Too expensive!

(yes, but only because they are very new technologies)

They receive lots of subsidies!

(yes, but actually fossil fuels have received much more, throughout the history of their development)

They create new jobs!

(actually, not as much as other developments)

They are perfectly environmentally friendly!

(No, renewables should also be evaluated in terms of RI, LCA, materials and energy in production/maintenance, etc..)

Fossil fuels:

Cheap and proven!

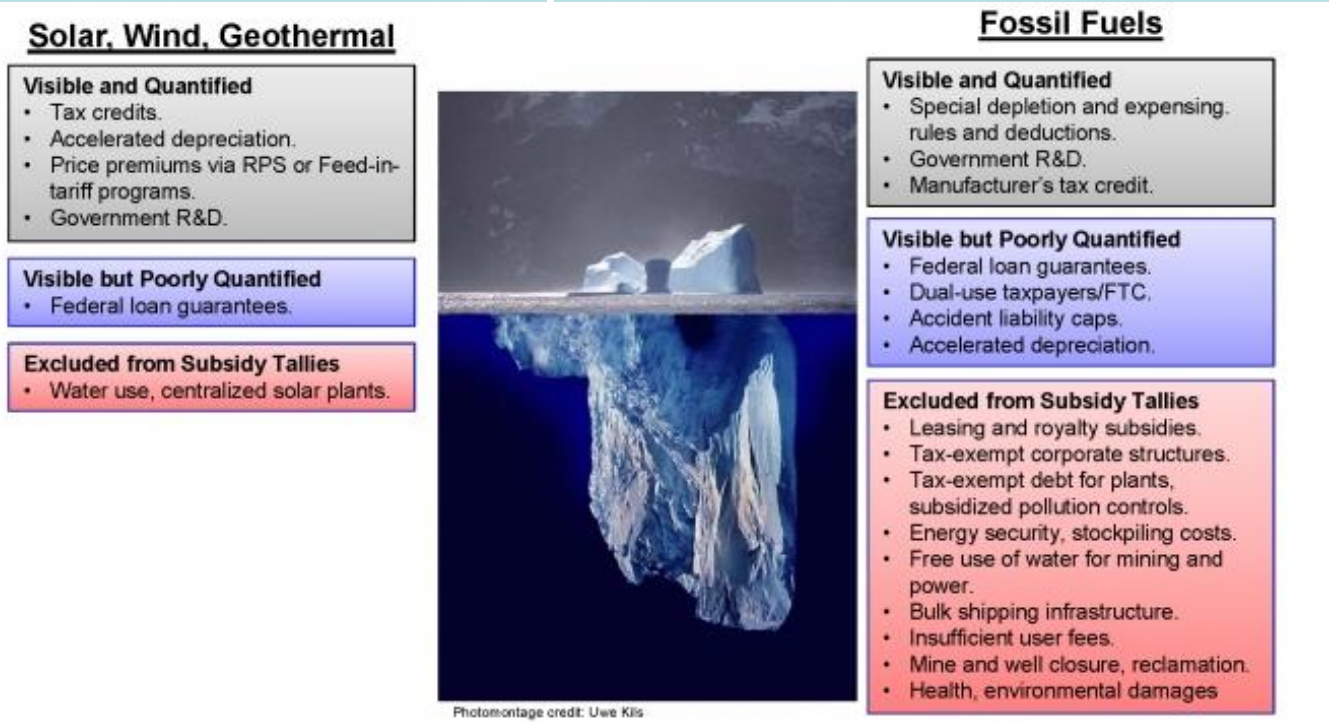
(yes, but only because they are "conventional", the technology is readily available and the equipment has already paid for itself)

Replacing them will lead to loss of jobs!

(maybe regionally, but this happens with every other industry)

Replacing them with renewables is easy!

(Unfortunately not! Renewables are not able alone to support the energy system as we have it today! We do need energy storage or conventional plants to cover up for the balance)



earth track
www.earthtrack.net

Historical development: The energy industry has always been heavily subsidized!

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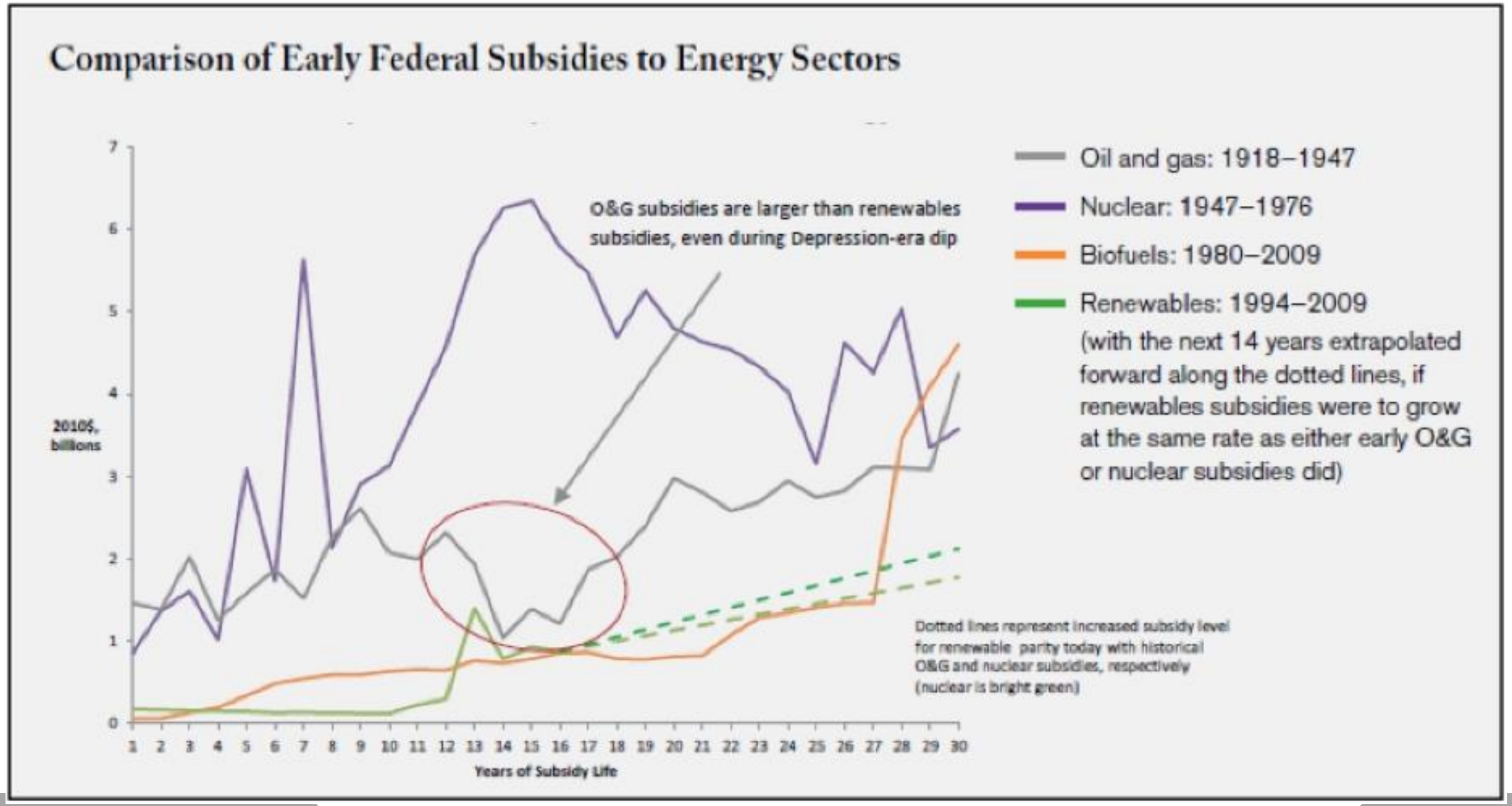
- The major development goals **in the past** were to deliver **abundant and affordable energy to everybody**
- The driving factors for conventional power system development in the past have been various sorts of governmental subsidies, all around the world and in all political landscapes
- The shift to renewable energy today should also deserve some help and sacrifice, in order to proceed ahead
- It is **always costly and difficult to build a new system** and invest in new hardware, instead of keeping the old one running that has already paid back for itself…

Subsidy examples from the USA



Social hypocrisy: Now the end-user pays for somebody else's private investment in renewable energy technology

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- Modern RE development should also avail of massive centralized investment and fast technology advancement, just like the conventional energy sources did in the past
- **However, we don't talk "abundant & affordable" anymore!** Now, end-users are forced to pay from their empty pockets for the modern technology shift and new energy developments, disguised under various public support schemes
- Unfortunately, the generous support for RE in many countries has been utilized by dark forces. This includes corruption, money-laundry by organized crime, unfair privileges, etc.!

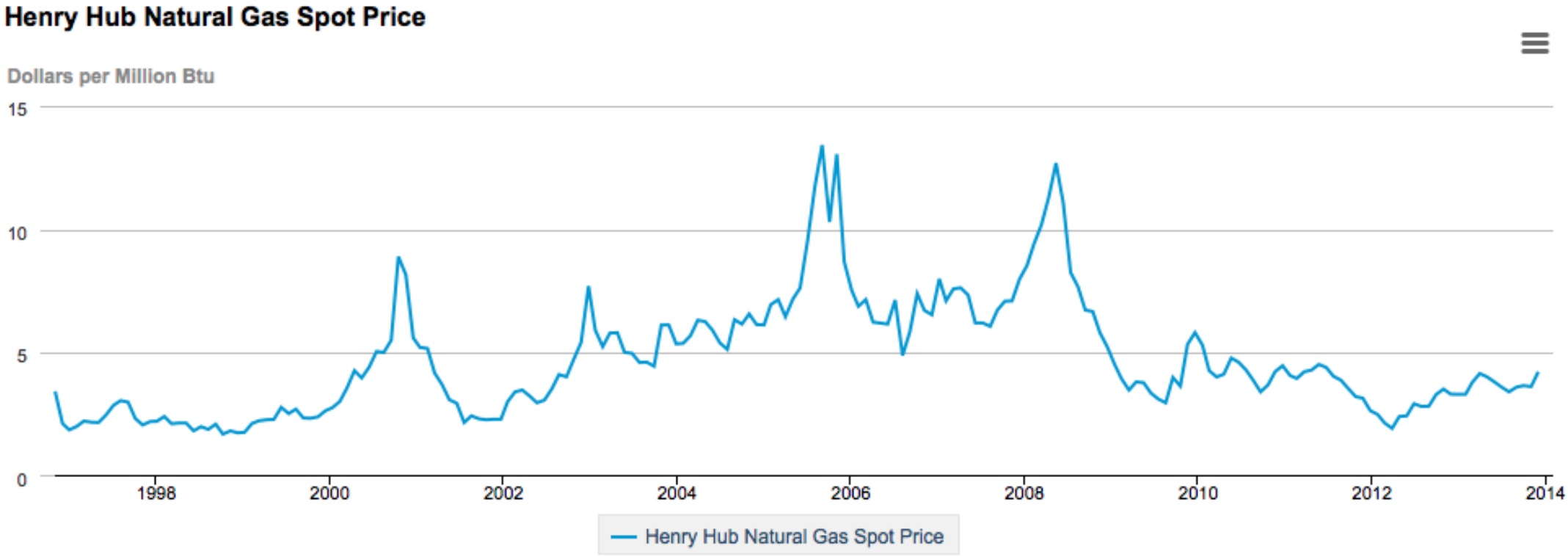
Recent power sector developments (1)

<u>The shale gas boom in the USA:</u>

- Technically, a real marvel of modern engineering.
- Practically, very controversial and allegedly polluting!
- Completely underestimated by the rest of the World.
- Has lead to sharp decrease of natural gas (NG) prices in the USA, down to around 3 times cheaper than in Europe and 4 times cheaper than in Japan.
- Cheap NG has resulted in decreased use of coal and thus ultimately a serious decrease of CO_2 and other pollutant emissions in the USA!!

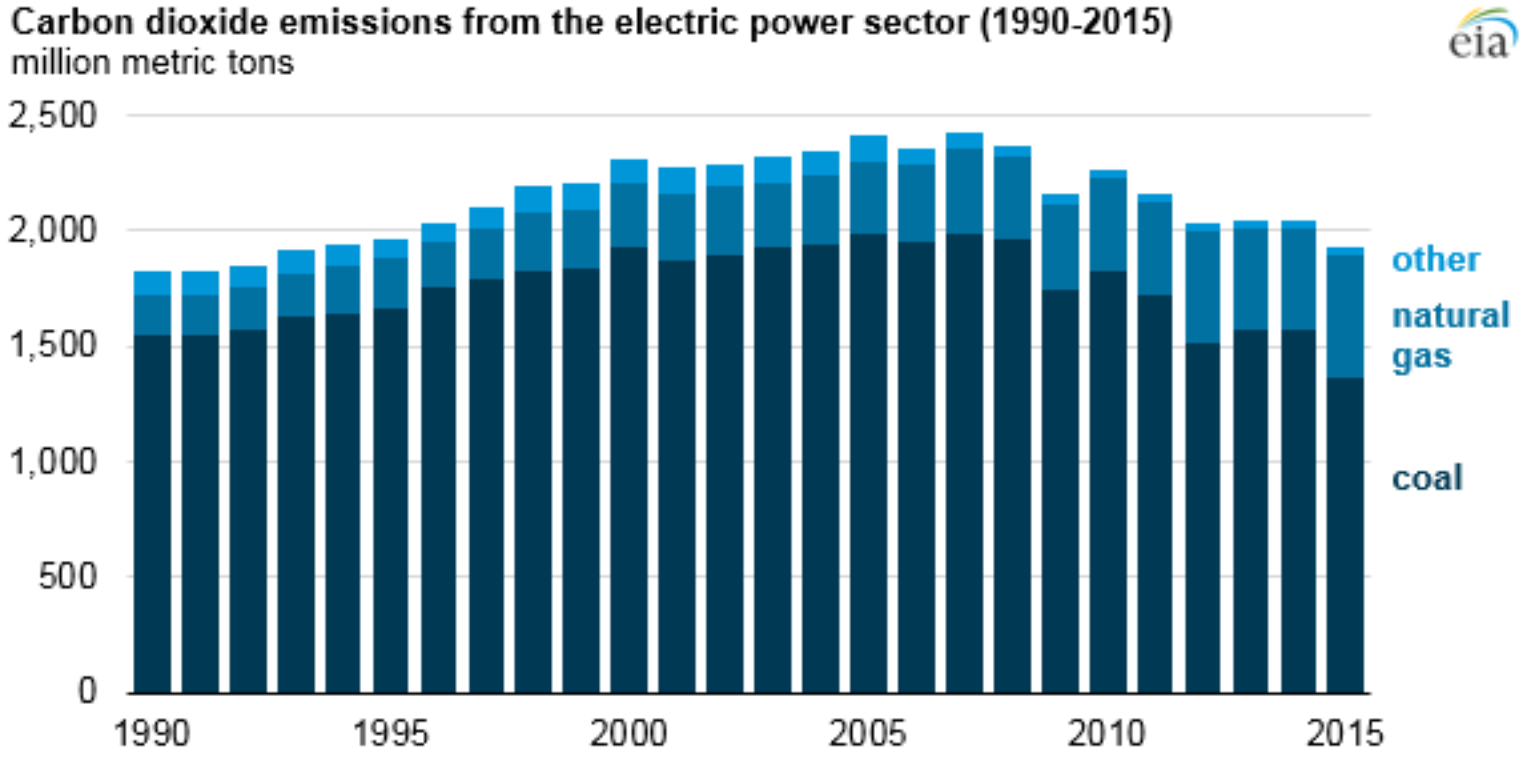
NG price drop in USA due to shale gas

Traditionally a large importer of oil and gas, the USA might soon become a net exporter! Nobody could predict this a few years ago.



USA's CO_2 emissions drop

CO2 emissions from power plants in the USA for 2015 have dropped down to the 1993 levels, without any specific incentives! This was mainly due to low-cost NG and to the fact that old coal plants were taken out of service.



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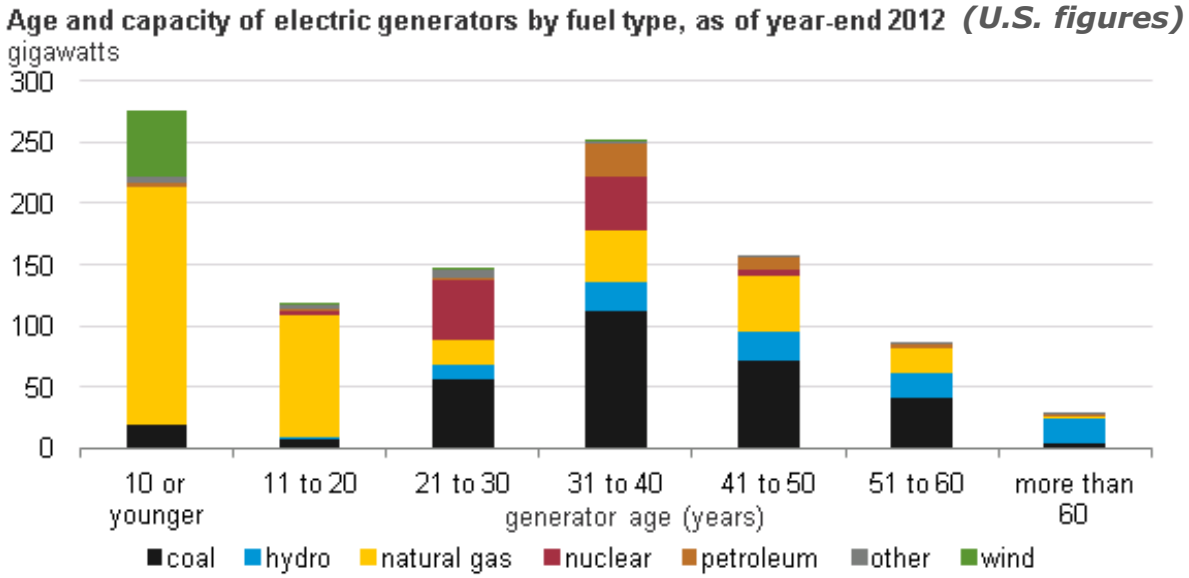
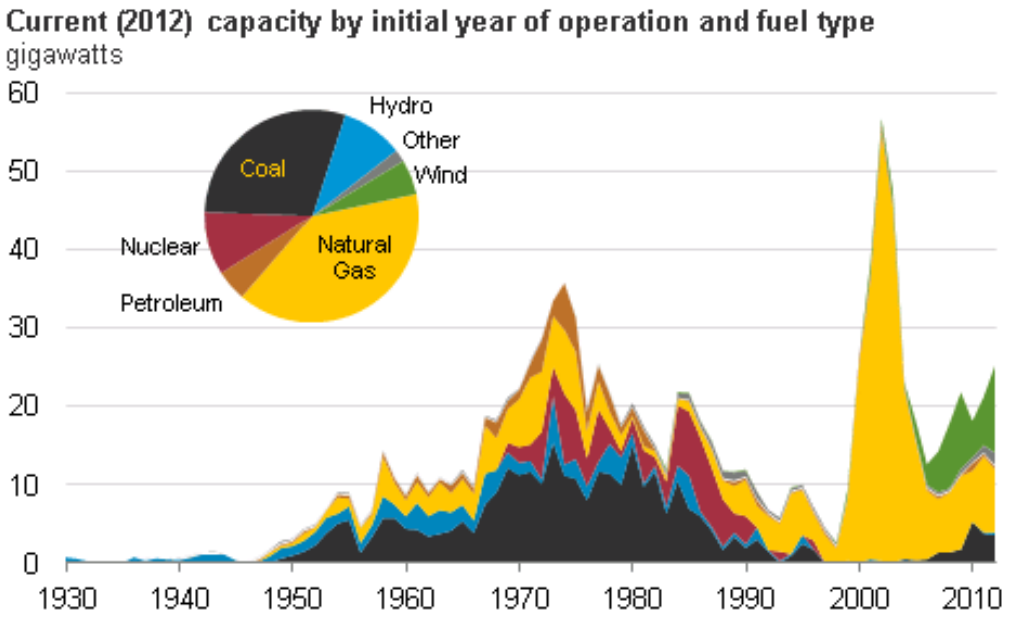
Aging conventional plants

It is cheaper to continue using conventional power plants because they’re already there, while building renewables should start from scratch and is inevitably expensive.

Nevertheless, most of the existing power plants are now **far too old** and need to be refurbished or replaced – so it might be best to **replace them with renewables!**





Source: www.eia.gov

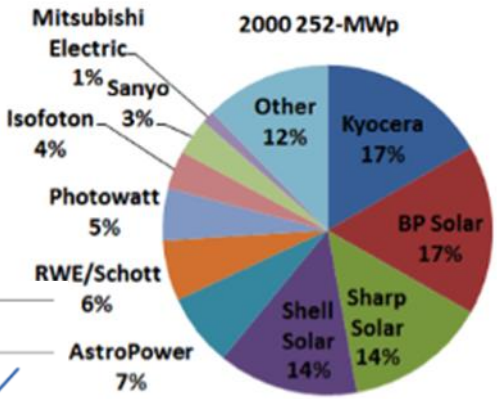
Recent power sector developments (2)

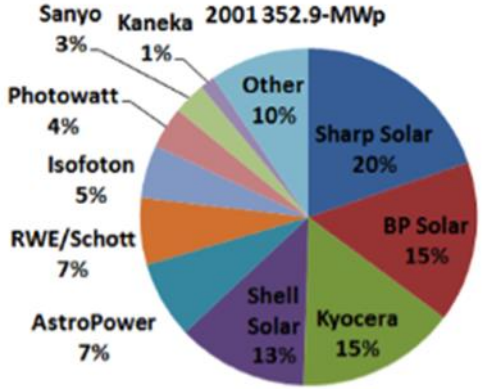
The PV price reduction:

- Very steep decrease of PV prices since 2009.
- Nobody expected it! Happened after China massively entered the PV production & market – *a bit controversial due to governmental aid, but certainly good for the environment.*
- Enormous expansion of PV capacity in the last years.
- PVs are getting close to "grid parity" in some places!
- Unfortunately still the balance-of-system costs and various "soft costs" are very high. As of 2017, the summed cost of auxiliary components, installation, permissions, connection to grid, etc, is ~4 times higher than the cost of PV panels.

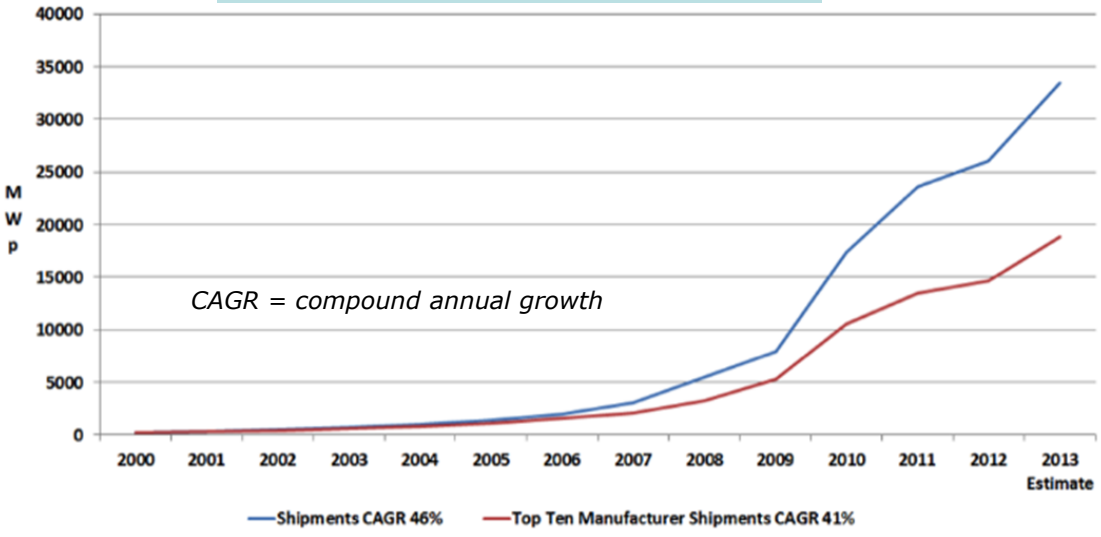
PV market and major manufacturers

Commercial PV technology developers → market shares in years 2000 and 2001





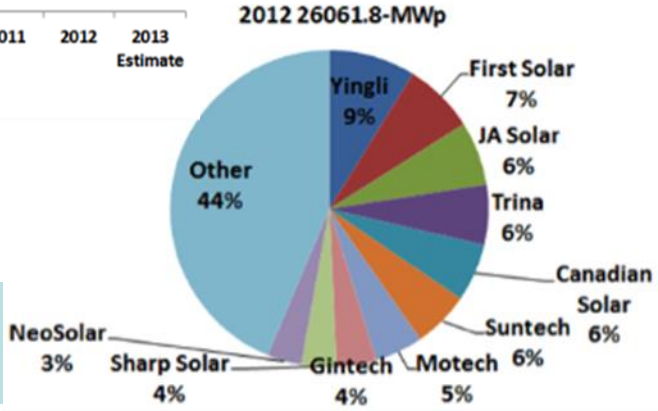
PV market expansion worldwide:

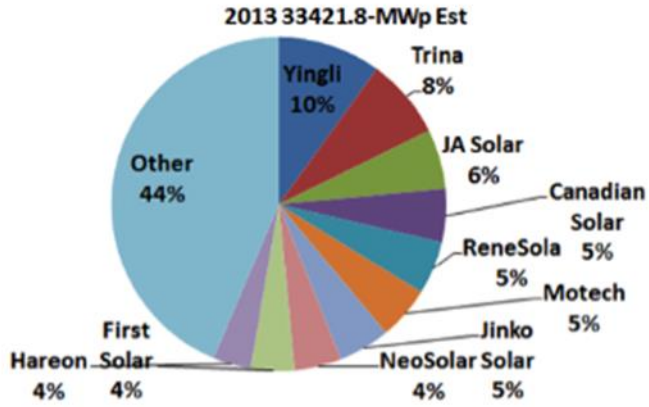


A complete change of status-quo in the PV business during the last decade! New manufacturers emerging and quickly taking over the market with exponential growth figures. Prices dropped without any major breakthrough in new technology, but only due to incremental improvements and mass production!

Source: SPV Market Research

Commercial PV panel producers → market shares in years 2012 and 2013





PV panel shipments in 2015 (48% by Chinese producers)

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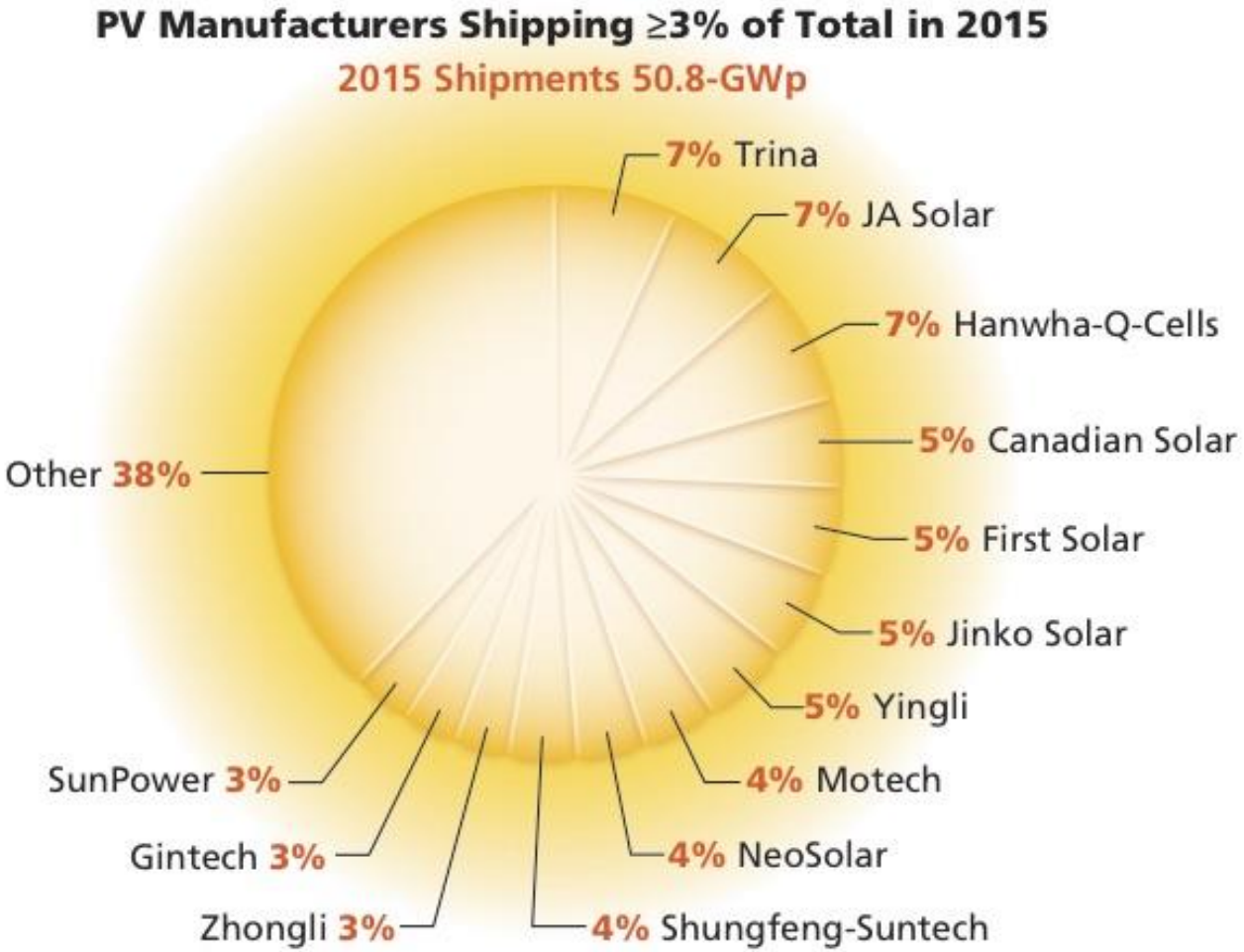
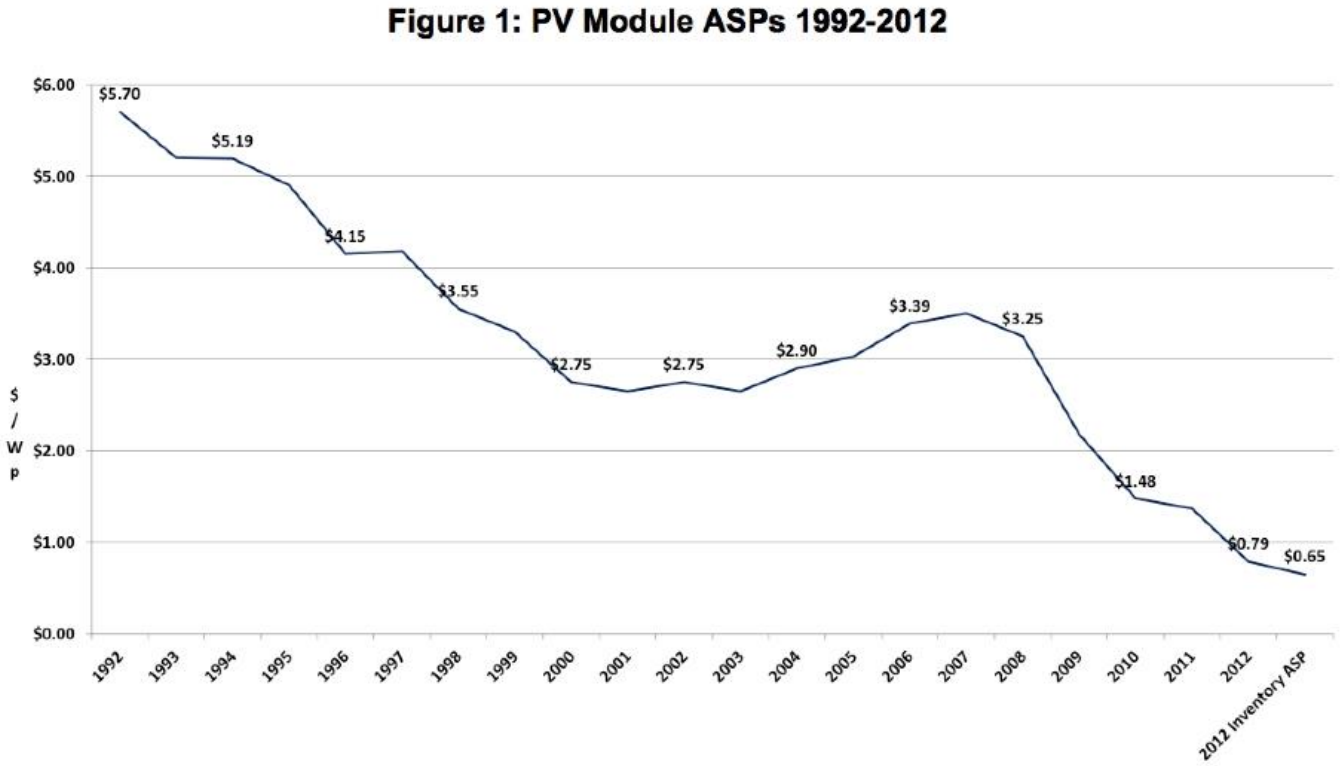
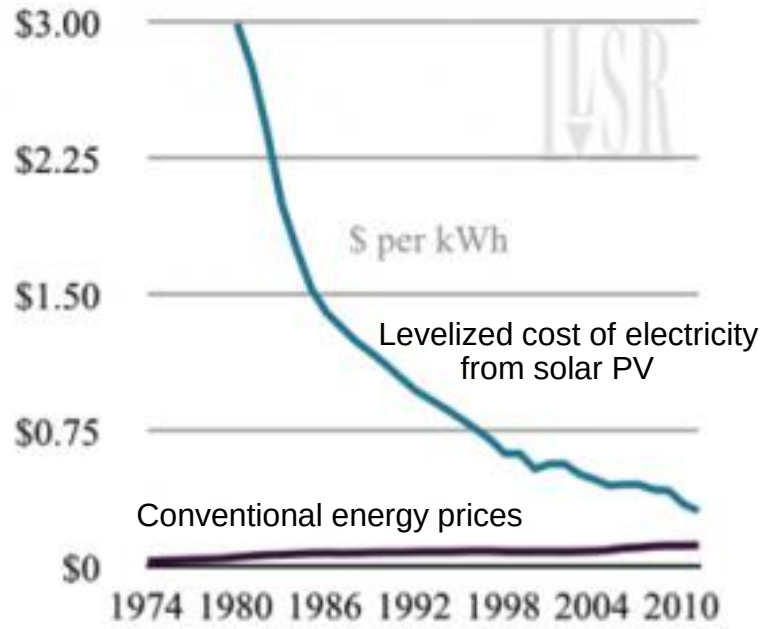
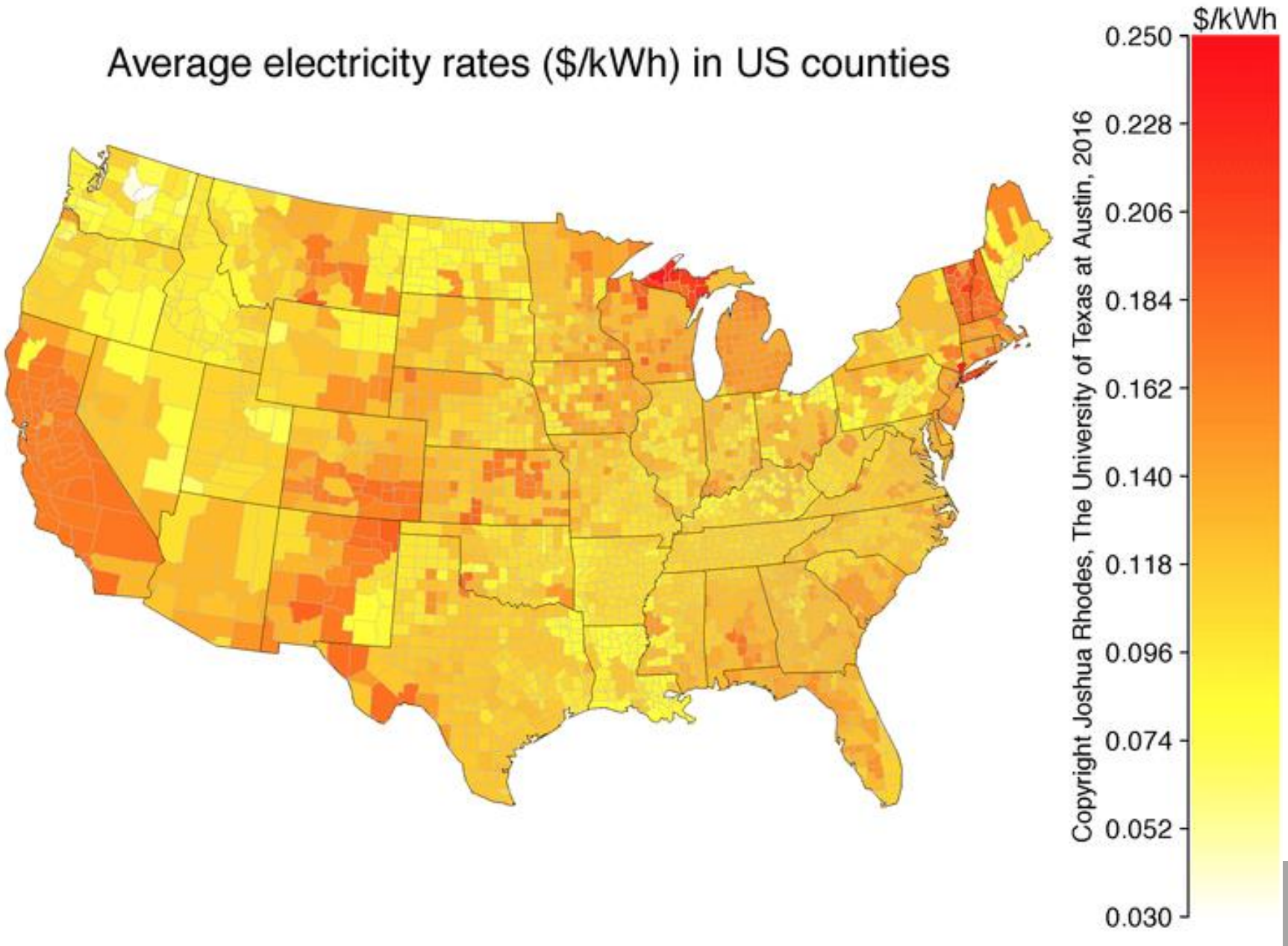


PV is closing the gap to grid parity





PV's LCOE on par with the grid?



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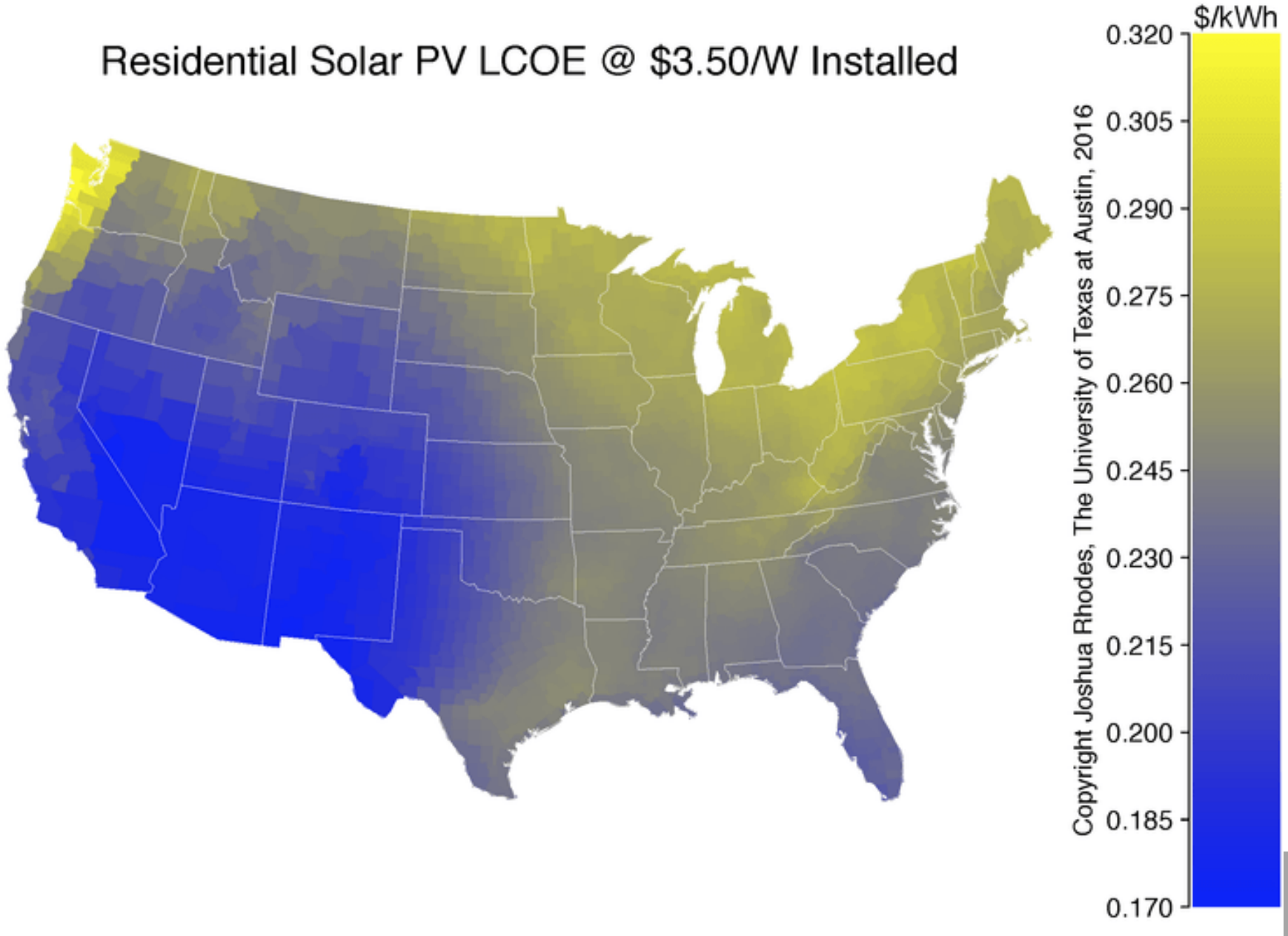
LCOE is a complex function



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High retail prices for grid electricity

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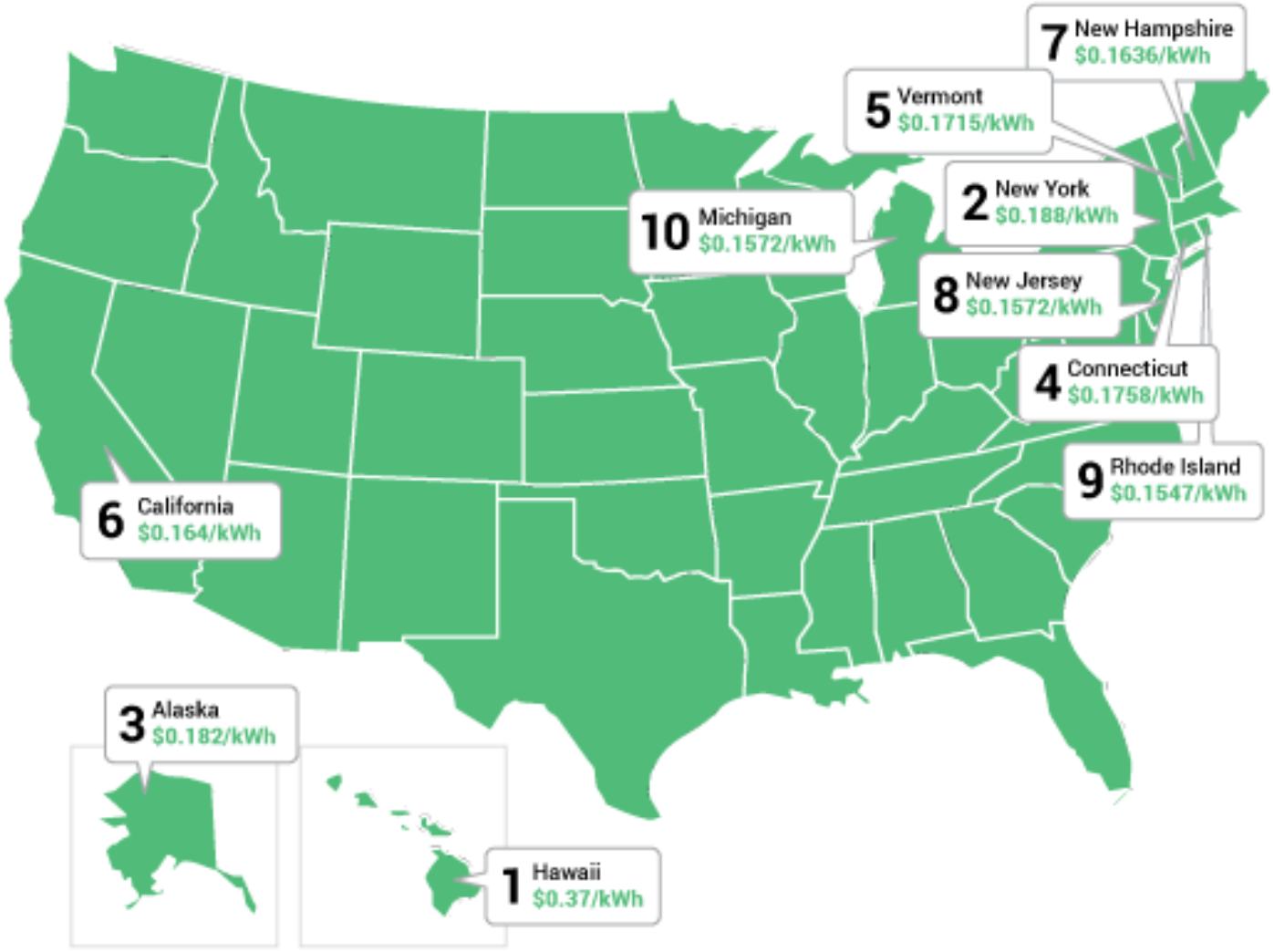

Data source:
Energy Information Administration. "Electricity Data Browser."
http://www.eia.gov/electricity/data/browser.

Infographic © Industry Dive 2014

…only a few more steps to bridge the gap…

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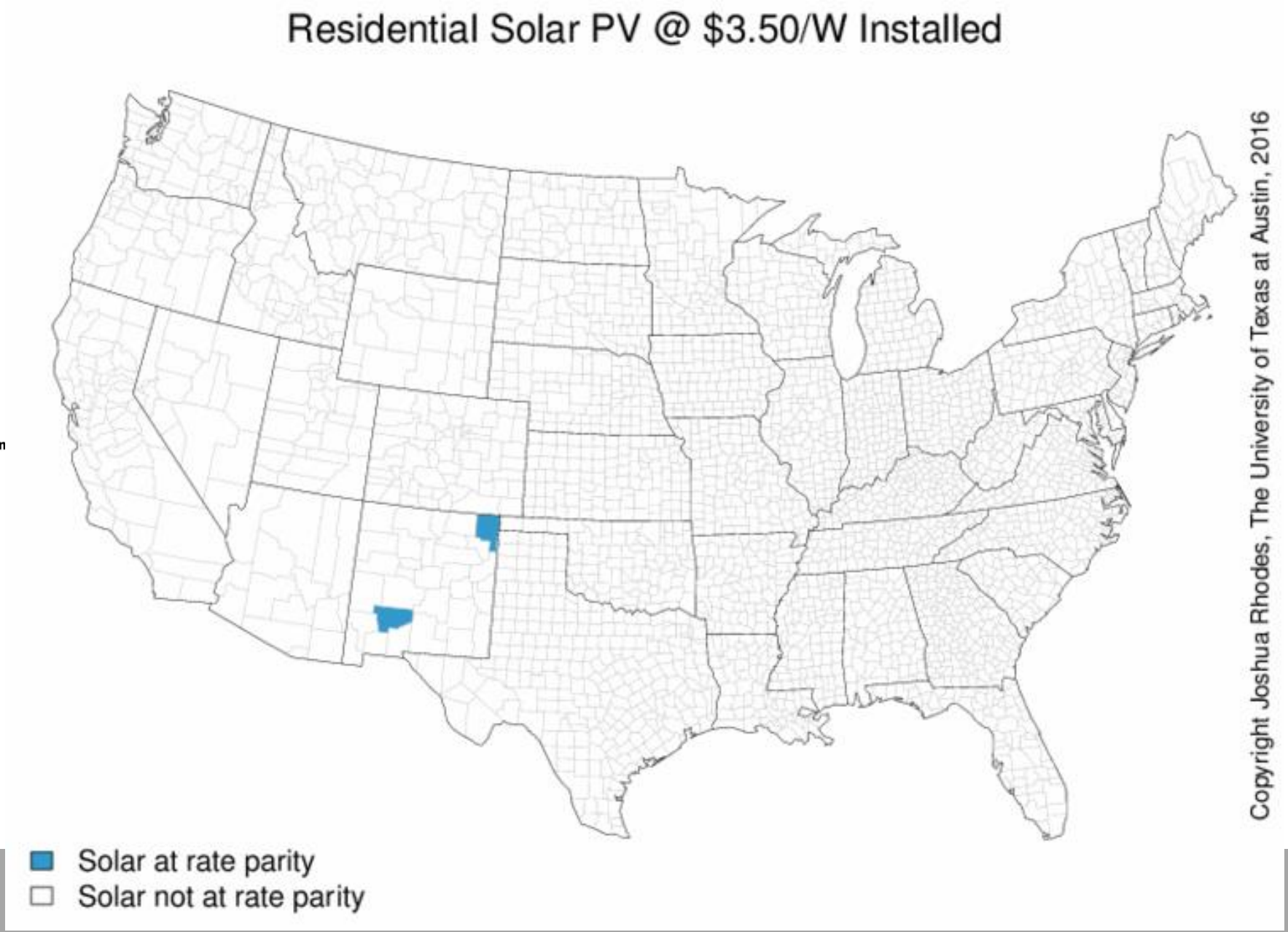

…only a few more steps to bridge the gap…

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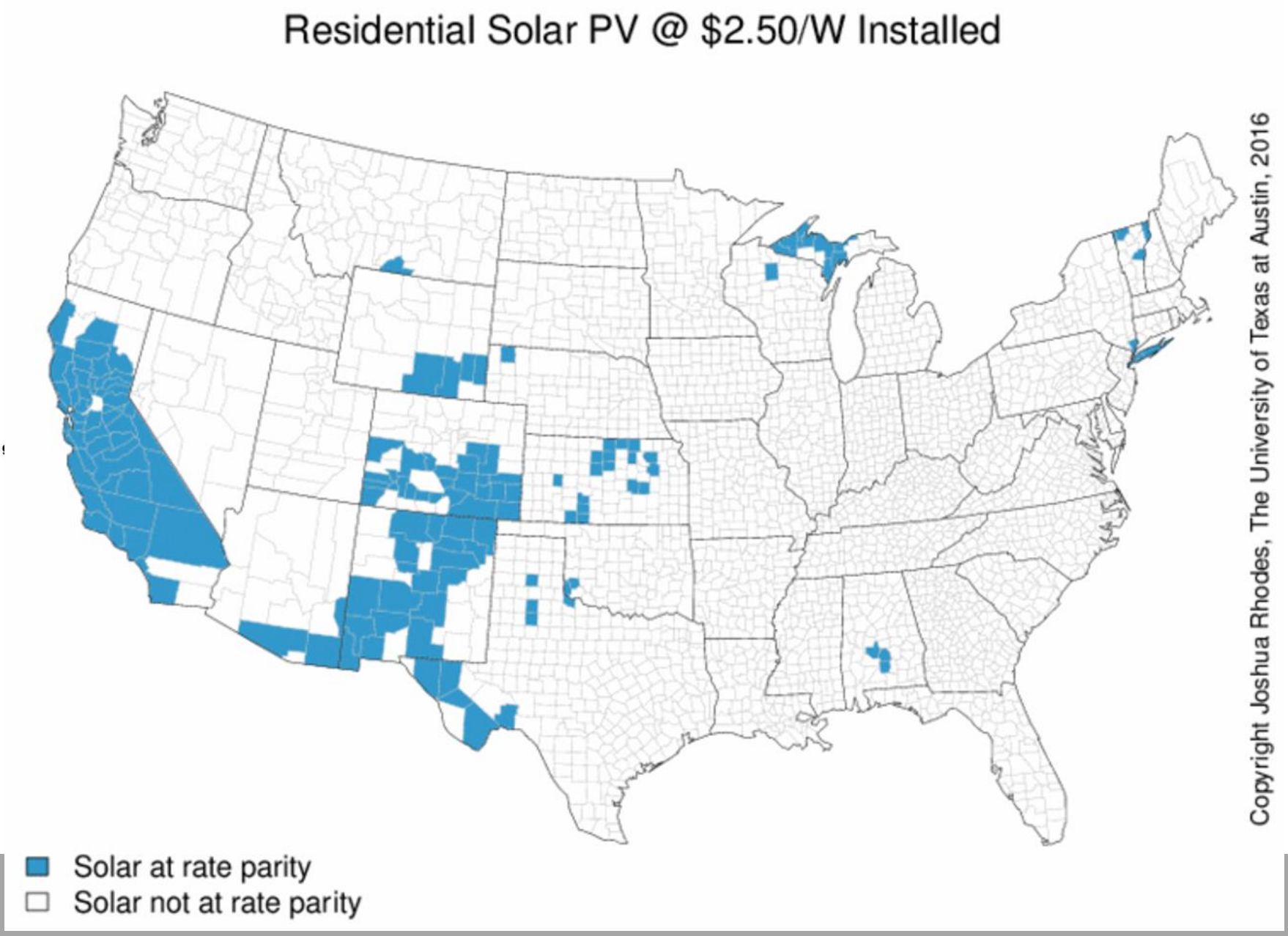

…only a few more steps to bridge the gap…

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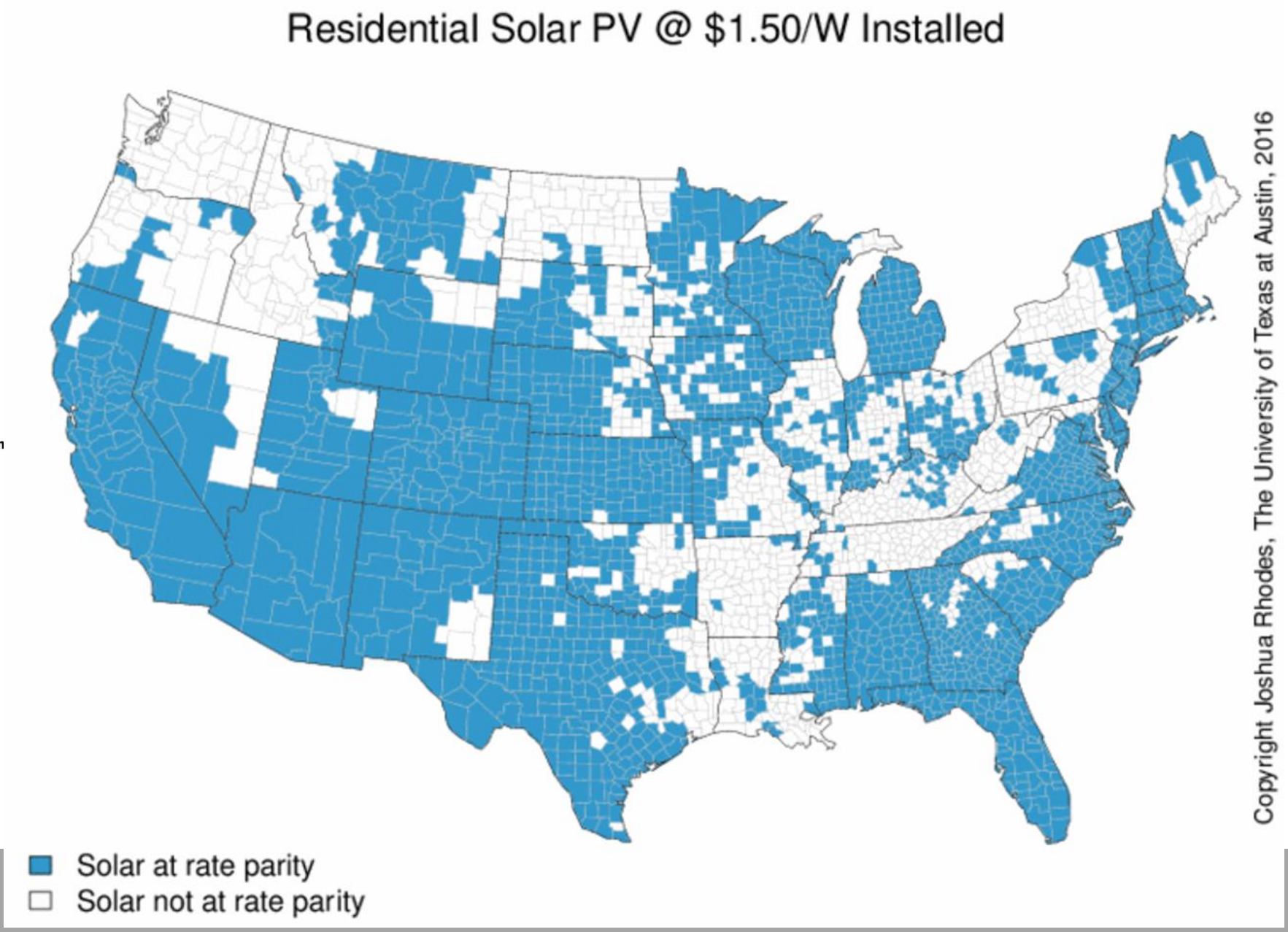
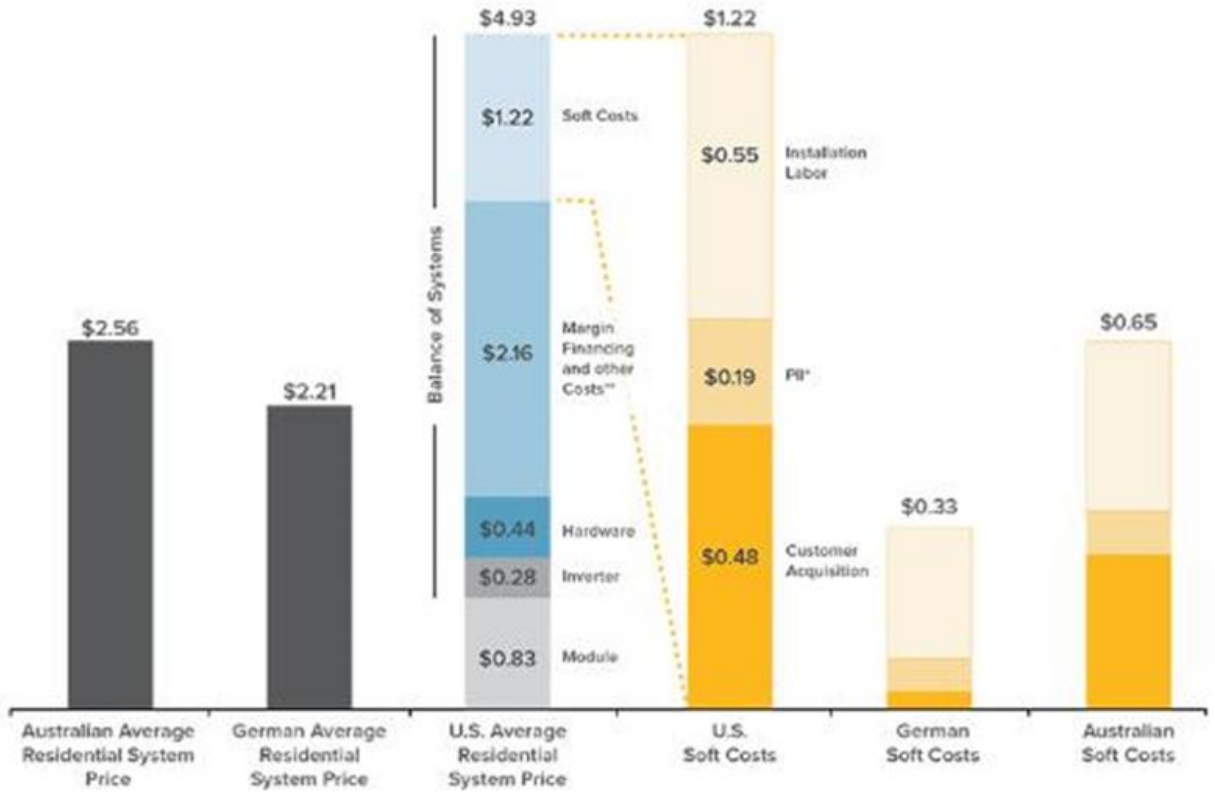


PV “soft costs” need to be reduced

FIGURE 1: RESIDENTIAL PV SOFT COSTS IN THE U.S., GERMANY, AND AUSTRALIA



Source: Renewable Energy World Magazine, June 2014

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Recent power sector developments (3)

A <u>dire need for energy storage</u> in any possible form!

The prophecy of the Li-ion battery:

- A similarly steep price plunge (like for PV cells) is also expected for the Li-ion battery in the near future
- If this happens, the massive deployment of distributed energy production with local energy storage would be economically justified; including the proliferation of electric vehicles
- Energy storage development would be the quantum leap towards the future power system able to operate with a high share of intermittent renewables

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Massive expansion of renewables: already a reality but not for granted

- Decreasing costs per kW installed capacity (like for PV cells) have also occurred in the wind power industry, even if only gradually and during a longer time period.
- Wind and Solar are already the most cost-effective and fastest-to-build options if new capacity needs to be added. However, their unpredictable variability has to be balanced out by conventional power plants. This problem would aggravate in the future unless affordable energy storage solutions were to be developed.
- The actual "cost" of new Wind or Solar capacity should be considered together with an equally large conventional plant (or energy storage option) that would cover up for the times when wind or solar resources are not available!

Challenges due to large amount of intermittent power

The grid should absorb the produced renewable power, despite its variability, while still operating reliably and guaranteeing a proper supply to cover the demand at any moment.

Expanding the transmission interconnections inside and between countries (even between continents) together with strategic reserve power, is crucial. New transmission capacity, however, also costs dearly.

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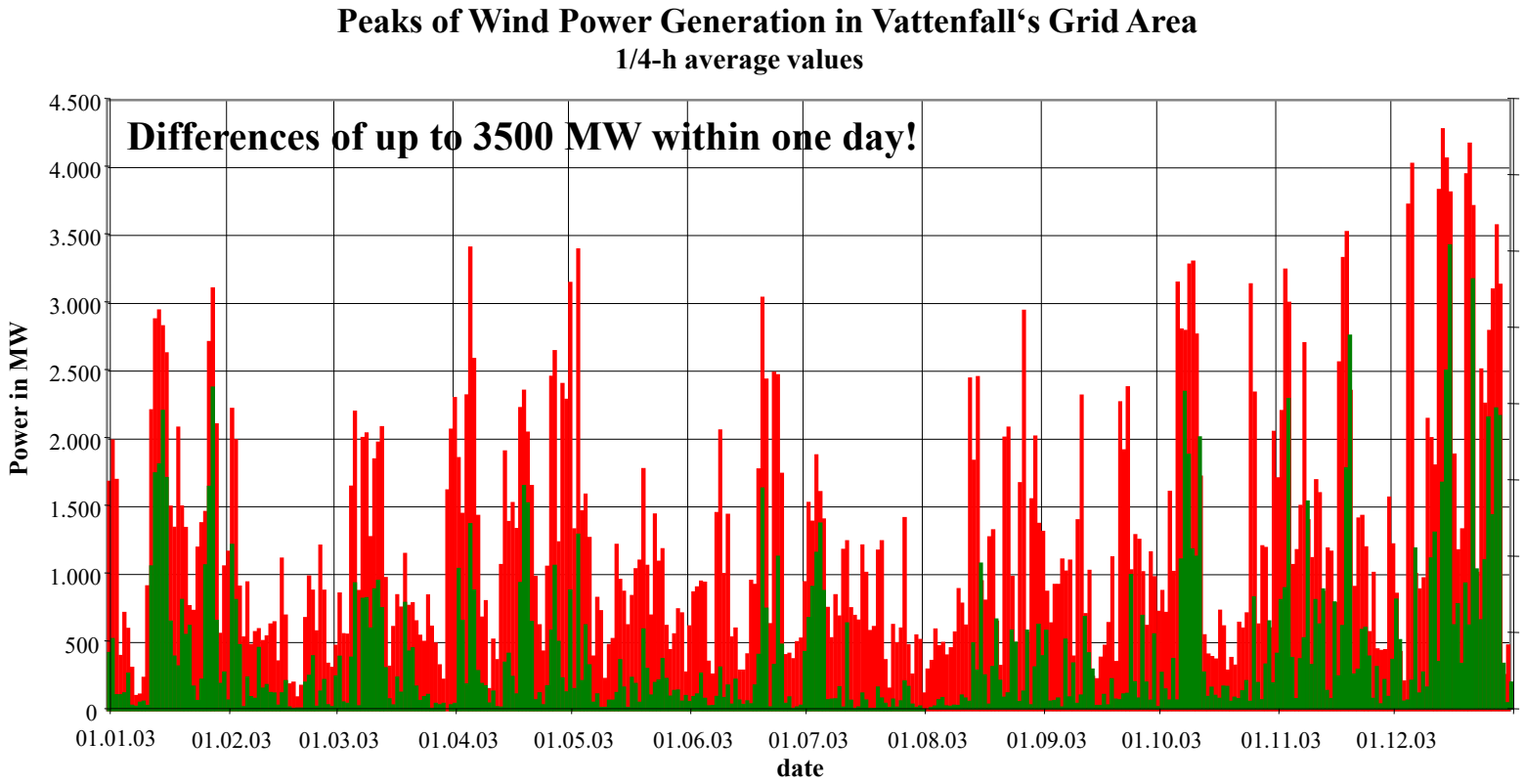

Lack of controllability and predictability of wind power

A more aggregated and widespread wind turbine fleet across a larger territory would offer a more predictable power output and a better capacity factor. This problem is a bit different for solar power, which is intrinsically easier to predict and plan for, but aggregation across a larger region does not directly lead to easier integration.

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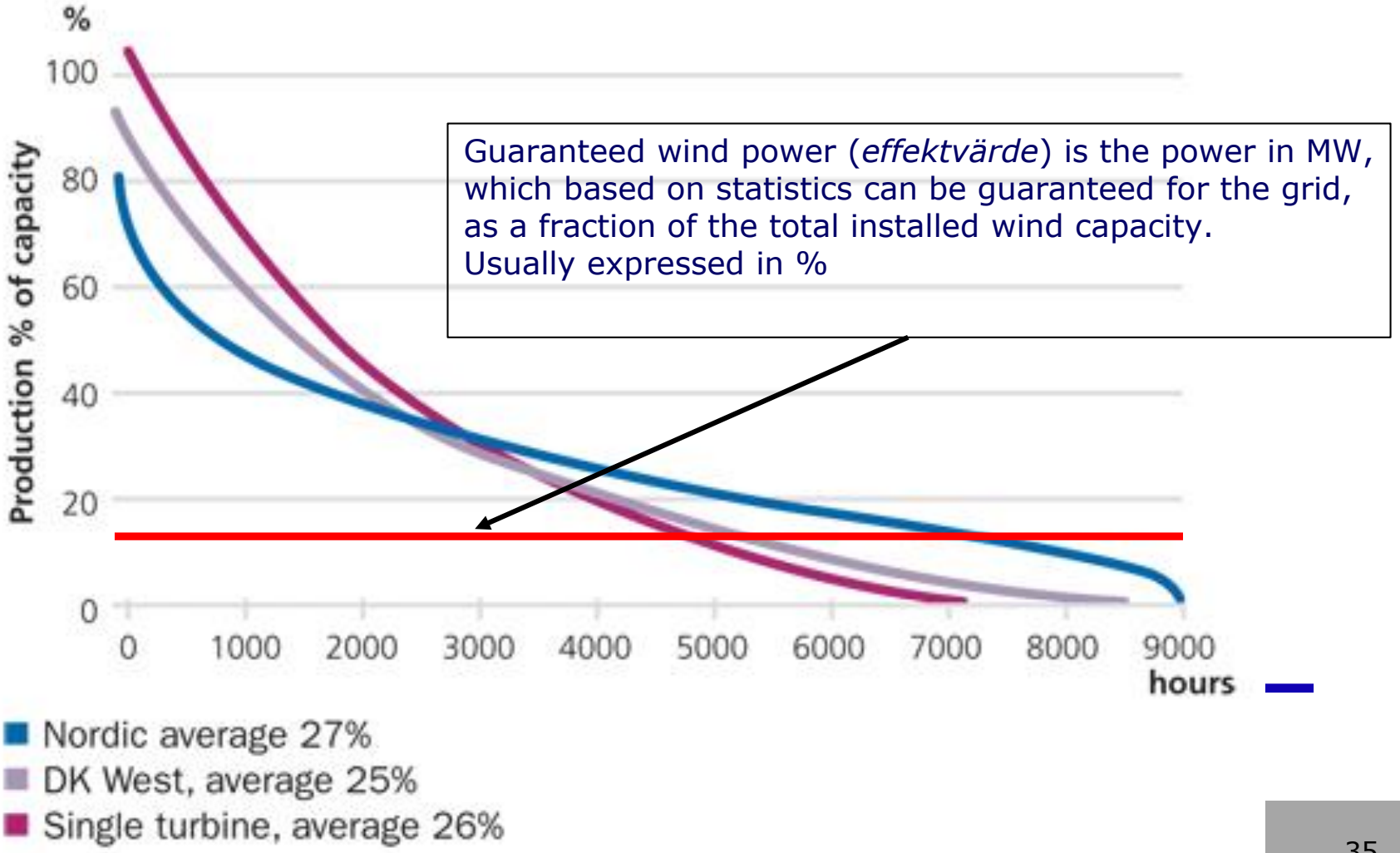
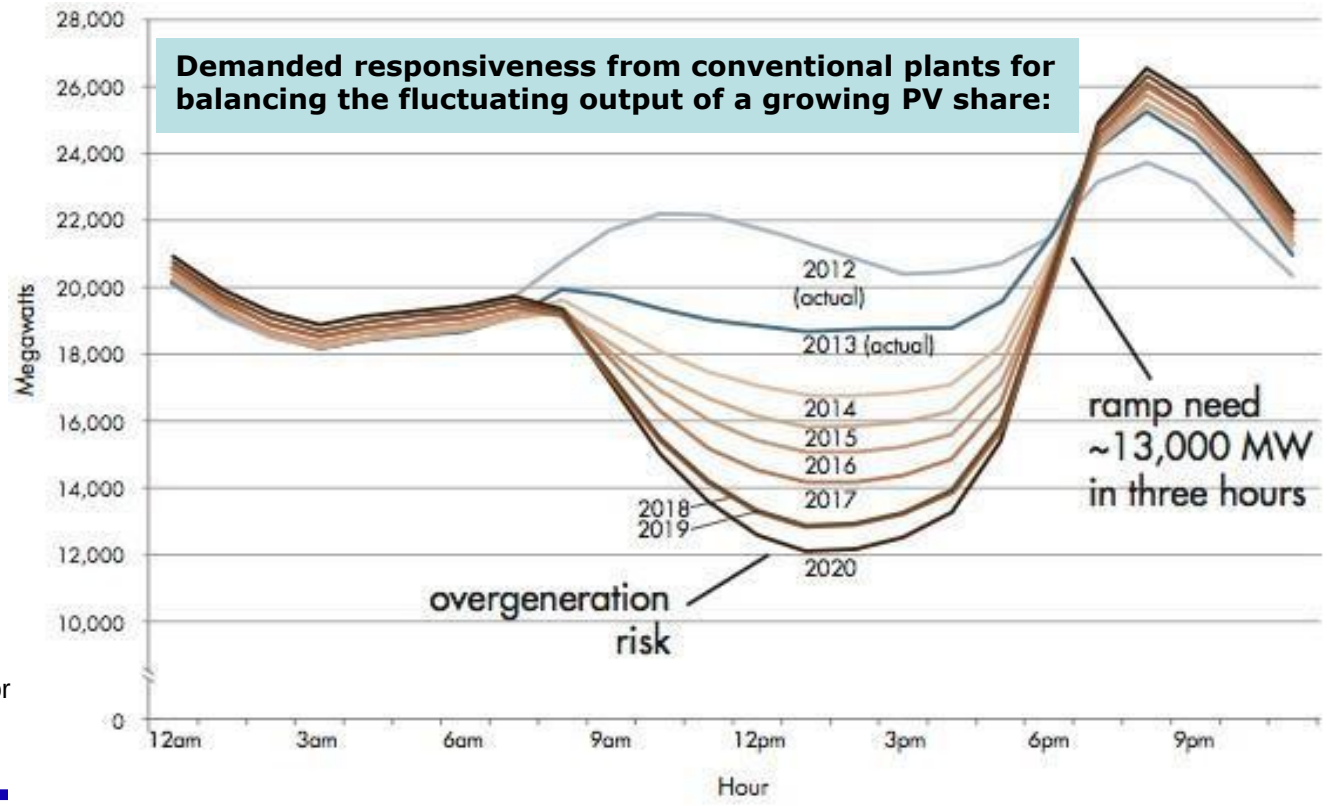


Are renewables easy to integrate?

The growing influx of variable renewable energy in the electrical grid is a big challenge.

The so-called "duck curve" below shows the increasing requirement for system flexibility and ramping capability due to the increasing share of solar PV in California:



Source: California Independent System Operator (CAISO)

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Curtailment of Renewable Energy

Highly valuable (but also highly variable) renewable electricity might need to be curtailed (wasted) if the grid is not able to accept the production in a particular moment or location.

For example, China now leads the world in installed wind power capacity: 140+ GW, but has the poorest capacity utilization rate. More than 40 000 GWh of wind power were curtailed in China in 2016, for various reasons.

Average aggregate utilization factor for all installed wind turbines in China is only ~10%! While in Europe this figure is ~30%

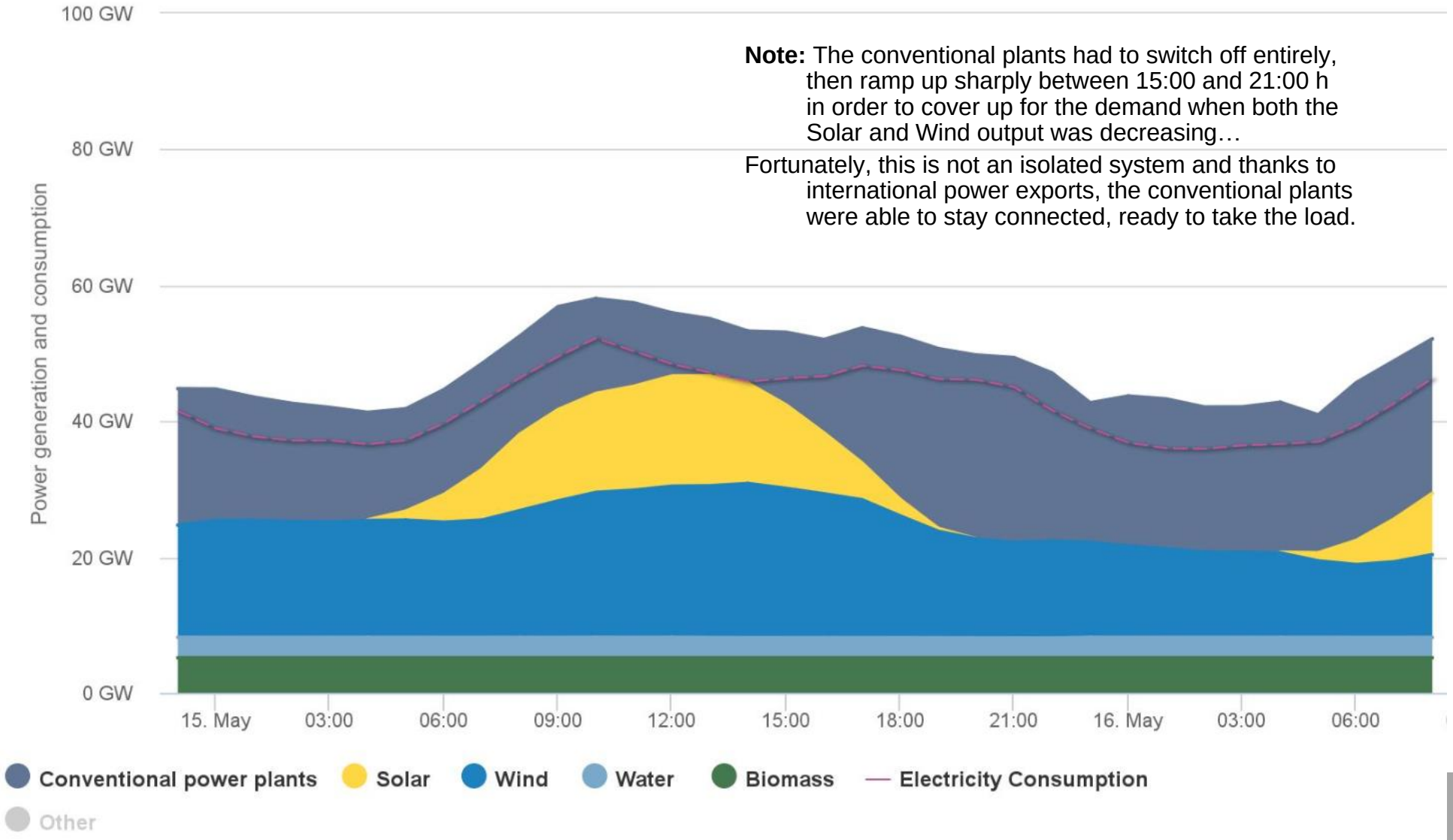
Recent power sector developments (4)

The massive deployment of Wind and PV in Germany and the imminent closure of all nuclear reactors:

- The "**Energiewende**" trend in Germany is a wonderful example of state-imposed sustainable development.
- It proved that with dedication and financial resources a quick transition to renewable energy is possible.
- HOWEVER, the balancing power becomes very important. High NG prices and low coal prices lead to modern gas plants closing down and leaving room to old coal plants!
- The CO_2 emissions increased! *(this will soon be negated by energy conservation measures and by modernizing the grid and the power plant fleet)…*
- Was the overall result sustainable? Almost, but not entirely!!

Energiewende has already arrived

Germany was entirely RE-powered for some minutes on May 15, 2016

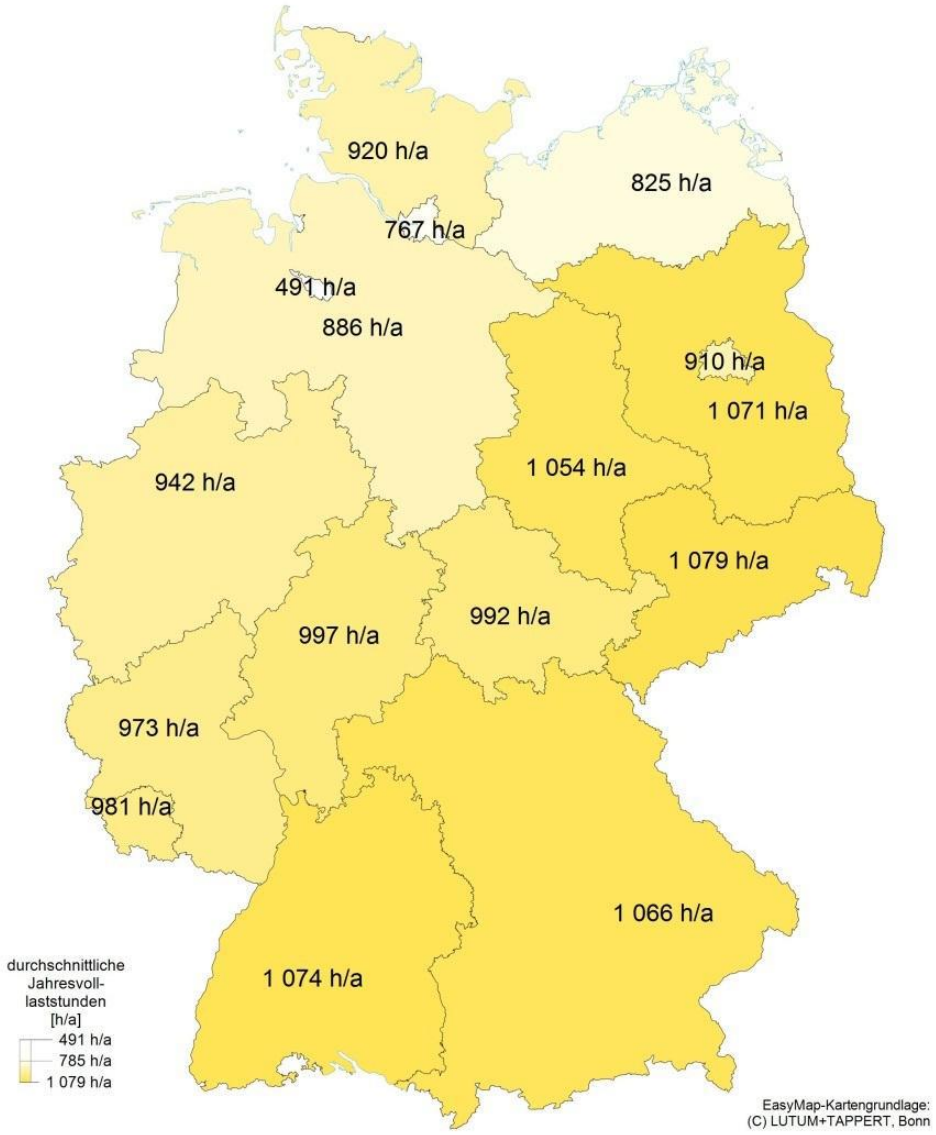


Note: The conventional plants had to switch off entirely, then ramp up sharply between 15:00 and 21:00 h in order to cover up for the demand when both the Solar and Wind output was decreasing…

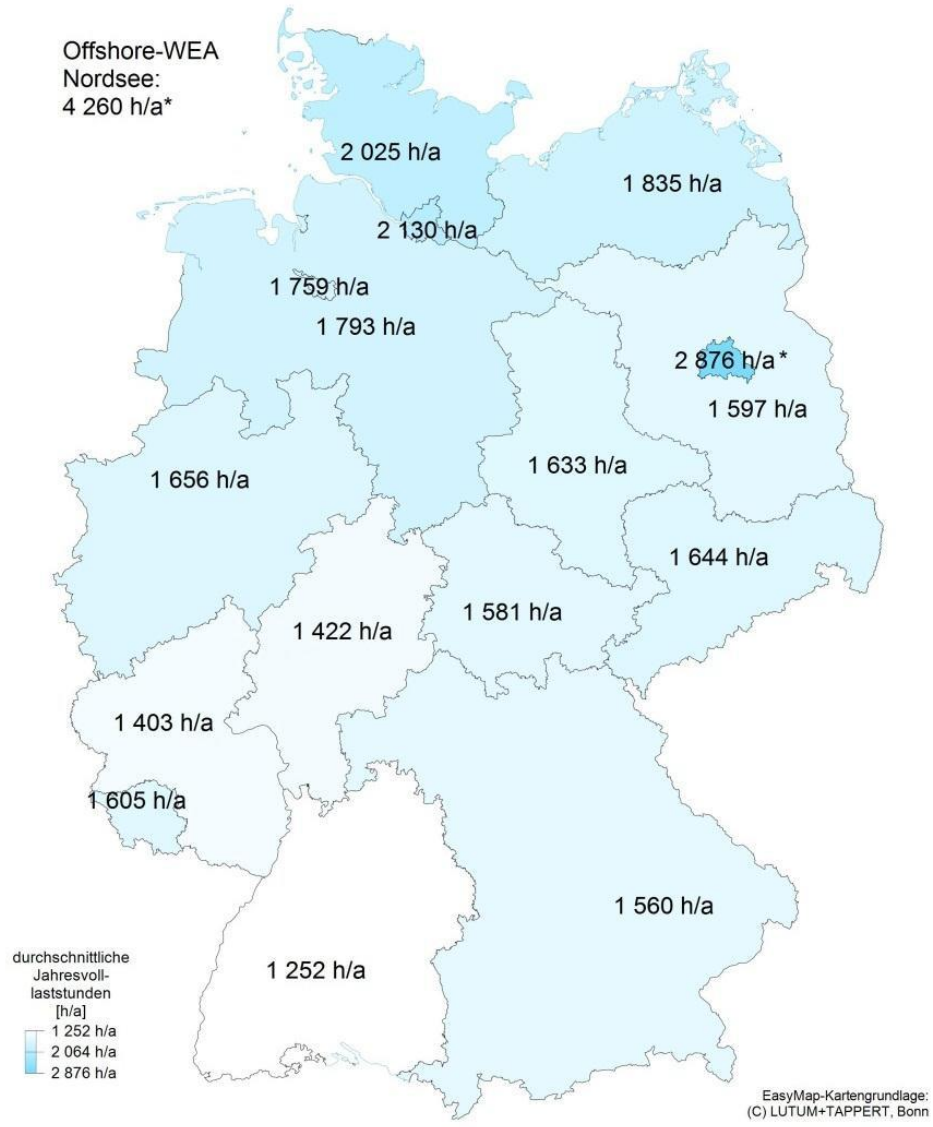
Fortunately, this is not an isolated system and thanks to international power exports, the conventional plants were able to stay connected, ready to take the load.

Equivalent full-load operating hours in Germany for Solar PV (left) and Wind turbines (right)

There is no large-scale cross-country transmission capacity yet able to send huge amounts of wind or solar power north-south or vice versa.



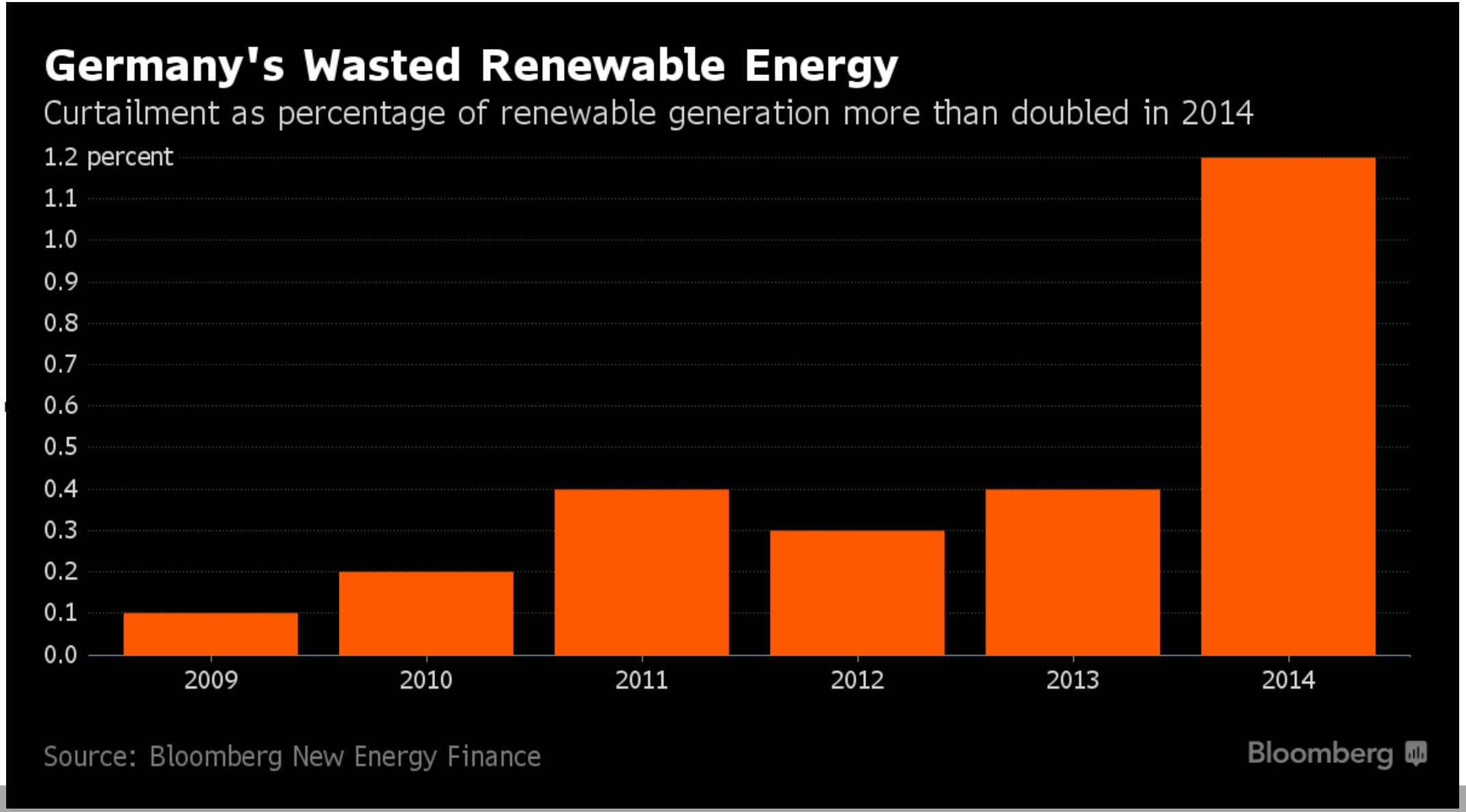
Quellen: BDEW-Jahresstatistik "Stromerzeugungsanlagen/Regenerativanlagen"; Meldungen der Übertragungsnetzbetreiber über die Einspeisung von EEG-Strom



* sehr geringe Anzahl, daher Werte nicht signifikant

Quellen: BDEW-Jahresstatistik "Stromerzeugungsanlagen/Regenerativanlagen"; Meldungen der Übertragungsnetzbetreiber über die Einspeisung von EEG-Strom

Curtailment of RE - even in Germany



Ultra-modern coal plants in Germany

The transition to renewables in Germany gave birth to, peculiarly, new coal-fired power plants!

They are not very big, neither super-efficient, but rather optimized for flexible power output, quick ramping, and low emissions.

And they will receive subsidies (similar to those for renewables) to act as a back-up and as a major balancing force in the new power system dominated by stochastically variable renewable sources such as wind and solar!

Capacity Market concept

The traditional approach of "get paid per kWh of electricity" does not function anymore for back-up power plants operating at low capacity factors, for example the peaking plants that work only for a few hours per day.

Capacity Tariffs have been proposed recently, paying per kW power capacity "anytime-ready-to-dispatch", instead of payment per produced kWh.

Already applied to many national electric grids around the world. Perfect for the future system based on energy storage.

Serious talks within EU and a decision pending for a common capacity remuneration mechanism (CRM).

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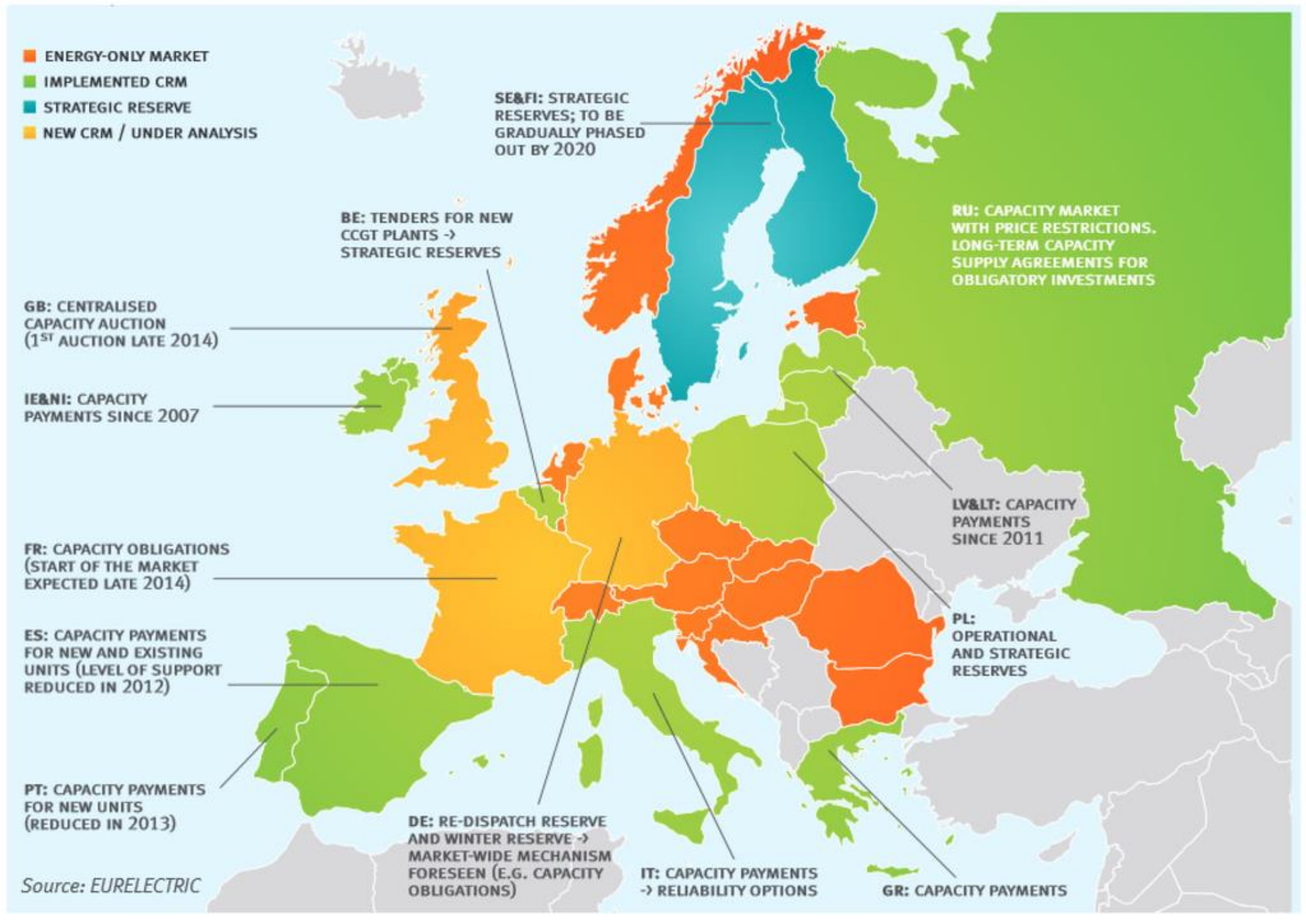

Source: EURELECTRIC

Recent power sector developments (5)

Transition to biomass is technically possible for coal power plants, but…

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Drax and Eggborough power stations in Yorkshire, England – a monster-large coal-fired complex: altogether 10 steam units with a total of 6000 MW installed capacity. Three units in Drax have been modernized to burn 100% biomass. There is an intention to make all units 100% biomass-fired, receiving wood pellets shipped from as far as North America and the Baltic states!

…Will this make them more sustainable?

And again:

Regardless of the primary energy source, most often it is a steam or gas cycle doing the job, including the flexible balancing power in a future renewable-dominated grid

The SPG course focuses on thermal power plants, so here we rather concentrate on the practical understanding of thermodynamic cycles and their possible improvements…

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