Insights from Germany’s Energiewende

State of affairs, trends and challenges

Last Update:
14.10.2015
Agora Energiewende – Who we are

Think Tank with 20 Experts
Independent and non-partisan

Project duration 2012-2017
Financed with 14 Mio. Euro by Mercator Foundation & ECF

Mission: How do we make the energy transition in Germany a success story?

Methods: Analyzing, assessing, understanding, discussing, putting forward proposals, Council of Agora
Agora Energiewende – How we work

### Stakeholder

Regular exchange and changing advisory committees in different projects

### Team of Agora

- Director
- Team Germany
- Team Europe
- Central Services

### Council of Agora

Internal discussion and exchange of the 28 permanent members

### Impulse

- Studies, public events etc.
Agora Energiewende – Council of Agora

27 members

Holger Krawinkel
Dr. Hildegard Müller
Dr. Martin Iffert
Dr. Boris Schucht
Regine Günther

Prof. Dr. Klaus Töpfer
Dr. Patrick Graichen
StS Rainer Baake
Min Franz Untersteller
Wolfgang Lemb
The Energiewende in the power sector in a nutshell
The Energiewende means fundamentally changing the power system

**Phase out of Nuclear Power**
Gradual shut down of all nuclear power plants until 2022

**Reduction of Greenhouse Gas Emissions**
Reduction targets below 1990 levels:
- 40% by 2020; - 55% by 2030; - 70% by 2040;
- 80% to - 95% by 2050

**Development of renewable energies**
Share in power consumption to increase to:
40 - 45% in 2025; 55 - 60% in 2035; ≥ 80% in 2050

**Increase in efficiency**
Reduction of power consumption compared to 2008 levels: - 10% in 2020; - 25% in 2050
The Energiewende implies a new energy world – characterized by flexibility, decentralized structures and a wide variety of actors

Illustrative visualisation of the old and the new electricity system

<table>
<thead>
<tr>
<th>high voltage</th>
<th>medium voltage</th>
<th>low voltage</th>
</tr>
</thead>
</table>

Own illustration
The Energiewende in the power sector

State of affairs 2015
Renewables are the most important source in the electricity system – followed by lignite and hard coal.
The nuclear energy act rules the nuclear phase out until 2022 – with renewables overcompensating the loss in nuclear power

Greenhouse gas emissions are currently at -26% compared to 1990 levels – with the energy sector being the largest emitter.

Greenhouse gas emissions by sector 1990 - 2014 and climate targets 2020 - 2050

AGEB (2015a), UBA (2015), own calculations

* preliminary
The Renewable Energy Act aims at increasing the share of renewables to 40 - 45% by 2025 and 55 - 60% by 2035.

Share of renewable energies in gross electricity consumption 2000 - 2014 and targets 2025 - 2035

% in gross electricity consumption


7% 8% 9% 12% 14% 16% 20% 24% 25% 27%

2014*: 27.3%

Target 2025: 40%-45%

Target 2035: 55%-60%

AGEB (2015a), EEG (2014)

* preliminary
Germany decoupled economic growth from energy consumption – but there is still work to do to reach the 2020 efficiency targets

Primary energy consumption, gross electricity consumption and GDP 1990 - 2014 and efficiency target 2020


* preliminary
Since 2001, Germany has produced more electricity than it consumes – 2014 marked a new record with 6% of power production being exported to neighbouring countries.

<table>
<thead>
<tr>
<th>Year</th>
<th>Gross Electricity Generation (TWh)</th>
<th>Gross Electricity Consumption (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>577</td>
<td>580</td>
</tr>
<tr>
<td>2001</td>
<td>586</td>
<td>585</td>
</tr>
<tr>
<td>2002</td>
<td>587</td>
<td>587</td>
</tr>
<tr>
<td>2003</td>
<td>609</td>
<td>601</td>
</tr>
<tr>
<td>2004</td>
<td>618</td>
<td>610</td>
</tr>
<tr>
<td>2005</td>
<td>623</td>
<td>614</td>
</tr>
<tr>
<td>2006</td>
<td>640</td>
<td>620</td>
</tr>
<tr>
<td>2007</td>
<td>641</td>
<td>622</td>
</tr>
<tr>
<td>2008</td>
<td>641</td>
<td>618</td>
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<tr>
<td>2009</td>
<td>596</td>
<td>618</td>
</tr>
<tr>
<td>2010</td>
<td>633</td>
<td>613</td>
</tr>
<tr>
<td>2011</td>
<td>630</td>
<td>607</td>
</tr>
<tr>
<td>2012</td>
<td>639</td>
<td>607</td>
</tr>
<tr>
<td>2013</td>
<td>639</td>
<td>605</td>
</tr>
<tr>
<td>2014*</td>
<td>625</td>
<td>590</td>
</tr>
</tbody>
</table>

AGEB (2015a) * preliminary

**2014*: 36 TWh
After significant increases in previous years, household electricity prices are relatively stable since 2013

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Price (ct/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>20.6</td>
</tr>
<tr>
<td>2008</td>
<td>21.7</td>
</tr>
<tr>
<td>2009</td>
<td>23.3</td>
</tr>
<tr>
<td>2010</td>
<td>23.7</td>
</tr>
<tr>
<td>2011</td>
<td>25.2</td>
</tr>
<tr>
<td>2012</td>
<td>25.9</td>
</tr>
<tr>
<td>2013</td>
<td>28.8</td>
</tr>
<tr>
<td>2014</td>
<td>29.1</td>
</tr>
<tr>
<td>2015*</td>
<td>28.7</td>
</tr>
</tbody>
</table>

Average household electricity prices in a 3-person household 2007 - 2015

BDEW (2015b) * preliminary

* Procurement, distribution, margin | Taxes | Grid charges | Concession fee | EEG surcharge | Other surcharges
The Energiewende is based on a broad consensus - public discussions is basically focussing on the concrete implementation

Voting results in the Bundestag on Energiewende

Deutscher Bundestag (2011)

Public opinion on Energiewende 2015

BDEW (2015a)
The Key Insight: It’s all about Wind and Solar!
Wind Energy has become a mature technology, with windmills of 2 - 3 MW being standard.

Size development of wind turbines 1990 - 2015

- **1990**: up to 0.1 MW
- **1995**: up to 0.3 MW
- **2000**: up to 0.8 MW
- **2005**: up to 1.5 MW
- **2010**: up to 1.8 MW
- **2015**: up to 3.0 MW

IEA (2013)
Due to falling module prices, feed-in tariffs for Solar PV dropped massively in the last 10 years - and the end of the cost digression is not yet reached.

Average PV feed-in tariff for new installations 2005 - 2015

- 2005: 53 ct/kWh
- 2006: 51 ct/kWh
- 2007: 47 ct/kWh
- 2008: 45 ct/kWh
- 2009: 40 ct/kWh
- 2010: 34 ct/kWh
- 2011: 27 ct/kWh
- 2012: 19 ct/kWh
- 2013: 13 ct/kWh
- 2014: 11 ct/kWh
- 2015: 9 ct/kWh

Expected cost digression for large-scale PV systems 2014 - 2050

- 2014: ~80%
- 2020: ~80%
- 2025: ~80%
- 2030: ~80%
- 2035: ~80%
- 2040: ~80%
- 2045: ~80%
- 2050: ~80%

ZSW et al (2014), own calculations

Fraunhofer ISE (2015)
Today, wind and solar are already cost competitive to all other newly built power plants

Range* of levelized cost of electricity (LCOE) 2015

<table>
<thead>
<tr>
<th></th>
<th>Germany</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind (onshore)</td>
<td>6 - 9 ct/kWh</td>
<td>6 - 13 ct/kWh</td>
</tr>
<tr>
<td>Solar PV (large scale)</td>
<td>8 - 9 ct/kWh</td>
<td>13 - 16 ct/kWh</td>
</tr>
<tr>
<td>Hard Coal</td>
<td>7 - 11 ct/kWh</td>
<td></td>
</tr>
<tr>
<td>Gas (CCGT)</td>
<td>7 - 12 ct/kWh</td>
<td></td>
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<tr>
<td>Nuclear</td>
<td></td>
<td></td>
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<tr>
<td>Hard Coal CCS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Agora Energiewende (2015e)  
* based on varying utilization, CO₂-price and investment cost
The integration cost of wind and solar (5 to 20 EUR/MWh) do not change the picture

<table>
<thead>
<tr>
<th>Components of integration costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (EUR/MWh)</td>
</tr>
<tr>
<td>60 – 90 EUR/MWh</td>
</tr>
</tbody>
</table>

Agora Energiewende (2015a)

* part of utilization effect
The key insight for the Energiewende: It’s all about wind and solar!

Gross electricity generation of renewable energies 2000 - 2035

With wind and solar, the new power system will be based on two technologies that completely change the picture.

Gross electricity generation of renewable energies 2000 - 2035

Electricity generation and consumption in a sample week 2023

Specific characteristics of Wind and Solar PV

1. Intermittent
2. High capital costs
3. Very low variable cost

AGEB (2015a), BNetzA (2014), BNetzA (2015b), own calculations

Fraunhofer IWES (2013)
The power system and power markets will need to cope with a highly fluctuating power production from wind and solar.

Electricity generation* and consumption* in three sample weeks, 2023

Fraunhofer IWES (2013)  
* Modelling based on 2011 weather and load data
**Flexibility** is the paradigm of the new power system – baseload capacities are not needed any more

<table>
<thead>
<tr>
<th>Electricity generation and consumption in a sample week with 50% RES share</th>
<th>Key flexibility options</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Graph showing electricity generation and consumption" /></td>
<td>Flexible fossil and bioenergy power plants (incl. CHP)</td>
</tr>
<tr>
<td></td>
<td>Grids and transmission capacities for exports/imports</td>
</tr>
<tr>
<td></td>
<td>Demand Side Management</td>
</tr>
<tr>
<td></td>
<td>Storage technologies (Batteries, Power-to-Gas)</td>
</tr>
<tr>
<td></td>
<td>Integration of the power, heat and transport sectors (power-to-heat, electric cars)</td>
</tr>
</tbody>
</table>

Own calculations on basis of Agora Energiewende (2015b)
Key challenges ahead towards a world with 50% renewable energies
**Challenge 1: Grids**

Build more grids to transport wind energy to the south of Germany – in 2016 a new grid power plan is expected

- Wind power will be installed mainly near the coast in the north of Germany, but key consumptions centres are located in the south.
- Additional power lines are necessary to transport wind electricity from north to south.
- In 2016, the government will propose a new transmission power plan which will enable to use underground cable whenever necessary.
- Measures to reduce consternation and compensation for concerned parties need to be considered from the very beginning.

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**Installed wind capacity (103 GW, Scenario „Best Sites“) 2033**

**Planned transmission grid extensions until 2022**

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Fraunhofer IWES (2013)  
Bundesbedarfsplangesetz (2013)
**Challenge 2: Climate Targets**
Gradual reduction of coal use is needed – in 2017, a “coal reserve” is planned, for 2030/2040 we need a “coal consensus”

\[ \text{CO}_2 \text{ emissions from electricity generation 1990 - 2014 and climate targets** 2020 - 2040} \]

- **2014**: - 13.5%
- **Target**: *2020*: - 40%
- **Target**: *2030*: - 55%
- **Target**: *2040*: - 70%

UBA (2015), own calculations

*preliminary, **application of a sectoral 40%-target
**Challenge 3: Energy efficiency**
Consequently implement the 2014 Energy Efficiency Action Plan in order to reach 2020 target

Gross electricity consumption 1990 - 2014

AGEB (2015a)  
*preliminary
Challenge 4: Power Market Design

At the current wholesale power prices, no new power plant can be financed – be it fossil or renewable

Wholesale electricity prices* 2007 - 2014

- 50%

Reasons for the decline in power prices

- **CO₂ price dropped**: CO₂ prices in the EU Emissions Trading system dropped since 2008 by around 70% due to high amount of excess certificates
- **Falling resource prices**: Coal prices decreased by a third since 2008
- **Merit-Order-effect**: Increasing power production of renewables is pushing expensive power plants out of the market
- **Decreasing demand**: Power demand is continuously falling since 2007 (-5% by 2014)
- **Excess capacities**: Large quantities of lignite and coal power plants are pushing gas power plants out of the market

EEX (2015)  * rolling annual futures
**Challenge 4: Power Market Design**

The government is planning to propose in 2016 both a new power market law and a new renewable energy law

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**Power Market 2.0**

Power market is to become highly flexible, so as to continuously let fossil power plants, renewables, demand and storage interact with each other.

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**Resource Adequacy**

Peak prices in times of scarcity are to refinance fossil backup power plants; for emergency situations, a capacity reserve is installed.

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**Renewables**

Renewables receive 20year-market premium, support level for large wind and solar power farms is to be determined by auctions as of 2017.

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**EU Emissions Trading**

CO₂ price is to be restored through ambitious EU ETS reform including enhanced market stability reserve and higher emission reduction factor.

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Schematic diagram of the governments’ envisaged power market design

- **Coordinate supply and demand**
  - **Power Market 2.0**
    (complemented by flexible markets for balancing energy)

- **Guarantee security of supply and build up of renewables**
  - **Resource Adequacy**
    - Capacity reserve (partly consisting of old lignite power plants)
  - **Renewables**
    - Auctions for large wind- and solar power plants, feed-in tariffs for small scale RES

- **Reaching climate targets**
  - **EU Emissions Trading**

Own illustration
Challenge 5: European Cooperation
Further enhance the cooperation between neighbouring countries and deepen European power market integration

Capacity mechanisms and RES support schemes 2013

Capacity mechanisms

- No capacity mechanism or discussion on an early stage
- Planned capacity mechanism
- Implemented capacity mechanism
- Implemented capacity reserve

RES support schemes

- Feed-in tariff
- Quota
- Feed-in premium
- Combination of quota and feed-in tariff
- Combination of feed-in premium and feed-in tariff

Own illustration
Is Germany a special case?
Europe: The EU 2030 targets imply a 50% renewables share in the European power sector – with high shares of wind and solar in many EU member states

Electricity generation and consumption in Central-Western Europe* in a sample week in 2030

Fraunhofer IWES (2015)

* Germany, France, Benelux, Austria, Switzerland
World: Global capacity additions in renewables have overtaken those of conventional sources (coal, gas, nuclear)

IRENA (2014)
There is wind available all over the world…

Average wind speed at 80m

3TIER (2011)
...and almost everywhere there is more sun than in Germany!

Global horizontal irradiance

3TIER (2011)
More information and studies available at our website
www.agora-energiewende.org
News on our website? Please subscribe to our Info-Update!

Agora Energiewende is a joint initiative of the Mercator Foundation and the European Climate Foundation.
Bibliography „Insights from Germany´s Energiewende“ (1)


Bibliography „Insights from Germany´s Energiewende“ (2)


Bibliography „Insights from Germany´s Energiewende“ (3)

3Tier (2011): Global Mean Wind Speed at 80m.
Calculation of LCOE
Today, wind and solar are already cost competitive to all other newly built power plants

<table>
<thead>
<tr>
<th>Power Source</th>
<th>LCOE 2015 (ct/kWh)</th>
<th>Germany</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind (onshore)</td>
<td>6 - 9</td>
<td>6 - 13</td>
<td>13 - 16</td>
</tr>
<tr>
<td>Solar PV (large scale)</td>
<td>8 - 9</td>
<td>7 - 11</td>
<td></td>
</tr>
<tr>
<td>Hard Coal</td>
<td>7 - 11</td>
<td>7 - 12</td>
<td></td>
</tr>
<tr>
<td>Gas (CCGT)</td>
<td>7 - 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hinkley Point C (UK)</td>
<td>11.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* based on varying utilization, CO₂-price and investment cost

Agora Energiewende (2015e)
Assumptions (1)

Range of full load hours

- Wind (onshore): 2,000 - 2,500
- PV (large scale): 1,000
- Hard Coal: 4,000 - 6,000
- Gas (CCGT): 2,000 - 4,000
- Nuclear: 6,000 - 7,500

Range of investment cost

- Wind (onshore): 1,250 - 1,500
- PV (large scale): 800 - 900
- Hard Coal: 1,500 - 1,600
- Gas (CCGT): 700 - 900
- Nuclear: 4,000 - 5,000

Agora Energiewende (2015e)
## Assumptions (2)

### Range of fuel- and CO₂-cost

<table>
<thead>
<tr>
<th></th>
<th>EUR/MWhₜh</th>
<th>EUR/kt CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Coal</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Gas (CCGT)</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>Nuclear</td>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Emission factors

<table>
<thead>
<tr>
<th></th>
<th>t/MWhₜh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Coal</td>
<td>336</td>
</tr>
<tr>
<td>Gas (CCGT)</td>
<td>202</td>
</tr>
</tbody>
</table>

### Efficiency of fossil power plants

<table>
<thead>
<tr>
<th></th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Coal</td>
<td>45%</td>
</tr>
<tr>
<td>Gas (CCGT)</td>
<td>59%</td>
</tr>
</tbody>
</table>

Agora Energiewende (2015e)
Assumptions (3)

- **WACC:** Wind and PV 7%, Hard Coal und Gas 12%, Nuclear 7% – 12%
- **Technical lifetime:** Wind 20 years, PV 30 years, Hard Coal 40 years, Gas 25 years, Nuclear 40 years
- **Fixed operation cost:** Wind 35 EUR/kW/a, PV 17 EUR/kW/a, Hard Coal 34 EUR/kW/a, Gas 19 EUR/kW/a, Nuclear 90 EUR/kW/a
- **Variable operation cost:** Wind 0 EUR/kW/a, PV 0 EUR/kW/a, Hard Coal 3 EUR/kW/a, Gas 2 EUR/kW/a, Nuclear 1 EUR/kW/a

Source: Agora Energiewende (2015e)
Levelized cost of electricity (LCOE) are calculated on the basis of total generation cost and total electricity generation over the technical lifetime of a plant.

Applied formulas for calculating LCOE

### Berechnung der Stromgestehungskosten je Technologie

\[ P_{\text{tech}} = \frac{\sum_{t} \text{Gesamte Kosten}}{\sum_{t} \text{Stromerzeugung}} \]

\[ P_{\text{tech}} = \left( \frac{\sum_{t} (I_t + BB_t + Z_t)}{\sum_{t} E_t} \right)
\]

\[ P_{\text{tech}} = \text{Stromerzeugungskosten je Technologie} \]

\[ \sum_{t} (\text{Werte}) = \text{Summe aller Werte über den Benutzungszeitraum} \]

\[ I_t = \text{Kapitalausgaben im Jahr} \ t \]

\[ BB_t = \text{Betriebs- und Brennstoffkosten im Jahr} \ t \]

\[ Z_t = \text{CO2-Zertifikatekosten im Jahr} \ t \]

\[ E_t = \text{Stromerzeugung im Jahr} \ t \]

### Kapitalkosten im Jahr \( t \)

\[ I_t = I_{\text{gesamt}} \times \frac{t \times (1 + i)^{BZ}}{(1 + i)^{BZ} - 1} \]

\[ I_{\text{gesamt}} = \text{Gesamte Investitionskosten für das Kraftwerk für die gesamte Benutzungsdauer, diskontiert auf} \ t = 0, [\text{in EUR/kW}] \]

\[ i = \text{Kalkulatorischer Zins für die gesamte Investition} \]

\[ BZ = \text{Benutzungszeitraum [in Jahren]} \]

IER Stuttgart (2008)
Levelized cost of electricity (LCOE) are calculated on the basis of total generation cost and total electricity generation over the technical lifetime of a plant.

Applied formulas for calculating operation-, fuel- and CO₂-cost

<table>
<thead>
<tr>
<th>Formula</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_t = M_{fix} + M_{var} + B_t$</td>
<td>Betriebs- und Brennstoffkosten im Jahr $t$</td>
</tr>
<tr>
<td>$M_{fix} = \text{Fixe Betriebskosten im Jahr } t$ (z. B. Personal, zeitabhängige Wartung), [in EUR/kW/Jahr]</td>
<td></td>
</tr>
<tr>
<td>$M_{var} = \text{Variable Betriebskosten im Jahr } t$ (z. B. nutzungsabhängige Wartung)</td>
<td></td>
</tr>
<tr>
<td>$m_{var} = \text{Variable Betriebskosten pro erzeugter Strommenge}$ [in EUR/MWh]</td>
<td></td>
</tr>
<tr>
<td>$B_t = \text{Brennstoffkosten im Jahr } t$</td>
<td></td>
</tr>
<tr>
<td>$W = \text{Wirkungsgrad der Umwandlung der Energie vom Brennstoff in Strom [in %]}$</td>
<td></td>
</tr>
<tr>
<td>$b = \text{Kosten je Einheit des eingesetzten Brennstoffs [in EUR/MWh]}$</td>
<td></td>
</tr>
</tbody>
</table>

$CO₂ – \text{Zertifikatekosten im Jahr } t$

$Z_t = \frac{E_t}{W} \times EF_{\text{Brennstoff}} \times z$

$EF_{\text{Brennstoff}} = \text{Emissionsfaktor des eingesetzten Brennstoffs [in } tCO₂/MWh_{\text{therm}}]$ |

$z = \text{Kosten für CO₂ – Emissionszertifikate [in EUR/tCO₂]}$

$Stromerzeugung im Jahr } t$

$E_t = P \times FLH$

$P = \text{Maximale Kraftwerksleistung [in MW]}$

$FLH = \text{Vollaststunden pro Jahr [in h]}$

IER Stuttgart (2008)
Bibliography „Calculation of LCOE“
