GERMANY'S ENERGY TRANSITION

A Survey of Energy Storage Policies

Adam Jones (211163250)
York University
Prepared for ENVS 6599: Energy Storage in Germany
Submitted to Prof. Mark Winfield

Adam Jones
[Email address]

Contents

Introduction

Germany has been a forerunner in the decarbonisation of energy systems as a strategy to meet greenhouse gas emissions targets. The country's Feed-In-Tariff program was emulated around the world as a successful initiative to increase the share of small-scale renewables in the energy system while supporting a domestic manufacturing sector. As of 2015, renewable energy makes up more than 30% of the German electricity supply with approximately 40GW of photovoltaic capacity and 45GW of wind turbine capacity. Balancing these intermittent and stochastic resources to provide stable base power requires the application of energy storage technologies in several different areas of the energy system.

This paper provides a description of the German energy system with a focus on the sectors which have been identified by the Federal Ministry for Economic Affairs and Energy (BMWi) as targets for further reform, an explanation of the drivers for the application of energy storage, descriptions of existing energy storage systems in Germany, and analysis of policies which have been undertaken and those which are in the development stages.

BMWi has identified the importance of four distinct areas for energy storage systems; self consumption of residential PV generation, grid-scale storage plants operating in the secondary electricity balancing markets, thermal energy storage to serve the heating and cooling requirements of residential and commercial buildings, and the use of mobile storage technologies to support electrification of the transportation sector.

Another important focus of scholarly and policy efforts regarding the future of the German energy system is sector coupling; the unification of the three parts of the energy sector. The two major components of sector coupling are electrification and power-to-gas. Electrification encourages as many energy processes as possible to be based on renewable energy. Power-to-gas describes the creation of synthetic gas through electrolysis which will then be injected into the natural gas network. The gas grid then acts as a storage medium for electricity from renewable sources because the gas can subsequently be used at cogeneration plants. Another part of this area of research is in developing power-to-X, which describes the creation of industrial inputs presently supplied by petroleum refineries.

Purpose of Research

The purpose of this research is to understand the role that energy storage plays in the current energy supply mix of Germany and identify existing and planned policies that encourage the application of energy storage to support the country's goal of an energy system based on renewable energy generation.

To achieve this goal, it was necessary to first understand the political, regulatory, and market arrangements under which the German energy system operates. Second, it was important to understand the social and political drivers for the application of energy storage. Finally, it was possible to describe the specific technical challenges that energy storage is being used to address within the energy system and the policies proposed to deal with these challenges.

Methodology

The research for this paper was conducted through a review of journal articles, media reports, government white papers, industry reports, conference presentations, and statistics related to German energy policy, Energiewende (Energy Transition), energy storage technology case studies, and German/European energy markets.

German Political Structure

Germany is a member of the European Union with a population of approximately 81 million. The political structure is a federal parliamentary republic; the parliament is comprised of two houses, the Bundestag and Bundesrat. The Bundestag is made up of 630 members, half of which are directly elected, the other half of which are selected based on proportional representation. The Bundesrat is made up of 69 state representatives with seats assigned based on state population.

Energy policy is administered by the Federal Ministry for Economic Affairs and Energy (BMWi) (aka Ministry of Economics and Technology[1]). The energy markets are overseen by Bundesnetzagentur, the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway (BNetzA).[2]

BNetzA is the agency responsible for implementation and execution of community law on energy supply and for guaranteeing "liberalisation and deregulation of the markets for energy ... via non-discriminatory network access and efficient system changes."[3] The agency is also tasked with ensuring compliance with EnWG, the Energy Act. Decisions made by BNetzA can only be challenged in court and not through political channels, for example a Ministerial decision issued by the BMWi.[4]

Several key pieces of legislation provide guidance in the energy sector including *EnWG* [Energiewirtschaftsgesetz: Energy Act][5], *GWB* [Gesetz gegen Wettbewerbsbeschränkungen: Act Against Restraints of Competition][6], *EEG* [Erneuerbare-Energien-Gesetz: Renewable Energy Sources Act][7], *KWKG* [Kraft-Warme-

---

[1] Germany. *Research for an environmentally sound, reliable and affordable energy supply: 6th Energy Research Programme of the Federal Government.* (Berlin: Federal Ministry of Economics and Technology, Public Relations, November 2011), 6.
[2] Bundesnetzagentur, *About the Bundesnetzagentur.* (Web, last updated 18 April 2013). *http://www.bundesnetzagentur.de/cln_1421/EN/General/Bundesnetzagentur/About/AboutTheBundesnetzagentur_node.html;jsessionid=6DF063ADA8A43E9321AA6995114DF9CE*.
[3] Bundesnetzagentur, *The Bundesnetzagentur's duties.* (Web, 2016). http://www.bundesnetzagentur.de/cln_1421/EN/General/Bundesnetzagentur/About/Functions/functions_node.html
[4] Bundesnetzagentur, *The Bundesnetzagentur's duties.* (Web, 2016).
[5] Bundesnetzagentur, *The Bundesnetzagentur's duties.* (Web, 2016).
[6] Joachim Rudo, *German Energy Law.* (Web: EnergyLaw.de, last updated 10 October 2013.)
[7] 50Hertz, *Annual Report 2015.* (Berlin: 50Hertz Transmission, 2015), 6.

Kop-plungsgesetz: Combined Heat and Power Act][8], *NEP 2025* [Netzentwicklungsplan: Grid Development Plan][9], *EnLAG* [Energieleitungsausbaugesetz: Energy Line Extension Act][10].

Additional electricity market regulations include the *Federal Regulation on Electricity Tariffs* (Bundestarifordnung Elektrizität – BTOElt)[11] and *Regulation on General Conditions for the Supply of Energy to General Customers* (Verordnung über Allgemeine Bedingungen für die Elektrizitätsversorgung von Tarifkunden – AVBEltV)[12]

Greenhouse Gas Emissions

In 2015, the European Environmental Agency (EEA) reports that Germany's total emissions were reduced to 891,522 Mt of CO_2e.[13] This is a decrease from 969,100 Mt in 2014, as reported by Eurostat, the statistical office of the European Union.[14]

The emissions attributable to the entire energy sector were reported as 762,338.4 Mt of CO_2e for 2014.[15] In 2015, the European Environmental Agency (EEA) reports that

---

[8] 50Hertz, *Annual Report 2015.* (Berlin: 50Hertz Transmission, 2015), 6.
[9] 50Hertz, *Annual Report 2015.* (Berlin: 50Hertz Transmission, 2015), 30.
[10] 50Hertz, *Annual Report 2015.* (Berlin: 50Hertz Transmission, 2015), 31.
[11] Joachim Rudo, *German Energy Law.* (Web: EnergyLaw.de, last updated 10 October 2013.)
[12] Joachim Rudo, *German Energy Law.* (Web: EnergyLaw.de, last updated 10 October 2013.)
[13] Spyridoula Ntemiri and John Van Aardenne, *Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015.* (Freiburg, Germany: European Environmental Agency, 23 November 2016), 99.
[14] Eurostat, "Energy," *Greenhouse Gas Emissions by Source Sector (source: EEA),* (Web: Eurostat, last update 07 December 2016). Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics
[15] Eurostat, "All sectors and indirect CO2(excluding LULUCF and memo items, including international aviation)," *Greenhouse Gas Emissions by Source Sector (source: EEA),* (Web: Eurostat, last update 07 December 2016). Retrieved from http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do.

emissions from the energy sector decreased to 757,005 Mt of CO_2e.[16] This includes the combustion of energy for power generation, manufacturing, transport and energy use in other sectors. From this it is apparent that the energy sector is the primary source of greenhouse gas emissions in Germany, making up more than 80% of total emissions (891,522 Mt of CO_2e[17]) in 2015.

This data contradicts the assumption made in a press release by AGEB, in early 2016, that reported a 1% increase in primary energy consumption. At that time, the research group "assume[d] that CO2 emissions will probably only increase slightly

compared to last year,"[18] in part because of weather and in part because of the growth in "low-emission or emission-free energy carriers".[19]

German Energy System Characteristics

In 1991 the Bundestag enacted a novel energy strategy, a feed-in-tariff for renewable energy, which began the process of replacing fossil fuel-based electricity generation with renewable energy.[20] Subsequent development of renewable energy

---

[16] Spyridoula Ntemiri and John Van Aardenne, *Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015.* (Freiburg, Germany: European Environmental Agency, 23 November 2016), 99.

[17] Spyridoula Ntemiri and John Van Aardenne, *Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015.* (Freiburg, Germany: European Environmental Agency, 23 November 2016), 99.

[18] AGEB, "2015 Exhibits Slight Increase in Energy Consumption," *Press Release No.1.* (Köln, Germany: AG Energiebilanzen, 2016.

[19] AGEB, "2015 Exhibits Slight Increase in Energy Consumption," *Press Release No.1.* (Köln, Germany: AG Energiebilanzen, 2016.

[20] Paul Hockenos, "Milestones of the German Energiewende," *Fact Sheets.* (Web: CleanEnergyWire.org, 16 June 2015).

technologies have led to an energy system that is beginning to deal with large fluctuations in supply and demand.

The German energy system is commonly categorized in three sectors; electricity, thermal, and transportation. A significant component of the energy transition is the electrification of both thermal and transportation sectors.[21] The following sections describe each component of the energy sector. For each, opportunities for storage systems are discussed and policies that support the application of energy storage technologies are described.

Sector coupling is a developing focus of the Energiewende which intends to unify the energy sector through electrification and power-to-X technologies. Sector coupling is dependent upon numerous policy changes throughout each component of the energy sector and thus goals and policies related to this process are discussed throughout.

BMWi states, "Sector coupling requires the development of infrastructure and adjustments to state-induced price components and grid charges. Electric vehicles need a charging infrastructure (cf. measure 11). Heat pumps require the installation of surface heating systems during the construction and refurbishment of buildings."[22]

---

[21] Hans-Martin Henning and Andreas Palzer. *What will the Energy Transition Cost? Pathways for Transforming the German Energy System by 2050.* (Frieburg, Germany: Fraunhofer Institute for Solar Energy Systems ISE, November 2015), 6.
[22] BMWi. *An electricity market for Germany's energy transition*. Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 82.

Electricity

In 2015, Germany's total electrical generation was 651.8TWh, with renewables making up 30.1% of the supply mix at 195.9TWh.[23] The total renewable capacity is estimated to rise to between 290 and 540GW by 2050 with a corresponding overall increase in electrical generation of 20-40%.[24] Figure 1 shows the installed power capacity of Germany by year, from 2002 through 2016. Figure 2 shows the electricity generation profile by year for the same period.

From these two graphs, it is possible to visualize the statement by Pegels and Lütkenhorst that Germany has, in effect, two electricity grids in parallel. These two systems, a "base-load focused, centralized and fossil fuel-based system…" and an "…intermittent, decentralized and renewable system," the authors state, "increasingly interact."[25]

---

[23] AGEB, *Gross electricity generation in Germany from 1990 for energy sources.* (Berlin: Arbeisgemeinschaft Energibilanzen, 02 August 2016).
[24] Hans-Martin Henning and Andreas Palzer. *What will the Energy Transition Cost? Pathways for Transforming the German Energy System by 2050.* Fraunhofer Institute for Solar Energy Systems ISE: Frieburg, Germany. November 2015, 6.
[25] Anna Pegels and Wilfried Lütkenhorst. "Is Germany's Energy Transition a Case of Successful Green Industrial Policy? Contrasting Wind and Solar PV." *Energy Policy* 74 (November 2014): 522–34.

Figure 1: Germany Installed Power Capacity 2002-2016[26]

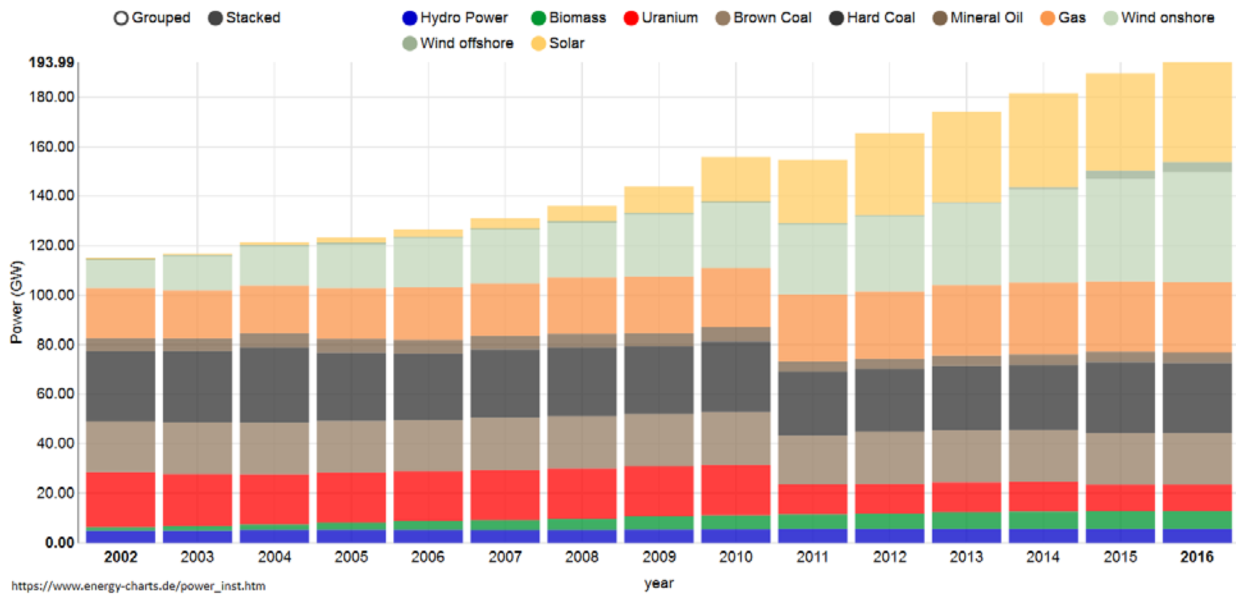
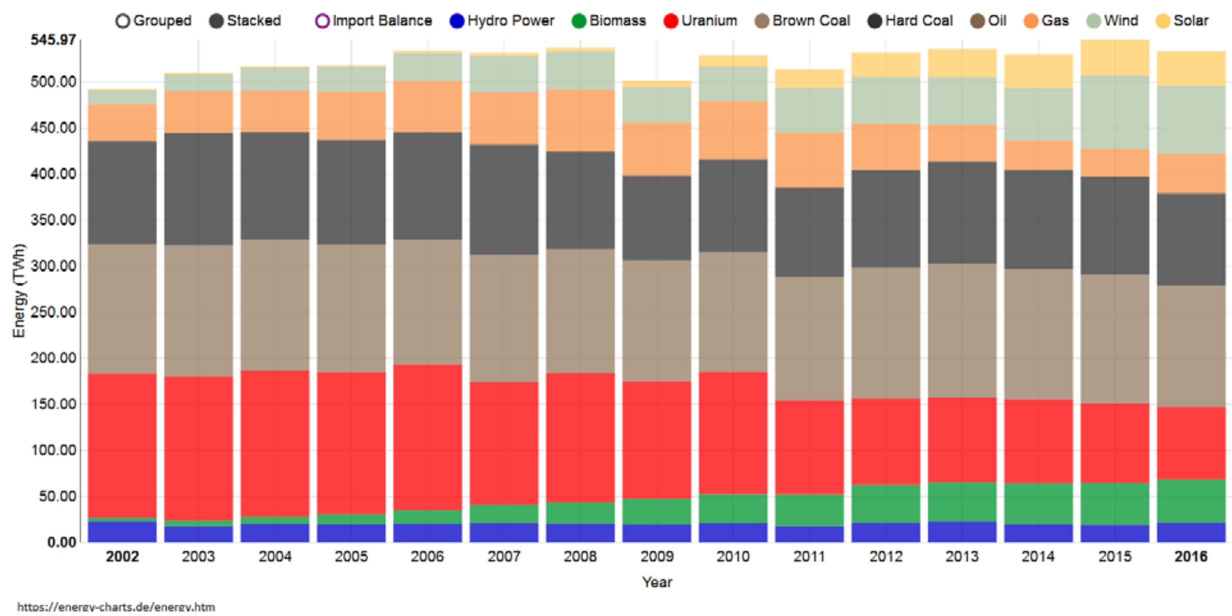


Figure 2: Annual Electricity Generation in Germany 2002-2016[27]



[26] Energy Charts, "Net installed electricity generation capacity in Germany," *Power; Installed Power in Germany.* (Web: Fraunhofer ISE, 30 November 2016). Retrieved from https://energy-charts.de/power_inst.htm

[27] Energy Charts, "Annual electricity generation in Germany," *Energy; Bar charts on electricity generation.* (Web: Fraunhofer ISE, 07 September 2016). Retrieved from https://energy-charts.de/energy.htm

Transmission System Operators

The German electrical system is served by four transmission system operators (TSOs); Tennet, 50Hertz, Amprion, and Transnet BW.[28] Figure 3 is a map of Germany showing the control areas for each TSO. The TSOs jointly manage imbalances in the transmission grid by sharing secondary control reserves through the *grid control cooperation*, which enables the optimization of the grid at a national scale through the exchange of energy consumption data every second.[29] This system is being expanded to include neighbouring countries through the *international grid control cooperation* beginning with Denmark in 2012, followed by Switzerland, Czech Republic and Belgium. Austria joined in 2014 and France in 2016.[30]

[28] Tobais Rothacher. *Geschaftschancen der Energiewende in Deutschland.* (Bern, Germany: Germany Trade & Invest, 09 March 2016), 17.
[29] RTE France. *Information on grid control cooperation and international development.* (La Defense, France: Réseau de Transport d´Électricité, 15 January 2016), 2.
[30] RTE France. *Information on grid control cooperation and international development.* (La Defense, France: Réseau de Transport d´Électricité, 15 January 2016), 1.

Figure 3: Map of German TSO Control Areas[31]

Distribution System Operators

The German electrical system is served by four major distribution system operators (DSOs), which include E.ON, Vattenfall, EnBW, and RWE.[32] The DSOs own and operate generation assets and provide retail electricity to consumers. BMWi has stated that battery storage systems will, in future, be able to replace grid expansion at the low-voltage distribution level and supplement other flexibility options (ie., demand response).[33]

---

31 Renewables International. *German Control Zones.* (Web: RenewablesInternational.com, 31 October 2016).
32 Morris, Craig and Martin Pehnt. *Energy Transition The German Energiewende.* (Berlin: Heinrich Boll Foundation, July 2016), 29.
33 BMWi. *An electricity market for Germany's energy transition*. Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 45.

Retail Market

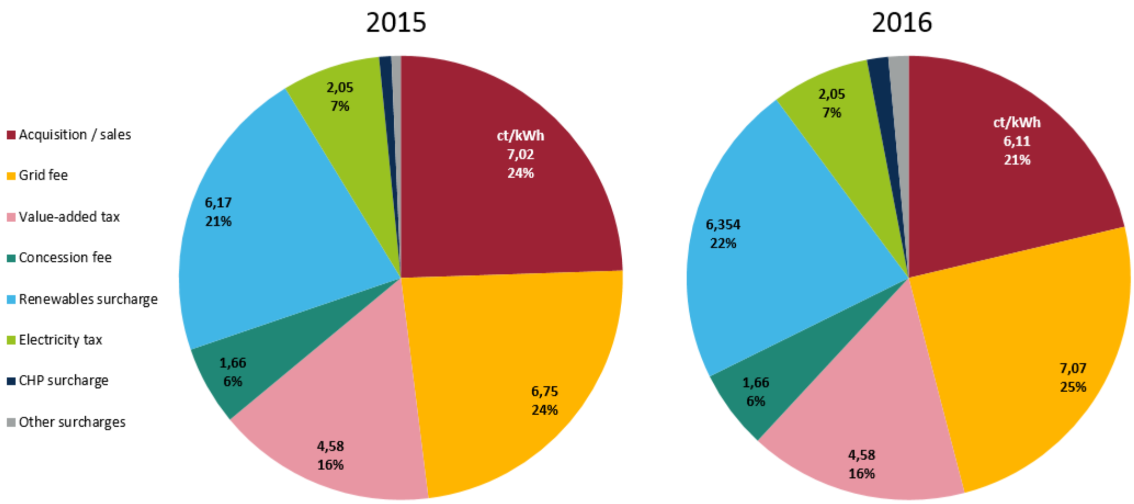
Consumers are entitled to purchase from any distributor.[34] Household electricity consumers paid an average of 28.68 c/kWh in 2015.[35] This price includes grid charges (24.6%), sales tax (16%), cost of power for suppliers (21.3%), renewable energy surcharge (22.2%), ecological tax (7.2%), levy for offshore liabilities (0.1%), surcharge for combined heat and power plants (1.5%), and a levy for grid charges to large users (1.3%).[36] Figure 4 shows the components of electricity prices in Germany for 2015 and 2016.[37]

The complex tariff structure is intended to guarantee all market operators a reasonable profit while ensuring customers are protected against excessively high prices. Several tariffs are applied with the purpose of ensuring funding for the transition away from fossil fuels.[38]

---

34 Edith Bayer, *Report on the German power system,* (Brussels, Belgium: Agora Energiewende, February 2015.), 22.
35 BDEW. *Strompreis für Haushalte {Electricity Price for Households}.* (Berlin: Bundesverband der Energie- und Wasserwirtschaft {Association of Energy and Water Industries}, January, 2016).
36 Ellen Thalman, "What German households pay for electricity." *Factsheet.* (Web: CleanEnergyWire.org, 26 July 2016).
37 Ellen Thalman, "What German households pay for electricity." *Factsheet.* (Web: CleanEnergyWire.org, 26 July 2016).
38 Joachim Rudo, *German Energy Law.* (Web: EnergyLaw.de, last updated 10 October 2013.)

Figure 4: Electricity Tariffs 2015 & 2016[39]



International Interconnections

Germany's electrical system has significant interconnections with neighbouring countries; the most significant electricity trading partners are Switzerland, Austria, Poland, Benelux (Belgium, Netherlands and Luxembourg), Czech Republic, and Denmark.

Two reputable sources, Fraunhofer ISE and AG Energiebilanzen (AGEB), report the total electricity import and export volumes for 2015 differently. Data collected directly from ENTSO-E most closely aligns with the report from AGEB; 85,328 GWh exported and 33,564 GWh imported.[40]

---

[39] Ellen Thalman, "What German households pay for electricity." *Factsheet.* (Web: CleanEnergyWire.org, 26 July 2016).
[40] ENTSO-E, *Detailed Electricity Exchange (In GWh)*. (Web:

AGEB (Working Group on Energy Balances) is a "market research group set up by several major German energy industry associations and economic research institutes,"[41] which reports annually on the energy sector in Germany. The group reports that in 2015 the total electricity flows into Germany from other countries was 33.5TWh and the total electricity flows out of Germany to other countries was 85.2TWh as shown in the chart below.[42]

Germany's International Electricity Flow as reported by AGEB[43]		
Electricity flow from foreign countries (2015): 33.5TWh		
Electricity flow into foreign countries (2015): 85.2TWh		
Country	**Export (GWh)**	**Import (GWh)**
Austria	17,775	3,482
Benelux	30,115	1,745
Czech Republic	6,267	6,103
Denmark	2,873	5,144
France	1,361	12,093
Poland	10,659	17
Sweden	166	1,935
Switzerland	16,089	3,020

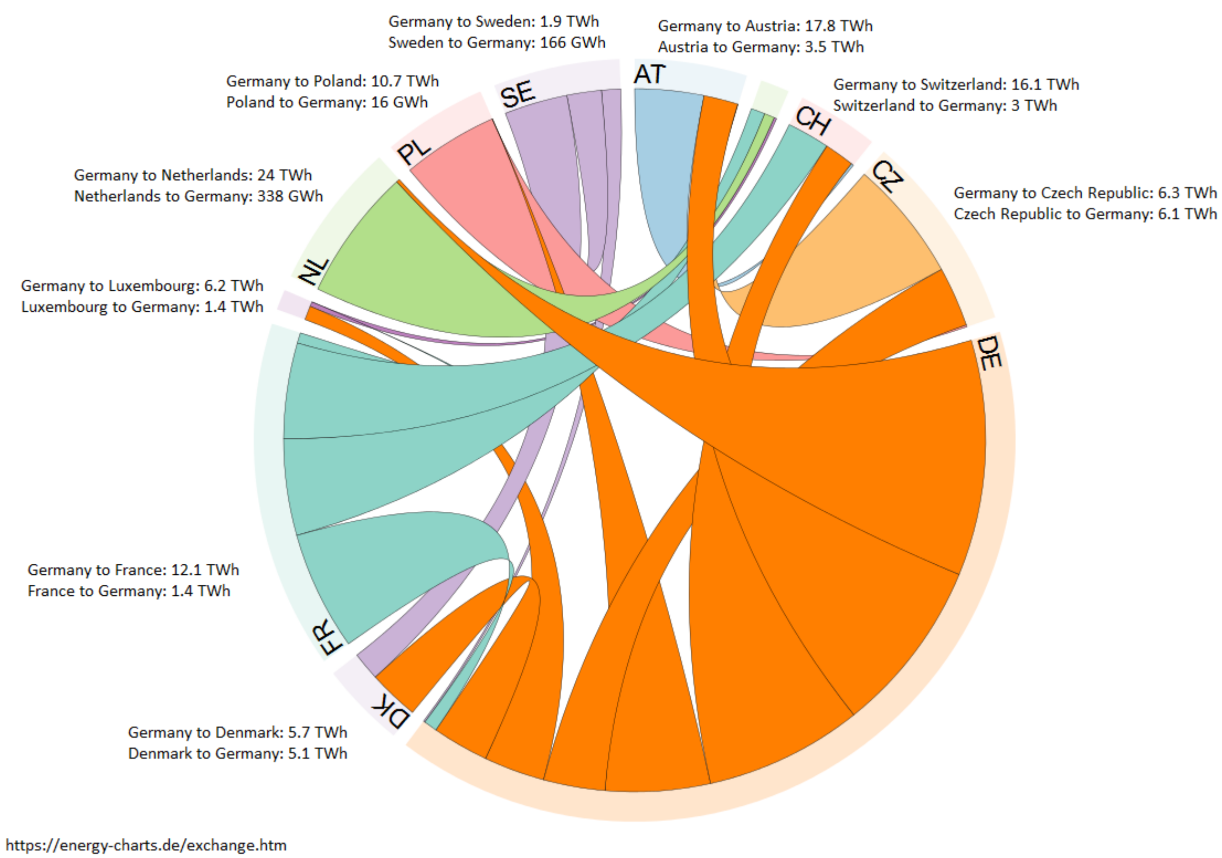
Fraunhofer ISE is "the largest solar energy research institute in Europe,"[44] and produces reports and analysis on the energy transition. Figure 5, generated from ENTSO-E data, shows the cross-border flows of electricity within the European Network of Transmission System Operators for Electricity (ENTSO-E) in 2015 with

---

[41] Clean Energy Wire, "AG Energiebilanzen e.V.," *Expert.* (Web: CleanEnergyWire.org, 16 August 2016).
[42] Hans-Joachim Ziesing, Editor. *Energy Consumption in Germany in 2015.* Arbeisgemeinschaft Energibilanzen: Berlin. March 2016, 29.
[43] Hans-Joachim Ziesing, Editor. *Energy Consumption in Germany in 2015.* Arbeisgemeinschaft Energibilanzen: Berlin. March 2016, 29, .
[44] Clean Energy Wire, "Franhofer ISE," *Expert.* (Web: CleanEnergyWire.org, 14 October 2016).

labels showing the total flows into and out of Germany. [45] This graph places the total exports at 88.2 TWh and imports at 42.04 TWh. Despite the inexact data, the graph gives a visual representation of the power flows and has been included for this purpose.

Figure 5: Fraunhofer ISE - Germany Electricity Import & Export 2015



[45] Energy Charts, *Electricity Import and Export of Germany and its Neighbours 2015.* (Web: Fraunhofer ISE, 07 September 2016). Retrieved from https://energy-charts.de/exchange_de.htm

Emissions

The EEA reports that energy industries specifically (excluding industry, transport, and other sectors) were responsible for 344,464 Mt of CO2e in 2015.[46] As stated above, the emissions attributable to the entire energy sector were reported as 757,005 Mt of CO_2e.[47]

Policy Measures

To address the emissions from electricity, the German government has enacted and changed numerous policies to encourage the development of a domestic renewable energy industry and the widespread installation of wind turbines, solar photovoltaic arrays and biomass/biogas plants. These policies include, but are not limited to, The Energy Act (*EnWG),* The Renewable Energy Sources Act (EEG), and the Combined Heat and Power Act (KWKG).[48]

Energy Storage

With more than 20 years' experience integrating intermittent solar and wind energy resources, the country has recognized the need to match supply and demand with the use of energy storage technologies at several different scales. Energy storage is

---

[46] Spyridoula Ntemiri and John Van Aardenne, *Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015.* (Freiburg, Germany: European Environmental Agency, 23 November 2016), 99.
[47] Spyridoula Ntemiri and John Van Aardenne, *Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015.* (Freiburg, Germany: European Environmental Agency, 23 November 2016), 99.
[48] 50Hertz, *Annual Report 2015.* (Berlin: 50Hertz Transmission, 2015), 6.

being promoted at various points within the energy system as solutions to several issues raised by increased shares of intermittent renewables. However, these systems are seen as future developments that require significant investment for RD&D and cost reduction.[49]

In 2011, several ministries launched the "Energy Storage Initiative," a joint program of BMWi, the Nature Conservation and Nuclear Safety (BMU) and Federal Ministry of Education and Research (BMBF).[50] This initiative had a focus on stationary storage systems and includes the development of electrical, material and thermal storage technologies.[51] Funding was directed to batteries, pressurized air storage, virtual storage and flywheels on the electrical storage branch; geological storage and hydrogen & methane conversion and reconversion on the material storage branch; and materials and design principles, solar thermal power station concepts and heating network integration on the thermal storage branch.[52] In addition, funding was given to

---

[49] BMWi, "Storage Technologies," *Storage Technology.* (Web: Federal Ministry for Economic Affairs and Energy, 2016.) Retrieved from http://www.bmwi.de/EN/Topics/Energy/Storage/storage-technology.html
[50] Germany. *Research for an environmentally sound, reliable and affordable energy supply: 6th Energy Research Programme of the Federal Government.* Berlin: Federal Ministry of Economics and Technology (BMWi) Public Relations, November, 2011, 22.
[51] Germany. *Research for an environmentally sound, reliable and affordable energy supply: 6th Energy Research Programme of the Federal Government.* Berlin: Federal Ministry of Economics and Technology (BMWi) Public Relations, November, 2011, 22.
[52] BMWi. "Energy Storage." *Energy Research and Innovation.* (Web: Federal Ministry for Economic Affairs and Energy, 2016.) Retrieved from http://www.bmwi.de/EN/Topics/Energy/energy-research-and-innovation,did=713528.html

research into overarching issues such as appropriate distribution of stationary systems, systems analysis and public acceptance of storage facilities. [53]

Germany possesses numerous large-scale storage systems including at least 3,300 MW[54] of pumped hydro storage and one of only two CAES systems in the world with a capacity of approximately 290MW.[55] Further development of CAES is also being considered."[56]

Applications

According to Germany Trade & Invest (GT&I) there are three main areas of focus for the application of energy storage; behind the meter PV consumption, power balancing, and storage of surplus energy at grid scale.[57]

Behind-the-meter PV consumption, termed *own-consumption*, is being promoted through a loan program to support the installation of small-scale battery systems with a mandate to store 50% (2013-2016) [58] to 60% (2016-2018)[59] of solar electric generation at

---

[53] BMWi. "Energy Storage." *Energy Research and Innovation.* (Web: Federal Ministry for Economic Affairs and Energy, 2016.) Retrieved from http://www.bmwi.de/EN/Topics/Energy/energy-research-and-innovation,did=713528.html
[54] Sources: E.ON and Vattenfall, see Appendix A.
[55] BBC. *Huntorf Air Storage Gas Turbine Power Plant, Publication No. D GK 90 202 E.* (Mannheim, Germany: Brown, Boveri & Cie Aktiengesellschaft, undated), 3.
[56] BMWi. "Energy Storage." *Energy Research and Innovation.* (Web: Federal Ministry for Economic Affairs and Energy, 2016.) Retrieved from http://www.bmwi.de/EN/Topics/Energy/energy-research-and-innovation,did=713528.html

[57] Tobias Rothacher. *Energy Storage in Germany: Incentives, regulatory framework and business cases.* (Berlin: Germany Trade & Invest, November 2012), 21.
[58] KfW, "KfW and Federal Environment Ministry launch programme to promote use of energy storage in solar PV installations," *Press Releases.* (Frankfurt am Main, Germany: KfW Group, 18 April 2013).
[59] KfW, "Follow-up programme for promoting battery storage systems in connection with photovoltaic installations starts on 1 March 2016," *Press Releases.* (Frankfurt am Main, Germany: KfW Group, 01 March 2016).

the source. The goal is to achieve an average *own-consumption* of 20% by 2025 and 35% by 2040.[60]

Balancing power will be increasingly important as renewables make up a larger share of the electrical system; a 50% increase over 2010 by 2025 and a 70% increase by 2040.[61]

According to GT&I the requirement in 2010 was approximately 7.4GW of balancing power, which extrapolates to about 11.1GW in 2025 and 12.58GW in 2040.[62]

Surplus energy storage is required to absorb hourly and daily fluctuations in generation output from large scale renewables, especially offshore wind, and GT&I calculated the storage demand in 2011 at 15GWh. They estimate that by 2025 the storage requirement will be 3.5TWh, increasing more than tenfold to 40TWh by 2040.

Three segments of ES focus:[63]

PV – Own Consumption	0.4% of the overall generated PV power is used for own-consumption	2025: 20% of PV generated power for own-consumption (35% in 2040)
Balancing Power	Required Balancing Power of ~7.4GW	In 2025 the demand for Balancing Power increases by 50% compared to 2010 and by 70% in 2040
Surplus Energy	Storage demand for a	Storage necessity 2025:

[60] Tobias Rothacher. *Energy Storage in Germany: Incentives, regulatory framework and business cases.* (Berlin: Germany Trade & Invest, November 2012), 21.
[61] Tobias Rothacher. *Energy Storage in Germany: Incentives, regulatory framework and business cases.* (Berlin: Germany Trade & Invest, November 2012), 21.
[62] Tobias Rothacher. *Energy Storage in Germany: Incentives, regulatory framework and business cases.* (Berlin: Germany Trade & Invest, November 2012), 21.
[63] Tobias Rothacher. *Energy Storage in Germany: Incentives, regulatory framework and business cases.* (Berlin: Germany Trade & Invest, November 2012), 21.

	surplus of 15GWh (2011)	3.5TWh 2040: 40TWh

The favoured approach for small-scale storage is direct incentives and loans, whereas grid-scale storage is being supported mainly through changes to market structure to make the technology more financially attractive. Additional support comes from research initiatives that fund technology research, development and demonstration projects.

As identified by GT&I, recent policy strategies are focused on further increasing the number of residential behind-the-meter storage systems and broad changes to the electricity market to enable increased flexibility to match and complement generation from intermittent renewable sources. The following sections describe two such strategies, the *Funding programme for decentralised battery storage systems,* and *Electricity Market 2.0.*

Residential Solar PV Own (Self) Consumption

Residential solar PV in Germany produced 38.4 TWh of electricity in 2015. To manage the impacts that this intermittent generation has on the electrical grid, the government has set targets for *own-consumption*, that is, behind the meter storage at the point of generation, at 20% by 2020 and 40% by 2040.[64] To achieve these goals a loan

[64] Tobias Rothacher. *Energy Storage in Germany: Incentives, regulatory framework and business cases.* (Berlin: Germany Trade & Invest, November 2012), 21.

program was initiated by BMWi in 2013 under which KfW Bank delivered approximately €60 million to support the installation of residential battery systems.

The program has been very successful and as of 2016, 35,000 such storage systems have been installed[65]. A second round of the program, with a budget of approximately €30 million,[66] began in 2016 and is expected to run until 2018[67] with the expectation that the number of storage systems will reach 100,000 by the time of completion.[68] The programme is also intended to "ensure that connecting PV installations to the grid will be even more beneficial to the overall system by limiting a PV installation's maximum feed-in to 50 per cent."[69]

Electricity Market 2.0

The German energy transformation is intended as a strategy to drastically reduce greenhouse gas (GHG) emissions by 80% below 1990 levels by 2050 by radically

[65] Tobias Rothacher. *Energy Storage in Germany: Incentives, regulatory framework and business cases.* (Berlin: Germany Trade & Invest, November 2012), 21.

[66] Photon, "Germany's new energy storage incentive program to start in March," *News.* (Web: Photon.info, 19 February 2016.) Retrieved from http://www.photon.info/en/news/germanys-new-energy-storage-incentive-program-start-march.

[67] KfW, "Follow-up programme for promoting battery storage systems in connection with photovoltaic installations starts on 1 March 2016," *Press Releases.* (Frankfurt am Main, Germany: KfW Group, 01 March 2016).

[68] Bernd Radowitz, "KfW halts storage subsidies for 2016 amid application rush," *Recharge, Solar.* (Web: Rechargenews.com, 25 October 2016.)

[69] BMWi, "Funding Initiative for Energy Storage," *Storage.* (Web: Federal Ministry of Economics and Technology, 19 January 2015.).

restructuring the energy system. Wherever possible the goal is to achieve a 95% reduction below 1990 levels.[70]

Organization of the German electricity market is changing to enable further penetration of renewable energy and simplify grid tariffs which has the potential to enable greater application of energy storage systems. In July 2015, BMWi published a white paper entitled *An electricity market for the energy transition* which identifies flexibility as a key component of the future energy system. This future market, which they have branded *Electricity System 2.0*,[71] is intended to permit fair competition between systems that provide flexibility to the grid, including "flexible power stations and flexible consumers, CHP, storage and European electricity trading."[72] The intention is to enable the market to determine which assets are most capable of addressing the intermittent and stochastic generation patterns of solar PV and wind turbines. A key priority in this reorganization is the removal of barriers to flexibility by making the electricity market technology-neutral.[73]

The Ministry opposed the introduction of a capacity market on the grounds that such a market would hinder the adoption of renewable technologies, and thus the goals

---

70 Hans-Martin Henning and Andreas Palzer, *What will the Energy Transition Cost? Pathways for Transforming the German Energy System by 2050.* (Frieburg, Germany: Fraunhofer Institute for Solar Energy Systems ISE, November 2015), 5.
71 BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 3.
72 BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 3.
73 BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 41-42.

of the energy transition, by favouring existing structures while exposing consumers to costs that would undermine a commitment to affordable electricity pricing.[74]

BMWi describes twenty measures to reform the electricity market to strengthen the existing market mechanisms, optimize the electricity supply, and provide supply security. Of the twenty measures, seven may have a positive influence on the application of energy storage. These seven measures are summarized below:

Measure 6: Opening up the balancing markets for new providers.[75] The balancing markets enable TSOs to balance supply and demand over short time periods on the transmission grid. BNetzA has been directed to stipulate new auction rules for balancing capacity that will permit new providers to participate in these markets. Storage units are specifically identified as potential participants in the balancing markets. This measure includes recommended adjustments to each level of balancing capacity – primary (available within 30 seconds of demand), secondary (5 minutes), and tertiary (15 minutes) – to enable new technologies to bid. These adjustments include shortening the secondary balancing blocks from 8 hour periods to 4 or 1 hour periods and the tertiary blocks from 4 hours to 1 hour, auctioning secondary balancing capacity for each calendar day (at present this is done on a weekly basis), relaxing the rule which states that operators can only use balancing energy from participants who they have

[74] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 3.
[75] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 63.

previously contracted through a capacity auction, and changing the pricing procedure from "pay-as-bid" to uniform pricing.

Measure 10: Clarifying rules for the aggregation of flexible electricity consumers.[76] Aggregators are able to combine numerous small and medium-sized electricity consumers in order to participate in demand side management through the balancing markets. At present they are only allowed to participate in the tertiary market – the minute reserve balancing groups. The Electricity Grid Access Ordinance will be revised to permit the secondary balancing markets to be opened to aggregators. This measure identifies the potential for consumers from heat and transportation sectors to participate in these markets, which suggests the potential for increased aggregation of thermal storage and electric vehicles. This will enable aggregation of small-scale battery systems of the type incentivized through the KfW loan program in order to participate in secondary and tertiary balancing markets.

Measure 12: Making it possible to market back-up power systems.[77] Germany has a significant number of emergency back-up power systems in place at facilities such as airports. Some of these systems are already active in balancing markets but most are not. These back-up systems will be included in BNetzA's new core market data register, which lists all generating assets and their characteristics, and it will be "ensured by law

[76] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 68.
[77] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 70.

that new installations will be able to play a greater role on the electricity market in future."[78] This will apply only to systems above a certain size. While this measure does not specifically describe the role that storage systems will play, the suggestion is that any asset that is capable of providing power to the grid will be enabled to do so, including behind-the-meter storage systems.

Measure 13: Gradually introducing smart meters.[79] To effectively integrate distributed supply and demand in a system where "flexible producers, flexible consumers and storage systems respond to the intermittent supply of wind and solar power,"[80] smart meters will be required. This measure details the standards for the roll-out of these meters. The installation of smart grid technologies will have a positive impact on the ability of grid operators to more precisely measure load profiles and respond more quickly to changes in demand. Though not directly stated, this could have a positive influence on the viability of storage systems as controllable assets within the grid.

Measure 14: Reducing the costs of expanding the power grid via peak shaving of renewable energy facilities.[81] This measure is intended to address the issue of covering the "last kilowatt-hour generated," or the rare output peak that extends above

---

[78] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 70.
[79] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 70-71.
[80] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 71.
[81] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 71-72.

the transmission grid capacity, and the costs of expanding the grid to accommodate this extra power. This has no direct relationship to energy storage but is a statutory requirement for TSOs to adopt a 3% annual curtailment standard in their grid planning procedures. However, in conjunction with the other measures, this may encourage owners of wind farms to install storage systems. With the knowledge that the TSO will not be required to build out the grid to accommodate the last-kilowatt-hour, an on-site storage system becomes more valuable to maximize production.

Measure 15: Evaluating minimum generation.[82] Thermal power stations are the primary providers of ancillary services which are required for system stability and therefore provide a certain level of minimum generation. This measure merely requires BNetzA to evaluate the minimum generation from thermal plants on a biannual basis starting in 2017. The purpose of this reporting however is that as new technologies, such as storage systems, are capable of providing ancillary services, the requirement for thermal power stations to operate may be lessened. The evaluations will take stock of the factors that influence minimum generation and give recommendations on how to reduce this through alternative provision of ancillary services.

Measure 16: Integrating combined heat and power generation into the electricity market.[83] Increasing the number of CHP stations and the share of electrical

[82] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 72-73.
[83] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 73-74.

generation they provide is a key component of the energy transition but many existing systems are at risk of closure because of decreases in electricity prices. Additionally, because of the increase in the share of renewables the targets set for CHP capacity, which were based on share of total electrical generation, no longer make sense because they would result in an increase in overall emissions. Changes will be made to the CHP Act to change the target from 25% of electricity generation to an equivalent share of thermal generation and the technical make-up of plants will be altered to have larger heat storage units to provide greater flexibility in operating times. Funding is to be provided in the amount of €500million to enable coal-fired plants to be retooled for natural gas.

Analysis

In laying out a plan for the development of Germany's electricity system through *Electricity System 2.0*, BMWi has described several measures that will aid the application of energy storage, in its various forms, to support the transition to an energy system based on renewable resources. This fits with the overall approach of the Energy Transition in Germany in that the Federal Government has directed its ministries and agencies to examine all relevant legislation to determine where changes can be made to encourage, incentivize, and fund technological adaptation.

A primary concern globally is the removal of market barriers to energy storage technologies. This has been addressed most effectively in this policy initiative by opening up the balancing markets to any technology, thereby enabling all technologies to compete based on the needs of the balancing market. While some[84] commentators[85] have advocated for capacity markets[86] as a method of promoting energy storage technologies by allowing access to significant sources of revenue, BMWi has stated that a major concern with this approach is the potential for existing systems to undercut renewable technologies.[87] Opening the balancing markets to new actors and placing a focus on technology neutrality will enable energy storage systems to generate revenue by selling the service of both power consumption and production to system operators.

Gas & Heating

Natural gas is considered by some to be an effective bridge fuel from more polluting fossil fuels such as coal and oil. Aside from the potential reduction in emissions from the replacement of these fuels with natural gas, German scholars and policy-makers are promoting the future use of the gas grid as a storage and transmission medium for synthetic gases created using renewable energies.

---

[84] K. Hillebrandt et al., *Pathways to deep decarbonization in Germany,* (Paris: SDSN – IDDRI, 2015), 60.
[85] Morris, Craig and Martin Pehnt. *Energy Transition The German Energiewende.* (Berlin: Heinrich Boll Foundation, July 2016), 35.
[86] IRENA, *Renewable Energy Prospects: Germany, Remap 2030 analysis.* (Abu Dhabi: International Renewable Energy Agency (IRENA), 2015).
[87] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 3.

The following section describes the extensive German gas grid, the gas market and interactions with the European market, and related emissions. Finally, policy initiatives that feature the gas network are described with particular attention to power-to-gas.

Transmission

According to Die Ferbleitungsnetzbetreiber (FNB Gas), the Association of Transmission System Operators Gas, Germany has approximately 40,000 km of natural gas transmission pipelines operated by 17 TSOs.[88] Transmission companies are required to grant access to distributors, based on the Gas Network Access Ordinance (GasNZV).[89]

The European Network of Transmission System Operators for Gas (ENTSO-G) includes 13 member companies from Germany.[90]

Gas Distribution

FNB Gas states that there are almost 700 regional gas distributors in Germany who operate downstream networks and deliver gas to retail customers.[91] End users pay different prices depending on their sector, with the main difference being price stability.

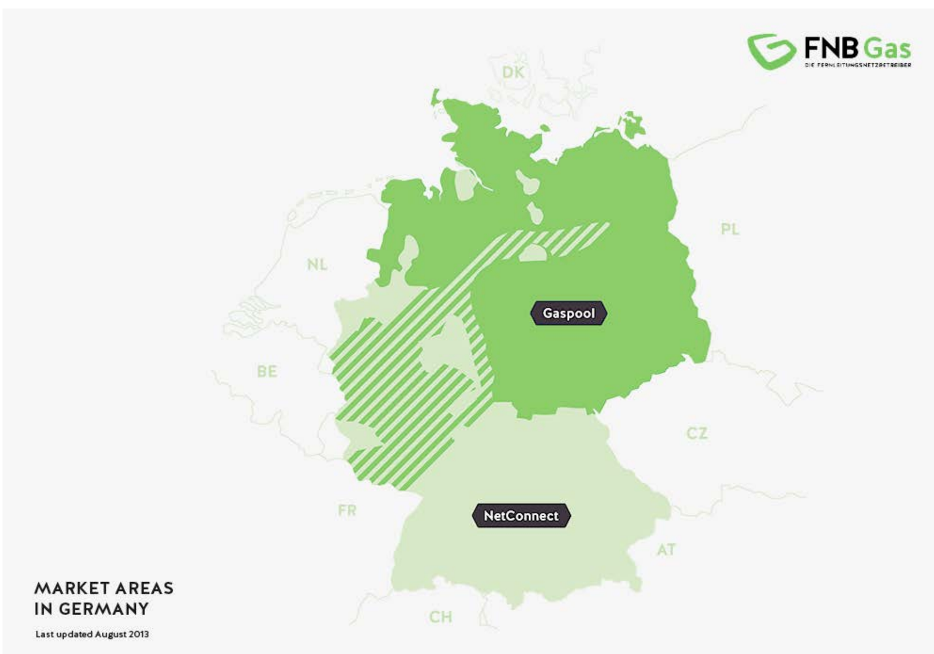
---

[88] FNB Gas, "Gas Transmission," *Transmission Systems.* (Web: FNB-Gas.de, 2016). Retrieved from http://www.fnb-gas.de/en/transmission-systems/gas-transmission/gas-transmission.html
[89] FNB Gas, "Gas Transmission," *Transmission Systems.* (Web: FNB-Gas.de, 2016). Retrieved from http://www.fnb-gas.de/en/transmission-systems/gas-transmission/gas-transmission.html
[90] ENSTO-G, "Members," *About Us.* (Web: European Network of Transmission System Operators for Gas, 2014.) Retrieved from http://www.entsog.eu/members.
[91] FNB Gas, "Gas Transmission," *Transmission Systems.* (Web: FNB-Gas.de, 2016). Retrieved from http://www.fnb-gas.de/en/transmission-systems/gas-transmission/gas-transmission.html

While household and commercial consumers pay relatively stable prices, industry and power plants are exposed to more volatile pricing.[92] BMWi notes that the country has more than 510,000 km of gas pipelines, including transmission and distribution, which "already transport twice as much energy each year as the entire electricity grid."[93]

Gas Market structures

Germany has two regional gas markets, GASPOOL and NetConnect, and both market operators are private companies that manage activities within their region under the regulation of BNetzA and BMWi.[94] Each market is made up of several TSOs and several hundred DSOs.



[92] 92 Hans-Joachim Ziesing, Editor. *Energy Consumption in Germany in 2015.* Arbeisgemeinschaft Energibilanzen: Berlin. March 2016, 20.
[93] BMWi, "Power to Gas," *Gas.* (Web: Federal Ministry for Economic Affairs and Energy, 2016.) Retrieved from http://www.bmwi.de/EN/Topics/Energy/Conventional-energy-sources/gas,did=679138.html
[94] FNB Gas, "Market Areas," *Transmission Systems.* (Web: FNB-Gas.de, 2016). Retrieved from http://www.fnb-gas.de/en/transmission-systems/market-areas/market-areas.html

Gas Consumption

AGEB reports that in 2015, Germany consumed 866 billion kWh of natural gas.[95] The consumption was split almost evenly between residential heating (359.3 billion kWh) and industrial use (352.6 billion kWh), with the remainder used in electricity generation (111.2 billion kWh).[96]

The inclusion of biogas upgraded to natural gas contributed 7.5 billion kWh to the system in 2015, with conversion losses of approximately 10% (8.4 billion kWh of biogas injected).[97]

District Heating

According to the IEA, Germany increased the share of net power production from combined heat and power (CHP) plants from 1.5% in 2002 to around 16% in 2010 with a target of 20% in 2020.[98] The Combined Heat and Power Act (KWKG 2002) is responsible for this increase and was successful enough to be renewed in 2008 and updated in 2016.

---

[95] Hans-Joachim Ziesing, Editor. *Energy Consumption in Germany in 2015.* Arbeisgemeinschaft Energibilanzen: Berlin. March 2016, 17.
[96] Hans-Joachim Ziesing, Editor. *Energy Consumption in Germany in 2015.* Arbeisgemeinschaft Energibilanzen: Berlin. March 2016, 18.
[97] Hans-Joachim Ziesing, Editor. *Energy Consumption in Germany in 2015.* Arbeisgemeinschaft Energibilanzen: Berlin. March 2016, 19.
[98] IEA., and OECD, *Energy Policies of IEA Countries: Germany 2013*. (Paris: OECD Publishing, 2013), 157.

KWKG 2016 focuses support toward CHP plants not fuelled by coal and contains funds for converting coal-fired plants to other fuel sources and, notably, cold storage.[99] Annual funding is EUR 1.5 billion with a 2020 goal of producing 110 TWh of electricity from cogeneration, increasing to 125 TWh by 2025.[100] This funding includes EUR500 million for retooling coal plants to run on natural gas. Note that these targets representing a scaling back of those of KWKG 2002/08, in which the target was 150 TWh of cogeneration.[101] As mentioned in Measure 16 of *Electricity System 2.0*, this is to ensure that CHP plants are not creating more emissions than necessary by matching cogeneration targets to existing thermal generation capacity. [102]

Due to the increase of CHP plants, German gas consumption for generating electricity is somewhat linked to heating. Similarly, the use of biogas in CHP plants makes up a small share of energy consumption, as shown in Figure 1, but reduces overall emissions by coupling thermal and electrical energy generation.

As a component of the *6th Energy Research Programme of the Federal Government*, BMWi identifies the need for increased research on using thermal storage systems to help stabilize the electricity grid and reduce the need for electrical storage. This

---

[99] Markus Gailfuss, "Germany's new CHP act explained," *Decentralized Energy.* (Web: Decentralized-Energy.com, 22 February 2016.) Retrieved from http://www.decentralized-energy.com/articles/print/volume-17/issue-1/features/germany-s-new-chp-act-explained.html
[100] Markus Gailfuss, "Germany's new CHP act explained," *Decentralized Energy.* (Web: Decentralized-Energy.com, 22 February 2016.)
[101] Heiko Huther, *District Heating in Germany, New CHP Law.* (Vancouver: IDEA evolvingENERGY Conference, 08 December 2015.), 10.
[102] BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 73-74.

requires, "significant improvements… in thermal storage technology and economic viability."[103] To this end, the Ministry has created the Market Incentive Program (MAP), "[w]ith funding exceeding €300 million a year… to expand the use of renewable energy on the heat market." [104]

Similarly, the TSO TenneT has identified the potential for "bio-mass installations with storage units [to] also provide positive balancing capacity."[105] In this scenario, district heating systems, fuelled by biomass, would be coupled with large water storage tanks (also referred to as heat storage) to enable overproduction of heat energy which the power plants could use to offset grid imbalances.

Power to Gas

Germany has directed significant attention and research funding to the development of the suite of processes known as "Power-to-X," also known as sector coupling. This term describes the use of electricity to produce other forms of energy; gas, hydrogen, methane, synthetic gas, industrial chemicals, heat, and mobility, among others. These are identified by sector; power-to-heat, power-to-mobility, and power-to-industry for example. BMWi recognizes that, "Demand for renewable electricity outside

---

[103] Germany. *Research for an environmentally sound, reliable and affordable energy supply: 6th Energy Research Programme of the Federal Government.* (Berlin: Federal Ministry of Economics and Technology (BMWi) Public Relations, November, 2011), 22.
[104] BMWi. "Market Incentive Programme (MAP)," *Energy transition in the buildings sector.* (Web: Federal Ministry for Economic Affairs and Energy, 2016). Retrieved from http://www.bmwi.de/EN/Topics/Energy/Buildings/market-incentive-programme,did=707926.html

[105] BMWi. *An electricity market for Germany's energy transition*. Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 16.

the electricity sector gives rise to new and efficient applications that convert electricity into heat and mobility." [106] The goal is to have markets drive investment in renewable energy as a way to enable private companies to determine which technology will reduce their carbon emissions most effectively.

Power-to-X is also seen as a strategy to increase energy security. "Germany spends tens of billions of euros every year on fuel imports of oil and gas."[107] Because a significant portion of Germany's energy is imported from neighbouring countries, sector coupling is a way to internalize energy production, increasing energy security by reducing dependency on oil and gas imports.

Specific policy measures to facilitate the application of these technologies have not been announced (at least in English) and it appears that, as with *Electricity System 2.0*, a series of small changes to a variety of legislation will be required. At this point research is the policy focus.

BMWi proposes to increase the use of the gas grid "as a composite system in which natural gas, biogas as well as hydrogen and synthetic methane produced from renewable energy are combined to form one huge energy source".[108] The proposal takes advantage of excess electricity from renewable sources to split water into hydrogen and

---

[106] BMWi. *An electricity market for Germany's energy transition*. Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 82.
[107] BMWi. *An electricity market for Germany's energy transition*. Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 82.
[108] BMWi, "Power to Gas," *Gas.* (Web: Federal Ministry for Economic Affairs and Energy, 2016.) Retrieved from http://www.bmwi.de/EN/Topics/Energy/Conventional-energy-sources/gas,did=679138.html

oxygen with electrolysis. The hydrogen can then be converted into methane and injected into the gas network.[109] There is no limit on the volume of methane that can be fed into the natural gas grid, though there is for hydrogen, and therefore this network capacity can be used to absorb energy that would otherwise be curtailed at the point of generation. The gas can be used for thermal electricity generation at CHP plants, used in LNG-based transport vehicles, or used for heating.[110]

German energy company E.ON opened a 2MW power-to-gas demonstration plant in 2014, the Falkenhagen Power-to-Gas pilot, that purchases electricity from wind farms during off-peak times and produces 360m^3 of hydrogen per hour which is fed into the local gas grid, ONTRAS.[111] E.ON now markets "green gas" in both Germany and Switzerland.[112]

This type of system is capable of producing hydrogen which, instead of being fed into the gas network, can be used in transport vehicles as hydrogen fuel-cells. One such system is a hydrogen-powered train which receives fuel from a dedicated electrolyzer,

---

109 BMWi, "Power to Gas," *Gas.* (Web: Federal Ministry for Economic Affairs and Energy, 2016.) Retrieved from http://www.bmwi.de/EN/Topics/Energy/Conventional-energy-sources/gas,did=679138.html

110 BMWi, "Storage Technologies," *Storage Technology.* (Web: Federal Ministry for Economic Affairs and Energy, 2016.) Retrieved from http://www.bmwi.de/EN/Topics/Energy/Storage/storage-technology.html

111 Zschocke, Andrei. *Compressed Air Energy Storage – one promising technology in the future energy storage business.* (Sevilla: Presented at IPHE Workshop, 15 November 2012), 19.

112 Hydrogenics, *Hydrogenics Investor Presentation.* (Web: Hydrogenics, 2014) Retrieved from http://www.hydrogenics.com/wp-content/uploads/investor-presentation-jan-14.pdf

built by Canadian company Hydrogenics and French train manufacturer Alstom.[113] This is described in more detail below.

Research Initiatives

A significant research initiative is the *Kopernikus Projects for the Energy Turnaround,* a component of which is entitled *Power-to-X (P2X).* The *Kopernikus Projects* are described in more detail below. The focus of *P2X* is to develop methods of producing fuels, synthetic natural gas and chemicals based on carbon dioxide in hydrocarbons and long-chained alcohols from electricity.[114] The first phase of the research project has approximately 40 partner organizations and funding of EUR30 million.[115]

Another stream of research funding is attached to a project entitled *Energy System 2050.* A topic of this project is "Hydrogen-based Energy and Resource Pathways," which is tasked with studying the role of hydrogen in a unified energy system and methods for developing interconnected infrastructure. [116] In addition the research teams are to "examine and assess option of energy and materials self-supply for industry and

---

[113] David Kennedy, "First hydrogen-powered train takes to the rails in Germany," *Clean Tech Canada.* (Web: CanadianManufacturing.com, 27 September 2016.) Retrieved from http://www.canadianmanufacturing.com/technology/first-hydrogen-powered-train-takes-rails-germany-176252/

[114] KIT, "Kopernikus," *Projects.* (Web: KIT – Karlsruhe Institute of Technology, 2016.).

[115] KIT, "Kopernikus," *Projects.* (Web: KIT – Karlsruhe Institute of Technology, 2016.).

[116] Helmoltz "Energy System 2050 – A Contribution of the Research Field Energy." http://www.helmholtz.de/en/research/energy/energie_system_2050/

households, and analyse the changes of global supply infrastructures for renewable energies and hydrogen."[117]

Transportation

Vehicles and Roads

The Kraftfahrt-Bundesamt (KBA), or Federal Motor Vehicle Office, reports the total vehicle stock including trailers at 61.5 million as of January, 2016.[118] Of this, 45.1 million are passenger vehicles.[119] The CIA World Factbook places the total roadways at 645,000 km and total railways at 43,468.3 km.[120]

Total emissions

The European Environmental Agency's annual greenhouse gas inventory states that Germany's GHG emissions from transport amount to 163.591 Mt of CO_2e.[121]

---

[117] Helmoltz "Energy System 2050 – A Contribution of the Research Field Energy." http://www.helmholtz.de/en/research/energy/energie_system_2050/

[118] KBA, "Zahlen zum 1. Januar 2016 im Überblick," *Statistik.* (Web: Kraftfahrt-Bundesamt, 01 January 2016.) Retrieved from http://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html#rechts

[119] KBA, "Zahlen zum 1. Januar 2016 im Überblick," *Statistik.* (Web: Kraftfahrt-Bundesamt, 01 January 2016.) Retrieved from http://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html#rechts

[120] CIA, "Germany," *World Factbook.* (Web: Central Intelligence Agency, 2016.) Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/gm.html

[121] Spyridoula Ntemiri and John Van Aardenne, *Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015.* (Freiburg, Germany: European Environmental Agency, 23 November 2016), 99.

Additional transport emissions come from international bunker fuel (32,227 Mt), aviation (25,506 Mt), and navigation (6,721 Mt).[122]

To address these emissions, Germany has been encouraging the adoption of electric vehicles (EVs) by incentivizing their purchase and supporting infrastructure development.

EVs & Hydrogen Vehicles

The IEA reported that in 2015, 12,080 battery electric vehicles (BEVs) and 11,110 plug-in hybrid vehicles (PHEVs) were registered. The cumulative total of all EVs in Germany, in 2015, was approximately 50,000 with a larger number of BEVs (30,560) than PHEVs (18,670).[123] The IEA places the German market share of electric cars in 2015 at 0.7%.[124] In addition, Fraunhofer ISE reports that as of 2015, there were more than one million electric bikes in Germany.[125]

For EVs to play a larger role in the storage of electricity, their numbers will have increase substantially. At present, the policy focus appears to be on battery research funding, developing infrastructure and researching control systems. *Electricity Market*

---

[122] Spyridoula Ntemiri and John Van Aardenne, *Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015.* (Freiburg, Germany: European Environmental Agency, 23 November 2016), 99.
[123] IEA, *Global EV Outlook 2016.* (Paris: OECD/IEA, 2016), 36.
[124] IEA, *Global EV Outlook 2016.* (Paris: OECD/IEA, 2016), 13.
[125] Fraunhofer ISE, *Recent Facts about Photovoltaics in Germany.* (Freiburg, Germany: Fraunhofer Institute for Solar Energy Systems ISE, 22 April 2016.), 71.

2.0 contains measures that are intended enable the aggregation of EVs (as well as other storage systems) through smart grid technology (Measure 10[126] and Measure 13[127]).

The target for EV stock in Germany for 2015 was 49,200, which appears to have been reached.[128] The 2020 EV stock target is 1.0 million, which means that EVs will need to make up 6% of all new cars sold between 2016 and 2020. The target share of EVs in total vehicle stock is 2% in 2020.[129]

The IEA report *Global EV Outlook 2016* summarizes policies supporting the adoption of EVs in several IEA countries. The report identifies the following policies in Germany; at a national level, there are circulation tax exemptions, waivers on fees (e.g. tolls, parking, ferries), tax credits (company cars), and increased fuel economic standards/regulation to encourage the purchase of an EV over an ICE (internal combustion engine) vehicle.[130]

At the subnational level, several jurisdictions have policies that encourage the use of EVs such as permitting EVs access to bus lanes, access to restricted traffic zones,[131]and free parking.[132]

---

126 BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 68.
127 BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 70-71.
128 IEA, *Global EV Outlook 2016.* (Paris: OECD/IEA, 2016), 20.
129 IEA, *Global EV Outlook 2016.* (Paris: OECD/IEA, 2016), 20.
130 IEA, *Global EV Outlook 2016.* (Paris: OECD/IEA, 2016), 13.
131 IEA, *Global EV Outlook 2016.* (Paris: OECD/IEA, 2016), 13, 20.
132 IEA, *Global EV Outlook 2016.* (Paris: OECD/IEA, 2016), 17.

Infrastructure development – the installation of charging stations – is proceeding with government support. Policies supporting EV infrastructure such as "direct or fiscal incentives at the national level…" for charging outlets seem to have led to a "…rapid increase in the stock of fast chargers in 2015."[133] At present in Germany, the number of publicly accessible slow chargers is reported by the IEA as 4,787 while the number of publicly accessible fast charging stations is 784.[134]

Research Initiatives

Batteries are presented as a long-term solution that will develop alongside the development of EV stock and infrastructure. BMWi states that, "electrochemical storage technologies (based on lithium, for example) are also considered as an option for supporting electricity grids."[135]

To support the growth of these technologies, research funding is dedicated to increasing the power and durability of batteries to hasten their capacity to replace petroleum and diesel fuels in transport and to act as storage units in the electricity grid. The BMWi website includes a section entitled "Key energy industry elements of e-mobility," which describes the two overall research goals as, first, improving reliability and performance of batteries and, second, enabling the integration of battery-powered

---

[133] IEA, *Global EV Outlook 2016.* (Paris: OECD/IEA, 2016), 28.
[134] IEA, *Global EV Outlook 2016.* (Paris: OECD/IEA, 2016), 38.
[135] Germany. *6th Energy Research Programme of the Federal Government.* (Berlin: Federal Ministry of Economics and Technology (BMWi) Public Relations, November, 2011), 22.

vehicles into the electricity grid to be optimised. This includes the use of EV batteries as storage assets on the grid.[136]

The state of Thüringen has initiated a program to support research on the utilization of EVs as demand response systems – storage for peak generation from intermittent renewables. Because EVs used as commuter vehicles spend a considerable portion of the day idle and connected to the electrical grid, the goal is to employ charge control systems in the cars to absorb electricity at specific points throughout the day. Broadening this from individual vehicles to groups of vehicles enables the creation of virtual storage units that, due to changes implemented through *Electricity Market 2.0,* are able to earn revenue on balancing markets. [137]

For heavy transport, RD&D funds are supporting liquid natural gas (LNG) and hydrogen fuel cells. Pilot projects are being supported to expand the use of LNG for maritime and inland shipping, which will enable future application of power-to-gas systems to convert renewable energy into LNG for transport.[138] Meanwhile, the development of hydrogen fuel-cell technology has reached the point of commercial adoption. Scheduled to open in December 2017, Germany's first zero emissions train, an Alstom Coradia iLint, will operate on a rail line between the cities of Buxtehude and

---

136 BMWi, "Key energy industry elements of e-mobility," *Energy and Research Innovation.* (Web: Federal Ministry of Economics and Technology, 2016.).
137 BMWi. *An electricity market for Germany's energy transition*. Berlin: Federal Ministry for Economic Affairs and Energy, July 2015.), 43.
138 BMWi, *The Energy of the Future, Fourth "Energy Transition" Monitoring Report – Summary.* (Berlin: The Federal Ministry for Economic Affairs and Energy (BMWi), November 2015), 12.

Cuxhaven on the northern coast.[139] The train has a dedicated hydrogen electrolyzer which produces enough hydrogen fuel to power the passenger train 800km at around 140 km/h. It also features on board lithium-ion batteries that are used for regenerative braking.

Battery-based trains are also being supported, EUR4 million in research funding has been awarded to Bombardier and the Technical University of Berlin for the development of lithium-ion batteries for use on railways that are not electrified.[140]

Broad Research Initiatives

The government is sponsoring numerous broad research initiatives to address climate change through several different ministries. Two such initiatives with a focus on the energy system, sector coupling and energy storage are the *Kopernikus Projects* and *Energy System 2050*, these are described below.

Kopernikus Projects

The Federal Government has committed EUR 400 million[141] to a broad research program called "Kopernikus Projects for the Energy Turnaround" which aims to develop "technological and economic solutions for the restructuring of the energy

---

[139] Feargus O'Sullivan, "Germany Has the World's First Hydrogen-Powered Passenger Train," *CityLab.* (Web: The Atlantic/CityLab, 26 September 2016.)

[140] "Germany gives Bombardier $5.9M for R&D on battery-powered train," *Canadian Manufacturing.* (Web: CanadianManufacturing.com, 20 September 2016.) Retrieved from http://www.canadianmanufacturing.com/research-and-development/germany-gives-bombardier-5-9m-rd-battery-powered-train-175858/

[141] EBF News, *Germany invest 400 million EUR in Copernicus projects.* (Web: EBFNews.com, 07 June 2016.).

system with support of science, economy and civil society."[142] Another EUR 30 million is directed to "Energy System 2050", headed by the Helmholtz Association of German Research Centres, which has a primary focus on modeling a future energy system that includes renewables, storage, and flexible consumers and producers.

The Kopernikus projects consists of four areas of research; *ENSURE* (*Neue Netzstrukturen*/New Power Grid Structures for the Energy Turnaround), *ENavi* (*Systemintegration*/System Integration and Networking of Energy Supply), *P2X* (*Power-to-X*/P2X: Investigation, Validation, and Implementation of Power-to-X Processes)[143], and *SynErgie* (Industrieprozesse/Alignment of industrial processes to fluctuating energy supply)[144]. Total funding for the Kopernikus projects is earmarked at EUR 400 million, with 30 million allotted for each section for phase one, leading to 2018. The second and third phases are planned to run until 2025 and cost EUR 280 million.[145]

ENSURE is tasked with answering the question "What is a technically, economically, and socially reasonable power grid structure and which fractions of centralized and decentralized supply does it comprise?"[146] Headed by Karlsruher

---

[142] Hydrogenious, *The Kopernikus Projects – A new research initiative for the German "Energiewende" started*. (Web: Hydrogenious.net, 03 November 2016.).
[143] KIT, "Kopernikus," *Projects.* (Web: KIT – Karlsruhe Institute of Technology, 2016.).
[144] FIM, "Prof. Buhl and Prof. Fridgen win together with the consortium Synergy a 100-million-euro project for the shaping of the energy transition," *Research Projects.* (Web: fim-rc.de, September 2016.).
[145] Walter Leitner, "Power-to-X: Entering the Energy Transition with Kopernikus," *University News.* (Web: RWTH Aachen University, 05 April 2016.).
[146] KIT, "Kopernikus," *Projects.* (Web: KIT – Karlsruhe Institute of Technology, 2016.).

Institute for Technology, ENSURE members include RWTH Aachen University, TenneT TSO, Siemens, and twenty other partners from academia and industry.[147]

ENavi is aimed at generating a complex, systems-level understanding of the energy sector and related segments such as industry in order to identify challenges that can only be met with a holistic approach.[148] This research is coordinated by the Institute for Advanced Sustainability Studies (IASS) with eight partners including the Fraunhofer Institutes for Solar and Wind energies.

SynErgie has been tasked with answering the question of how "flexible energy-intensive industrial processes as power consumers can utilize the volatile supply of renewable energies and at the same time … stabilize the future electricity market." This research is coordinated by the Technical University of Darmstadt and the University of Stuttgart with more than 40 partners.

P2X concentrates on new technological processes which have, until the advent of this program, been developed separately. The focus is those technologies that harness renewable electricity to support production of fuels, synthetic natural gas and chemicals based on carbon dioxide in hydrocarbons and long-chained alcohols.[149] This research project is headed by RWTH Aachen University with Forschungszentrum Jülich and Dechema, both non-profit research organizations, as well as 37 other firms and

---

[147] German Government. "Hier erforschen die Projektpartner die Zukunft der Energiewende {Here, the project partners are researching the future of power generation}," *Kopernikus-Proekte.* (Web: kopernikus-projekte.de). Retrieved from https://www.kopernikus-projekte.de/projekte
[148] KIT, "Kopernikus," *Projects.* (Web: KIT – Karlsruhe Institute of Technology, 2016.).
[149] KIT, "Kopernikus," *Projects.* (Web: KIT – Karlsruhe Institute of Technology, 2016.).

institutions with a range of specialties. The Ministry of Education and Research (BMBF) will fund the first phase of this research project with EUR 30 million until 2018.

Energy System 2050

Another research program focused on the energy transition is "Energy System 2050", headed by the Helmholtz Association of German Research Centres. This research consortium has five areas of focus including storage and grids, bioenergy, hydrogen-based energy and resource pathways, system level sustainability analysis, and data modeling. Under the "Storage and Grids" research topic, the focus is on modeling each aspect of the energy system to build coupled grids that include heat, electricity and gas.

The topic "Hydrogen-based Energy and Resource Pathways" is identifying ways that hydrogen can be utilized in various sectors, such as transport and industry, as a strategy to transfer renewable energies from the power sector. The final topic, "Toolbox and Data Models", attempts to develop a "fundamental understanding of the dynamic and systemic interconnections of all components and of the process and control variables". This requires accurate description of key components of a future energy system and the development of sub-models of individual components (ie, generators, storage, consumers) and energy grids (electricity, gas, district heating, etc.).[150]

[150] Henselka, Sontheimer, Sturzer, "Energy System 2050 – A Contribution of the Research Field Energy." *Research.* (Web: Helmholtz Association, 2016). Retrieved from http://www.helmholtz.de/en/research/energy/energie_system_2050/

Conclusions

Germany is a global leader in the transition to renewable energy and provides numerous examples of how a highly-industrialized economy can accommodate large shares of intermittent renewable resources without sacrificing energy security and stability. The application of energy storage is a theme that runs throughout the Energiewende from small-scale residential batteries to large-scale pumped hydro systems. Several past programs have proven successful at integrating energy storage into the existing electrical system and new initiatives are focused on increasing the number of those systems (ie., stationary and mobile batteries) while other initiatives focus on developing the infrastructure necessary to implement new technologies in the future.

Research, development and demonstration projects are supported across all sectors with the aim of increasing efficiency wherever possible and reducing the need to burn fossil fuels for energy, heating and transportation. While the effects of many of the RD&D initiatives may not be felt for several years, the government of Germany regularly evaluates and updates programs to ensure constant improvement and progress toward the goal of reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050.

Fundamentally, it is the national devotion to this goal that enables such strong action in reforming the electricity market, transportation systems and energy sector as a whole. While there are numerous policies and strategies that can be translated to other countries, the most important takeaway is that only a strong commitment to deep, systemic change can lead to significant reductions in carbon emissions.

References

50Hertz, *Annual Report 2015*. (Berlin: 50Hertz Transmission, 2015).

AGEB, "2015 Exhibits Slight Increase in Energy Consumption," *Press Release No.1*. (Köln, Germany: AG Energiebilanzen, 2016).

AGEB, *Gross electricity generation in Germany from 1990 for energy sources*. (Berlin: Arbeisgemeinschaft Energibilanzen, 02 August 2016).

BBC. *Huntorf Air Storage Gas Turbine Power Plant, Publication No. D GK 90 202 E*. (Mannheim, Germany: Brown, Boveri & Cie Aktiengesellschaft, undated). Retrieved from https://www.eon.com/content/dam/eon-content-pool/eon/company-asset-finder/asset-profiles/shared-ekk/BBC_Huntorf_engl.pdf

BDEW. *Strompreis für Haushalte {Electricity Price for Households}*. (Berlin: Bundesverband der Energie- und Wasserwirtschaft {Association of Energy and Water Industries}, January, 2016). Retrieved from https://www.bdew.de/internet.nsf/id/20160122-pi-steuern-und-abgaben-erreichen-neues-rekordhoch-de/$file/160122%20BDEW%20zum%20Strompreis%20der%20Haushalte%20Anhang.pdf.

Bernd Radowitz, "KfW halts storage subsidies for 2016 amid application rush," *Recharge, Solar*. (Web: Rechargenews.com, 25 October 2016.) Retrieved from http://www.rechargenews.com/solar/1445956/kfw-halts-storage-subsidies-for-2016-amid-application-rush.

BMWi, "Energy Storage," *Energy and Research Innovation*. (Web: Federal Ministry of Economics and Technology, 2016.) Retrieved from http://www.bmwi.de/EN/Topics/Energy/energy-research-and-innovation,did=713528.html.

BMWi, "Funding Initiative for Energy Storage," *Storage*. (Web: Federal Ministry of Economics and Technology, 19 January 2015.). Retrieved from http://www.bmwi.de/EN/Topics/Energy/Storage/funding-initiative-for-energy-storage.html

BMWi, "Key energy industry elements of e-mobility," *Energy and Research Innovation*. (Web: Federal Ministry of Economics and Technology, 2016.). Retrieved from http://www.bmwi.de/EN/Topics/Energy/energy-research-and-innovation,did=717372.html.

BMWi, *The Energy of the Future, Fourth "Energy Transition" Monitoring Report – Summary*. (Berlin: The Federal Ministry for Economic Affairs and Energy (BMWi), November 2015).

BMWi. *An electricity market for Germany's energy transition*. (Berlin: Federal Ministry for Economic Affairs and Energy, July 2015).

Bundesnetzagentur, *About the Bundesnetzagentur.* (Web, last updated 18 April 2013). http://www.bundesnetzagentur.de/cln_1421/EN/General/Bundesnetzagentur/About/AboutTheBundesnetzagentur_node.html;jsessionid=6DF063ADA8A43E9321AA6995114DF9CE.

Bundesnetzagentur, *The Bundesnetzagentur's duties.* (Web, 2016). http://www.bundesnetzagentur.de/cln_1421/EN/General/Bundesnetzagentur/About/Functions/functions_node.html

Cavallo, Alfred, "Controllable and affordable utility-scale electricity from intermittent wind resources and compressed air energy storage (CAES)," *Energy*, Volume 32, Issue 2, February 2007, Pages 120-127, ISSN 0360-5442, http://dx.doi.org/10.1016/j.energy.2006.03.018.

Clean Energy Wire, "AG Energiebilanzen e.V.," *Expert.* (Web: CleanEnergyWire.org, 16 August 2016).

E.ON. *Facts & Figures.* (Essen, Germany: E.ON, March 2015). Retrieved from http://www.eon.com/en/about-us/publications/facts-and-figures.html.

EBF News, *Germany invest 400 million EUR in Copernicus projects.* (Web: EBFNews.com, 07 June 2016.) Retrieved from http://www.ebfnews.com/2015/germany-invest-400-million-eur-in-copernicus-projects.html.

Edith Bayer, *Report on the German power system,* (Brussels, Belgium: Agora Energiewende, February 2015).

Energy Charts, *Electricity Import and Export of Germany and its Neighbours 2015.* (Web: Fraunhofer ISE, 07 September 2016) Retrieved from https://energy-charts.de/exchange.htm.

ENSTO-G, "Members," *About Us.* (Web: European Network of Transmission System Operators for Gas, 2014.) Retrieved from http://www.entsog.eu/members.

Eurostat, "Energy," *Greenhouse Gas Emissions by Source Sector (source: EEA),* (Web: Eurostat, last update 07 December 2016). Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics

Feargus O'Sullivan, "Germany Has the World's First Hydrogen-Powered Passenger Train," *CityLab.* (Web: The Atlantic/CityLab, 26 September 2016.) Retrieved from http://www.citylab.com/commute/2016/09/germany-hydrogen-passenger-train/501575/

FIM, "Prof. Buhl and Prof. Fridgen win together with the consortium Synergy a 100-million-euro project for the shaping of the energy transition," *Research Projects.* (Web: fim-rc.de, September 2016). Retrieved from http://www.fim-rc.de/Seiten/en/Research/Research_Projects/SynErgie.aspx

Fraunhofer ISE, *Recent Facts about Photovoltaics in Germany*. (Freiburg, Germany: Fraunhofer Institute for Solar Energy Systems ISE, 22 April 2016).

Gailfuss, Markus, "Germany's new CHP act explained," *Decentralized Energy*. (Web: Decentralized-Energy.com, 22 February 2016.) Retrieved from http://www.decentralized-energy.com/articles/print/volume-17/issue-1/features/germany-s-new-chp-act-explained.html

German Government. "Hier erforschen die Projektpartner die Zukunft der Energiewende {Here, the project partners are researching the future of power generation}," *Kopernikus-Proekte.* (Web: kopernikus-projekte.de). Retrieved from https://www.kopernikus-projekte.de/projekte

Germany. *Research for an environmentally sound, reliable and affordable energy supply: 6th Energy Research Programme of the Federal Government.* (Berlin: Federal Ministry of Economics and Technology (BMWi) Public Relations, November 2011), 6.

Germany. Trade & Invest. *Geschaftschancen der Energiewende in Deutschland.* Tobias Rothacher. Bern, Germany: 09 March 2016.

Henning, Hans-Martin and Andreas Palzer. *What will the Energy Transition Cost? Pathways for Transforming the German Energy System by 2050.* Frieburg, Germany: Fraunhofer Institute for Solar Energy Systems ISE, November 2015.

Henning, Hans-Martin and Andreas Palzer. *What will the Energy Transition Cost? Pathways for Transforming the German Energy System by 2050.* (Frieburg, Germany: Fraunhofer Institute for Solar Energy Systems ISE, November 2015), 6.

Henselka, Sontheimer, Sturzer, "Energy System 2050 – A Contribution of the Research Field Energy." *Research.* (Web: Helmholtz Association, 2016). Retrieved from http://www.helmholtz.de/en/research/energy/energie_system_2050/

Hillebrandt, K. et al., *Pathways to deep decarbonization in Germany*, (Paris: SDSN – IDDRI, 2015).

Hockenos, Paul, "Milestones of the German Energiewende," *Fact Sheets.* (Web: CleanEnergyWire.org, 16 June 2015). Retrieved from https://www.cleanenergywire.org/factsheets/milestones-german-energiewende.

http://forschung-energiespeicher.info/en/ - "Energy Storage systems – research for the energy transition"

Huther, Heiko, *District Heating in Germany, New CHP Law*. (Vancouver: IDEA evolvingENERGY Conference, 08 December 2015.).

Hydrogenious, *The Kopernikus Projects – A new research initiative for the German "Energiewende" started*. (Web: Hydrogenious.net, 03 November 2016). Retrieved from http://www.hydrogenious.net/en/2016/11/kopernikus-projects-new-research-initiative-german-energiewende-started/

IEA., and OECD. *Energy Policies of IEA Countries: Germany 2007*. Paris: OECD Publishing, 2007.

IEA., and OECD. *Energy Policies of IEA Countries: Germany 2013*. Paris: OECD Publishing, 2013.

IRENA, *Renewable Energy Prospects: Germany, Remap 2030 analysis.* (Abu Dhabi: International Renewable Energy Agency (IRENA), 2015).

Jentsch, Mareike, Tobias Trost, and Michael Sterner. "Optimal Use of Power-to-Gas Energy Storage Systems in an 85% Renewable Energy Scenario." *Energy Procedia* 46. (January 1, 2014), 254–61. doi:10.1016/j.egypro.2014.01.180.

KfW, "Follow-up programme for promoting battery storage systems in connection with photovoltaic installations starts on 1 March 2016," *Press Releases.* (Frankfurt am Main, Germany: KfW Group, 01 March 2016). Retrieved from https://www.kfw.de/KfW-Group/Newsroom/Aktuelles/Pressemitteilungen/Pressemitteilungen-Details_341696.html.

KfW, "KfW and Federal Environment Ministry launch programme to promote use of energy storage in solar PV installations," *Press Releases.* (Frankfurt am Main, Germany: KfW Group, 18 April 2013). Retrieved from https://www.kfw.de/KfW-Group/Newsroom/Aktuelles/Pressemitteilungen/index.jsp.

KIT, "Kopernikus," *Storage and Cross-linked Infrastructures (SCI).* (Web: KIT – Karlsruhe Institute of Technology, 2016.). Retrieved from https://www.svi.kit.edu/152.php.

Leitner, Walter, "Power-to-X: Entering the Energy Transition with Kopernikus," *University News.* (Web: RWTH Aachen University, 05 April 2016.). Retrieved from http://www.rwth-aachen.de/cms/root/Die-RWTH/Aktuell/Pressemitteilungen/April/~kvyv/Mit-Kopernikus-in-die-Energiewende/?lidx=1

Lund, Henrik and Georges Salgi, The role of compressed air energy storage (CAES) in future sustainable energy systems, Energy Conversion and Management, Volume 50, Issue 5, May 2009, Pages 1172-1179, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2009.01.032.

Morris, Craig and Martin Pehnt. *Energy Transition The German Energiewende.* (Berlin: Heinrich Boll Foundation, July 2016).

Pegels, Anna, and Wilfried Lütkenhorst. "Is Germany′s Energy Transition a Case of Successful Green Industrial Policy? Contrasting Wind and Solar PV." *Energy Policy* 74. (November 2014), 522–34. doi:10.1016/j.enpol.2014.06.031.

Photon, "Germany's new energy storage incentive program to start in March," *News.* (Web: Photon.info, 19 February 2016.) Retrieved from http://www.photon.info/en/news/germanys-new-energy-storage-incentive-program-start-march.

Renewable Energies Agency. *The German Energy Transition Press Fact Sheet.* (Berlin: Berlin Energy Transition Dialogue, March 2016).

Renewables International. *German Control Zones.* (Web: Renewables International, 31 October 2016). Retrieved from http://www.renewablesinternational.net/files/smthumbnaildata/original/4/6/4/8/2/7/Regelzonen_deutscher_bertragungsnetzbetreiber_neu.png.

Rothacher, Tobais, Germany. Trade & Invest. *Energy Storage in Germany: Incentives, regulatory framework and business cases.*

Rothacher, Tobais, *Geschaftschancen der Energiewende in Deutschland.* (Bern, Germany: Germany Trade & Invest, 09 March 2016).

RTE France. *Information on grid control cooperation and international development.* (La Defense, France: Réseau de Transport d´Électricité, 15 January 2016). Retrieved from https://www.regelleistung.net/ext/download/marktinformationenApgEn.

Rudo, Joachim, *German Energy Law.* (Web, last updated 10 October 2013.) www.energylaw.de

Thalman, Ellen, "What German households pay for electricity." (Web: CleanEnergyWire.org, 26 July 2016). Retrieved from https://www.cleanenergywire.org/factsheets/what-german-households-pay-power.

Transmission System Operators, 2013. Grid development plan 2013 (summary in English). Retrieved from http://www.netzentwicklungsplan.de/sites/default/files/

Vattenfall, "Goldisthal," *Powerplants.* (Web: Vattenfall, 2016.) Retrieved from http://powerplants.vattenfall.com/goldisthal

Vattenfall, "Hohenwarte I," *Powerplants.* (Web: Vattenfall, 2016.) Retrieved from http://powerplants.vattenfall.com/hohenwarte-i

Vattenfall, "Hohenwarte II," *Powerplants.* (Web: Vattenfall, 2016.) Retrieved from http://powerplants.vattenfall.com/hohenwarte-ii

Vattenfall, "Markersbach," *Powerplants.* (Web: Vattenfall, 2016.) Retrieved from http://powerplants.vattenfall.com/markersbach

Vattenfall, "Niederwartha," *Powerplants.* (Web: Vattenfall, 2016.) Retrieved from http://powerplants.vattenfall.com/niederwartha

Zschocke, Andrei. *Compressed Air Energy Storage – one promising technology in the future energy storage business.* (Sevilla: Presented at IPHE Workshop, 15 November 2012).

Appendix A: Large-scale Energy Storage Systems

CAES

Huntorf Power Plant. Huntorf, Niedersaschen, Germany. Owned by E.ON. Original capacity 290MW.[151] Commissioned in 1978. This system stores compressed air in a 300,000m3 reservoir between 650 and 800 meters below ground (5).[152] Charging requires 60MW for 8 hours daily at low demand periods and discharging delivers 290MW for 2 hours at peak periods (5).

Pumped Hydro

System Name	Capacity	Owner	Reservoir Volume	Commission Date	Site Location (State)
Goldisthal[153]	1,053MW	Vattenfall	12 million m^3	2003/2004	Thuringia
Makersbach[154]	1,036MW	Vattenfall	6.3 million m^3	1979	Saxony
Niederwartha[155]	119MW	Vattenfall	1,981 million m^3 591MWh	1930/59	Saxony
Hohenwarte I[156]	63MW	Vattenfall	180.86 million m^3	1942	Saalfeld-Rudolstadt

151 BBC. *Huntorf Air Storage Gas Turbine Power Plant, Publication No. D GK 90 202 E.* (Mannheim, Germany: Brown, Boveri & Cie Aktiengesellschaft, undated), 3.
152 BBC. *Huntorf Air Storage Gas Turbine Power Plant, Publication No. D GK 90 202 E.* (Mannheim, Germany: Brown, Boveri & Cie Aktiengesellschaft, undated), 5.
153 Vattenfall, "Goldisthal," *Powerplants.* (Web: Vattenfall, 2016.)
154 Vattenfall, "Markersbach," *Powerplants.* (Web: Vattenfall, 2016.)
155 Vattenfall, "Niederwartha," *Powerplants.* (Web: Vattenfall, 2016.)
156 Vattenfall, "Hohenwarte I," *Powerplants.* (Web: Vattenfall, 2016.)

			27km length of river		
Hohenwarte II[157]	317.87MW	Vattenfall	3.02 million m^3	1966	Saalfeld-Rudolstadt
Waldeck I[158]	73MW	E.ON		1933/2009	
Waldeck II[159]	480MW	E.ON		1974	
Langenprozelten[160]	164	E.ON (78%) /EnBW/Lechwerke		1976	
Happurg[161]	160	E.ON		1963/65	
PSP Oberberg[162]	7	E.ON		1960	

157 Vattenfall, "Hohenwarte II," *Powerplants.* (Web: Vattenfall, 2016.)
158 E.ON. *Facts & Figures.* (Essen, Germany: E.ON, March 2015), 37.
E.ON. *Facts & Figures.* (Essen, Germany: E.ON, March 2015), 37.
160 E.ON. *Facts & Figures.* (Essen, Germany: E.ON, March 2015), 37.
161 E.ON. *Facts & Figures.* (Essen, Germany: E.ON, March 2015), 37.
162 E.ON. *Facts & Figures.* (Essen, Germany: E.ON, March 2015), 37.