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Energy transformation in Germany. Progress, shortfalls and prospects

Statement for the
6th Roundtable of the Japanese Minister of Economy, Trade and Industry (METI) on Studying Energy Situations

Berlin,
5th February 2018

Dr. Felix Chr. Matthes

Öko-Institut e.V.

Office Berlin
Schicklerstrasse 5-7
10179 Berlin
Germany
Phone +49 30 405085-0

Office Freiburg
Merzhauser Strasse 173
79100 Freiburg i.Br.
Germany
Phone +49 761 45295-0

Office Darmstadt
Rheinstrasse 95
64295 Darmstadt
Germany
Phone +49 6151 8191-0

info@oeko.de
www.oeko.de

1. Preliminary remarks

Assessing the experiences gathered over more than 20 years of climate and energy policy with high levels of ambition in Germany is a complex exercise. Such an assessment needs, at many points, to view the broader context as well as the changes of targets, strategies and implementation mechanisms that have evolved over time. Three key overarching lessons learned from involvement in German and European policy design and discussions are:

- Effective and efficient policy outcomes depend strongly on giving equal attention to targets, strategies and implementation mechanisms.
- The suitability of implementation mechanisms depends strongly on the different phases of the transformation process. Major shortfalls with regard to the outcomes of policies or even policy failures can occur if the specific (and changing) conditions resulting from different needs and opportunities in the different phases of the energy transformation are not sufficiently reflected.
- Holistic views are needed. The transformation process needs to manage scarce resources on different levels: costs, infrastructures, natural resources like land availability or conflicting uses of underground geological structures and public acceptance. Economic perspectives are necessary but not necessarily sufficient.

The answers to the questionnaire submitted in advance to the roundtable are mostly structured along these lessons learned and are intended not only to provide narrow answers to the mostly rather specific questions but also to explain some history and the broader context. It should be noted that German energy and climate policies are at a crossroads and the new incoming government faces major challenges with regard to the traditional policy approaches. In the current legislative term German policy makers will need to explain to the domestic and international public the extent to which and why the greenhouse gas emission reduction target for 2020 (40% compared to 1990 levels) will probably be missed, what is planned to fill the gaps and what strategic, implementation and institutional measures shall be taken to avoid such policy failures in future, especially with a view to the emission reduction targets for 2030 (55%), 2040 (70%) and 2050 (80 to 95%). It should be noted that the political programme of the new German government was not yet fully known at the time this statement was written.

This statement is structured as follows. Section 2 contains the answers to the questionnaire submitted to the author in advance. Section 3 provides a compact assessment of the current status of the energy transformation in Germany, which is based on four generic strategies for deep decarbonisation targets. Section 4 lists some references for further reading and section 5 provides data and figures intended to be of use to those interested in more in-depth quantitative or structural information.

Last but not least, it should be noted that parts of the information and analysis provided in this statement is based on research funded by German government institutions. However, the positions presented in this paper do not necessarily represent official German positions.

The author would like to thank Vanessa Cook (Öko-Institut) for the language review of this paper.

2. Answers to the Questionnaire

Q1: Renewables

Germany is an "advanced renewable energy country" which introduced an FIT system ahead of Japan and has been promoting shifting of power sources to renewable energy. Japan needs to learn a lot from its experiences towards using renewable energy as the main power sources in the future. From that point of view:

Q1.1 Regarding the FIT system that was introduced to promote renewable energy, what kind of initiatives have been taken to date and what kind of initiatives may be required in the future to facilitate to be independent from relevant support schemes?

The German Feed-in Tariff (FiT) was, without a doubt, a key driver for the roll-out of power generation from renewable energy sources. It should, however, be pointed out that two other regulatory frameworks have been key for the outcome of the German strategy to phase in power generation from renewables:

- The liberalisation of the European and German energy markets, e.g. the unbundling of the networks from the generation and retail businesses as well as the freedom of customers to choose their supplier. The unbundling of networks has created a level playing field and removed barriers regarding network connection and the free customer's choice has triggered a lot of business models around green (and local) electricity.
- The permitting and licensing procedures were streamlined to the needs of renewable power generation, which at least in some fields differ significantly from the issues traditionally regulated by these procedures (land use planning, building laws etc.).

The feed-in tariff has been a successful mechanism for the first stage of phasing in a structurally new power generation option into the German system. It has:

- kick-started the power generation from renewables;
- created the non-technical infrastructure which is needed for a broader roll-out (project developers, specialised and experienced planning, engineering, quality insurance and maintenance companies, specialised and experienced economic and financial advisors, experienced financing institutions, experienced licencing institutions, experienced utilities and network operators);
- made a major contribution to "buying down" the costs for renewables, notably for solar photovoltaics, onshore wind and during last years also offshore wind;
- proved to the public and public policies that the quantities and the speed of using renewable energies for power generation go significantly beyond the levels that were assumed in the mainstream debate (in the early 1990s German utilities ran advertisements with the message that the technical potential for power generation from renewables would be 4%, 15 years later a level of 36% was reached).

The traditional feed-in tariffs also showed some downsides after the initial roll-out of renewables and after the power generation from renewables exceeded the level of 20%:

- Legislators and regulatory authorities were not able to readjust quickly enough the level of tariffs during very dynamic cost decreases (e.g. of PV) between 2009 and 2012;
- The rents of land owners and technology suppliers reached levels that were no longer acceptable after other goals of the robust and very comfortable financing arrangements under the traditional FiT scheme (e.g. establishing the non-technical infrastructures as mentioned above) had been achieved;
- The total level of costs for smaller customers reached a comparatively high level due to the high share of technology learning costs (approx. 50% of the total costs of the FiT scheme) and the strong effects of exempting significant shares of German industries from contributing to the system; and
- The system of fixed tariffs started to create regulatory inflexibilities in the market that led to negative prices in the wholesale market after renewables began to dominate the system in an increasing number of periods.

Against this background the system was fundamentally re-organized in 2014 with the shift to the obligation for direct marketing, a sliding market premium (filling the gap between a strike price and the wholesale market price) and the introduction of large-scale tenders. The latter led to major decreases of remuneration levels for new installations.

The system of direct marketing and sliding market premiums will remain the dominant feature of the support scheme for renewables in Germany in the years ahead. There is, however, an emerging debate on complements and/or alternatives to the existing system. These can be divided into the following three tracks:

- creating a framework that allows marketing of power from renewables to market segments that are willing to pay a premium for clean power (private customers, green power purchasing agreements with computing centres, sustainability-oriented businesses etc.) without taking part in any remuneration mechanism;
- internalising externalities for conventional power generation (e.g. via a significant price on carbon) that would create a competitive advantage for renewable power generators;
- advancing the remuneration system towards fixed premiums, e.g. on system-friendly capacity.

The first track has a rather limited potential and will probably only be able to cover a small share of the total market. The second track is an interesting option for the next decade when conventional power still sets the price in the wholesale electricity market (and e.g. a price on carbon would materialise in higher market prices). As soon as renewables start to dominate the market and impact largely the price in the wholesale market (at extremely low levels or zero) the revenues from the wholesale market for electricity will no longer be sufficient to pay back investments.

This is, however, not an issue for renewables exclusively but for all system elements in markets that are dominated by generation options with low operational (marginal) costs as is typically the case for zero-carbon options (renewables, nuclear). Against this background, the central question is not whether generation (or other options like storage etc.) will be in need of additional revenue streams to those from the energy only markets. Rather, the more important question is how these complementary revenue streams (closure mechanisms for the investment-payback gap) can be designed as consistent market segments, e.g. markets for firm capacity (which are gaining increasing attention in many markets) or markets for variable renewable capacities (which exist today as remuneration mechanisms for renewables).

Based on my research, supplementary market segments for today's energy only and ancillary system services markets will be needed in liberalised or restructured electricity markets, irrespective of whether renewables shall play a major role in the future system or not. If, however, the current remuneration schemes for renewables are transformed into appropriate market segments in a more broadly redesigned electricity market, it can and will play a major role for the decarbonisation of the power sector.

Q1.2	*There is criticism stating that, in Germany, construction of north-south power transmission lines to connect the northern area as the supplier of renewable energy and the southern area as the consumer of electric power is stagnating due partly to objection from local residents. Including construction of such north-south power transmission lines, what is your assessment on the current move towards re-establishing power transmission lines associated with the large-scale deployment of renewable energy? In particular, what is your assessment in regard to criticism stating that renewable energy generated in the northern area is transmitted to the southern area via other countries? Taking that into account, what kind of initiatives would be required in the future, do you think, to re-establish power transmission lines?*

The lack of infrastructure roll-out to readjust the network infrastructures to the new spatial patterns of power generation (onshore and offshore wind power mainly in the North, PV mainly in the South, coal phase-out mainly in the West and the East, nuclear phase-out mainly in the South, load centres in the West and the South) is one of the main deficits of energy transformation in Germany. This is not exclusively caused by resistance from local residents; more notable causes are a) a lack of coordination between the federal states (*Länder*), b) the fact that the legal basis of the regulatory and planning framework has changed several times and a lack of clarity in federal energy policies (how to proceed with the coal-based power generation in regions that are relevant for network congestion, how to reflect regionalisation in the different remuneration schemes, design of bidding zones). Some of these barriers have been overcome (planning and licensing procedures, better participation and planning processes, raising public acceptance by going from overhead lines to cables etc.); others have not yet been sufficiently addressed (cooperation between federal states, still a lack of compensation measures etc.).

The issue of loop-flows through Eastern European countries due to intra-German net congestions is a specific and interim issue. The situation can be summarised as follows:

- Cross-border loop-flows are not a new phenomenon in the Central European electricity system. They have been taking place on a much larger scale between France-Germany-Switzerland and France-Germany-Netherlands (Western loop-flows) for decades.

- The situation with loop-flows across Poland and the Czech Republic (Eastern loop-flows) has different facets. Firstly there was and is not only a network congestion between Northern and Southern Germany but also between Eastern Germany (the area of the former German Democratic Republic) and the other parts of the country. With Eastern Germany emerging as a major hot spot of wind generation (the East German Transmission System Operator 50Hertz manages a capacity of 55% renewables and 45% conventional plants[1]), increasing levels of unscheduled cross-border electricity flows from Germany to Poland and the Czech Republic occurred, which re-entered Germany in Bavaria.
- This firstly led to some technical problems, secondly limited the capacity for cross-border electricity trading and thirdly emerged as a topic for broader politics between the countries.
- A series of technical measures was implemented to solve the issue. After phase-shifters between Germany and Poland as well as Germany and the Czech Republic have been built, it becomes possible to control the electricity flows.[2] A new AC line between South-Eastern Germany and Southern Germany with a capacity of 5,000 MW went into operation in 2017 and significantly decreased congestion management costs and unscheduled loop-flows.[3]

There are different tracks for dealing with network congestions in the further transformation of the energy system to renewables in Germany:

- completing the North-South DC corridors (which will probably be commissioned in the mid-2020s)
- upgrading the existing AC networks,
- making use of new technologies that can increase the capacities of existing lines (temperature monitoring, high-temperature wires, hybrid AC/DC systems etc.),
- introducing real-time processes for system security assessments and procedures,
- reflecting more regionalisation elements in the market design (or remuneration mechanisms),
- introducing mechanism and procedures that allow an integrated analysis and assessment of network investments and operations, generation management, demand response, storage etc.), and
- finding more appropriate compensation measures for individuals, communities, network operators and federal states that are affected by infrastructure investments.

1 More details can be found at http://www.50hertz.com/Portals/3/Content/Dokumente/Medien/Publikationen/2016/50Hertz_Facts_Figures_E.pdf

2 More details can be found at http://www.50hertz.com/Portals/3/Content/NewsXSP/50hertz_flux/Dokumente/20170117_PM_PST_50Hertz_CEPS_EN.pdf and http://www.50hertz.com/Portals/3/Content/NewsXSP/50hertz_flux/Dokumente/20160413_Press%20Release_PSE_50Hertz_Temporary-disconnection-interconnector-Krajnik-Vierraden_FINAL.pdf

3 More details can be found at http://www.50hertz.com/Portals/3/Content/NewsXSP/50hertz_flux/Dokumente/Pressemitteilungen/20170914_Pressemitteilung_50Hertz_Inbetriebnahme_S%C3%BCdwest-Kuppelleitung_English.pdf

The key challenge for an appropriate network design, upgrade and roll-out are the necessary lead-times for the full process chain of designing, planning, permitting and building networks and providing a robust regulatory and political framework, which has sometimes been lacking in recent years. Furthermore, the debate about how to consider regionalisation in the electricity market design (network pricing versus regional price elements for investment remuneration mechanisms etc.) is still underdeveloped and without a doubt needs more (political) reflection in the years ahead. Last but not least, the necessary lead-times for infrastructure adjustments also raise the issue of how far technology-neutral approaches in energy policy can go.

Q1.3	*To accommodate power generation fluctuations of variable renewable energy (solar power, wind power) thermal power generation is required. On the other hand, deployment of battery systems may be required in the future, instead of thermal power generation, from the viewpoint of realizing carbon-free power generation by renewable energy with backup systems. Regarding that point, what are the initiatives currently in place and what is your future perspective?*

There is a broad range of analysis and increasingly robust evidence on the structures of the future energy system. Variable renewables (onshore wind, offshore wind, solar PV) will form the major pillar of the future electricity system. There is a broad range of options available to complement the variable power generation in the upcoming phases of the transformation process:

1. For the next one to two decades, matured flexibility options will play a major role:
    - network upgrades to gain from larger area portfolio effects,
    - flexible conventional power generation as long as the CO_2 emission reduction goals allow for this (future residual peak or medium load[4] will be covered by the same generation we use traditionally for peak and medium load),
    - load shifting and demand response (recent trends for modularisation – e.g. industrial processes that are traditionally rather inflexible but with modularisation can be very flexible – are extremely promising),
    - using power-to heat technologies in combination with cogeneration plants and district heating networks to use thermal networks for indirect storage,
    - short-term storage (pump-storage, centralised and decentralised batteries, e.g. combined with smart electric vehicle charging management etc.).
2. For the transformation phases beyond the next two decades: If the goal is full decarbonisation and 100% supply from renewables and depending on the long-term structure of renewable power generation (the necessary flexibility patterns will depend significantly from the mix of PV, onshore wind and offshore wind), storage technologies and sector integration will play a crucial role:

4 The term "residual load" is used for the shape of the load curve that remains after the generation of wind and solar energy is subtracted from the load curve for the final consumers.

- more powerful battery storage systems,
- power-to-chemical technologies,
- power-to-hydrogen options for seasonal storage etc. (combined with generation technologies that can use hydrogen, in a first phase hydrogen might be blended with natural gas).

All these options are subject to intense research and development and/or commercialisation activities and need to be made into matured technologies for the time horizon beyond 2030/2035.

Beyond technology (which is and will be available in plenty of options), the key challenges will be:

- how to coordinate the extremely diverse and at least partly decentralised system, and
- how to create a market framework that provides sufficiently robust pay back for the manifold elements of generation, demand respond, storage and other flexibility options.

Creating a sustainable and market-based economic basis for the future electricity system that triggers coordination based on prices signals and provides the necessary certainty and incentives for investments is key for the transformation towards a fully decarbonised system based on renewable energies. There is much debate and intense disagreement about this in Germany and Europe but there is a consensus that a future market design, creating a sustainable economic basis for the energy system needs to evolve from “learning by doing” on the one hand. On the other hand, such market design can be a major driver for the modernisation of the governance structures for energy policy and the energy sector.

Q1.4 Regarding the goal to reduce greenhouse gas emissions by 80% based on the Paris Agreement, reduction of CO_2 emissions is not currently progressing as planned in Germany due to the high reliance on coal-fired power generation (current share in power generation mix is over 40%). As in a mid- to long-term carbon-free strategy, what are the initiatives currently in place and what is your future perspective? (For example, the UK is working on reduction of greenhouse gas emissions by setting five-yearly carbon budgets. Please give us your evaluation of Germany’s initiatives in comparison with those in other countries.)

German energy and climate policy follows a target-driven approach that is built on national and sectoral targets. The outcomes with regard to these targets are mixed:

- the 2005 target for CO_2 emissions (25% compared to 1990) was not met,
- the 2008/2012 (Kyoto) target for total greenhouse gas emissions (21% compared to the Kyoto base period 1990/1995) was met,
- the 2020 target for total greenhouse gas emissions (40% compared to 1990) will be certainly not met (recent analysis projects an emission reduction of 32% to 33%).

The reasons for missing the 2020 target are manifold. The most significant shortfalls are the following:

- German policy has focused strongly on the roll-out of renewables. It was ignored that in a highly interconnected energy system the exit game for the high-carbon assets needs to be designed. Coal-fired power generation was only partly substituted by renewables and continued operation for exports to neighbouring countries. The hugely increasing net electricity exports, amounting to more than 50 billion kilowatt hours, represent a lack of emission reductions of between 4 and 6 percentage points.
- The efforts for emission reductions in the transport sector are very much lagging behind what needs to be done. An inconsistent system of energy taxation (favouring high-carbon fuels) and ineffective standards for fuel efficiency still create major barriers for emission reductions.
- Emission reductions in the building sector are lacking. In Germany this sector has long-lived capital stocks and long renovation cycles; progress in emission reduction suffers from a lack of steady efforts, financing deep renovation and triggering the crowding out of outdated building equipment.

Missing the 2020 target and the major efforts needed for meeting the 2030 and 2050 targets have created heated political debate and will probably lead to an agreement in the upcoming coalition accord of the new government to adopt a Climate Act which defines the emission reduction goals in a legally binding way. Whether this Climate Act will also include interim targets, strategies for action and/or sanctions (which I would suppose) remains to be seen.

The traditional German climate policy approach with a strong focus on targets, a deficit in strategies and significant gaps in implementation measures, certainly needs a major overhaul.

Q1.5	*(As topics derived from renewable energy,) what is your assessment on distributed power sources and potential of microgrids? What is the source of competitiveness of Stadtwerke where local governments provide community-oriented power supply services by utilizing biomass energy and cogeneration, and what are the impacts on energy policy?*

Decentralised and distributed generation and flexibility options will certainly play a significant role in the future German energy system but, due to economics and restrictions on potentials and public acceptance, will only be one part of a broader mix of decentralised and centralised options. These decentralised and distributed options range from self-generation, micro grids to more distributed approaches which combine decentralised technology options with more centralised optimisation of operations. This will and needs to be combined with more centralised options (onshore wind generators in the North, offshore wind farms in the North and the Baltic Sea). Recent projections see shares of up to 40% of the future electricity supply from more decentralised generation options. Other key elements of the future system, e.g. demand response and many storage options will be, by definition, of a more decentralised nature. Last but not least, the role of distribution networks in different configurations will play an increasing role in future.

Decentralised system elements and players can benefit from some specifics that increase their competitiveness:

- better local information,
- access to more flexibility options,
- major synergy potentials from integrating electricity, heat and gas supply,
- typically lower requirements on the return on investment,
- typically access to a broader range of financing options,
- better local acceptance and lower implementation risks,
- existing and experienced commercial and institutional structures and traditions (municipal utilities, cooperatives etc.).

There are, however, also significant downsides for more local or decentralised players:

- smaller project and technology portfolios, if any,
- lower economies of scale (which is especially significant with regard to digitalization), and
- fewer experiences or standard procedures on design, planning, permitting, tendering etc.

Creating a level playing field for decentralised players is a traditional objective declared by German energy and climate policy. Experiences gathered with integrating this issue in specific implementation mechanisms are mixed but three key lessons can be drawn:

- no or low barriers to system and market access are important;
- the specific circumstances for local and decentralised players are very diverse and flexible instruments are crucial in this regard (which is another argument for market-based approaches);
- many issues for decentral or local players concern the structure of taxation, pricing structures and network access; the more consistent, accountable, robust and simple the respective regulatory and policy framework is, the better the changes are for the players who are to play a significant role in the future energy system.

If the regulatory or market framework is changed significantly, especially when the transformation process moves from one phase to the next, all relevant provisions need to be re-assessed with a view to these criteria. The experiences gathered with the recent changes in the remuneration system for power generation from renewable energy sources in Germany underline that priority should be given to design options that allow for learning by doing as broadly as possible.

Q2: Progress of electrification in the transportation

As a trend toward electrification in the transportation sector, in recent years, the UK, France, and China have announced a policy to ban manufacturing and sale of gasoline and diesel vehicles and regulations on introduction of EV. Meanwhile, it is said that Germany has not shown its stance on future prospect of EV, due to the competitive advantage of internal-combustion engines. Regarding electrification in the transporta-

tion sector, what is your evaluation on the initiatives currently in place and what is your future perspective?

The transport sector is the most challenging sector with regard to the significant emission reduction needs in the medium and long term and the lack of progress made in recent years. Compared to the emission levels of 1990 the greenhouse gas emissions from transport have not been reduced. The limited progress on emissions from cars (approx. 15%) has been fully compensated by the increasing emissions from freight transport.

Against the background of experiences gained from other jurisdictions the breakthrough of electric (or other zero-emission vehicles) requires activities on three different levels:

- At the level of targets: A clear and strategic long-term target for the phase-in trajectory of zero-emission mobility, i.e. a clear end-date for cars with internal combustion engines (not necessarily for other vehicles for freight transportation etc. where other approaches will be necessary) does not (yet) exist for Germany. It has been, however, an extremely controversial issue in the last election campaign. From the perspective of targets a short-term target of one million electric cars was set for 2020 (which will probably be missed). The target framework of Germany's recent Climate Action Plan 2050 sets an emission reduction target for the transport sector of 40-42% below the 1990 levels.
- At the level of strategies: German mainstream policy has been reluctant to issue clear strategies for the transformation of the transport sector and still follows the paradigm of technology-neutrality which considers or declares electric mobility, fuel cells and internal combustion engines fuel by novel (zero carbon) motor fuels as equal options. The perception that the roll-out of infrastructures, consumer acceptance and maturity or market availability of technologies (e.g. with regard to novel fuels) will require – at the least for certain phases of the transformation process – clear technology-specific strategies is a minority position but is increasingly gaining attention.
- At the level of implementation mechanisms: The most effective mechanisms to drive the market penetration of electric or zero-emission vehicles are (very) high subsidies (e.g. in Norway) or market or fleet quotas (e.g. China, California), both embedded in broader policy packages (infrastructure, privileges for parking, driving etc.). In Germany such policy packages are in early stages but there has not been a breakthrough for a major take-off of electric mobility. It should, however, be noted that a broad range of measures have been taken in German to drive innovation with regard to zero-emission mobility.

A broad range of modelling and other analyses also show for Germany that the market penetration of electric vehicles is a key strategy for meeting the medium- and long-term decarbonisation objectives. The phase-in of electric vehicles in the German car market gained momentum in 2016 and 2017 (sales of all-electric and plug-in-hybrid vehicles more than doubled in 2017 compared to 2016) but is still significantly behind the needs and the official target to bring 1 million electric vehicles into the system by 2020.

As mentioned above, there is a range of support measures from the government (a subsidy programme, called “Environment Bonus” of € 600m[5], subsidies for charging infrastructures of € 300m and other measures like tax deductions for all-electric and hydrogen-fuelled cars), the federal states, municipalities, utilities (building charging infrastructures, privileges with parking management etc.).

All measures in the transport sector are subject to heated political debate in which the strong position of the German car manufacturing industry has traditionally played a key role. In addition to this, the traditional German climate policy paradigm that increasing the share of diesel cars (supported by significant deductions of excise duties for diesel) would play key role in achieving GHG emission reduction targets has not yet been revised although this paradigm is no longer based on empirical evidence.

It remains to be seen whether the political momentum on zero-emission will grow if the (partly legal) conflicts on inner-city air pollution will further escalate, the promised expansion of model portfolios of (German) car manufacturers will materialise around 2020 or the announced political efforts to make the 2030 emission reduction targets legally binding in the next two years will support processes to fill the strategy gaps and to establish more ambitious and effective implementation mechanisms.

In addition to this, a fundamental overhaul of the asymmetric system of implicit carbon pricing (excise duties and/or energy taxes are typically higher for more carbon-intensive motor fuels) and the distorting effects from tax benefits for high-consuming business cars will be measures that are needed to achieve emission reduction in the short and medium term.

Last but not least, it should be noted that stronger efforts to roll-out electric or other zero emission mobility will also require stronger efforts on the roll-out of power generation from renewable energy sources.

[5] This program shall trigger sales of 300,000 electric vehicles. It provides a subsidy of € 2,000 for zero-emission vehicles (all-electric or fuel-cell) and € 1,500 for a plug-in hybrid vehicle with emissions of less than 50 g CO_2/km. The subsidy can only be paid if the vehicle was purchased and registered after 18th May 2016, the list price of a car does not exceed € 60,000 (net) and the car manufacturer offers a price deduction at the same level as the state subsidy. The number of applications under the program amounts to 50,963 per 31st January 2018, of which were 29,465 for all-electric vehicles, 21,482 for plug-in hybrid vehicles and 16 for vehicles with fuel cell engines. For more details see http://www.bafa.de/DE/Energie/Energieeffizienz/Elektromobilitaet/elektromobilitaet_node.html

3. The status of energy transformation in Germany at a glance

The current status of the German energy transformation ("Energiewende") might be characterized on different levels as follows:

1. Paving the way for the clean options:
   - ☺ roll-out of power generation from renewable energy sources and cogeneration (more needs to be done in both cases, target model for market design is lacking)
   - 😐/☹ energy efficiency (clear strategy on "efficiency first", some progress but major gaps for deep renovation of buildings and systematic exploration of energy efficiency potentials)
   - 😐 zero- and low-emission heating systems (no consistent pricing and taxation system, inconsistent carbon-pricing)
   - ☹ zero-emission vehicles (no consistent phase-in strategy)
2. Designing the exit game for the non-sustainable assets:
   - ☺ nuclear phase-out (clear schedule, on track)
   - ☹ coal phase-out (nor strategy for forced shut-downs, no consistent carbon pricing)
   - 😐 outdated heating equipment (no accountable strategy, no consistent pricing and taxation system, inconsistent carbon-pricing)
   - 😐 modal split in the transport sector
   - ☹ high emitting vehicles (no clear phase-out strategy, no consistent carbon-pricing)
3. Triggering the necessary infrastructure adjustments with sufficient lead times:
   - ☹ electricity transmission systems (urgent need for action, some progress but still major delays)
   - ☹ electricity distribution systems (urgent need for action, some progress but still major delays, network pricing approaches need modernisation)
   - 😐 heat networks (short- to mid-term need for action, conceptual framework still under discussion)
   - 😐 gas networks (mid-term need for action, conceptual framework still under discussion)
4. Making innovation work in time:
   - ☺ a broad range of innovation in the pipeline in many fields in all sectors
   - 😐 attribution of innovation to the different phases of the energy transformation

This overview underlines that the German approach on energy transformation has achieved some progress but needs significantly broader, more consistent and deeper efforts. Among other strategies, carbon pricing will need to play a more prominent role as well as strengthened European and international efforts.

4. References and further reading

Cludius, J.; Hermann, H.; Matthes Felix Chr. & Graichen, V. (2014). The merit order effect of wind and photovoltaic electricity generation in Germany 2008–2016: Estimation and distributional implications. Energy Economics, 44, pp. 302–313.

Fabra, N.; Matthes, F. C.; Newberry, D.; Colombier, M.; Mathieu, M. & Rüdinger, A. (2015). The energy transition in Europe: initial lessons from Germany, the UK and France: Towards a low carbon European power sector. Centre on Regulation in Europe (CERRE). Brussels. Available at http://www.cerre.eu/sites/cerre/files/151006_CERREStudy_EnergyTransition_Final.pdf, last accessed on 14 Dec 2017.

Matthes, F. (2016). The History of the Energiewende: The Origin and Adoption of an Energy Policy Concept for the Future, and Its Prospects. In: Newinger, C., Geyer, C. & S. Kellberg (Eds.): energie.wenden. Energy Transitions as Chance and Challenge in Our Time. Munich: oekom, pp. 16–19.

Matthes, F. (2017a). Energy transition in Germany: a case study on a policy-driven structural change of the energy system. Evolut Inst Econ Rev, (14), pp. 141–169.

Matthes, F. C. (2017b). The current electricity costs of energy-intensive industries in Germany. Berlin. Available at https://www.oeko.de/publikationen/p-details/the-current-electricity-costs-of-energy-intensive-industries-in-germany-2/, last accessed on 17 Dec 2017.

Matthes, F. C. (2017c). Costs of new electricity generation plants. Berlin. Available at https://www.oeko.de/fileadmin/oekodoc/Memo_Power_generation_costs_2017.pdf, last accessed on 14 Dec 2017.

Matthes, F. C. (2017d). Decarbonizing Germany's Power Sector: Ending Coal with A Carbon Floor Price? (Notes de l'Ifri). Paris. Available at https://www.ifri.org/sites/default/files/atoms/files/matthes_decarbonizing_germany_power_sector_2017.pdf, last accessed on 19 Dec 2017.

Matthes, F. C. & Hermann, H. (2013). Contribution to the consultation on generation adequacy, capacity mechanisms and the internal market in electricity. Berlin. Available at https://www.oeko.de/oekodoc/1638/2013-008-en.pdf, last accessed on 14 Dec 2017.

Öko-Institut (2010). Greenhouse gas emissions trading and complementary policies: Developing a smart mix for ambitious climate policies. Report commissioned by German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Berlin. Available at https://www.oeko.de/oekodoc/1068/2010-114-en.pdf, last accessed on 19 Dec 2017.

Öko-Institut (2013). Impacts of Germany's nuclear phase-out on electricity imports and exports. Report commissioned by Greenpeace Germany. Berlin. Available at https://www.oeko.de/oekodoc/1635/2013-005-en.pdf, last accessed on 14 Dec 2017.

Öko-Institut (2017). Renewables versus fossil fuels – comparing the costs of electricity systems: Electricity system designs for 2050 – An analysis of renewable and conventional power systems in Germany. Report commissioned by Agora Energiewende. Berlin. Available at https://www.oeko.de/publikationen/p-details/renewables-versus-fossil-fuels-comparing-the-costs-of-electricity-systems/, last accessed on 14 Dec 2017.

Öko-Institut; LBD Beratungsgesellschaft & Raue LLP (2012). Focused capacity markets: A new market design for the transition to a new energy system. A study for

WWF Germany. Berlin. Available at https://www.oeko.de/oekodoc/1631/2012-004-en.pdf, last accessed on 14 Dec 2017.

Öko-Institut & Prognos (2017). Germany's electric future: Coal phase-out 2035. Report for WWF Germany. Berlin. Available at https://www.oeko.de/fileadmin/oekodoc/Coal-phase-out-2035.pdf, last accessed on 14 Dec 2017.

Öko-Institut; Prognos & Dr. Ziesing (2009). Blueprint Germany - A strategy for a climate safe 2050. Report for WWF Germany. Basel/Berlin. Available at https://www.oeko.de/publikationen/p-details/blueprint-germany-2/, last accessed on 14 Dec 2017.

5. Supplementary graphs and tables

Figure 1: German climate & energy programs

Climate policy in Germany: A long history of climate policy programs – with increasing ambition

Year	Climate Policy Program	Key targets (all programs also contain policies & measures)
1990 (June)	First Climate Policy Program (West Germany)	CO_2 emission reduction of 25% by 2005 (compared to 1987)
1990 (November)	First Climate Policy Program (incl. E Germany)	CO_2 emission reduction of 25% by 2005 (compared to 1987) and more in East Germany
1992	Second Climate Policy Program	CO_2 emission reduction of 25-30% by 2005 (compared to 1987)
1994	Third Climate Policy Program	CO_2 emission reduction of 25-30% by 2005 (compared to 1987)
1997	Fourth Climate Policy Program	CO_2 emission reduction of 25% by 2005 (compared to 1990)
2000	National (Fifth) Climate Policy Program	CO_2 emission reduction of 25% by 2005 (compared to 1990) GHG-6 emission reduction of 21% by 2008/2012 (compared to 1990
2007	Integrated Energy and Climate Program	GHG-6 emission reduction of 30% (unconditional) or 40% (conditional) by 2020 (compared to 1990)
2010	Energy Concept	GHG-6 emission reduction of 40% by 2020 (unconditional), 55% (2030), 70% (2040), 80-95% (2050, compared to 1990), energy efficiency & RES targets
2011	Energy Concept and Nuclear Phase-out	GHG-6 emission reduction of 40% by 2020, 55% (2030), 70% (2040), 80-95% (2050), all unconditional and compared to 1990, nuclear phase-out by 2022
2014	Climate Policy Action Plan	Gap closure for GHG-6 emission reduction of 40% by 2020 (compared to 1990)
2016	Climate Policy Plan 2050	Approval of 2020, 2030, 2040 and 2050 targets, sectoral targets for 2030

Memo items:
1. Germany's National Climate Change Programs are embedded in European Union Climate Policy Programs/Packages (2000, 2005, 2008, 2011, 2014, 2017/2018)
2. All German and EU programs were based/accompanied on/by extensive modelling exercises (modelling cycles of typically 2 years)

Matthes 2017

Source: Compilation by the author

Figure 2: (Current) German energy and climate policy targets

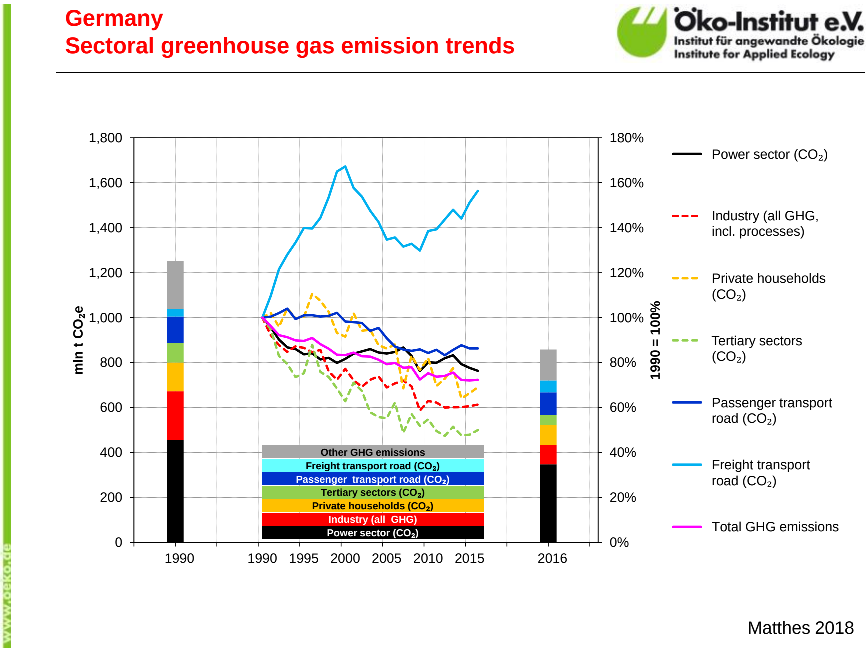
A comprehensive target framework
Creating sectoral accountability is crucial

	Targets as of …												
	2010	2016	2016	2016	2016	2016	2010	2014	2010	2010	2010	2010	2011
	Greenhouse gas emissions						Renewable energies		Energy efficiecy				Nuclear energy
	Total	Energy sector	Buildings	Transport	Industry	Agri-culture	Gross final energy	Power gene-ration	Primary energy	Space heating	Final energy ransport	electricity con-sumption	
2011													-41%
2015													-47%
2017													-54%
2019													-60%
2020	-40%						18%	35%	-20%	-20%	-10%	-10%	
2021													-80%
2022													-100%
2025								40 to 45%					
2030	-55%	-61 to -62%	-66 to -67%	-40 to -42%	-49 to -51%	-31 to -34%	30%						
2035								55 to 60%					
2040	-70%						45%	65%					
2050	-80 to -95%						60%	80%	-50%	-80%	-40%	-25%	
Base year	1990	1990	1990	1990	1990	1990	-	-	2008	2008	2005	2008	(2010)

BReg 2010, 2011, 2016, BT 2014

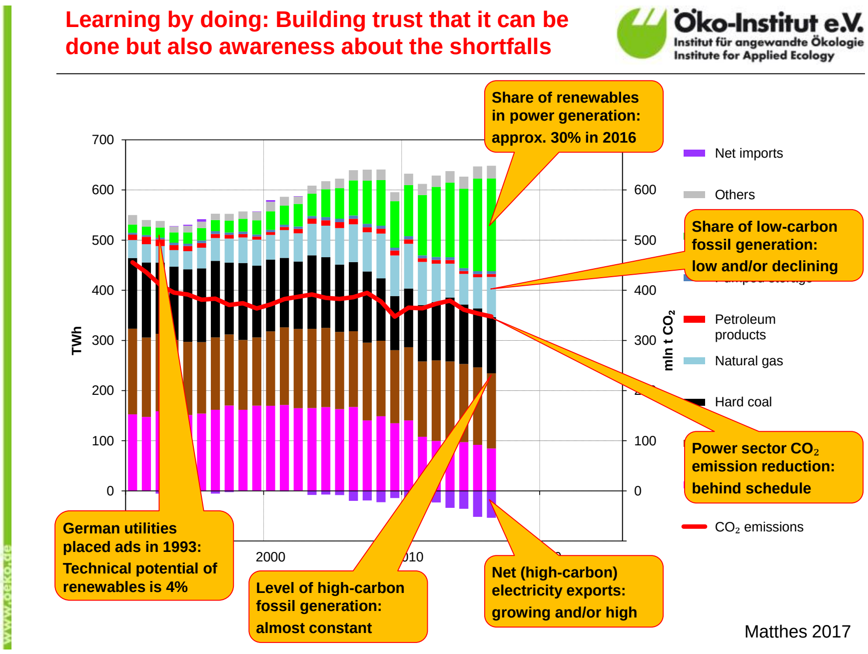
Source: Compilation by the author

Figure 3: Greenhouse gas emission trends for Germany



Source: Compilation by the author

Figure 4: Power generation in Germany

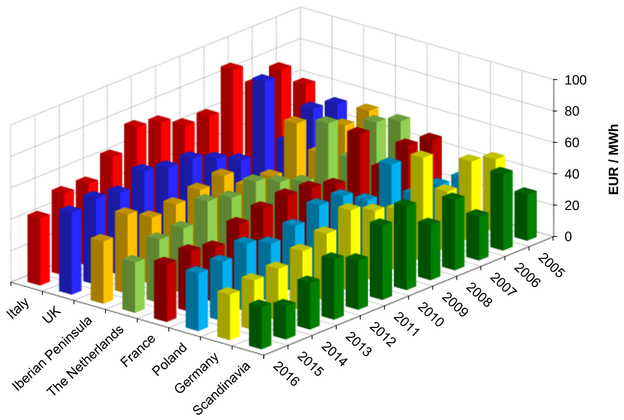


Source: Compilation by the author

Figure 5: Wholesale electricity prices in Europe

Europe
Wholesale electricity prices in different countries

Öko-Institut e.V. Institut für angewandte Ökologie Institute for Applied Ecology



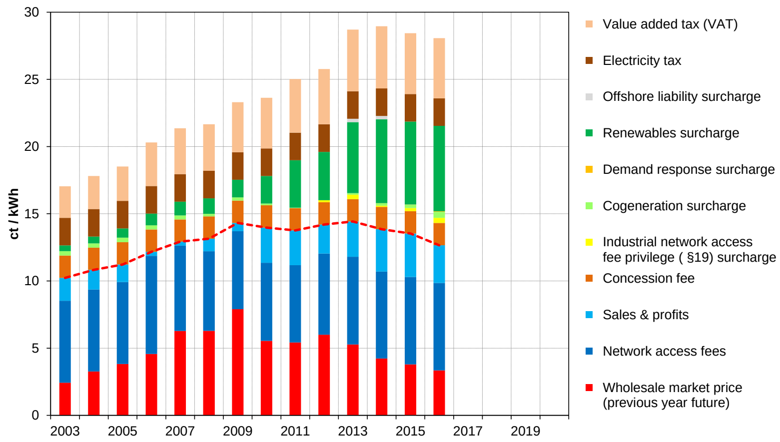
EEX, EPEX, APX, NordPool, TGE, OMIE, IPEX, Öko-Institut

Source: Compilation by the author

Figure 6: Residential power prices in Germany

Germany
Retail electricity prices for private households

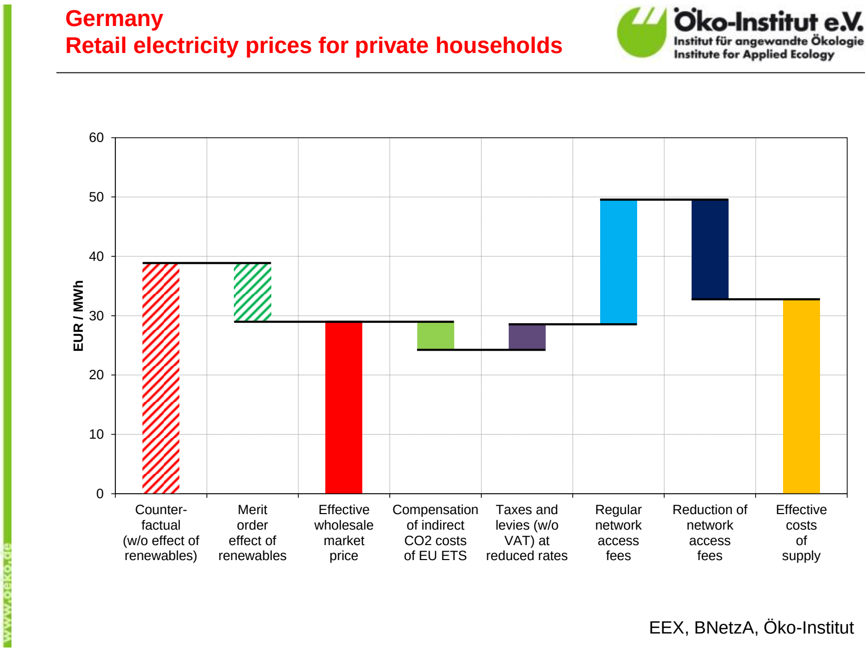
Öko-Institut e.V. Institut für angewandte Ökologie Institute for Applied Ecology



BDEW, EEX, BNetzA, Öko-Institut

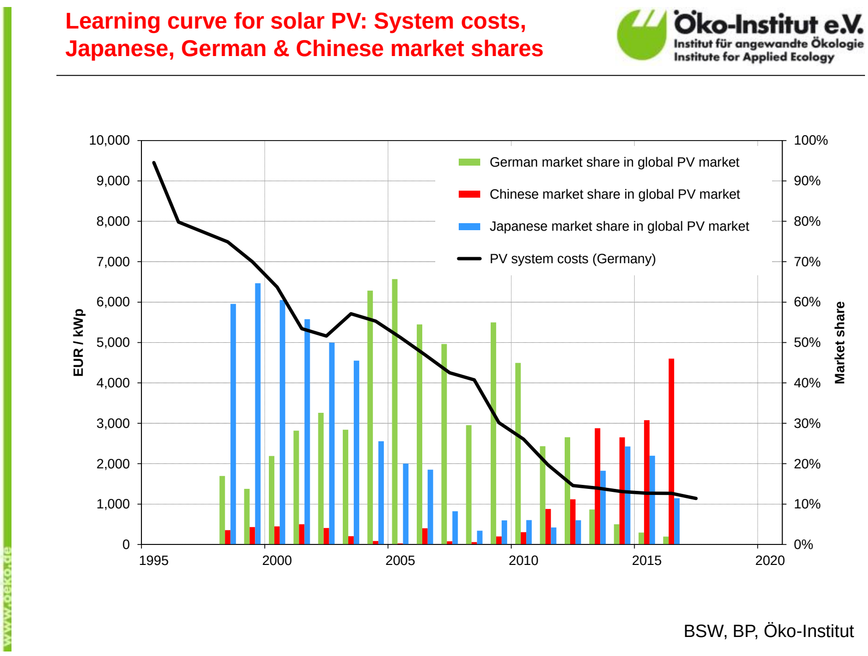
Source: Compilation by the author

Figure 7: Electricity prices for German electricity-intensive industries



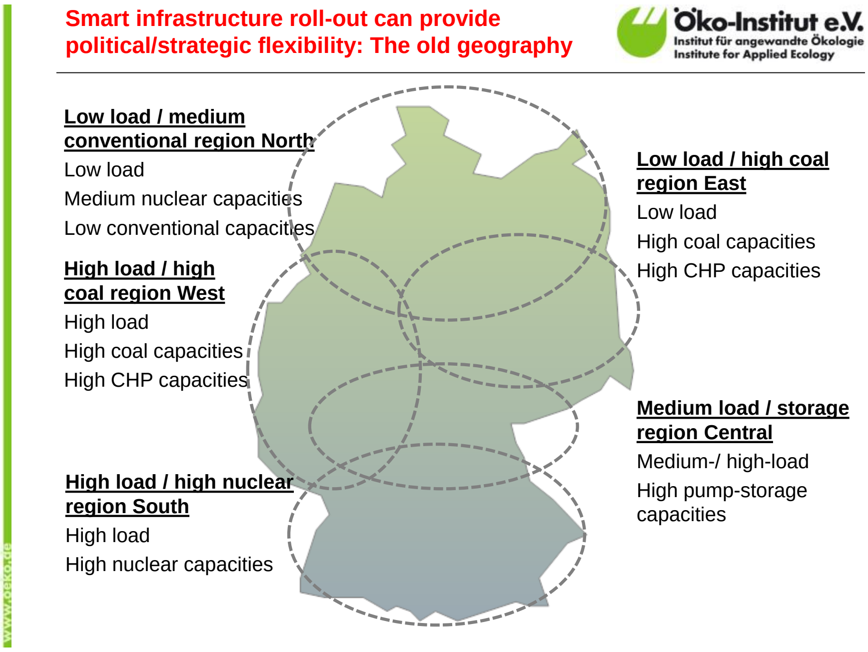
Source: Compilation by the author

Figure 8: The role of the Japanese, German and Chinese PV market for global cost decreases



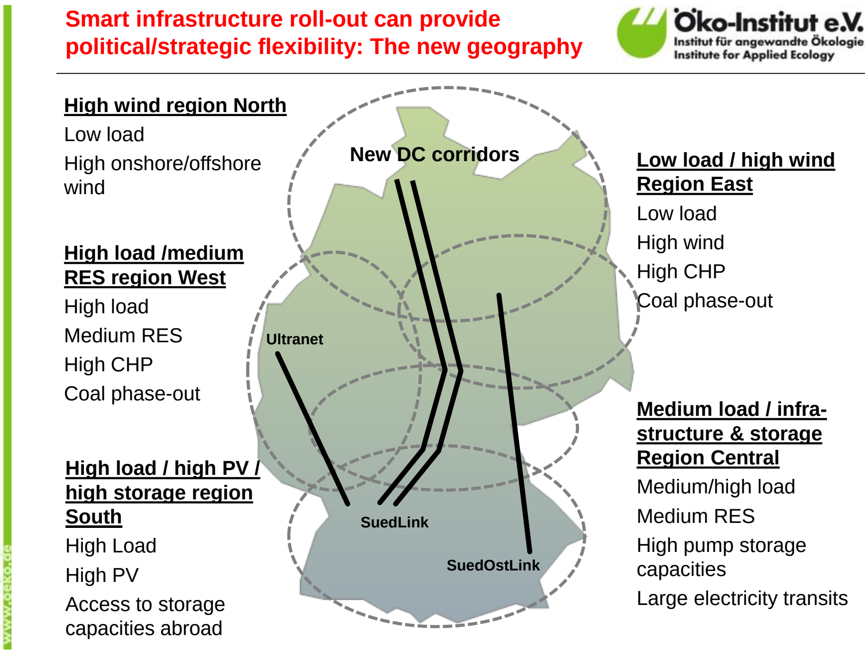
Source: Compilation by the author

Figure 9: The old spatial patterns of the German power system



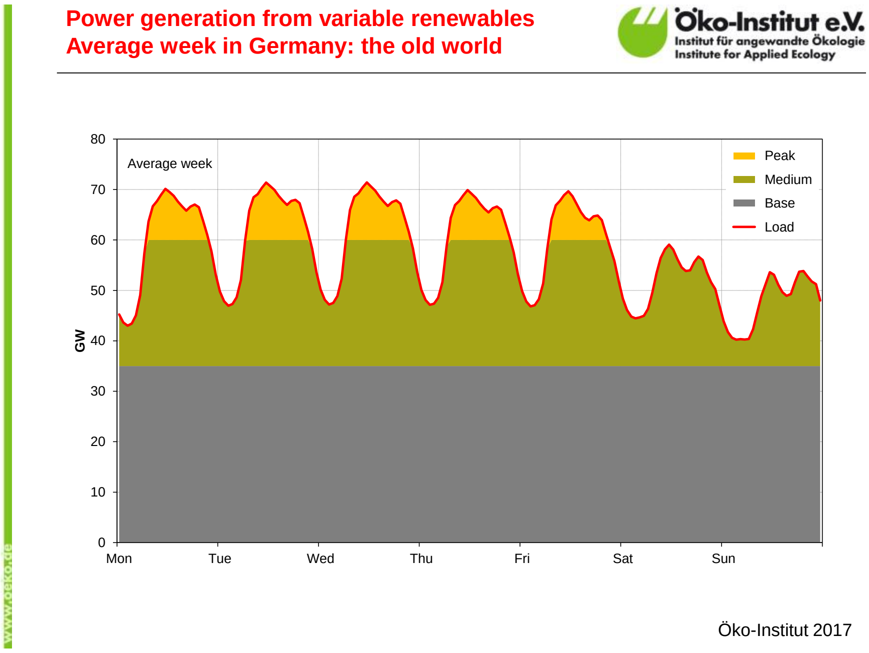
Source: Compilation by the author

Figure 10: The new spatial patterns of the German power system



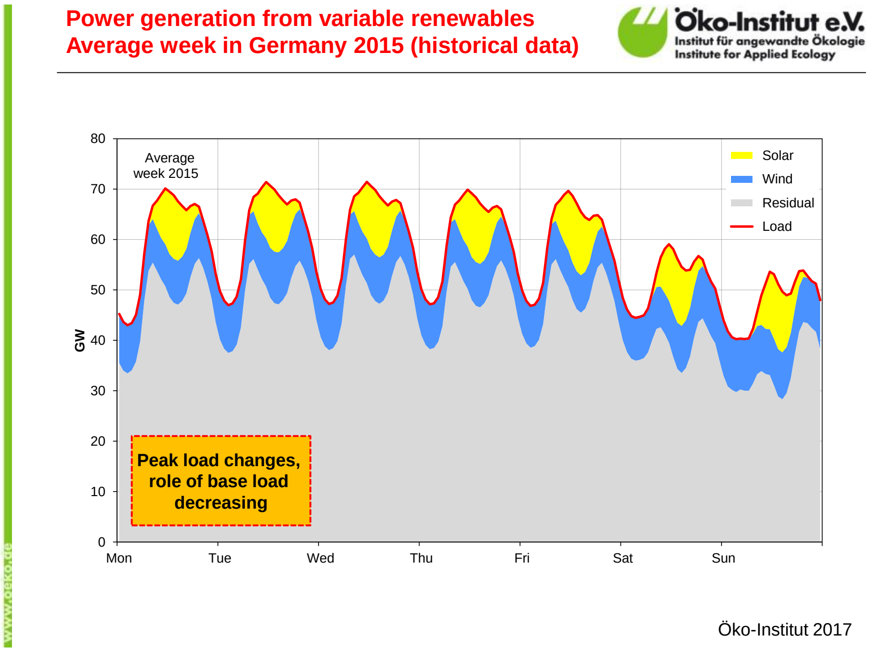
Source: Compilation by the author

Figure 11: Structural change in Germany's power market (1)



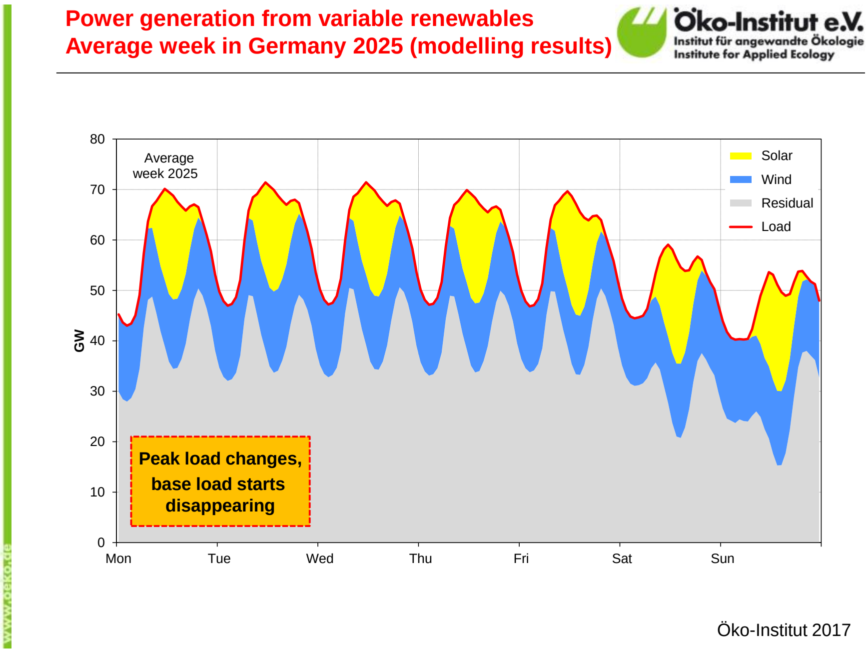
Source: Compilation by the author

Figure 12: Structural change in Germany's power market (2)



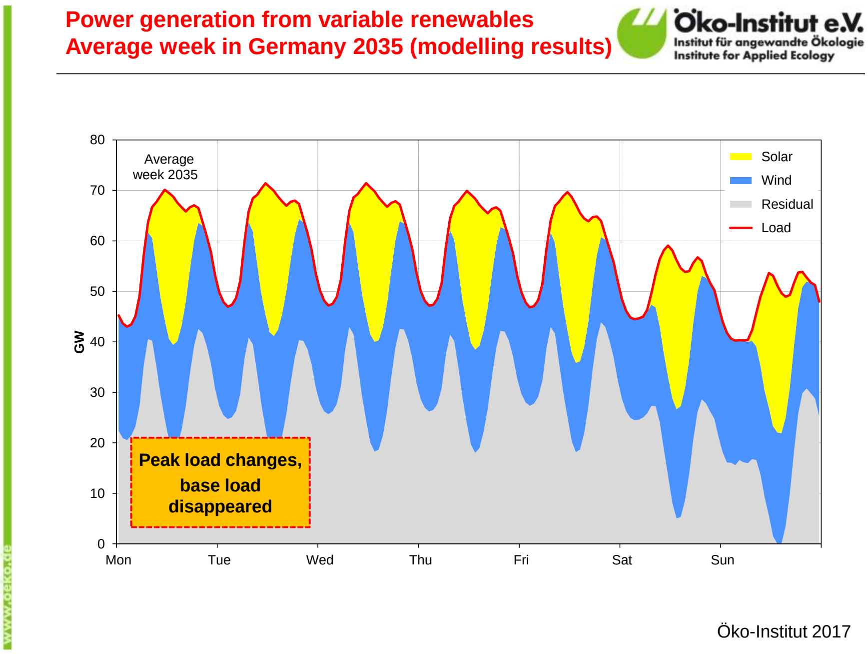
Source: Compilation by the author

Figure 13: Structural change in Germany's power market (3)



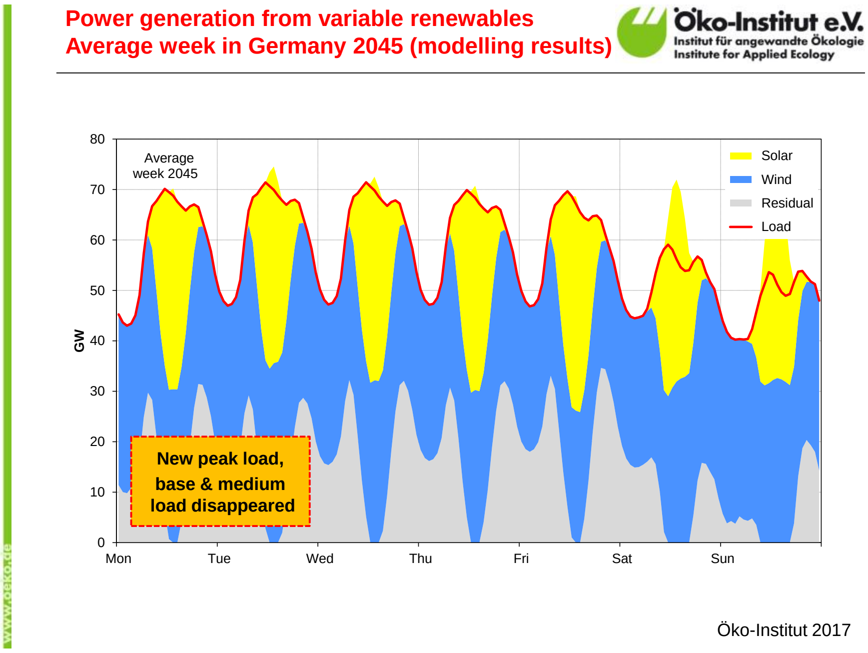
Source: Compilation by the author

Figure 14: Structural change in Germany's power market (4)



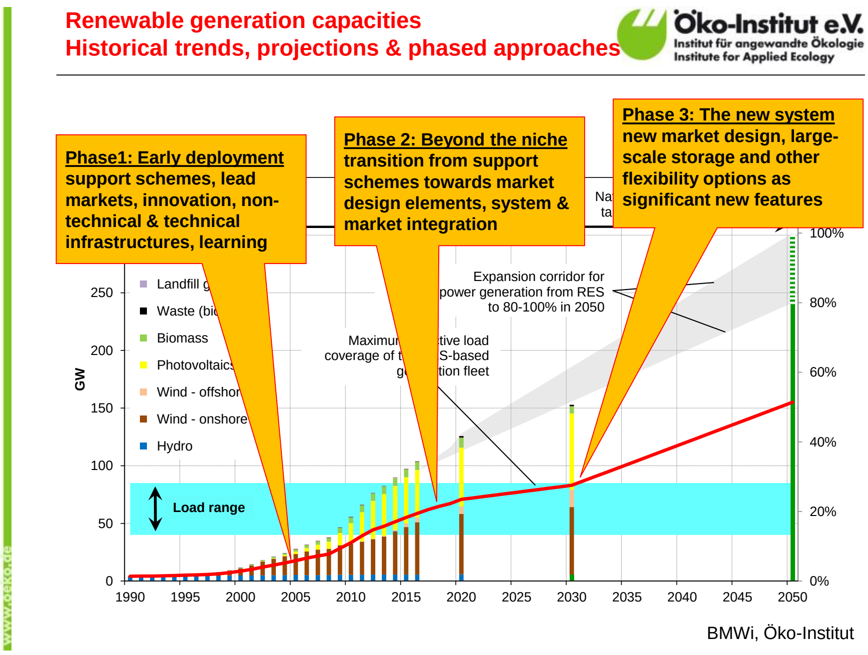
Source: Compilation by the author

Figure 15: Structural change in Germany's power market (5)



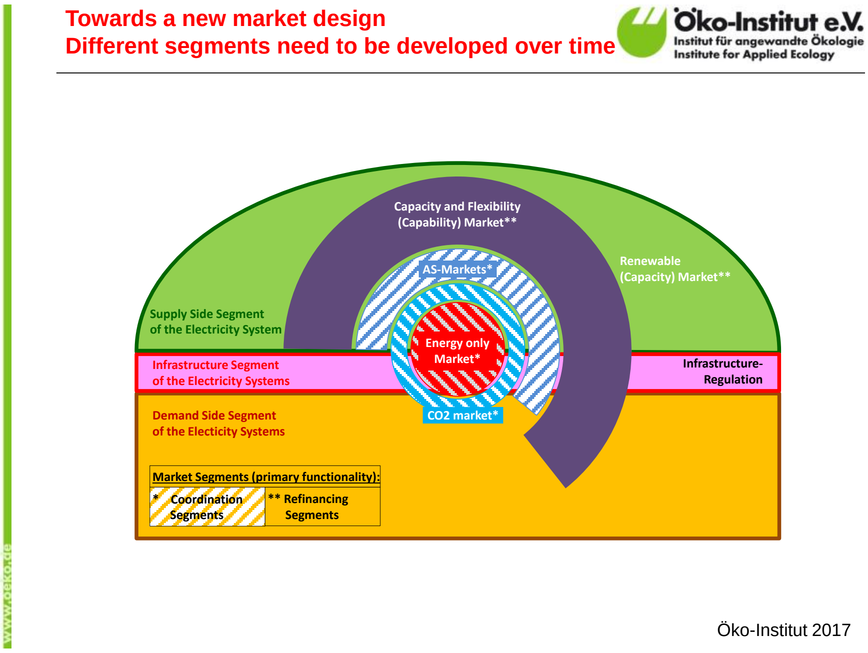
Source: Compilation by the author

Figure 16: Phased approaches for the roll-out of power generation from renewable energies in Germany



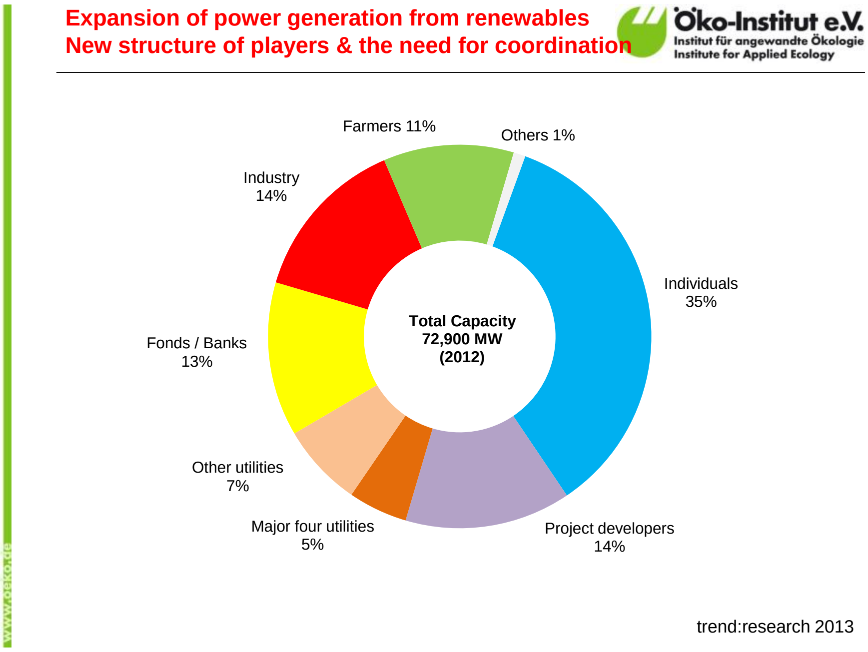
Source: Compilation by the author

Figure 17: Key segments of a future power market design



Source: Compilation by the author

Figure 18: Ownership structures of renewable capacities in Germany



Source: Compilation by the author

Table 1: (Implicit) carbon pricing in Germany

		Nominal tax rate	Implicit tax rate	Excl. infrastructure costs*		Excl. counter-factual invest**
				€ 15b p.a.	€ 35b p.a.	
		€ per unit	€ per t CO_2	€ per t CO_2	€ per t CO_2	€ per t CO_2
Gas oil	EUR/1,000 l	61.35	23.03			
Heavy fuel oil (heating)	EUR/t	25.00	7.87			
Heavy fuel oil (power)	EUR/t	25.00	7.87			
Natural gas (heating)	EUR/MWh	5.50	30.23			
Natural gas (motor fuel)***	EUR/MWh	13.90	76.40	-26.00	-198.20	
LPG (heating)	EUR/100 l	6.06	20.56			
LPG (motor fuel)***	EUR/100 l	18.03	61.16	-11.37	-159.73	
Gasoline leaded***	EUR/1,000 l	721.00	315.90	279.79	134.93	
Gaseline unleaded***	EUR/1,000 l	654.50	286.76	253.99	122.49	
Diesel***	EUR/1,000 l	470.40	179.06	165.55	35.23	
Coal (non-power)	EUR/GJ	0.33	3.47			
Electricity ETS	EUR/EUA	5.35	5.35			
Electricity tax	EUR/MWh	20.50	22.78			
Electricity surcharges	EUR/MWh	76.84	85.38			45.20
Electricity total	EUR/MWh	102.69	113.51			73.33

Notes: * Considering road infrastructure financing from motor vehicle tax (€ 8.7b) and truck toll (€ 3.1b). The lower range of infrastructure costs represents the annual investments and the upper range the annuity of total road system costs. - ** Considering a counterfactual investment of 36 €/MWh. - *** The implicit CO_2 tax rate for motor fuels covers also other significant transport externalities (other pollutants, noise, health impacts) which are less significant for other energies.

Source: Calculations by author

Table 2: Registration of cars in Germany by fuel, 2007-2017

	Total	Gasoline	Diesel	Liquified petrol gas	Natural gas	All-electric	Plug-in hybrid	Other hybrid	Other
2007	**3,148,163**	51.5%	47.7%	0.2%	0.4%	0.0%	0.0%	0.2%	0.0%
2008	**3,090,040**	54.9%	44.1%	0.5%	0.4%	0.0%	0.0%	0.2%	0.0%
2009	**3,807,175**	68.5%	30.7%	0.3%	0.3%	0.0%	0.0%	0.2%	0.0%
2010	**2,916,260**	57.3%	41.9%	0.3%	0.2%	0.0%	0.0%	0.4%	0.0%
2011	**3,173,634**	52.0%	47.1%	0.2%	0.2%	0.1%	0.0%	0.4%	0.0%
2012	**3,082,504**	50.5%	48.2%	0.4%	0.2%	0.1%	0.0%	0.7%	0.0%
2013	**2,952,431**	50.9%	47.5%	0.2%	0.3%	0.2%	0.0%	0.8%	0.0%
2014	**3,036,773**	50.5%	47.8%	0.2%	0.3%	0.3%	0.1%	0.8%	0.0%
2015	**3,206,042**	50.3%	48.0%	0.1%	0.2%	0.4%	0.3%	0.7%	0.0%
2016	**3,351,607**	52.1%	45.9%	0.1%	0.1%	0.3%	0.4%	1.0%	0.0%
2017	**3,441,262**	57.7%	38.8%	0.1%	0.1%	0.7%	0.9%	1.6%	0.0%

Source: German Federal Motor Transport Authority, calculations by author