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Summary of the Position Paper

Coupling the different energy sectors – options for the next phase of the energy transition

German National Academy of Sciences Leopoldina
acatech – National Academy of Science and Engineering
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The development of German greenhouse gas emissions in recent years stands in contrast to the declared goal of continuous reduction – even though the share of renewable energy in the power supply has continually risen. This is only one of several observations the working group "Coupling the Energy Sectors" initially made. The Academies' Project has now come to the conclusion that the targets for climate protection can only be achieved when the energy system is taken into consideration holistically and optimised across all sectors, and when society consciously confronts this task. The core results are:

- **Electricity** from renewable sources will become the **prevailing energy source** in the energy system. Demand for electricity could almost double by the year 2050. As a consequence, the capacity of wind and **photovoltaic plants** would have to grow by a factor of five to seven.
- Technologies such as electric vehicles and heat pumps, which make use of electricity directly and efficiently, will become increasingly significant in the future. But **synthetic combustibles and fuels** are expected to be vital as well.
- **Short- and long-term storage facilities** as well as **flexible power consumption models** will have to help compensate for the volatile generation of electricity. Also, **reserve capacities** will be needed to safeguard supply during the so-called "dark and windless periods". Its scope is roughly the equivalent of today's conventional power plant complex.
- The energy transition leads to **additional systemic costs** every year amounting to one to two percent of the German gross domestic product.
- The central regulatory element here is a **unified, effective price for CO_2**. This can be achieved once the European Emissions Trading System is extended to all sectors and applied with a minimum price, or a carbon tax is introduced.

Key technologies for the future energy supply

On the basis of **expert panel discussions, a comparison of relevant energy scenarios** and **their own model calculations**, the working group has identified key positions within the energy system, analysed the role of a growing coupling of the sectors for the future energy supply, and derived various options for policy makers. The model calculations were carried out by the Regenerative Energy Model *REMoD-D* of the Fraunhofer Institute for Solar Energy Systems ISE. The model calculates the cost-optimised transformation path for the energy system from now until 2050 with prescribed carbon reduction targets, taking all sectors and energy carriers into consideration.

Energy carriers of the future

Electricity from wind power and photovoltaic plants is becoming the prevailing energy source. Using it directly is, from a technical standpoint, often more efficient and cost-effective than transforming electricity into hydrogen or methane. Electricity produced renewably can drive, for example, electric vehicles or heat pumps. Using **bioenergy, solar thermal energy and geothermal energy** efficiently can contribute to limiting the expansion of wind power and photovoltaics and securing the societal acceptance of the energy transition.

In addition, **synthetic combustibles and fuels** will become an important pillar for the energy system of the future. They are easy to store and can, for example, be used in sea and air transportation, whereas purely electric solutions are difficult or impossible to implement. **Hydrogen** plays an important role because it can take on many functions within the energy system: it can be deployed in industrial processes, used for heat supply in buildings or as fuel for transport, used for time-delayed power production and converted into methane and/or liquid fuels. **Gas** – natural gas, biogas and synthetic gases – has low emissions, can be deployed in many different ways and could become, parallel to electricity, a central energy carrier over the long term.

The sectors at a glance

Lower energy consumption and lower-emission technologies – these are the main levers for the heat supply for **buildings** to become more environmentally friendly. By 2050, all existing buildings will need to be refurbished. To do this, the rate of renovation would have to be increased. At the same time, it will be necessary to decrease the specific CO_2 emissions of heating technologies to a third of the current value. In addition to electric heat pumps, which will take on a key function in the process, gas-driven heat pumps, solar heat and central cogeneration plants offer important options for this purpose. Heating grids will play an important role. They could potentially supply about one-third of all buildings with electricity.

In **industry**, the electrification of thermal processes and the deployment of biogas can contribute to a decrease in CO_2 emissions. There are, however, limitations to this: heat pumps cannot be used above approximately 200 degrees Celsius (392 degrees Fahrenheit), and alternative technologies such as power-to-heat (cogeneration) are less efficient. Furthermore, many processes require chemical fuels for process-related purposes. Hybrid systems consisting of electricity and gas could help to make power consumption more flexible. But the disadvantage is the high investment costs for two sets of infrastructure. In order to use energy sources efficiently, the utilization of waste heat can be an important factor, for example by feeding it into the heating grid.

The **transport sector** is currently the poorest performer in the energy transition. Efficient drive systems and fuels as well as a more robust deployment of renewable energies are crucial approaches to reducing greenhouse gas emissions. Battery-powered electric vehicles, driven by electricity from renewable energy sources, will become indispensable for mobility in the future. Hybrid cars with both electric and internal combustion engines are able to circumvent the disadvantage of insufficient range in the electric vehicles. Conversely, in heavy-load and long-haul transport, no clear solutions have emerged thus far. Hydrogen, synthetic natural gas, synthetic fuels or electric overhead lines offer possible options from a present-day perspective. These technologies should be developed further and intensively tested in pilot projects.

Efficiency, flexibility and supply security

In order to cover the rising demand for electricity from renewable sources, **wind and photovoltaic plants** will have to be significantly expanded. For an environmentally-friendly energy supply, future capacity compared to the current situation would have to be increased five to even seven-fold. **Provisions for the efficient use of energy** could be helpful in limiting this expansion. The output quantities foreseen in the Renewable Energy Sources Act of 2017 will, however, not be sufficient to meet future demand.

Short- and long-term storage as well as **flexible power consumption models** will be needed in order to smooth out volatility in the production of electricity. In addition to pumped storage and batteries that cushion fluctuations for a few hours, flexible electrolysis facilities for the production of hydrogen will increase in significance. As a long-term storage, the natural gas grid with its respective cavern and pore storage facilities is worth considering.

In order to secure the supply in all weather conditions and seasons, even the energy system of the future cannot escape the need for **reserve capacity** – presumably with about 100 gigawatts the scope should roughly correspond to today's conventional power plant complex. For reasons of climate protection, low emission **gas-fired power plants** run on hydrogen, natural gas, synthetic methane or **fuel cells** are suitable. Flexible **cogeneration plants** can also ensure the supply. Coal-fired power plants, on the other hand, will no longer play a role in the energy supply in the future.

Since all power plants within the energy system of the future will be run only during longer so-called "dark and windless periods", the market framework has to offer business models so that these power plants are able to remain profitable even at low operating hours.

Costs and control elements

Costs of the energy transition

Due to the expansion of wind power and photovoltaic plants, the introduction of new technologies and the necessary buffering capacity, the **electricity system of the future will become significantly more complicated** than it is today. In comparison to a fossil-fuel based supply system, the energy supply system will thus lead to considerable **additional annual costs**. These costs amount to – in light of the uncertainties associated with such projections – on average **between one and two percent of today's German gross domestic product**. This includes costs for the technical conversion of the energy system, in other words, for the development, conversion and maintenance of the infrastructure (such as power plants, networks and fleets of vehicles), and the costs for the energy sources and the renovation of buildings to make them more energy efficient.

Political regulatory elements

Thus far, environmentally-friendly technologies have had difficulties in establishing themselves on the marketplace. Electricity, for example, is encumbered with higher fees, levies and taxes than natural gas and heating oil. So that the coupling of the sectors is able to achieve its full potential, the markets for electricity, heat and transport have to grow together and offer the same conditions for all energy carriers. **A consistent, effective CO_2 price for all emissions** could play a central role here.

One possibility is to expand the **European Union Emissions Trading Scheme (EU ETS)** to all sectors and to establish a price corridor. If this does not succeed, a **Europe-wide or national carbon** tax could be introduced. It would have to be designed in such a way that it logically complements the EU ETS and, at the same time, sets an effective minimum price. With a price corridor in the EU ETS or a carbon tax, companies could foresee the development of the carbon price. This would provide companies with more reliability as far as their potential investments in environmentally-friendly technologies are concerned. A further advantage: previous **fees, levies and taxes** could be partially **replaced, i. e. phased out**, by a sector-overlapping carbon price. In order to create internationally fair competitive conditions, the **taxation of emissions-intensive imports** could also be taken into consideration.

However, a consistent carbon price is not a panacea. In all areas within the energy system, obstacles can encumber climate-neutral technologies. In order to dismantle these obstacles, **additional measures** are required. In addition to financial incentives such as investment grants, tax breaks, market incentive programmes and governmental co-financing of infrastructure, it can be necessary to either retain or establish regulatory provisions such as emissions ceilings and technical standards. Also, research and development assistance or information and consultation offers can help to spread new technologies.

So that market actors are able to invest in environmentally-friendly technologies at all, they need **planning security**. Prerequisites for this are the political **commitment to climate protection**, the trust of all groups involved in the **obligation to the climate protection targets**, as well as the long-term continuance of carbon prices.

Phases of the energy transition

Germany is now entering a new phase in the energy transition. Now that wind power, photovoltaic plants as well as biomass technologies have been developed, built out and the costs significantly decreased over the last 25 to 30 years, the **basic technologies** have been made available for a comprehensive **systemic integration**. From now on, the priority is to promote and implement technologies to interlink the sectors. Specifically, this means that electricity should be used directly where it is most efficient, such as in electric vehicles and heat pumps, batteries should be introduced as short-term storage, and digitally-controlled power consumption models should be developed.

Hydrogen will have a considerable impact on the third phase of the energy transition: on the one hand, it is necessary for areas of application in which no purely electrical solutions can be foreseen – either directly or in connection with a broader transformation in **synthetic combustibles and fuels**. On the other hand, the further expansion of fluctuating renewable energy will increasingly lead to large quantities of electricity that can no longer be used directly or through short-term storage and load management. Hydrogen can help to store this energy. In the fourth and last phase of the energy transition, **fossil fuels** will be **driven out** of the energy system once and for all. In Germany, this will presumably only be possible if additional electricity or chemical energy produced from renewable sources are imported from countries that have an abundance of wind and solar power.

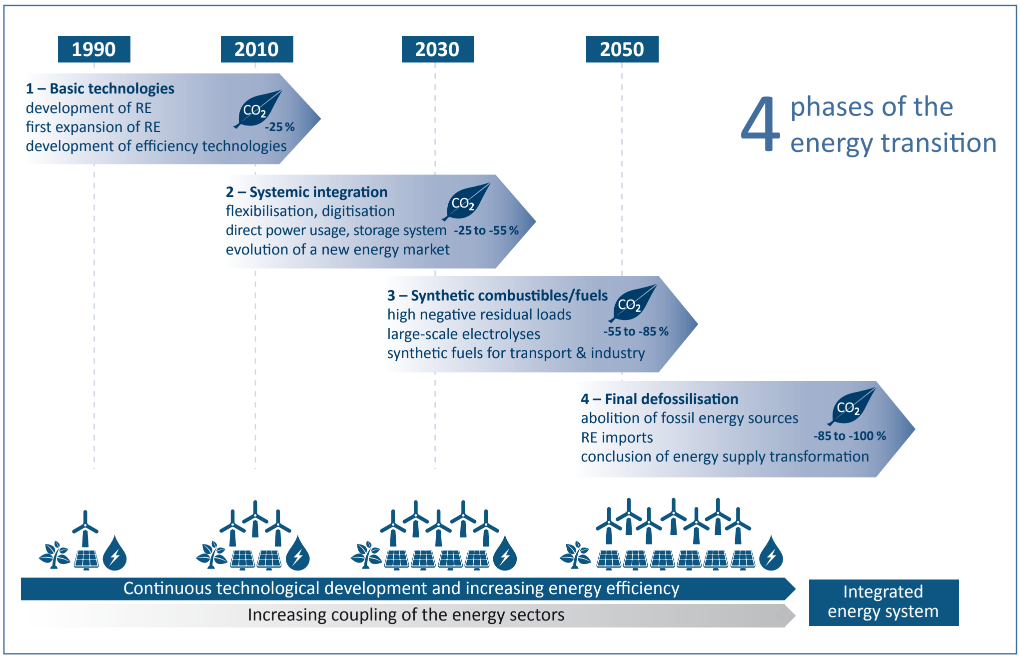

Figure 1: The four phases of the energy transition

The Academies' Project "Energy Systems of the Future"

The position paper *»Coupling the Sectors« – Options for the next phase of the energy transition* evolved within the framework of the Academies' Project "Energy Systems of the Future". In interdisciplinary working groups, about 100 experts are working on different courses of action for the pathway to an environmentally sustainable, safe and affordable energy supply.

Participants in the working group "Coupling the Sectors"

Members: Prof. Dr Hans-Martin Henning (chairman; Fraunhofer ISE), Prof. Dr Eberhard Umbach (chairman; acatech, Executive Board), Dr Frank-Detlef Drake (innogy SE), Prof. Dr-Ing. Manfred Fischedick (Wuppertal Institute), Prof. Dr Justus Haucap (Heinrich Heine University Düsseldorf), Prof. Dr Gundula Hübner (Martin Luther University Halle-Wittenberg), Prof. Dr Wolfram Münch (EnBW), Prof. Dr Karen Pittel (Ifo Institute), Prof. Dr-Ing. Christian Rehtanz (TU Dortmund University), Prof. Dr Jörg Sauer (Karlsruhe Institute of Technology), Prof. Dr Ferdi Schüth (MPI für Kohleforschung), Stephan Stollenwerk (innogy SE), Prof. Dr Kurt Wagemann (DECHEMA), Prof. Dr-Ing. Hermann-Josef Wagner (Ruhr-Universität Bochum), Prof. Dr Ulrich Wagner (Technical University of Munich)

Scientific Coordinators: Dr Florian Ausfelder (DECHEMA), Dr Berit Erlach (acatech), Dr Christoph Kost (Fraunhofer ISE), Dr Katharina Schätzler (Karlsruhe Institute of Technology), Dr Cyril Stephanos (acatech), Philipp Stöcker (RWTH Aachen University), Michael Themann (RWI – Leibniz Institute for Economic Research)

Contact

Dr Ulrich Glotzbach
Head of Project Office "Energy Systems of the Future"
Markgrafenstraße 22, 10117 Berlin, Germany
phone: +49 (0)30 2 06 79 57-0 | e-mail: glotzbach@acatech.de
web: energiesysteme-zukunft.de/en

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German National Academy of Sciences Leopoldina
Jägerberg 1
06108 Halle (Saale)
Phone: +49 (0) 345 47239-600
Fax: +49 (0)345 47239-919
E-Mail: leopoldina@leopoldina.org

Berlin Office:
Reinhardtstraße 14
10117 Berlin

acatech – National Academy of Science and Engineering
Karolinenplatz 4
80333 München
Phone: +49 (0) 89 520309-0
Fax: + 49 (0) 89 520309-9
E-Mail: info@acatech.de

Berlin Office:
Pariser Platz 4a
10117 Berlin

Union of the German Academies of Sciences and Humanities
Geschwister-Scholl-Straße 2
55131 Mainz
Phone: +49 (0) 6131 218528-10
Fax: +49 (0) 6131 218528-11
E-Mail: info@akademienunion.de

Berlin Office:
Jägerstraße 22/23
10117 Berlin