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Summary of the Position Paper

Towards a Climate-neutral Germany

Policy Options for the Technological Transition, Reducing Consumption and Carbon Management

German National Academy of Sciences Leopoldina
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To meet Germany's current climate targets, far-reaching measures will need to be taken concurrently in every sector.

1. If current **energy consumption patterns** continue, renewable energy and other technologies will need to be rolled out at an extremely rapid rate that will be very difficult to achieve. As well as improving energy efficiency, it is thus vital to reduce demand for energy services.
2. **Achieving this reduction in demand will require policy measures** to create an appropriate framework that involves more than just carbon pricing. **Good, climate-friendly alternatives** for housing and mobility will be key to enabling a socially equitable transformation.
3. **Climate-neutral production** must go hand in hand with **sustainable consumption**. Product demand can be reduced by sharing goods, using them for longer, and reusing and reconditioning them. Climate-neutral production can be achieved through new production processes using green hydrogen and electricity, closed material cycles and zero-carbon raw materials.
4. **A rapid transition to a one hundred percent renewable energy supply, widespread direct electrification and a ramp-up of hydrogen production and imports** will all be necessary, even if energy consumption is reduced.
5. Residual emissions will need to be counterbalanced by **carbon dioxide removal**. It will be necessary to revisit the option of **geological CO_2 storage** for this and for unavoidable process emissions captured from industry.

Methodology and focus

The latest version of the Federal Climate Change Act sets a deadline of 2045 for Germany to achieve net greenhouse gas neutrality. The aim of this study is to identify transformation pathways for meeting this target. While its focus is on the German energy system, it also considers how Germany fits into the wider European context and discusses imports of hydrogen and other electricity-based energy carriers.

The findings presented in this paper were arrived at using the following three methodologies:

1. the working group's own simulations,

2. a systematic review of existing scenarios for a climate-neutral Germany, and

3. expert discussions in an interdisciplinary working group.

The **working group's own simulations** used the REMod energy system model developed by the Fraunhofer Institute for Solar Energy Systems. A **review of climate neutrality scenarios in seven German studies** was carried out in parallel. The review aimed to contextualise the results of the working group's own simulations and identify the areas where the experts largely agree on the main aspects of the pathway for transitioning to climate neutrality. It also sought to identify the areas that are more contentious – i.e. where there is still considerable uncertainty about the technologies most likely to deliver the desired results.[1] Conclusions are also drawn about areas not covered by the REMod simulations, primarily industrial process emissions and carbon dioxide removal technologies used to counterbalance hard-to-abate residual emissions. The **expert discussions** provided an opportunity to reflect on the findings of the working group's simulations and the meta-analysis and formulate recommendations for policy measures and instruments based on the overall picture presented by the different scenarios.

The study focuses on the following aspects:

1. the **importance of reducing demand** in order to meet the climate targets,

2. the role of **faster technology rollout** in helping to meet the targets,

3. the assumptions that would allow a **climate-neutral energy supply** to be achieved **before 2045**,

4. the strategies required to achieve climate neutrality in **industrial production**, and

5. how **net-negative emissions** can help to achieve climate neutrality.

1 However, it should be stressed that most of these transformation pathways are scenario-based projections (i.e. "what-

Previous scenario studies have barely considered the extent to which **reducing demand** for energy services could create some leeway if the technology rollout targets are not met, or even help to meet the climate targets a few years earlier. Consequently, this was addressed in the working group's own simulations. In order to explore the full extent of the leeway in the transformation pathways, extreme assumptions were deliberately chosen both for demand reduction and for **faster technology rollout**.

It has become apparent that the sum of current national climate targets will not be enough to meet the targets set out in the Paris Climate Agreement. Consequently, it is urgently necessary to enable the possibility of achieving a climate-neutral energy system in Germany even sooner than 2045. This was investigated by simulating the achievement of a **climate-neutral energy supply by 2040**. The energy system model was only able to identify a transformation pathway that meets this deadline by assuming either a very strong reduction in demand or an even faster technology rollout than in the main scenario, which already assumes an ambitious rollout rate. However, regardless of the deadline for meeting the targets, these simulations should not mislead anyone into thinking that the transition to climate neutrality can be achieved without a tremendous effort and far-reaching transformation.

If Germany is to stay within a carbon budget that is **compatible with the 1.5 degree Celsius target** and also reflects equal global per capita distribution, it will need to reduce its emissions to almost zero by 2035. This scenario was also modelled and was only found to be achievable if the technological transition happens even faster and final energy demand is reduced even more quickly. During their discussions within the working group, the experts concluded that it would be impossible or almost impossible to achieve the rate of technology rollout and conversion required by this scenario. They reached a similar conclusion about the feasibility of the required rate of behavioural change throughout society as a whole.

In addition to accelerating the transformation of the energy system, the achievement of climate neutrality will also call for a greater focus on reducing industrial process emissions and greenhouse gas emissions from farming wherever possible. Regardless of the measures taken, however, some residual emissions will always be unavoidable. These will need to be counterbalanced by **carbon dioxide removal**. Accordingly, one of the working group's key priorities was to undertake a specific, separate analysis of options for achieving net-negative emissions.

Key message 1: The transition to climate neutrality will require extensive social and policy changes

Our continued existence on this planet will be in jeopardy unless we transition to a climate-neutral lifestyle and economy within a few short decades. Integrated social, technological and economic solutions will be key to achieving the far-reaching changes that are required. This will call for overarching packages of measures that enable the transformation by fundamentally promoting technologies and behaviours that prevent CO_2 emissions.

Overarching policy options: policy areas (PAs)
PA 1: Define wider targets and pursue a wider range of solutions for a sustainable energy transition To achieve climate neutrality, it will be necessary to use renewable resources instead of fossil resources, implement closed-loop material cycles, improve energy and material efficiency and reduce demand for energy services. The significance of these measures is even greater if, in addition to the climate effects, other planetary boundaries and the global impacts of energy and resource consumption are also taken into account.
PA 2: Address the energy transition as a social process The energy transition is much more than a technological transformation – it is also about how we shape the future socially, culturally and as a society. It is about reconciling a high standard of living with long-term environmental sustainability. The policy framework should aim to make climate-friendly behaviour the easiest option and to actively promote sufficiency. Transparent processes, opportunities for active participation and a perception that the benefits and burdens are shared fairly are all key to achieving public acceptance.
PA 3: "Getting the Price Right" to achieve climate neutrality A sufficiently high carbon price across all sectors is key to eliminating the use of fossil fuels. Grandfather clauses and the importance of reliable forward planning mean that carbon prices usually start off at a moderate level before subsequently rising. Consequently, additional support may be needed for technologies that are still in the early stages of development and will therefore be more expensive at the start of the transition. The phasing out of this support should also be planned for from the outset. Future carbon price increases must also be predictable for businesses. Carbon Contracts for Difference (CCfDs) can help companies to plan ahead with confidence and support new technologies during their market rollout phase. Current subsidies for fossil fuel use undermine carbon pricing and should be ended.
PA 4: Upgrade the key network infrastructure in good time Because of its long lifespan and planning timeframe, new network infrastructure should be built with an eye on future requirements. The electricity transmission and distribution grids are in particular need of upgrading. Increased sector coupling will call for an overarching system development plan geared towards the integrated development of the electricity, gas, hydrogen and CO_2 networks. This will require close cooperation at European level. It will also be important to find ways of overcoming the multiple barriers to network expansion associated with local opposition to specific projects.

Overarching policy options: policy areas (PAs)
PA 5: Establish transparent and consistent guidelines for the deployment of electrification, hydrogen, PtX and biomass In many cases, renewable electricity, green hydrogen and its derivatives and biomass can be used as alternatives for the same applications. Energy scenarios indicate that a high percentage of direct electrification results in a more efficient and cheaper overall system. The limited potential of sustainably produced biomass and climate-neutral hydrogen should be preferentially used in applications where there is no direct electric alternative, for example certain industrial processes, shipping, aviation and some types of heavy goods transport. The use of biomass as a raw material should be prioritised over its use as an energy source.
PA 6: Strengthen energy transition skills among industry professionals and provide free information A training campaign for the relevant manual and technical professions could help to meet the urgent need for more skilled professionals to implement the transition. Continuing professional development can help to keep installers and consultants up to date with the latest developments in the field. Among other things, this is important because they often have a significant influence on private purchasing decisions (e.g. for heating systems). Information campaigns that include sufficiency options can also help households with their choices in the housing, mobility and consumer sectors.
PA 7: Continuously monitor policy effectiveness Achieving the goal of climate neutrality by 2045 will call for a rapid, concurrent transition in every sector. It is no longer enough to start by focusing only on cheap measures. An early indicator system can help to quickly identify where targets are likely to be missed so that corrective measures can be taken.

Table 1: Overarching policy options: policy areas (PAs)

Key message 2: It will be almost impossible to meet the climate targets without reducing demand

The simulations indicate that a strategy focused predominantly on technological solutions would require an extremely extensive and rapid transition and would also necessitate the use of particularly costly technologies. For instance, it would call for extremely rapid and extensive modernisation of the entire building stock. If current behaviour patterns remain unchanged, the implementation of a purely technology-focused transformation would be associated with huge pathway risks. The requirements for land and other resources as well as the availability of imports would also be very challenging. Consequently, the technological transition must be accompanied by an active sufficiency policy that promotes climate-friendly behaviours and creates the conditions for a significant reduction in energy service demand. This should not be interpreted as a call to reduce demand through individual "sacrifice" driven mainly by price signals. Instead, it is necessary to create an overall framework that is geared towards people's needs, creates accessible climate-friendly alternatives for everyone, and can thus enable positive side effects over and above demand reduction. New housing, mobility, consumption and production concepts can play a particularly important role in this regard.

Policy measures for reducing consumption: policy areas (PAs)

PA 8: Strengthen scientific research on the integration of strategies to reduce consumption
Previous transition scenarios for Germany have barely considered sufficiency strategies. Policy advice in partic should place greater emphasis on them, with a view to quantifying the potential, limitations and timeframe strategies to reduce consumption and formulating appropriate policy options.

PA 9: Reimagine mobility
The efficiency gains achieved thanks to technological advances in the transport sector have not translated in reduction in CO_2 emissions. This is because they have been accompanied by an increase in passenger and fre transport use and in average vehicle size and weight. Consequently, rather than simply relying on technolo developments, it will be vital to develop an integrated strategy that defines mobility as a means of accessing partic destinations such as workplaces, social activities and shops. The strategy should aim to reduce motorised pri transport by promoting high-quality public transport, cycling and walking and by making the appropriate long-t urban planning and settlement structure policy choices. Economic regionalisation could help to reduce freight transp

PA 10: Focus on housing quality, land use and climate adaptation
In addition to heating systems, the building sector's environmental footprint is also determined by building mater resource consumption and embodied emissions, i.e. the greenhouse gas emissions arising from the mater production. Other factors include land use and soil sealing. Reversing the trend towards higher per capita living spa key to reducing the building sector's climate and environmental footprint. This could be facilitated by more flexible of existing buildings, enabled for example by senior-friendly refurbishments or house swapping services, and by gre use of communal areas. While this is a long-term goal, the relevant policy decisions should be made as soon as poss Adaptation to rising temperatures and other impacts of climate change should also be addressed in long-term strate for the building sector.

PA 11: Reduce energy demand through sustainable consumption and production
Systematic pricing of climate impacts and other externalities can reduce demand for products that are damaging to climate. Policy measures can ensure that climate-friendly alternatives are accessible to all social groups. This ca supported by simple and transparent labelling of products' climate impacts and by incentives to produce products are durable and repairable.

Key message 3: The technological transition must happen much faster

Both the scenario study meta-analysis and the working group's own simulations indicate that various technologies will need to be rolled out much faster if climate neutrality is to be achieved by 2045. Wind and solar power, technologies for producing hydrogen and synfuels, electric mobility, heat pumps and building modernisation measures will need to be rolled out at rates that, in some cases, are at the limit of what the experts currently deem possible. The relevant technologies will still have to be rolled out extremely quickly even if there is a strong fall in demand as a result of extensive sufficiency measures. It is thus vital to implement the most efficient system solutions without delay.

Modernising the energy supply: policy areas (PAs)
PA 12: Transition to a one hundred percent renewable electricity supply as soon as possible The electricity supply will need to be almost one hundred percent renewable by 2035. This will call for a significantly faster expansion of wind and solar power. It will also be necessary to upgrade electricity grids and storage systems in order to optimise the integration of renewables. In addition to financial measures to incentivise investment in the necessary technologies, it will be necessary to expedite planning and licensing procedures and make sufficient land available for their expansion.
PA 13: Enable a rapid ramp-up of the hydrogen and synfuel markets in areas where they can deliver system benefits A rapid ramp-up of the hydrogen market will play a particularly important role in helping industry to meet its climate targets. This will require the development of both domestic hydrogen production and the relevant import relationships and infrastructure. Supply and demand side support for hydrogen production and use will be necessary until such a time as the projected reductions in the cost of electrolysis are achieved through economies of scale and a liquid market has been established for green/low-emission hydrogen. In the future, hydrogen derivatives such as methanol will be required, primarily for use as fuels in the international aviation and shipping sectors but also as raw materials in the chemical industry. In addition to hydrogen, in the long term a climate-neutral source of carbon will also be needed to produce these derivatives. The scenarios analysed all agree that most of Germany's demand for hydrogen derivatives will be met by imports.
PA 14: Switch to a climate-neutral heating supply Key requirements for a climate-neutral heating supply include more favourable conditions for the widespread adoption of centralised and decentralised heat pumps, a higher building modernisation rate, the expansion of heating networks, compulsory connection of waste heat sources and the use of deep geothermal energy. Mandatory municipal heating planning, as promised in the German government's coalition agreement, is a key instrument for the development of an efficient, long-term heating supply strategy that reflects local conditions, and should therefore be introduced as soon as possible.
PA 15: Drive the technological transition to a climate-neutral transport sector A shift from private car use to cycling, walking and public transport will be key to achieving climate-neutral mobility. This will call for the redistribution of traffic space in urban areas. Ambitious measures must also be introduced to accelerate the switch to battery electric vehicles in the passenger car sector. Further expansion of the charging infrastructure will be crucial, as will systematic leveraging of the potential to improve electric vehicle efficiency. In the freight transport sector, close coordination will be required at European level. In principle, both direct electric solutions in the shape of battery-powered vehicles and overhead line systems have potential in this sector. However, it will also be important for the rail freight system to take over as much freight transport as possible. This will require investment in and extensive digitalisation of the European rail network. In the international shipping and aviation sectors, synfuel quotas can kickstart the market diffusion of climate-neutral fuels that will be vital in the long term.

Table 3: Modernising the energy supply: policy areas (PAs)

Key message 4: Industry requires a three-pronged approach of climate-neutral processes, circularity and material efficiency

The long lifespan of production assets and the imperatives of global competition mean that it will be particularly challenging for industry to achieve climate neutrality by 2045. Pan-European regulatory solutions will be required to prevent offshoring to regions with lower climate standards.

Strategies for climate-neutral industry: policy areas (PAs)
PA 16: Climate-neutral processes Since approximately one third of industrial emissions are process emissions, it is not enough simply to replace fossil fuels with renewables. Instead, it will be necessary to completely redesign industrial processes. In steel production, for example, blast furnaces will need to be replaced with direct reduction by hydrogen. In the long term, fossil feedstocks such as the gas and oil used to produce plastics will have to be replaced by biogenic alternatives or feedstocks made with green hydrogen and CO_2 removed from the atmosphere. Appropriate instruments such as Carbon Contracts for Difference and investment support schemes will be needed to stimulate new investment in climate-neutral processes. Emissions that cannot be prevented in this way, especially in the cement industry, will need to be captured using carbon capture and storage technology or counterbalanced by negative emissions. If the captured CO_2 is used to produce goods, the entire chain will only be climate-neutral if the products have a very long lifespan, if recycling keeps the carbon in a closed-loop system for a very long time, or if the CO_2 released when the product is incinerated at end-of-life is captured and stored geologically.
PA 17: Creation of a circular economy The creation of a circular economy can significantly reduce resource consumption and industrial emissions. Policymakers can draw on a wide range of instruments to implement a circular economy. In order to achieve closed-loop material cycles and enable efficient recycling, manufacturers could be required by law to design products that are simple to disassemble into easily recyclable components. Take-back obligations for manufacturers and better collection and logistics systems could also improve the supply of raw materials for secondary production. Quotas for the use of secondary materials in production could reduce demand for primary raw materials.
PA 18: Promote material efficiency and material substitution Mandatory carbon footprint labelling covering every stage of a product's life would create transparency and help consumers to make climate-friendly choices. Quotas or binding sustainable procurement rules could be introduced in the public sector. The use of climate-friendly building materials will require some aspects of building and product standards to be updated.
PA 19: Strengthen carbon price effectiveness and investment security In the current system, where free carbon allowances are allocated to industry, there is a danger that carbon prices will not always be fully reflected in production costs. However, since many companies compete in global markets, the goal of more effective carbon pricing must be balanced against the need to prevent carbon leakage, i.e. the relocation of production to regions with lower climate standards. Between now and 2030, Carbon Contracts for Difference could encourage companies to switch to climate-neutral production processes even while carbon prices are still relatively low. At EU level, it will be necessary to develop a version of the Carbon Border Adjustment Mechanism that the member states can agree on, but that still provides effective incentives for the transformation of industry.

Table 4: Strategies for climate-neutral industry: policy areas (PAs)

Key message 5: Carbon dioxide removal is necessary as well as but not instead of preventing CO_2 emissions

Carbon dioxide removal from the atmosphere will be necessary to counterbalance unavoidable emissions and stay within the Paris Climate Agreement temperature limit. The carbon dioxide removal strategy should be coordinated at European level and form an integral part of an overarching carbon management strategy that also encompasses carbon utilisation (CCU) and the geological storage of fossil CO_2 emissions (CCS) that cannot be reduced sufficiently within the required timeframe.

In some cases, there is still considerable uncertainty about the potential of carbon dioxide removal and the cost, threats to the environment and social impacts of different CDR methods. Consequently, climate action strategies should not be over-reliant on carbon dioxide removal and should prioritise the prevention of CO_2 emissions wherever possible. In other words, carbon dioxide removal should not be used instead of emission prevention.

Carbon management: enabling the transition to net-negative emissions: policy areas (PAs)

PA 20: CDR – removing carbon from the atmosphere
It is important to ensure that the ambition of measures to prevent CO_2 emissions is not diminished by the prospect of carbon dioxide removal (CDR) at some point in the future. CDR is associated with numerous risks and uncertainties in terms of its potential, cost, and environmental and social impacts, as well as the length of time that the carbon will remain stored. The introduction of a statutory target for the ratio of emission reduction to CDR would ensure that the prevention of greenhouse gas emissions was prioritised. There is an urgent need for further research into the different CDR methods. These must also be trialled on an industrial scale and evaluated in a broad public debate process that addresses their potential and risks. The risk of stored CO_2 escaping back into the atmosphere varies depending on the method used. For instance, it can be released by forest fires where afforestation has been used as a carbon sink. It will therefore be necessary to develop appropriate accounting rules. Temporary, technology-specific funding will be required to help bring methods that are still under development to market.

PA 21: CCS – geological carbon storage
Until a few years ago, CCS was primarily seen as a solution for CO_2 emissions from coal-fired and gas-fired power plants. Today, on the other hand, it is mainly viewed as a means of dealing with emissions that are difficult to avoid (for example from the cement industry and waste incineration) or carbon dioxide that has been removed from the atmosphere in order to counterbalance residual greenhouse gas emissions (especially from farming). This change calls for a new public debate about the extent to which CCS should be implemented in Germany and where the carbon should be stored – e.g. in Germany or in other European countries, and onshore or offshore. The development of a European CO_2 storage and transport infrastructure should commence as soon as possible.

PA 22: CCU – climate-friendly carbon utilisation
It is also necessary to find replacements for the fossil carbon used as a raw material for products like plastic (Carbon Capture and Utilisation – CCU). Potential climate-neutral carbon sources include biomass and CO_2 that has been removed from the atmosphere. In contrast, if CO_2 derived from fossil fuels is utilised, the entire chain is not carbon-neutral, since the CO_2 is released into the atmosphere at the end of the product's life. Regardless of where the carbon comes from, the length of time that it remains locked away is key – the longer this time, the greater the climate benefits. Accordingly, incentives for CCU should be based on the actual climate benefits delivered rather than simply on carbon utilisation per se.

The Academies' Project "Energy Systems of the Future"

The Position Paper *Towards a Climate-neutral Germany. Policy Options for the Technological Transition, Reducing Consumption and Carbon Management* evolved within the framework of the Academies' Project "Energy Systems of the Future". In interdisciplinary working groups, about 160 experts are working on different courses of action for the pathway to an environmentally sustainable, safe and affordable energy supply.

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