Ad hoc statement – June 2020

Energy transition 2030: Europe's path to carbon neutrality

German National Academy of Sciences Leopoldina
acatech – National Academy of Science and Engineering
Union of the German Academies of Sciences and Humanities

Preliminary remarks

With its upcoming presidency of the EU Council, Germany has the opportunity to set European climate policy on a new path. The complete transformation of our energy systems with the aim of greenhouse gas neutrality by the middle of the century is an important and appropriate project involving our entire society. While it is easy to state the target, it is difficult to set out the best way of achieving it. Science has the task of using analysis and advice to contribute to this project in a way that widely considers the latest knowledge possessed by all relevant scientific disciplines. With this in mind, the present ad hoc statement by the German National Academy of Sciences Leopoldina, acatech – National Academy of Science and Engineering, and the Union of the German Academies of Sciences and Humanities aims to provide the German government, in light of its upcoming presidency of the EU Council, with a compact series of recommendations for giving the desired European energy transition the momentum it requires, not least amidst the challenge posed by the coronavirus pandemic.

Premises of this statement

Climate change and climate protection

- Human activity is the primary cause of the global warming that has been observed since the mid 20th century.[i]
- The atmosphere, along with the ocean and biodiversity, is a global common-pool resource. In the future, it must no longer be used for depositing unlimited greenhouse gas emissions. Instead, a limited "budget" for greenhouse gas emissions follows from the internationally binding Paris Climate Targets (Article 2.1: 2°C target, 4.1: Carbon neutrality by the end of the century at the latest). Once the budget has been exhausted, the economy must be run in a greenhouse-gas-neutral manner.[ii]
- If the climate target of a maximum of 2°C of warming is to be achieved, humanity as a whole must conduct business in a carbon-neutral way and cope with a limited budget for greenhouse gas emissions. Europe will not be able to seal itself off from the direct or indirect consequences of climate change. Long-term public interest and climate protection therefore require the state to act. The European Union has set itself the aim of becoming carbon neutral by 2050.[iii, iv] This concerns not only CO_2, but all anthropogenic greenhouse gases, such as methane.
- Limiting global warming will benefit all forms of life, including nature and biodiversity. Direct threats (e.g. flooding, heat waves, water shortage, extreme weather) will increase due to the onset of climate destabilisation. There will also be direct knock-on effects on, for example, the global financial, food and health systems. Climate protection and greater resilience including in the areas of land use and public health services are important in stabilising the social foundations of the common good.
- The limited greenhouse gas budget makes it essential to start reducing greenhouse gas emissions soon. The longer we wait, the more dramatic later reductions in greenhouse gas emissions will have to be, necessitating even more radical restructuring.
- The objective of carbon neutrality should be pursued in a sustainable manner which is technologically feasible, economically and ecologically viable, socially fair and moderated by society. However, these requirements must also not undermine the objective itself.
- Climate protection comprises all the sectors, systems and services which are necessary for life as well as inter-dependent. This includes, in particular, the effects of land use and changes to land use, which can contribute to both greenhouse gas emissions and carbon sequestration. Where competition for land is an issue, food cultivation and biodiversity are to be prioritised over use for renewable raw materials for the purpose of material or energy use.

A sustainable energy system

- Carbon neutrality can only be achieved with a fundamentally restructured energy system, the design of which gives due consideration to the remaining quantities of permitted greenhouse gas emissions for the energy sector.
- The fundamental transformation of the energy system is technologically possible.

- Transitioning to a carbon-neutral energy system is the key challenge of climate protection. In 2017, around 80% of emissions in the 28 EU member states were related to energy. Carbon neutrality would be achieved by quickly ceasing the use of fossil fuels (defossilisation) in all areas of energy use.
- The energy system should be analysed and managed as a whole (systemically). The state needs to drive the energy transformation by creating the framework for a sustainable energy system, as this cannot be guaranteed by free market principles alone.
- Energy supply is a highly complex, dynamic system strongly influenced by path dependence. In light of these factors, it is vital to embark on a path before 2030 which will guarantee carbon neutrality by 2050.
- Industrial infrastructure comprises numerous long-lasting and energy-intensive assets (e.g. furnaces, steam crackers, cement kilns). It is therefore vital to only invest in assets which can either already be operated in a greenhouse gas-neutral manner or can later be operated carbon neutrally (e.g. with renewable energy sources) and thus adapted to the increasingly stringent climate protection targets.
- Obvious technological necessities ("no regret" measures) should be implemented without delay. These include the construction of wind farms and photovoltaic systems, high-performance transmission and distribution networks equipped with storage and other flexibility elements, increased electrification, the setting up and expansion of hydrogen technologies, and investments in energy efficiency.

Why the EU now has to make decisive progress in climate protection

Effective climate protection helps to guarantee the foundation of life in Germany, Europe, and the world. The consequences of human-made climate change are already affecting increasing numbers of people and ecosystems in the form of extreme weather events such as drought and hurricanes, forest fires unprecedented in both quantity and scope, the accelerating rise in sea levels, and melting ice sheets. The indirect consequences of increasing climate change include the rapid loss of habitable territory and biodiversity as well as more human migration.

Without rapid mitigation efforts that limit climate change to below 2°C, there is a risk that climate change will become uncontrollable and threaten the very foundations of civilisation. Climate change is thus not a luxury concern for an elite minority, but an urgent issue affecting humanity in its entirety. Early and rapidly increasing investments in climate protection, especially in transforming the energy system, can pave the way for a carbon-neutral society.

The coronavirus pandemic has unleashed a dramatic crisis on the world with devastating economic and social effects. In the next few years, enormous sums will have to be spent to aid recovery. With respect to climate protection, it is vital that these funds are aligned to the targets of the Paris Climate Agreement. In the European Union it is therefore essential to establish the political momentum for an effective Green Deal which can be realised via binding, ambitious and effective regulations. It is very important to do this in a manner that is both economically efficient and socially fair.

In light of Germany's upcoming presidency of the EU Council, this ad hoc statement indicates possible ways in which and reasons why political capital should be used to advance Europe's collective and resolute journey towards carbon neutrality. The statement focuses on key energy policy strategies which the German National Academy of Sciences Leopoldina, acatech – National Academy of Science and Engineering, and the Union of the German Academies of Sciences view as priorities for successful European climate protection. The statement details how this transformation can be set in motion.

How the EU should act now

In 2050, the EU aims to be a carbon-neutral, resource-efficient union which is nevertheless economically competitive. The energy transition forms the basis for this transformation.[v] It is a mammoth task which requires major innovation and investment in infrastructure and industrial equipment. Investment periods in the areas of energy and industry often span 30 to 50 years. What is built today will still be in use in 2050.Therefore, the current task is to join forces to lay the groundwork on a political, technological and regulatory level and to do so simultaneously. A European energy transition can be achieved without overburdening economy and society:

- On the political level, it is necessary to develop a coherent strategy and to agree on joint collective action,
- On the technological level, it is necessary to introduce new technologies at the required scale and combine them systematically (Box),
- On the regulatory level, it is necessary to create effective and cost-efficient systems of incentives.

The only way to achieve the EU's climate protection targets is via a joint climate and energy strategy which emphasises collective action based on solidarity and long-term objectives. This requires agreements rooted in trust and decision-making processes which are fully transparent. A shared approach should take precedence over national interests and short-term considerations. At the same time, a European energy transition must take the various starting positions of the respective member states into consideration.[vi]

Technological necessities and "no regret" measures

When it comes to major projects such as the transformation of our energy system, it is advantageous to adopt an open-minded attitude toward technology in order to prevent premature and potentially erroneous determinations. However, with respect to energy, there are very few technological options available in order to achieve the ambitious 2030/2050 climate targets. Due to ever changing technological, economic and social circumstances, there is no static, optimal solution. For this reason, as well as due to the long-term nature of implementing technologies on the scale demanded by the energy system, it is essential to begin the transformation along key lines now and with all means available. The following technological necessities are self-evident and ought to be implemented without delay:

1. If the aim is to provide energy with minimal CO_2 emissions, then the use of fossil energy carriers must be stopped as soon as possible. Photovoltaics and wind energy offer alternatives which can be used on a large scale and further developed and which have also attained a sufficient level of technological maturity. Bioenergy, geothermal energy and hydropower are limited in their potential. Some other European countries emphasise nuclear energy as a low-CO_2 solution, but even in those countries, its economic viability is questioned. In Germany and many other European countries, there has been a rejection of nuclear energy on principle, leaving only photovoltaics and wind energy as viable alternatives. Great emphasis should therefore be placed on further developing these energy technologies. The energy they provide will undoubtedly be required in the future, making them "no regret" investments.

2. Renewable energy needs to be transported and distributed with as few shortages and bottlenecks as possible. High-performance transmission and distribution networks equipped with storage and other flexibility elements designed to accommodate the fluctuating nature of regenerative technologies are therefore essential. An ongoing and rapid expansion of the network is thus also a “no regret” strategy.
3. As renewable energy will increasingly become the primary source of energy in most sectors, it is also strongly advisable to keep developing electrical appliances including, above all, heat pumps for heat supply, and electromobility along with the necessary infrastructure.
4. It will be extremely difficult to meet Europe’s energy needs via photovoltaics and wind energy alone. Importing energy will therefore continue to be necessary in the long term. High voltage, direct current (HVDC) electric power transmission lines, for example from the Middle East and North Africa (MENA region) to Central Europe, are one option, though they are difficult to realise on the necessary time scale due to complex political coordination processes. Sun and wind could be used to produce hydrogen relatively cheaply in MENA countries over the next few decades. Pilot systems should be put in place now, as hydrogen, being the first basic element in the chain from electrical energy to material energy carriers, will have to play a key role in future energy systems. Hydrogen can be used in many different ways (for example in the steel industry and as a raw material in chemistry), which makes such investments highly worthwhile. The same applies to demonstration plants for processing hydrogen into a transportable form, whether via ammonia, liquid organic hydrogen carriers (LOHC) or via systems for producing liquids by hydrating CO_2 – initially from major point sources, subsequently from air capture processes. “Green” fuels will certainly be needed as alternatives to fossil fuels in aviation, shipping, and in the off-road area including agriculture, and can thus also be seen as “no regret” developments.
5. Investments in energy efficiency, which can be highly varied in nature, reduce overall energy demand and, with an appropriate cost-benefit relationship, can be termed “no regret” investments. The less energy that is used, the fewer wind farms, electricity lines and storage units will be required, which in turn reduces the associated drawbacks of such technologies.

What Germany should be working towards during the presidency of the EU Council

The German government should actively initiate a reorientation of the climate protection debate in Europe, up to and including decisions about specific paths of transformation. In this, Germany can set a positive example and act as a first mover to open up new markets. It also has the potential to mobilise technological and financial resources for cooperation within the EU and with selected non-EU countries if it serves EU interests.

In the Academies' view, Germany should use its Presidency of the EU Council to focus energy and climate policy on the following points:

- **Politically stabilising the European and global climate agenda** as a means of safeguarding the Paris Climate Agreement should be a top priority for the EU. The coronavirus crisis in no way reduces the urgency of this task. The post-coronavirus economic recovery and the public and private investments which are part of this recovery should focus on sustainable defossilisation and effective reductions in emissions.
- **A regulatory framework should be established to help achieve the necessary transformation.** The core of this framework is an effective, comprehensive and uniform pricing of greenhouse gas emissions ("CO_2 price") in all sectors. Suitable instruments must be selected to achieve this.
- It is important to advance the **development of a trans-European energy system** with the expansion of renewable energies, especially at locations with high natural potential and transmission capacities. The use of material forms of transport such as hydrogen and its derivatives will complement the direct transmission of electricity. These strategies will together enable a rapid reduction in greenhouse gases and greater economic convergence between Northern and Southern Europe, including as part of Europe's post-coronavirus economic recovery.
- The EU should establish **international technology, investment, science and training partnerships** with select, suitable non-EU countries in order to develop production capacities for material energy carriers (gases, fuels, basic chemicals). An important aspect of this cooperation ought to involve policies which support the development of supply chains for green energy carriers.
- The **development and local production of renewable energies** in Europe should be further promoted, with citizens' involvement.
- **Sustainable finance** with unified global standards should be systematically developed.

The most important fields of action for a European energy transition

Establish a cross-sector CO_2 price as a key instrument for climate protection

A standard CO_2 price would create an economically efficient, stable and long-term framework for the transformation of the energy system and should therefore be established as a key climate policy instrument. The aim should be to create a uniform price for all greenhouse gases[vii], covering all sectors, regions, stakeholders and technologies. From an economic perspective, whether the CO_2 price is based on quantity (certificates trading) or price (taxes/charges) is of secondary importance.[viii] The specific form that the CO_2 price takes should primarily be based on its rapid introduction and EU-wide harmonisation as far in advance of 2030 as possible. The ability to implement the policy with legal certainty as an aspect of EU and member state legislation is key.

The EU's Emissions Trading System (ETS) has established itself as a functional instrument for the energy sector, industry and aviation within Europe, and already covers some 45 percent of the EU's greenhouse gas emissions.[ix] In EU negotiations, Germany should argue strongly in favour of the further development and improvement of this system:

- The European Commission's climate protection target of **EU-wide greenhouse gas neutrality by 2050** should be binding for all member states and anchored in EU climate legislation.
- There is a risk that due to the recession resulting from the coronavirus, uncertainty about the long-term price development will increase. An effective **minimum price for CO_2** is thus more important than ever in order to enable planning and long-term incentives for sustainable investments in climate protection.
- To meet the climate protection target of EU-wide greenhouse gas neutrality by 2050, the EU-ETS **emissions allowances should be reduced in accordance with the remaining CO_2 budget.**
- The **EU-ETS** should be expanded to also cover the **heat and transport sector** as far in advance of 2030 as possible. The income available to EU member states from the CO_2 price could, in accordance with national circumstances, be used to achieve social equity through compensation payments.
- If swift integration of the heat and transport sector in the EU-ETS proves politically impossible in the near term, a CO_2 price can nevertheless be established via **separate emissions trading for the heat and transport sector** or by **focusing energy taxes on CO_2 emissions**. In the latter case, the minimum tax rates in the Council Directive 2003/96/EG should be adjusted. A separate emissions trading system and energy tax reform could both be introduced on a national level. However, the aim should be to harmonise the regulations as far as possible within the EU or at least in the largest possible group of EU countries.
- Suitable regulatory mechanisms such as **border adjustments** or a **consumption tax** for CO_2 will be required to bring international CO_2 prices into line and thus ensure the economic viability of

investments within Europe. A transparent, science-based, but also workable evaluation of the CO_2 footprint of imported goods will be necessary to ensure this.

- An **energy price reform** is necessary to successfully make the German and European energy transition part of the global energy transition. This reform would establish suitable conditions for sector coupling and could be part of a comprehensive EU-wide ecological tax reform.

International cooperation: incentivising change

A uniform and system-wide CO_2 price should be established as a cornerstone of the European Green Deal. If it proves to be effective and compatible with the system, this new economic policy paradigm can set a positive example for other stakeholders in the global energy network. The decisive factor here will not be the amount of money invested, but rather the stringency of economic and climate policy activity. This will primarily be based on using the markets' ability to self-organise in response to incentives, supplemented by suitable sanctions and controls.

Efficiently guiding the transformation of the energy system with a CO_2 price is only part of the solution. The other part consists in reaching agreement on sharing the burden that this step will entail. Since the CO_2 price will initiate a division of labour in preventing emissions, these efforts will zero in on the cheapest solution. This is desirable, as it means the burdens of transitioning will be kept to a minimum. However, to ensure that all EU member states as well as all sectors and industries pull together with respect to an efficient solution, the conflicts over distribution which are associated with this solution must be resolved. The following alternative approaches are available:

- A sufficiently large proportion of cost savings will be distributed to those countries in which the cost of preventing emissions is low, or political resistance high. Germany will profit from a solution in which German funds are transferred to other member states as long as savings made by the choice of a CO_2 price as an efficient form of prevention are sufficiently high compared to alternative approaches. However, it is difficult to state precisely what the extent of these transfers needs to be.
- If the European CO_2 price is implemented by expanding the European Emissions Trading System, agreement could be ensured via an initial allocation of emissions certificates which for otherwise hesitant member states exceeds their share in European CO_2 emissions.
- The use of funds from the "European Recovery Fund" proposed by Germany and France could be conditional upon agreement to a uniform and comprehensive CO_2 price as a cornerstone of climate policy.

A European strategy for binding agreements on coordinated global efforts aimed at finding a uniform international CO_2 price can draw on several elements:

- The EU should introduce a mandatory, uniform and comprehensive CO_2 price for all sectors, regions, emitters, and technologies in Europe and thus set an example to the world. This would demonstrate that a comprehensive transformation of the energy system can be achieved effectively and affordably, without major social upheaval or an unsustainable loss of competitiveness.

- In line with this objective, the EU should develop and test technologies and approaches designed to reduce the costs of transforming the global energy system. This would simultaneously allow European industry to achieve technology leadership and obtain export opportunities.
- The EU can make adaptation investments in non-EU countries or those countries' access to the European Single Market dependent upon their willingness to introduce a CO_2 price.

Strategically advance changes in European infrastructure

A CO_2 price can help to effectively steer private investments towards defossilisation. On its own, however, it will not be enough to set the necessary major overhaul of the energy system in motion. Targeted public investments and additional supporting measures are also urgently required. In the case of transmission networks, hydrogen infrastructure, charging stations and digital infrastructure, close European coordination is required in order to create a harmonised European energy system. A key part of this process involves striking the right balance between market approaches and the need to quickly develop the infrastructure. Germany should help to coordinate the positions on an EU level and use the present moment to develop a proposal for a European solution.

- The impetus provided by the CO_2 price ought to be complemented by a **strategy for investments in infrastructure** and an **investment programme** in the areas of energy, industry, construction and housing, transport as well as digitisation and other services. Further development of the **EU Structural Funds** can be used to steer infrastructure development in the direction of carbon neutrality.[x]
- Over the next ten years, there will be a **need for reinvestment** of between 30% and 60% in sectors such as the steel, chemical and cement industries. Due to the long service life of the capital-intensive production plants, it is vital to use the period up to 2030 for restructuring, so as not to prevent these sectors from contributing to climate protection targets for the next few decades. Suitable means of support need to be developed and implemented for the temporary or structural economic disadvantages that will arise as a result.
- In addition to infrastructure development in a narrow sense, the strategy should also address **research and development, innovation, diffusion and the adoption** of new low-carbon technologies and their interaction in the energy system.
- Strategic planning should at the very least be oriented towards the goal of a European, and ideally a **global energy transition**. After all, the type and scope of energy imports (including electricity and hydrogen) will determine the necessary course with respect to policy and infrastructure.

Ensure progress through an independent scientific monitoring and advisory commission

The EU should establish a comprehensive monitoring system so as to promptly and precisely evaluate the effectiveness of European energy and climate policy and, if necessary, initiate its readjustment. The central target and unit of measurement should be the remaining greenhouse gas emissions budget (CO_2 equivalents in tonnes per year; see box “premises of this statement”). Monitoring long-term investments and infrastructure is also essential in order to quickly recognise the resulting path dependence and assess it with respect to compatibility with long-term objectives.

- An **independent scientific monitoring and advisory commission** should regularly check the development of total emissions (including of imported and exported goods) and provide a nuanced assessment of the effectiveness of specific strategies and instruments and of the European strategy as a whole.
- A **European energy model forum** could be set up in order to evaluate policy effectiveness and create a shared basis for discussion. On the basis of transparent and freely accessible calculations (open source and open access), the forum would regularly discuss the approaches of the various national and European energy models. This might help to develop a shared understanding of the European energy system and to overcome the focus on national interests.
- In the medium-term, it would be desirable to set up a **global monitoring process**. Globally, there are very different starting positions and requirements, but also varying strategies for approaching the transformation of the energy system. Comparable data and standardised indicators would make it possible to compare ambitions, to evaluate transformation processes and to learn from successful policy models.[xi]

Contributors

Prof. Dr. Antje Boetius, Director of the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research Bremerhaven
Prof. Dr. Harald Bradke, Head of Competence Center Energy Technology and Energy Systems, Fraunhofer Institute for Systems and Innovation Research
Dr. Frank-Detlef Drake, Senior Vice President Strategy & Technology, innogy SE, Essen (in advisory capacity)
Prof. Dr. Ottmar Edenhofer, Director of the Potsdam Institute for Climate Impact Research (PIK)
Prof. Dr. Maximilian Fleischer, Munich (in advisory capacity)
Prof. Dr. Bärbel Friedrich, former Vice President of Leopoldina, Humboldt University Berlin
Prof. Dr. Sibylle Günter, Scientific Director of the Max Planck Institute for Plasma Physics, Garching
Prof. Dr.-Ing. Jutta Hanson, Institute for Electrical Power Systems, Technical University of Darmstadt
Prof. (ETHZ) Dr. Gerald Haug, President of the German National Academy of Sciences Leopoldina (for the Standing Committee)
Prof. Dr. Hans-Martin Henning, Director of the Fraunhofer Institute for Solar Energy Systems, Freiburg i. B.
Prof. Dr. Reinhard F. Hüttl, Vice President of acatech – National Academy of Science and Engineering (for the Standing Committee)
Prof. Dr. Jürgen Leohold, Wolfsburg
Prof. Dr. Andreas Löschel, Chair of Microeconomics with a Focus on Energy and Resource Economics, University of Münster (WWU)
Prof. Dr. Christoph Markschies, President Elect of the Berlin-Brandenburg Academy of Sciences (for the Standing Committee)
Prof. Dr. Karen Pittel, Director of the ifo Center for Energy, Climate, and Resources, ifo Institute – Leibniz Institute for Economic Research
Prof. Dr. Jürgen Renn, Director at the Max Planck Institute for the History of Science, Berlin
Prof. Dr. Dirk Uwe Sauer, Institute for Power Electronics and Electrical Drives, RWTH Aachen University
Prof. Dr. Sabine Schlacke, Institute of Environmental and Planning Law, University of Münster (WWU)
Prof. Dr. Robert Schlögl, Director at the Fritz Haber Institute of the Max Planck Society & Max Planck Institute for Chemical Energy Conversion, Mülheim/Ruhr (Spokesperson of the Working Group)
Prof. Dr. Christoph M. Schmidt, RWI – Leibniz Institute for Economic Research, Essen (Spokesperson of the Working Group)
Prof. Dr. Ferdi Schüth, Director at the Max Planck Institute for Coal Research, Mülheim/Ruhr
Prof. Dr. Indra Spiecker genannt Döhmann, Chair in Public Law, Information Law, Environmental Law and Legal Theory, Goethe University of Frankfurt am Main

Scientific officers of the working group
Dr. Christian Anton, German National Academy of Sciences Leopoldina
Dr. Berit Erlach, acatech – National Academy of Science and Engineering
Dr. Kathrin Happe, German National Academy of Sciences Leopoldina
Johannes Mengel, German National Academy of Sciences Leopoldina
Philipp Stöcker, RWTH Aachen University

About the working group

The results of the Academies' project "ESYS – Energy Systems of the Future" serve as the basis for the present statement. The ad hoc working group "Energy Transition 2030" (German: "Energiewende 2030"), established by the Standing Committee of the German National Academy of Sciences Leopoldina, differs from a standard ESYS working group in two ways: Firstly, all members of the ESYS Board of Directors as well as several members of the ESYS Board of Trustees (as guests) are involved in the group. Secondly, in order to adopt the statement in a timely manner, the ad hoc statement is adopted directly by the presidents of the partner academies which are part of the Standing Committee, rather than in the ESYS Board of Trustees instated by the Standing Committee.

[i] IPCC, 2018: Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above preindustrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland, 32 pp.

[ii] In the understanding of this report, greenhouse gas neutrality means that the balance of greenhouse gases emitted and removed from the atmosphere in the EU would be net zero by 2050. Emission credits bought from other regions in the world are not included.

[iii] In Article 2 (1) of the EU Commission's draft for EU climate regulation (COM(2020) 80 final), the goal of carbon neutrality is defined much more pragmatically as follows: Union-wide emissions and removals of greenhouse gases regulated in Union law shall be balanced at the latest by 2050, thus reducing emissions to net zero by that date.

[iv] Germany has merely "committed to pursuing" the long-term goal of carbon neutrality by 2050 in accordance with Section 1 of the Federal Climate Change Act (KSG), not tying itself to a concrete definition.

[v] For example, at present the Scoping Paper of the Group of Chief Scientific Advisors of the European Commission (2020) forms the basis of a statement due to be published in 2021 by SAPEA – Science Advice for Policy by European Academies on the European Commission's options for action with respect to the European energy transition.

[vi] The report of the Euro-CASE Energy Platform (2019) "Energy transitions in Europe: common goals but different paths" contrasts the different approaches of EU member states to defossilisation and analyses the respective reasons.

[vii] Other greenhouse gases such as methane and nitrous oxide are measured as CO_2 equivalents. One CO_2-equivalent tonne corresponds to the effect on climate that one tonne of CO_2 has over a specific period (usually 100 years).

[viii] Cf. special report from the German Council of Economic Experts "Setting Out for a New Climate Policy" (2019). Wiesbaden, https://www.sachverstaendigenrat-wirtschaft.de/fileadmin/dateiablage/gutachten/sg2019/sg_2019.pdf (As of: 11.06.2020) and acatech/Leopoldina/Akademienunion (2019) and acatech/Leopoldina/Akademienunion (2017) "Coupling the different energy sectors − options for the next phase of the energy transition" and Leopoldina (2019) "Climate targets 2030: Towards a sustainable reduction of CO_2 emissions" compare the advantages and disadvantages of different approaches to CO_2 pricing.

[ix] https://ec.europa.eu/clima/sites/clima/files/factsheet_ets_de.pdf (As of: 11/06/2020).

[x] Cf. acatech/Leopoldina/Akademienunion 2018 "Governance for the European Energy Union". https://energiesysteme-zukunft.de/fileadmin/user_upload/Publikationen/PDFs/ESYS_Stellungnahme_Energieunion.pdf (As of: 11/06/2020).

[xi] Löschel, Großkurth et al. (2018). Establishing an expert advisory commission to assist the G20's energy transformation processes. Economics: The Open-Access, Open-Assessment E-Journal, 12 (2018-12): 1.-12. http://dx.doi.org/10.5018/economics-ejournal.ja.2018-12.