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ALIGNING GROWTH AND CLIMATE PROTECTION

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At a glance

The study "Aligning Growth and Climate Protection" shows that, contrary to what is often claimed, degrowth approaches do not lead to more climate protection. On the contrary: a deindustrialization of Germany or the European Union (EU) would significantly reduce the opportunities to contribute to climate protection worldwide. It is crucial for the success of the transformation that climate protection and economic growth go hand in hand. An effective climate policy can be achieved with the help of appropriate framework conditions, in particular rigorous carbon pricing, complementary government measures and, above all, international cooperation.

Prof. Dr. Veronika Grimm, Dr. Christian Sölch and Johannes Wirth identify the following interrelationships between economic growth and climate protection:

- Decoupling economic growth and CO_2 emissions is possible, but is not yet achieved everywhere in the world.
- Growth and innovation are key drivers for the transition to a climate-neutral economy worldwide.
- Growth enables Germany and Europe to play an active role in shaping global climate protection.
- Deindustrialization is likely to counteract Europe's contributions to climate protection and weaken its growth potential and influence.
- Economic growth is closely linked to people's living standards and secures jobs and tax revenues as the basis of the social market economy.
- Economic growth opens up leeway to cushion social hardships coming along with the climate transformation – a prerequisite for acceptance of the transformation.

Policy needs to set the right course for the transformation of the economy as quickly as possible and thereby prevent deindustrialization, which would have a negative impact on both growth and climate protection. Energy policy must create framework conditions for an affordable energy supply, promote the expansion of central infrastructure (particularly for electricity and hydrogen) and achieve a reduction in critical dependencies through the smart diversification of value chains. In addition, a reliable, transparent and long-term climate policy is required, with effective CO_2 pricing as a key instrument. Climate protection will only succeed both nationally and internationally if growth and climate protection are considered together.

The key to combining growth and climate protection is innovation and technological progress. Germany and the EU are leaders in many climate technologies, but other regions, above all China, are catching up and are often quicker to build up extensive production capacities for key transformation technologies. Investment in research and development and a common European energy and climate policy are essential to secure and further expand Europe's position in key technologies. In view of geopolitical developments, it is also essential to strive for closer cooperation among the western industrialized nations – for example with the USA – despite possible upcoming differences in climate policy.

Ultimately, climate protection can only succeed globally. The transformation requires international cooperation, in which major emitters in Asia and resource-rich countries in Africa and South America play a central role. International climate policy must be further developed – from common goals and unilateral commitments towards joint binding institutions that implement climate protection targets, such as a minimum CO_2 price or binding sectoral agreements. In a climate club, a group of committed countries could initially establish binding standards together. The European border adjustment mechanism could serve as a model to ensure the competitiveness of climate-friendly industries in these countries.

The reorganization of trade and cooperation relationships, which will become necessary due to the climate transformation, enables Europe to respond to current geopolitical changes. Many countries with great potential for renewable energies can also benefit from a reorganization of global value chains. Technology transfer from advanced economies can enable them to build their upcoming growth on climate-friendly energy instead of fossil resources (leapfrogging). Europe, in turn, could be strengthened by diversifying its imports of clean energy and raw materials. In order to take advantage of these opportunities, international trade agreements and climate protection must adopt an approach that is less characterized by rigid principles and instead focuses more strongly on the achievement of joint objectives. A more flexible approach geared towards global realities could help to support global climate goals more effectively and at the same time take into account the economic interests of cooperation partners.

In the final chapter, the authors provide an overview of the key policy recommendations that can be derived from the study:

- Creating a reliable and effective framework for energy markets and climate protection
- Limited and targeted state subsidies to ensure an affordable energy supply and security of supply
- Rigorous reduction of ineffective regulation and bureaucracy
- International climate protection cooperation through joint and binding institutions
- Strengthening growth potential, for example by increasing the volume of work, reforms in the social and education system and better integration of capital markets

Readers who are already well informed and are primarily interested in specific policy recommendations can start reading the final chapter and then selectively read the details of the individual proposals in the earlier chapters, to which reference is made in an overview table. Otherwise, the study is structured in such a way that the knowledge required for understanding is developed gradually in the respective chapters.

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List of abbreviations

AFIR	Alternative Fuels Infrastructure Regulation
BEHG	Brennstoffemissionshandelsgesetz (German Fuel Emissions Trading Act)
BMF	Bundesministerium der Finanzen (German Federal Ministry of Finance)
CBAM	Carbon Border Adjustment Mechanism
CCMT	Climate Change Mitigation Technology
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CDR	Carbon Dioxide Removal
CSRD	Corporate Sustainability Reporting Directive
ct	Eurocent
EEG	Erneuerbare Energien Gesetz (German Renewable Energy Sources Act)
EEM	Expert commission on energy transition monitoring
EJ	Exajoule
EPO	European Patent Office
ETS	Emissions Trading System
EU	European Union
EUR	Euro
GCEE	German Council of Economic Experts
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	Gigajoule
GVA	Gross value added
ICT	Information and communication technology
IEA	International Energy Agency
IPF	International patent family
IRA	Inflation Reduction Act
KTF	Klima- und Transformationsfond (Climate and transformation fund in Germany)
kWh	Kilowatt hour
l	Liter
LCOE	Levelized cost of electricity
LCOLC	Levelized Cost of Load Coverage
MENA	Middle East and North Africa
Mt	Megaton
MWh	Megawatt hour
OECD	Organization for Economic Co-operation and Development
OWID	Our World in Data
PPP	Purchasing power parity
PV	Photovoltaics
RED	Renewable Energy Directive
RGGI	Regional Greenhouse Gas Initiative
SME	Small and Medium-sized Enterprise
t	Ton
TFP	Total factor productivity
TTIP	Transatlantic Trade and Investment Partnership
TWh	Terawatt hour
UK	United Kingdom
UN	United Nations
UOM	Unit of Measure
USD	US Dollar
WTO	World Trade Organization

1
INTRODUCTION

Climate change is one of the most significant challenges of the 21st century and presents the global community with complex and urgent responsibilities. The continuing rise in greenhouse gas emissions (GHG emissions), mainly caused by the use of fossil fuels, is leading to far-reaching changes in the global climate system and threatens not only ecological, but also economic and social stability. In industrialized countries such as Germany and in the European Union (EU), designing effective climate policies is therefore a high priority. Innovative strength and economic dynamics are essential to drive forward the necessary changes in the energy, industry and mobility sectors – both in the EU and worldwide. A more efficient use of resources can also provide new impetus for growth and strengthen competitiveness, which means that the careful use of resources does not contradict economic growth, but on the contrary can promote it.

However, the situation in Germany is particularly challenging, as the economy was already facing structurally weak growth before the coronavirus crisis began in 2020, and the situation has now been further worsened by the recent crises. Against this backdrop, it is important to foster economic growth and at the same time play a leading role in strengthening the global efforts to reduce GHG emissions. One condition for success is that international competitiveness of the European economies is maintained and social inequalities do not increase.

This study examines how Germany and the EU can reconcile their economic and climate policy goals. Chapter 2 first examines the causes and drivers of GHG emissions as well as the global development of relevant technologies, institutions and framework conditions that are of central importance for linking growth and climate protection. Particular attention is paid to the role of technological innovations, suitable framework conditions for their dissemination and international cooperation in the transition to a climate-neutral economy. The availability of climate protection technologies, but also their costs and implementation hurdles, as well as the institutional framework conditions that are essential for the acceptance and success of the transformation are analyzed.

Chapter 3 of the study uses various examples to illustrate that growth and climate protection are not only compatible, but also mutually dependent. In contrast to degrowth theories, which propagate a deliberate shrinking of the economy as a means of climate protection, this study shows that turning away from economic growth is likely to be counterproductive. Particularly with regard to the risk of carbon leakage, i.e., the shifting of emissions by outsourcing production to countries with less stringent environmental regulations, the study underlines the need to actively (but efficiently) shape industrial structural change and to anchor it internationally. It also shows by way of example that a degrowth approach would not be compatible with the fulfillment of state tasks in the areas of social security, education and defense. Such a degrowth approach could therefore hardly serve as a model for successful climate protection in other countries.

In chapter 4, the study outlines how climate protection and growth can be reconciled against the backdrop of the current global framework conditions. Specific recommendations are formulated that address different levels and fields of action. On the one hand, the focus is on options for deepening and strengthening global climate cooperation against the backdrop of current geopolitical developments. In order to effectively pursue common climate goals, it is necessary to establish joint (reciprocal) institutions of communities of states instead of unilateral commitments. In addition, measures for transforming the energy supply in Germany and Europe are outlined, which must be supported by strengthening the institutional framework. In order to secure the necessary resources and financial leeway for the transformation, it is essential to strengthen the production potential in

Germany again. This requires a growth-oriented economic policy based on comprehensive structural reforms in various areas. A sustainable financial policy that ensures the state's long-term ability to act is just as crucial as a credible strategy to mitigate social hardship in order to ensure broad social acceptance for a long-term climate policy.

Chapter 5 summarizes key policy recommendations that show how a coherent and future-oriented climate policy can be successfully designed both from an ecological and an economic perspective. The study treads a fine line due to the comprehensive nature of the topic. In order to shed meaningful light on how growth and effective climate protection are mutually dependent, the scope and complexity can only be reduced to a limited extent: both the global dimension of effective climate protection and competitiveness as well as the importance of key policy areas, such as financial, defense and social policy, must be addressed for a successful European and global energy transition. For this reason, an in-depth examination of the interrelationships in some areas may be appropriate, which was not possible within the scope of the study. In these cases, a systematic attempt is made to provide starting points for a more in-depth discussion by referring to further literature. Where no such literature is available, this should provide an opportunity to shed more light on the connections in future studies and thus make them accessible for public discussion.

2
GROWTH AND CLIMATE PROTECTION:

GERMANY AND THE EU IN A GLOBAL CONTEXT

With the Green Deal, the EU decided in 2019 to achieve climate neutrality by 2050. The German government is even going one step further and has been aiming to achieve this goal by 2045 since the 2021 amendment to the Climate Protection Act (Klimaschutzgesetz). While progress has so far been made primarily in areas where decarbonization was comparatively inexpensive to achieve, future efforts will increasingly focus on sectors in which the mitigation costs – i.e., the costs of reducing CO_2 emissions – are higher and which also have a direct impact on people's lives. Some of these fields of action, such as the transformation of mobility and heat generation, are politically challenging as they pose challenges for private households. Others, such as the transformation of industry, pose particularly great challenges because they will have a decisive impact on the growth potential and therefore also the prosperity of the economy as a whole.

Politicians in many European countries are increasingly focusing on the connection between ambitious climate protection, international competitiveness and economic growth [1], [2], [3]. The global shift in locational advantages (such as relative energy costs) in the course of the transformation to renewable energies will trigger far-reaching structural change within Europe and at the same time alter international trade relations. Germany and the EU are heavily integrated into global supply chains, and imports of energy and raw materials will continue to play a central role, but must be made increasingly sustainable and resilient. Emerging economies, many of which are hoping for a significant increase in prosperity in this century, will have to reconcile their growth targets with sustainable economic activity, both on their own initiative and under pressure from the global community. For developing countries, this transformation offers potentially far-reaching opportunities to benefit from the changes.

2.1 Greenhouse gas emissions

2.1.1 The drivers of GHG emissions worldwide

In order to shed light on the interplay between growth and climate protection, it is first important to look at the global perspective and the various roles of the EU in the global context. A simple method for analyzing GHG emissions is to break them down using the Kaya identity, which illustrates the various factors influencing global emissions through human activity. Figure 1 shows the Kaya identity and assigns the individual influencing factors to the areas of "consumption" and "technology".

Figure 1: Factors influencing GHG emissions – the Kaya identity

$$Emissions = \underbrace{Population \times \frac{GDP}{Population}}_{\text{Consumption}} \times \underbrace{\frac{Energy\ demand}{GDP} \times \frac{Emissions}{Energy\ demand}}_{\text{Technology}}$$

Sources: Own illustration based on [4], [5], [6].

On the consumption side, population growth and rising global prosperity (expressed in the Kaya identity by gross domestic product (GDP) per capita) have an impact on GHG emissions (the first two terms of the Kaya identity). These developments, which are mainly taking place outside Europe, pose considerable challenges, as they influence both the achievement of climate protection targets and the competitiveness of European countries in an international context (cf. e.g. [7]). In addition, global megatrends, such as the sharp increase in energy consumption by data centers and developments in the field of artificial intelligence, are exacerbating these challenges [8], [9], [10], [11]. It is therefore important to analyze precisely in which regions of the world population growth and dynamic economic growth can be expected, whether rents (revenues) from the use and trade of fossil fuels will continue to play an important role there and which political goals and regulations will influence developments. It is also crucial to precisely analyze which levers Germany and Europe can use to enable an efficient interplay between growth and climate protection worldwide and who are possible cooperation partners on this path.

The third and fourth terms of the Kaya identity show the opportunities offered by technological progress. Both the reduction of energy intensity in production (for example through energy efficiency measures) and the reduction of emissions in energy generation (for example by switching to renewable energies) offer potential for climate protection and the competitiveness of European countries. It is important to understand which regions are leading the way in the development and implementation of energy transition technologies and how climate-friendly processes can be made competitive with conventional production processes. Here, too, the global perspective must be taken into account in order to correctly assess the opportunities and risks for Europe.

Figure 2 sheds light on the various components of the Kaya identity (emissions on the one hand and population growth, GDP, energy intensity of production and the availability of renewable and fossil energy on the other) in an international comparison. Figure 2 a) illustrates the development of the shares of energy-related GHG emissions. The EU27 currently accounts for around 7 % (Germany 2 %), India also 7 %, the USA 13 % and China 30 % of global emissions. In the "Announced Pledges" scenario of the International Energy Agency (IEA), which assumes that all climate protection commitments made by governments and industries worldwide are met in full and on time, emissions in the EU, the USA and China are forecast to fall by 2030, while India could see a moderate increase of 5% compared to 2022 [12], [13].

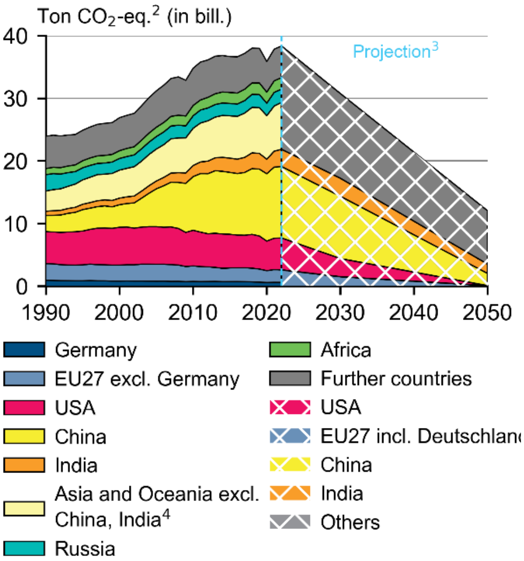
Figure 2 b) shows the expected population development as an important influencing factor. Not only in terms of GHG emissions, but also with regard to the size of markets (for CleanTech or generally as trading partners), it is clear that Asia and, in the future, Africa will also play an important role. Europe's focus as a technology supplier should not only be on these regions due to their market potential, but also with regard to progress in climate protection.

Figure 2 c) shows the development of GDP per capita in the various regions of the world. While the USA and Western Europe have been able to significantly increase their prosperity since the Second World War, the other regions of the world are still in the process of catching up. As GDP per capita increases, the urgency of effective climate protection in these regions is also likely to grow.

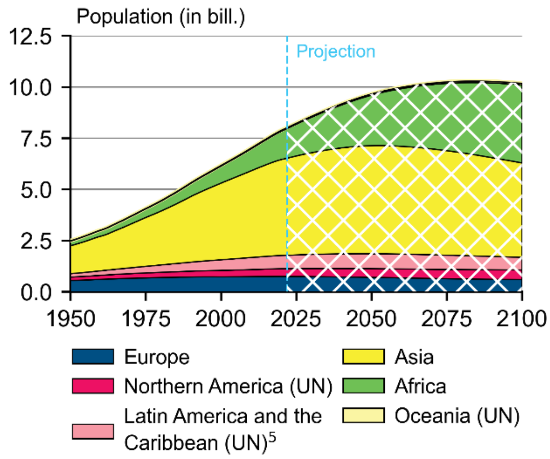
In Figure 2 d), the third term of the Kaya identity – the energy intensity of production – is examined for various regions of the world, thus highlighting the opportunities for avoiding emissions. In the advanced economies, energy intensity has been significantly reduced in recent decades. In emerging and developing countries, on the other hand, it may initially rise with increasing industrialization. The decisive factor here will be how quickly the technology transfer takes place and whether the current level of technology can be leapfrogged in the course of catching up ("leapfrogging" ↘ **Background 2** in Section 2.2.1).

Figure 2: Influencing factors of the Kaya identity

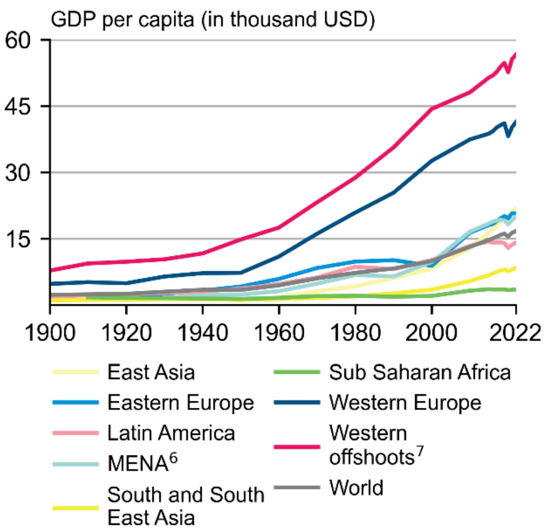
a) Energy-related[1] GHG emissions from 1990 to 2050 (forecast: IEA Announced Pledges)



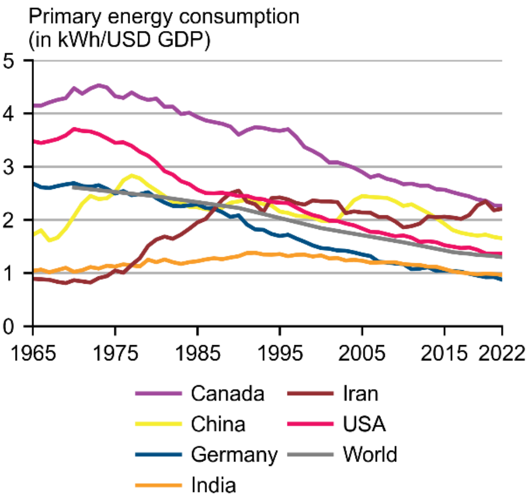
b) Development and forecasts of the world population by region



c) Development of GDP per capita by world region



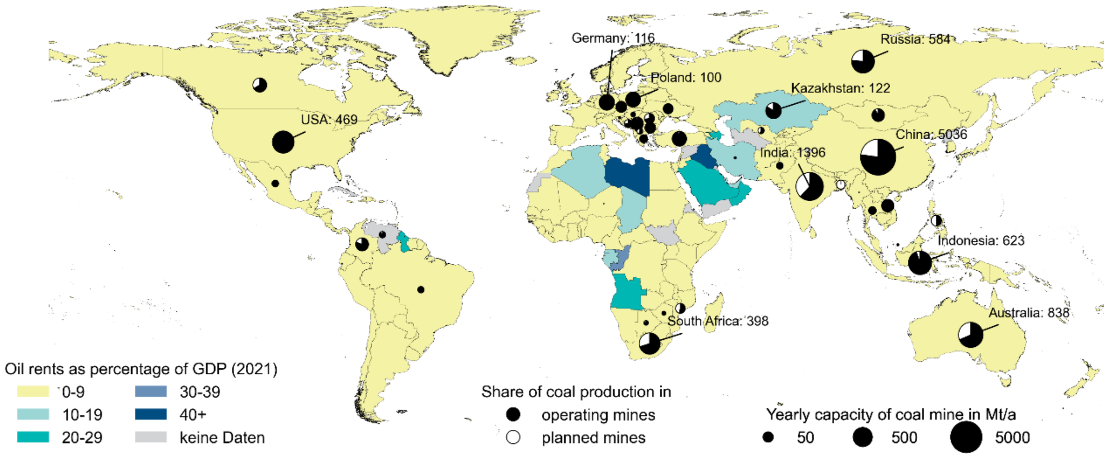
d) Energy intensity of production (selected countries)



Notes: 1 – Includes emissions from the combustion of fossil fuels. Emissions from the LULUCF sector ("Land Use, Land Use-Change and Forestry") are not included. 2 – For better comparability, GHG emissions other than CO_2 are converted into CO_2 equivalents that cause the same global warming over a given period of time. 3 – Projections based on linear interpolation of the IEA's "Announced Pledges" scenario [12]. 4 – includes the regions "OECD Asia Oceania" and "Asia (excl. China)" from [13]. 5 – Classification of regions according to the United Nations (UN). 6 – MENA: Middle East and North Africa. 7 – "Western Offshoots" includes the USA, Canada, Australia and New Zealand.

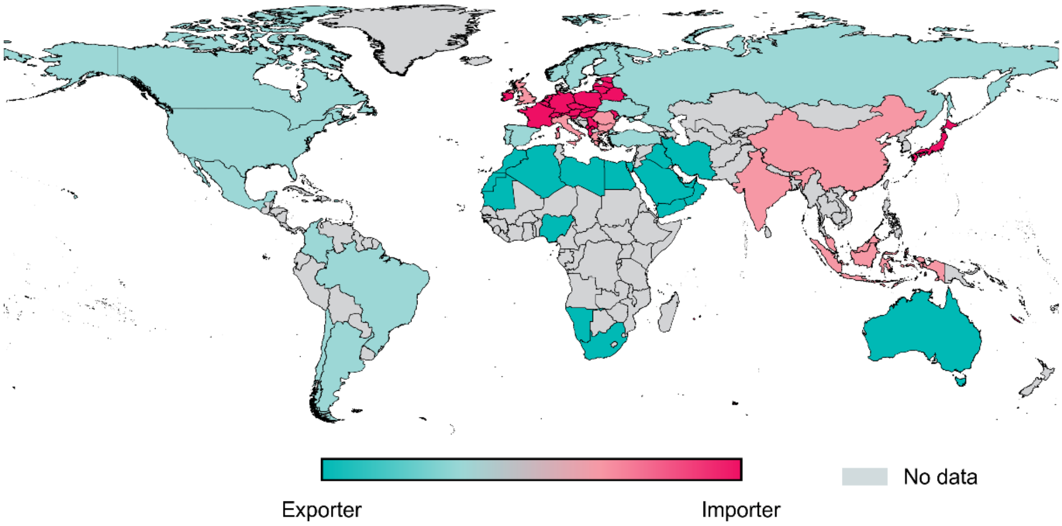
Sources: Own illustration based on **a)** [12], [13] and own calculations; **b)** [14] – edited by OWID; **c)** [15] – edited by OWID. The Maddison Project database is based on the work of many researchers who have produced estimates of economic growth and population for individual countries. The full list of sources for this historical data can be found in [15] and **d)** [15], [16], [17] – edited by OWID.

e) Fossil fuels: oil rents and coal production capacities by country



Sources: Own illustration based on [18], [19], [20]. Country boundaries based on [21].

f) Renewable energy carriers: potential for import and export of green hydrogen and derivatives



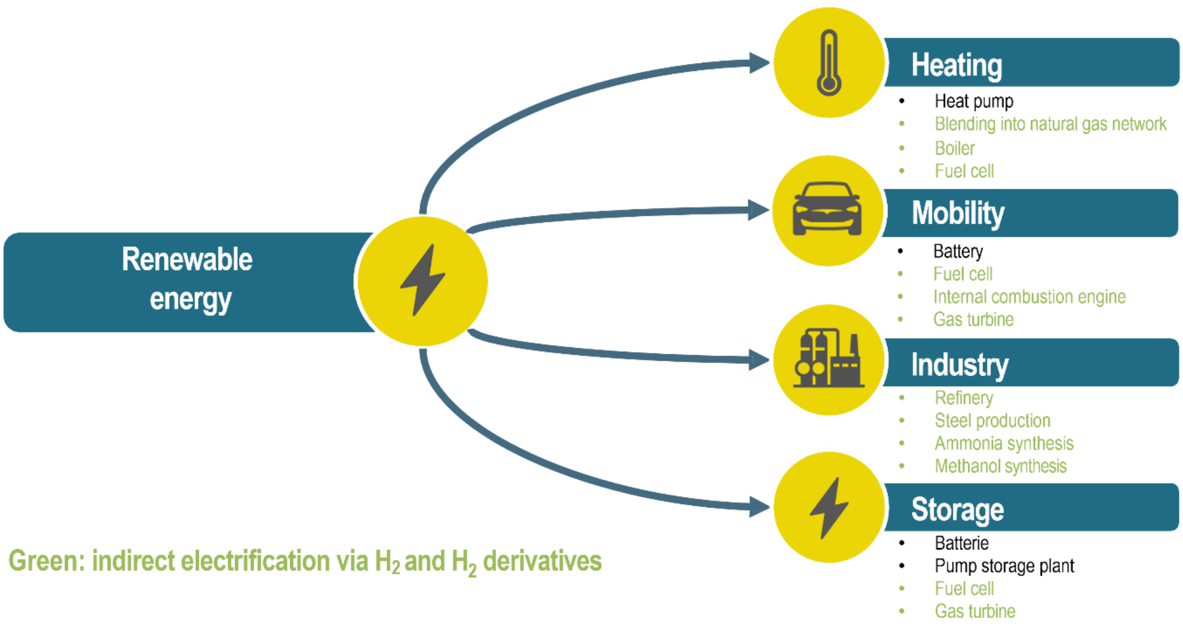
Sources: Own illustration based on [22], [23], [24] and own estimates. Country boundaries based on [21].

Figure 2 e) and Figure 2 f) shed light on the last term of the Kaya identity, which relates to emissions from energy production. Figure 2 e) shows the challenges: Many countries where strong growth is expected today generate high revenues from the sale of fossil fuels. Political decision-makers are often closely linked to the energy sector and new fossil fuel projects continue to be promoted on a large scale. Europe, today a major importer of fossil fuels, is striving to replace these imports with climate-friendly energy carriers. However, as demand from industrialized countries decreases, fossil fuels will increasingly be available to developing and emerging countries. Climate protection can only succeed if the switch to renewable energies becomes more attractive for these countries than the use of fossil fuels, or if technologies such as carbon capture and storage (CCS) reduce the CO_2 intensity of fossil fuels.

Background 1: The role of hydrogen and its derivatives in the future energy system

In order to achieve a completely climate-neutral energy system, direct and indirect electrification is crucial. All consumption sectors - heating, mobility, industry and electricity generation - must be supplied by climate-friendly energy, as shown in Figure 3 schematically. Renewable energies, such as photovoltaics (PV), wind, hydropower or geothermal energy, are at the beginning of the energy process chain. In some countries, nuclear power will also be used for defossilization. Many applications currently supplied by the fossil fuels coal, oil and natural gas can be directly electrified in the future, such as the heating sector through the installation of heat pumps, or private transportation through the use of battery electric vehicles. Other applications, such as in the chemical industry or heavy goods vehicles, cannot be fully electrified directly for technical or economic reasons. In addition, it is difficult (both technically and economically) to store (renewable) electricity in large quantities and for long periods of time, or to transport it over long distances. If direct electrification of energy-intensive processes is not possible or not economical, climate-neutral energy carriers are gaining in importance. These energy carriers are based on climate-friendly hydrogen, which is used either directly or in the form of derivatives such as ammonia, methanol or synthetic fuels. If the hydrogen is produced (directly or as a starting product for derivatives) using renewable electricity by the electrolysis of water, this is referred to as "green" hydrogen. Regions that generate surpluses minus their own demand for renewable energy due to particularly good conditions for renewable electricity generation will be able to export these surpluses in the form of green hydrogen or hydrogen derivatives to regions with less favorable conditions for renewable electricity and thus also hydrogen production.

Figure 3: Direct and indirect electrification



Source: Own illustration.

If nuclear power is used for electrolysis, this is referred to as "red hydrogen". Another option for producing hydrogen is the steam reforming of natural gas, which produces significant amounts of CO_2. The resulting CO_2 can be captured by technical systems during the process and injected underground in suitable storage facilities (CCS), which can achieve a significant reduction in GHG emissions [25]. If the hydrogen is produced by this process route, it is referred to as blue hydrogen. Studies have shown that blue hydrogen can play an important role, especially in the ramp-up phase of a global hydrogen economy, due to its financial attractiveness and faster availability compared to green hydrogen [26], [27], [28], [29], [30]. In connection with blue hydrogen, however, the effective capture and safe injection of the CO_2 is of crucial importance within the climate-neutral transformation [25].

The global potential for renewable energies and the associated production of green hydrogen and its derivatives ↘ **Background 1** is large worldwide, as shown in Figure 2 f) (see also e.g. [24], [31], [32], [33], [34], [35], [36]). In the figure, countries that have considerable potential to export hydrogen in the future are shown in green. It is striking that many countries that have fossil resources are also well placed to export hydrogen and climate-friendly energy carriers. The advanced economies could take this into account in their climate, trade and economic policies. Countries that will have to cover a significant proportion of their future demand for climate-friendly energy carriers (hydrogen and derivatives) through imports are shown in red. Europe, like Japan and Korea, is one of the regions that cannot meet its own demand, unlike the USA, for example. This must be taken into account in all climate, energy and trade policy measures.

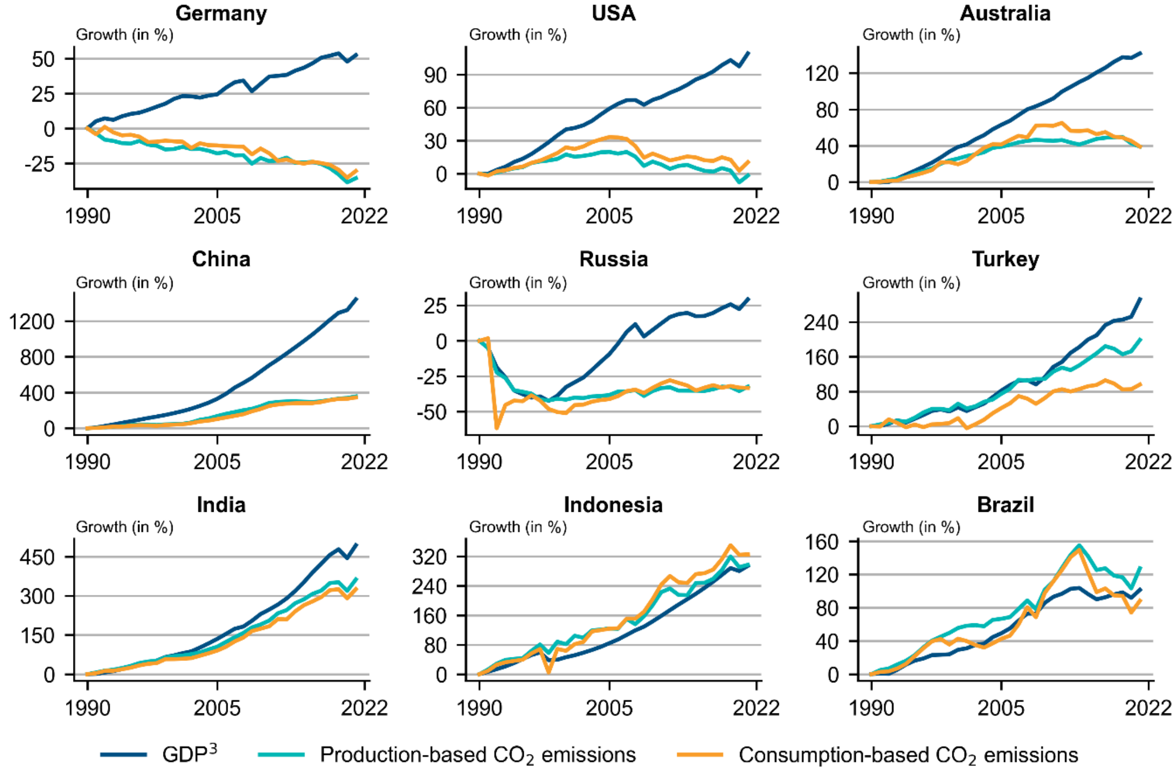
2.1.2 Decoupling growth and emissions possible, but not a reality everywhere

Developments in recent decades show that the decoupling of growth and GHG emissions is possible. In developed economies in particular, emissions have been falling since the 1990s in tandem with economic growth. Other countries, such as China, Russia and Australia, are characterized by emissions growing at a significantly lower rate than GDP. A third group of countries is experiencing similarly strong growth in emissions and GDP.

Figure 4 a) shows examples of some countries from each of the three groups. Figure 4 b) divides the countries into the three categories and shows that some developed economies have already implemented decoupling (green). Other countries are experiencing lower growth in emissions than in gross domestic product (yellow). The red countries in Figure 4 b) have not yet decoupled emissions and growth.

Figure 4: Decoupling growth and emissions successful, but not yet everywhere

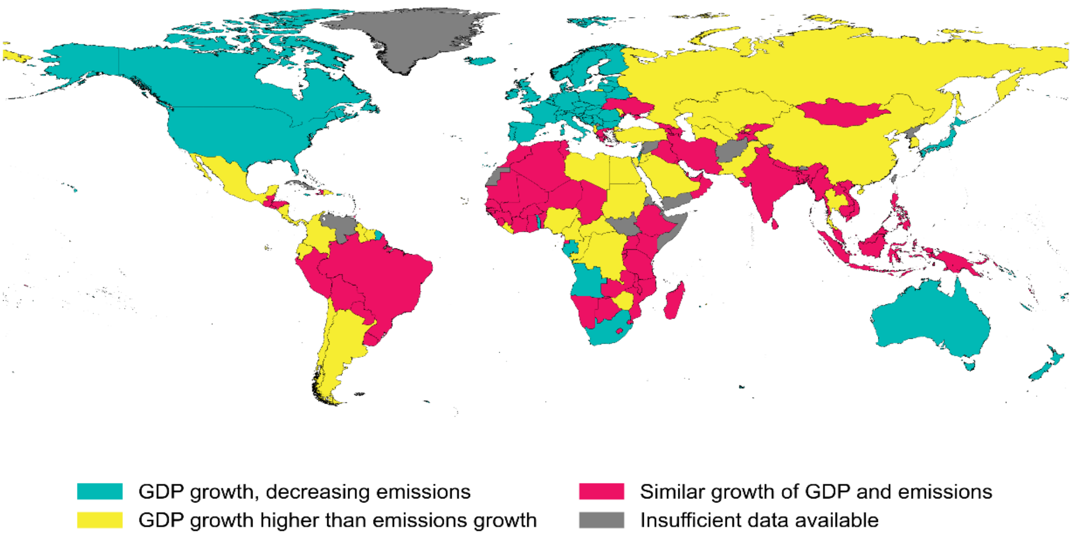
a) Development of economic growth and CO_2 emissions (footprint of production[1] vs. consumption[2]) in selected countries



Notes: 1 – CO_2 emissions that a country causes on its territory through its production – corresponds to the emissions shown in Figure 2 a). 2 – Total direct and indirect CO_2 emissions worldwide caused by the consumption of goods and services in the country in question. 3 – in international dollars (purchasing power parities, PPP, base year 2017).

Sources: Own illustration based on [37], an update of [38], [39] – edited by OWID.

b) Decoupling growth and CO_2 emissions by country



Notes: For the classification, the relative changes in GDP and production-related emissions between 2010 and 2022 were considered. Green: GDP increases while emissions fall; yellow: ratio of emissions growth to GDP growth is less than or equal to 0.66; red: ratio of emissions growth to GDP growth is greater than 0.66.

Sources: Own illustration based on [37], an update of [38], [39] – edited by OWID. Country boundaries based on [21].

2.2 Technologies

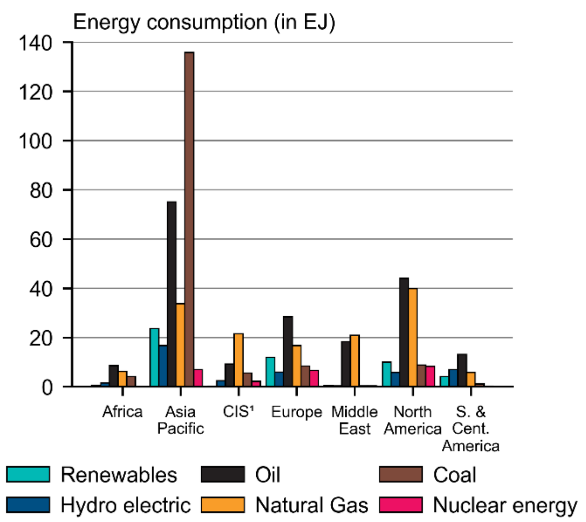
In order to decouple growth and emissions, a global switch to renewable energies or at least climate-friendly energy use and the transformation of industry is necessary. Today, the majority of energy consumption worldwide is still based on fossil fuels. While oil and gas still play a major role in all regions of the world, coal is particularly important in Asia (cf. Figure 2 e) and Figure 5 a)). However, Asia also has the largest increase in renewable energies, which is due in particular to China [40].

2.2.1 Climate protection technologies: Available today, cheaper in the future thanks to progress

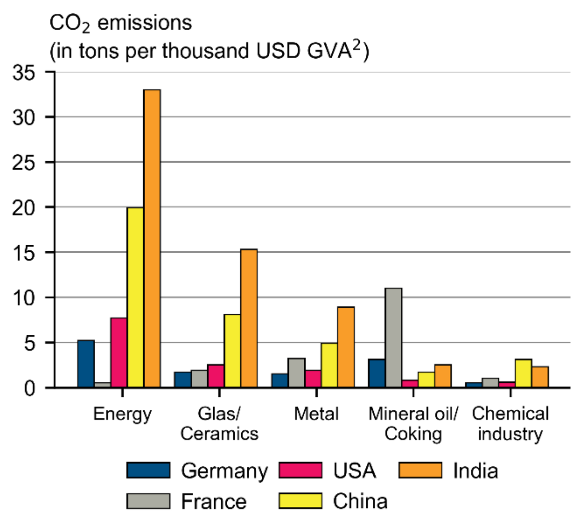
Figure 5 b) illustrates an important channel for decoupling economic growth and GHG emissions. The figure shows the specific emissions intensity, i.e., the amount of GHGs produced per USD 1,000 of gross value added, for various economic sectors and for selected economies worldwide. It is clear that emissions could be significantly reduced in many countries by using technologies that are already available today. For example, the use of technologies already established in Europe today could reduce emissions in India by 70 % and in China by 60 % [41, pp. 390–391]. Currently available or foreseeable technologies could significantly reduce the GHG intensity of production even further. This illustrates that it is not so much technological feasibility that is decisive, but rather the incentives for the continuous further development and use of climate-friendly production methods. It will also depend on how quickly the replacement of emission-intensive plants can be implemented. In order to achieve the climate targets, it must be possible to realize expected growth – due to the large population share, especially in Asia and Africa – on the basis of climate-friendly technologies and, if possible, to leapfrog the current state of the art (“leapfrogging” ↘ **Background 2**).

Figure 5: Importance of technologies for successful climate protection

a) Energy mix by world region



b) CO_2 intensity of production



Notes: 1 – CIS: Commonwealth of Independent States (Russia, Belarus, Kazakhstan, Kyrgyzstan, Armenia, Azerbaijan, Moldova, Tajikistan, Uzbekistan). 2 – GVA: Gross value added.

Sources: Own illustration based on **a)** [16] and **b)** [41], [42], [43].

Background 2: Leapfrogging

Leapfrogging describes the phenomenon when countries or regions skip technological development steps instead of going through them in the order that has historically been the case in industrialized countries. For example, instead of initially relying on fossil fuel technologies as the basis for future growth and gradually replacing them with renewable energies, leapfrogging involves relying directly on modern, low-emission or climate-neutral technologies to achieve growth. This makes it possible to build sustainable infrastructures faster and more cost-effectively. Leapfrogging is a decisive factor for global climate protection, as emerging and developing countries in particular can achieve their desired economic growth with lower emissions. The direct use of advanced technologies can prevent the establishment of additional energy-intensive and environmentally harmful infrastructures on a large scale. This can limit or even prevent the increase in emissions caused by growth in developing and emerging countries.

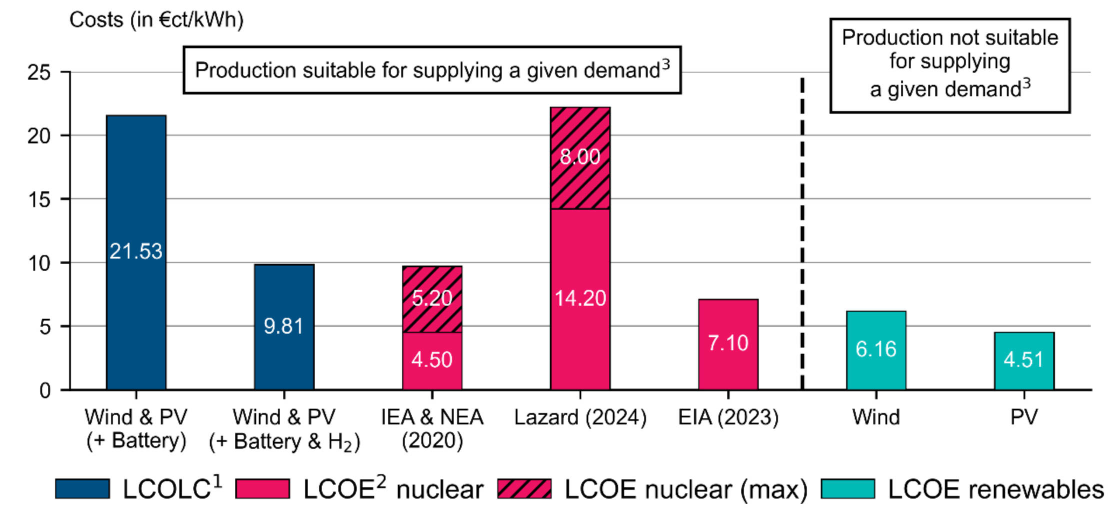
2.2.2 Costs of climate-neutral power supply as a decisive factor

The lower the electricity costs that can be realized with the help of renewable energies, the better the "leapfrogging" of current technologies, some of which are still fossil-based. In this context, it is appropriate to take a closer look at the development of electricity generation costs. The generation of electricity from renewable energies, particularly wind and PV, has become increasingly cheaper in recent years. Current estimates of the LCOE, i.e. the costs for the construction and operation of a power plant in relation to the amount of electricity generated over its entire lifetime, are 3.1 to 5.0 ct/kWh for PV and 3.9 to 8.3 ct/kWh for onshore wind in Germany in 2045 [44]. The LCOE varies greatly depending on the size of the systems, especially for PV systems [44], [45]. Estimates have recently been adjusted upwards due to higher interest rates, and higher raw material prices can also have a significant impact on the expected costs. In particularly sunny regions, such as the Arabian Peninsula, PV electricity can already be generated at a cost of less than 3 ct/kWh [46].

However, wind and PV alone cannot secure the electricity supply in an industrialized country, as their supply is dependent on hours of sunshine and wind. Around the world, various technologies will be used to complement renewables in order to fill the gaps in supply, make use of generation peaks and thus complete the energy mix. It is important to realize that these technologies will often have a larger share of the resulting production costs than the renewable energies themselves. On the generation side, gas-fired power plants, battery storage, flexibility in the electricity system and also nuclear power plants will play an important role in a climate-neutral electricity system, depending on the transformation path of the country in question.

Calculations show that the costs of meeting the demand for electricity in a completely climate-neutral way can vary greatly depending on the technology mix. Estimates in [47] show generation costs of around 10 ct/kWh (excluding grid costs, taxes, levies and surcharges) if hydrogen-powered gas-fired power plants are used as long-term storage and batteries are also used as short-term storage. If the residual load, i.e., the electricity demand not covered by wind and PV, is covered exclusively with previously stored electricity from batteries in an extreme scenario, the average costs of electricity generation increase significantly (cf. Figure 6).

Figure 6: Comparison of electricity production costs



Notes: 1 – LCOLC – Levelized Cost of Load Coverage: the minimum cost (in ct/kWh) of meeting a given electricity demand, taking into account the investment and operating costs of all technologies required in the minimum power plant mix (e.g., wind, PV, batteries, gas-fired power plants, etc.). 2 – LCOE – Levelized Cost of Electricity: the average cost of generating electricity (in ct/kWh) by a specific technology, whereby the investment and operating costs of the specific technology (wind, PV) are broken down to the average cost per kWh. 3 – To calculate the LCOLC values shown, a constant demand over all periods was assumed. The calculations for covering a demand following the standard load profile lead to similar results with regard to the comparison of the technologies used, see [47], [48].

Sources: Own illustration based on [47], [49], [50], [51].

In some countries, nuclear power will play an important role in the transformation. Existing estimates of the production costs (without taking into account the perpetual costs for the final storage of nuclear waste and the costs of insurance against a nuclear accident, which are not priced in) are in the best case below the costs of a system of renewable energies and hydrogen-fired gas-fired power plants, and in the worst case significantly above (cf. Figure 6). Due to their generation profile, nuclear power plants will not supplement renewables, but will cover a proportion of demand, meaning that a smaller proportion of demand will have to be met by renewables and complementary power plants.

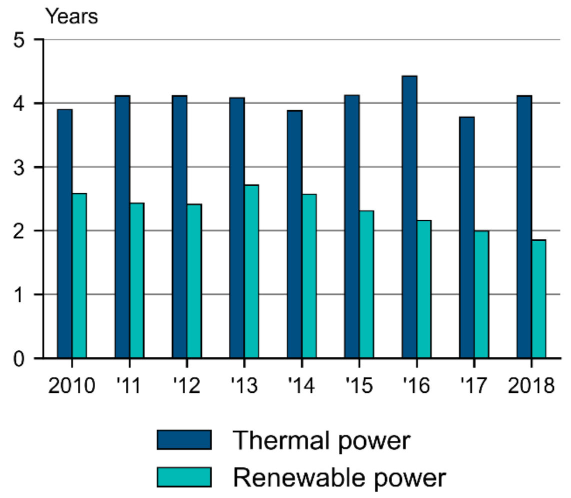
In addition to the conversion of generation to climate-neutral generation technologies, extensive investments in transportation grids for electricity and hydrogen are required. The necessary investments at transport and distribution grid level differ depending on the structure of generation and consumption. A more decentralized electricity system with many small feed-in points requires more extensive grid expansion, especially at the distribution grid level, and comprehensive digitalization that enables coordination of the many decentralized players. Although the expansion of renewables primarily at particularly high-yield locations reduces their production costs, it increases the need for transport grids to transport the electricity to the consumption centers. Grid expansion could therefore be lower and therefore more cost-effective if an attempt is made to take the necessary grid expansion into account when transforming the generation mix [52], [53], [54].

2.2.3 Lack of production capacities and long completion times for plants

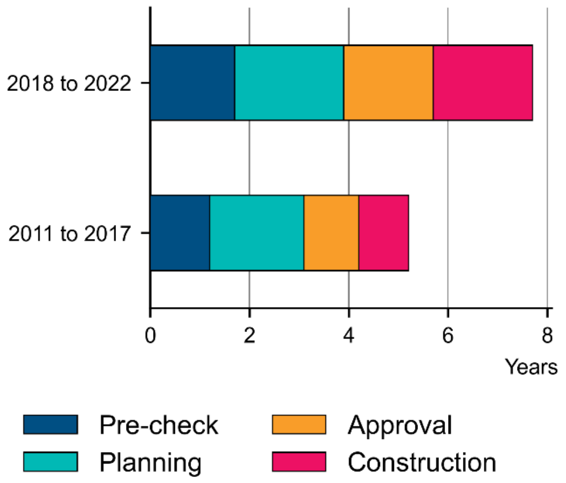
Considering the time required to build up capacity is not only crucial in order to avoid unnecessarily high costs. It is also a prerequisite for success due to the limited production capacities for new systems and the long completion times.

Figure 7: Barriers to the energy transition

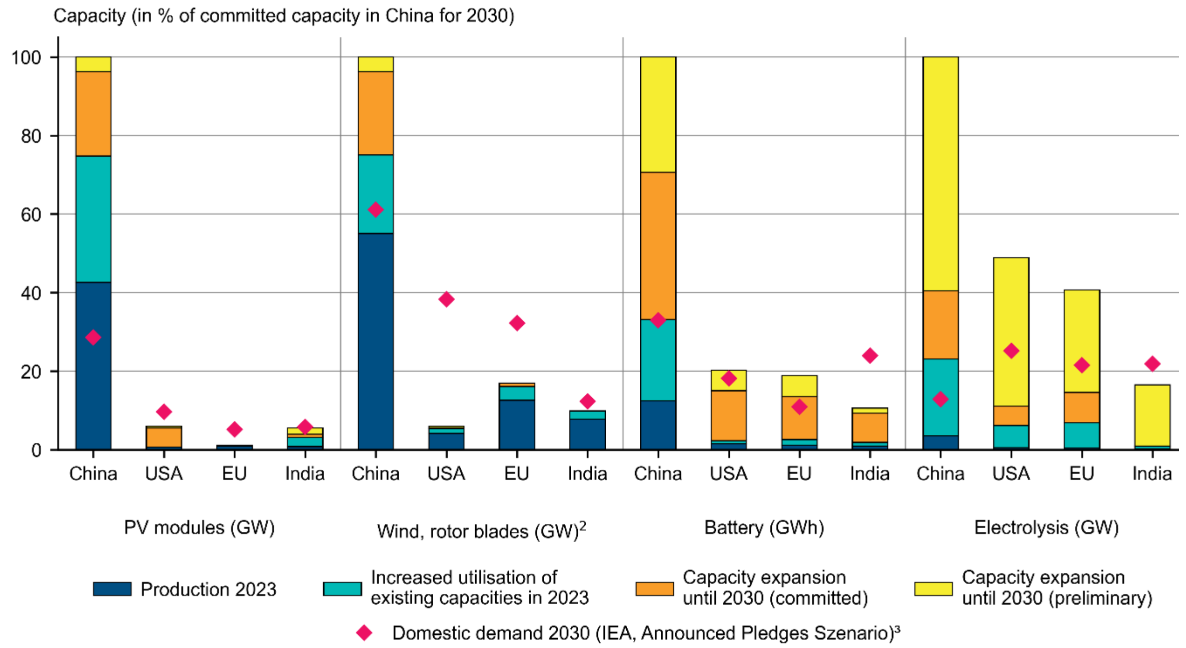
a) Average construction time[1] of electricity generation (capacity-weighted), 2010-2018



b) Duration of wind project development in Germany



c) Installed and planned production capacities for energy transition technologies



Notes: 1 – The construction period (worldwide, IEA data) is measured as the time between the final investment decision and commissioning. 2 – For wind turbines, the IEA reports separate values for rotor blades, towers and nacelles, with comparable trends between regions for all three components [55]. 3 – The red dots refer to the forecast demand for the respective technology in Germany in 2030 according to the IEA's 'Announced Pledges Scenario'.

Sources: Own illustration based on **a)** [56]; **b)** [57] and **c)** [55].

Today, the completion of a renewable energy plant takes around two years from the start of construction to completion, while the completion time for a thermal power plant is more than four years (cf. Figure 7 a)). The construction times for nuclear power plants and grid capacities are significantly longer. The projects are often delayed by several years compared to the original planning due to planning and approval procedures as well as acceptance problems among the population (cf. [23, Ch. 3.4.2]). Added to this are the significant times required for the application and approval of construction projects, particularly in Germany (cf. Figure 7 b)). In recent years, various laws have been passed to speed up and simplify procedures at national and European level, although it will only be possible to assess their effectiveness in the coming years.

On the one hand, achieving the climate targets therefore only seems possible if the transformation path does not overstretch the realistically available production capacities for plants - worldwide. On the other hand, a consistent and predictable climate policy must ensure that sufficient additional production capacities are built up. This is currently being achieved to a greater extent in Asia than in Europe and the USA (see Figure 7 c)). If Europe wants to compete for global markets and also establish production capacities for its own transformation in strategically important areas, it is important to adapt the ramp-up of production capacities to its own level of ambition by strengthening the corresponding framework conditions.

2.2.4 Innovative strength and capital markets as important growth drivers

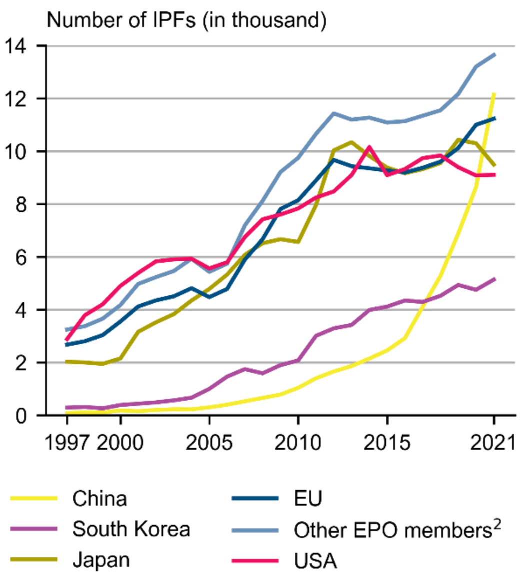
Europe, and Germany in particular, has various locational advantages with regard to the development of production capacities in the clean tech sector. Research at universities is a world leader in many technologies relevant to the energy transition and is closely interlinked with the numerous applied research institutes and industry.

A large proportion of patents relevant to the energy transition are therefore in the hands of domestic companies (cf. Figure 8 b)). Here too, however, China has caught up rapidly in recent years (Figure 8 a)). Not only the number, but also the quality of patents plays a decisive role when it comes to gaining or maintaining a competitive advantage. However, it is particularly important whether the technologies protected by these patents can be established as international standards. The more widespread and established a product or technology becomes, the more valuable the associated patent becomes. This is why Asian companies and the governments are specifically involved in standardization committees to ensure that their technologies become the global benchmark.

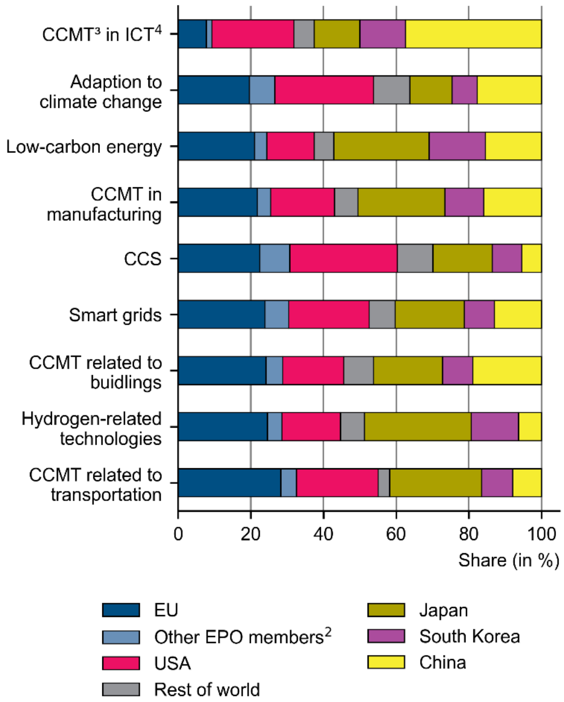
In order to make research and development results usable for new value creation in CleanTech, framework conditions are also required that incentivize investment in start-ups and financing in the growth phase. The framework conditions must first ensure that the corresponding business models are profitable so that financing via banks or the capital markets is possible at all. In addition, deep and efficient capital markets are of great importance. In Europe, for example, the diversity of national and sometimes even regional regulations as well as the diversity of languages means that available capital cannot be put to the best use and is not available to innovative players in the CleanTech sector in particular [58].

Figure 8: Innovative strength through patents

a) Trends of international patent families[1] in the CleanTech sector, 1997–2021



b) Region-specific share of patents in the field of "clean & sustainable technologies", with first publication in the years 2017–2021



Notes: 1 – An international patent family (IPF) is a group of patent applications relating to the same or similar technical content. The applications of a family are linked by priority claims (which allow the filing date of an earlier patent application to be claimed for subsequent international applications) (cf. [59]). 2 – Other European Patent Office (EPO) member states include Albania, Switzerland, Iceland, Monaco, Montenegro, North Macedonia, Norway, Serbia, San Marino, Turkey. 3 – CCMT: Climate change mitigation technologies. 4 – ICT: Information and communication technology.

Source: Own illustration based on [60].

2.2.5 International division of labor and cooperation remain important

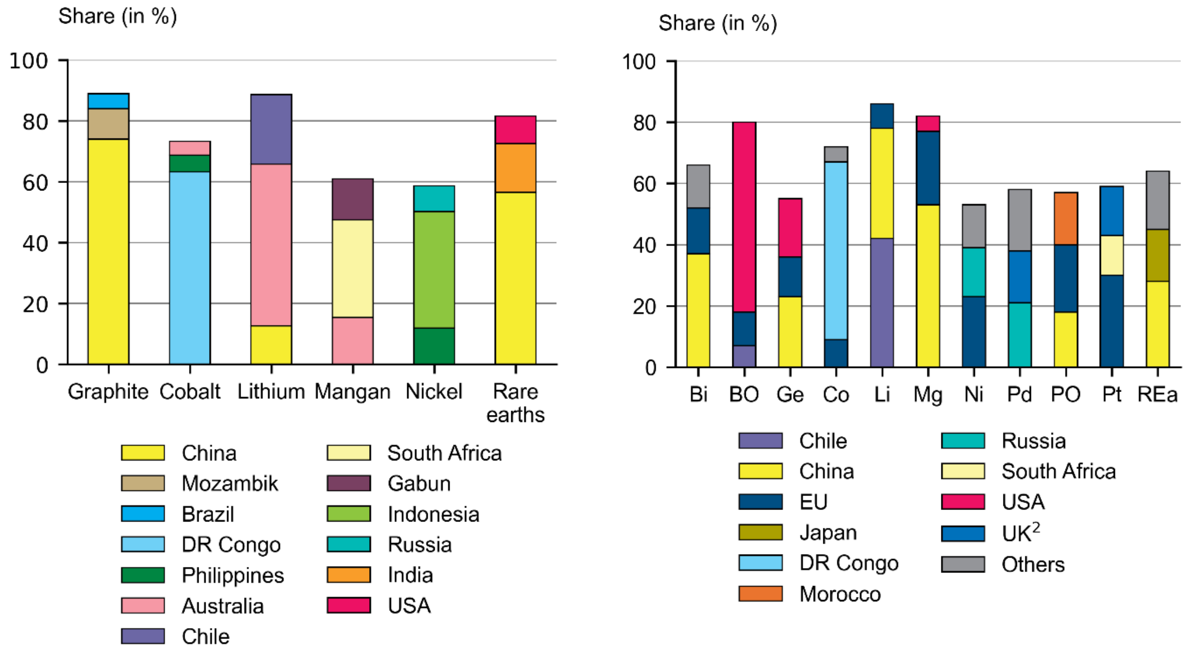
Not every technology that is developed in Europe and initially produced in small volumes can ultimately be transferred to mass production locally. Depending on the production process, other countries around the world may have comparative advantages, with the result that the international division of labor ultimately makes Europe a net importer of products that are important for the energy transition. We are already seeing this today with PV modules, heat pumps and, increasingly, battery electric vehicles. The discussion as to whether industrial policy is needed to keep production capacities in Europe or bring them back is omnipresent. It is a challenge – not least due to the numerous interest groups – to recognize where there are good arguments for state intervention and where this is not the case.

In order to create the conditions for climate-friendly industrial value creation in Germany and Europe, it will be necessary to switch to climate-friendly energy carriers. The necessary speed of the conversion of energy imports represents both a challenge and a prerequisite for success. It will be crucial to negotiate wisely with existing exporters of fossil fuels as well as potential suppliers of renewable energy carriers. Today's energy exporters are threatened with significant losses in income from the fossil energy business, which could potentially jeopardize political stability and trigger conflicts. For countries with pipeline connections to Europe in particular, negotiation solutions are therefore required that take into account the opportunities and risks for the regions affected [61]. On the other hand, with regard to climate protection, it is clear that countries with fossil resources will find customers who also want to promote their growth and prosperity on the basis of fossil fuels (cf. [41] and Figure 2). Countries that have great potential for renewable energies, but have not been among the energy suppliers to date due to a lack of fossil resources, often do not have the necessary infrastructure for energy transportation. They are also often not in a financial position to develop structures on their own.

Figure 9: Extraction and processing of strategic raw materials

a) Share of the largest producing countries for critical raw materials in global demand, as at 2019

b) Share of the three largest exporters in global exports of processed raw materials[1], as at 2020



Notes: 1 – Bi-bismuth, BO-borates, Ge-germanium, Co-cobalt, Li-lithium, Mg-magnesium, Ni-nickel, Pd-palladium, PO-phosphates, Pt-platinum, REa-rare earths. 2 – UK: United Kingdom.

Sources: Own illustration based on **a**) [62] – edited by EEM and **b**) [7].

In addition to traditional energy carriers, non-energy raw materials will also play a key role in the transformation to a climate-neutral energy system in the future. These so-called critical raw materials are indispensable for the production of the technologies required for a climate-neutral energy system, such as PV systems or electrolysers. In the future, their importance for the energy industry will be similar to that of traditional energy carriers. Figure 9 a) shows which countries have the largest share in the production of these raw materials. It is striking that the three largest producing countries account for at least 60 % of global production of each resource. In addition, mining mainly takes place in countries of the global South and in Asia. The processing of strategic raw materials is also of crucial importance (see Figure 9 b)). There is also a strong concentration of activities here, particularly in China, which has deliberately invested in the establishment of processing facilities in recent years.

The high market concentration and limited availability of strategic raw materials along the value chain pose a risk to the success of the energy transition. In view of the expected increase in demand and the resulting surplus, prices for these raw materials are expected to rise. If global production cannot be increased sufficiently in the short term, this could also lead to a slowdown in the progress of the energy transition [7], [23, Ch. 6.3]. As the relevance of this issue has also been recognized by politicians, strategies and guidelines have been adopted at both national and European level to ensure the availability of critical raw materials [63], [64] which also focus on strengthening domestic extraction and processing. The scientific community is calling for an even greater diversification of trade relations and a focus on partnerships with like-minded countries, e.g. in the field of rare earths, which Germany currently purchases from only two of the world's five largest exporters [65], [66]. This can reduce dependence on China in particular.

2.3 Institutions

2.3.1 Global climate cooperation – first steps have been taken

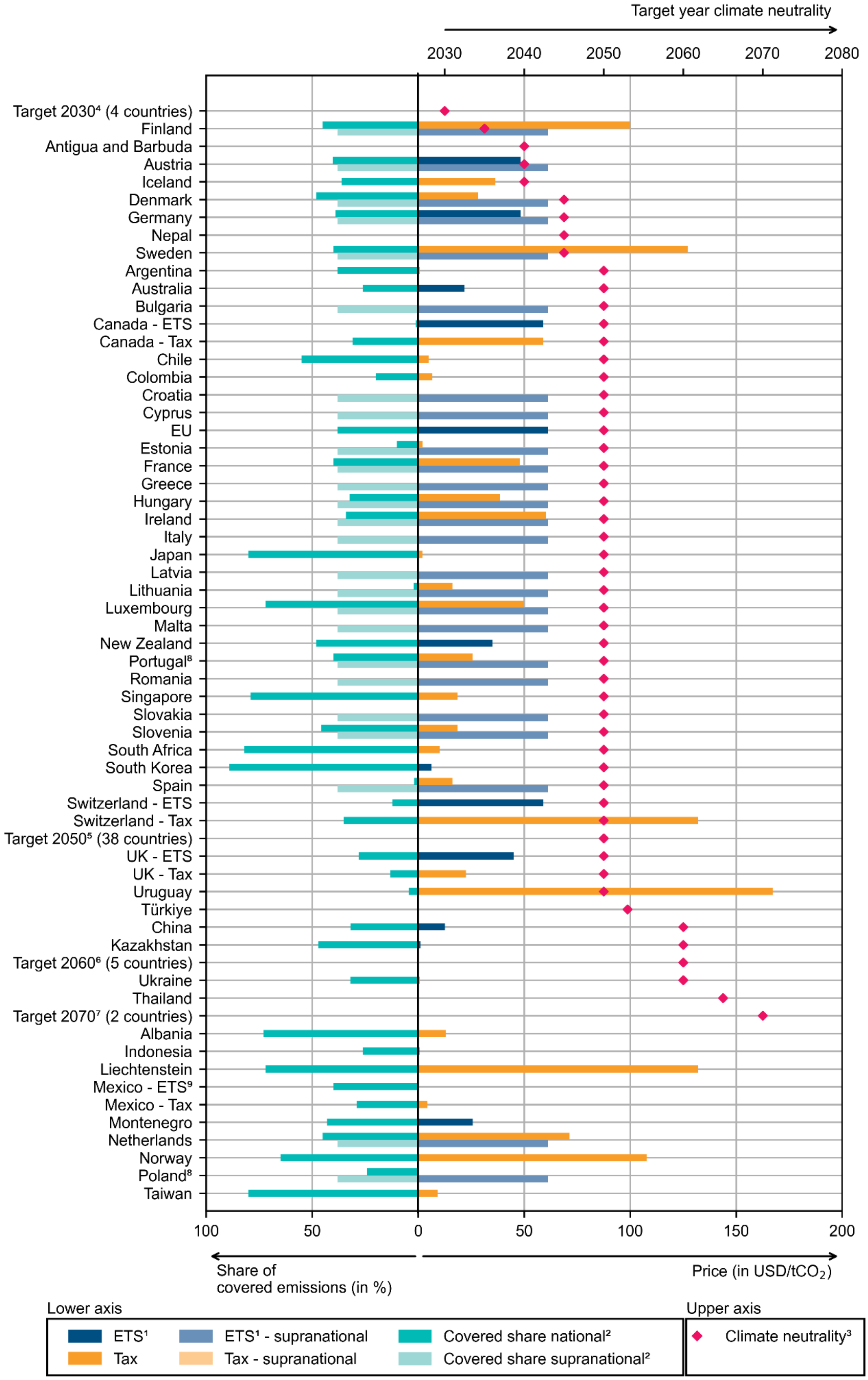
As both the future growth of populous economies and megatrends such as artificial intelligence will increase the hunger for energy in the future, global cooperation in climate policy is crucial for success. Negotiations have been taking place at global climate conferences since 1992, with repeated breakthroughs that are nevertheless not yet sufficient. The commitments made to date are still insufficient to curb global warming at a sufficient pace [67].

Since all major economies will be extensively affected by the effects of climate change, there is potential for cooperation, although this is repeatedly limited by political realities and current debates [41]. Figure 10 a) illustrates that many countries around the world have already defined climate neutrality targets. Most countries worldwide have committed to the year 2050. However, some populous economies are not planning to achieve climate neutrality until later, such as China (2060) or India (2070).

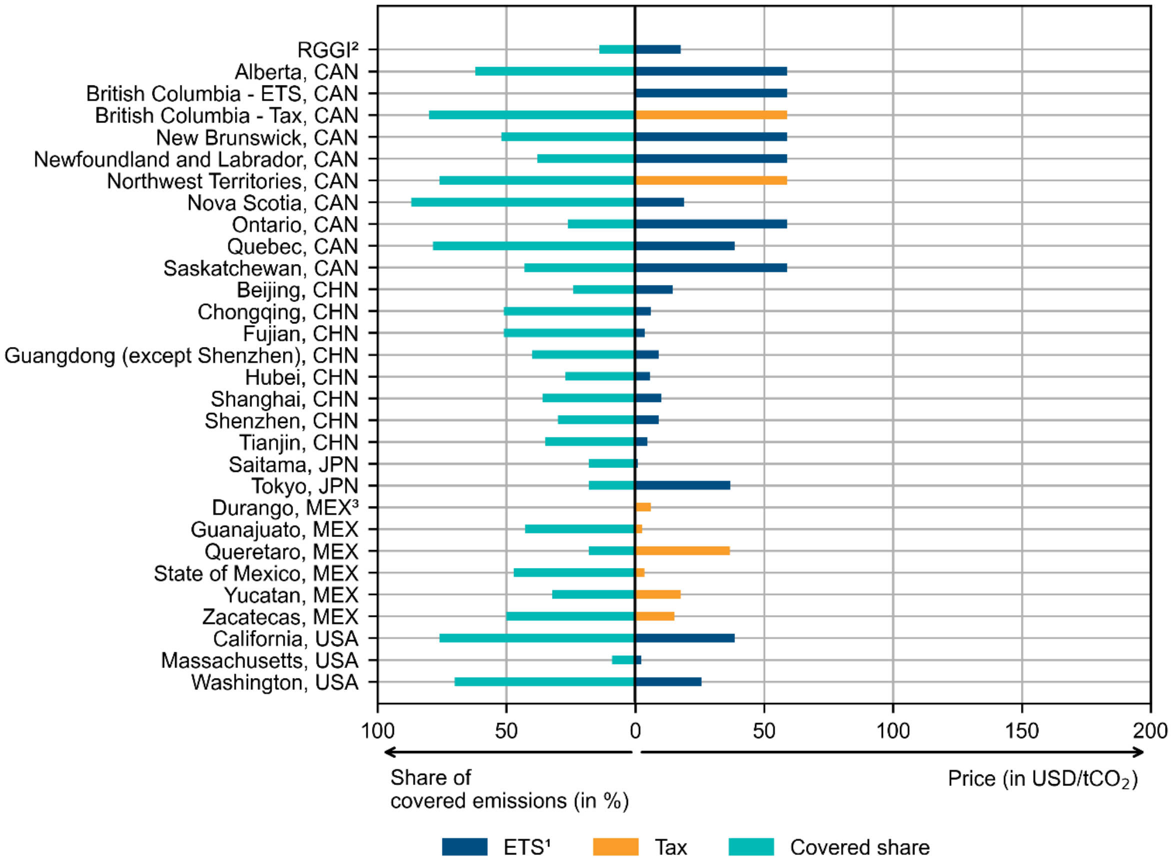
On a positive note, a large number of countries have already implemented emissions trading or carbon pricing. Although not all emissions are generally covered, a significant proportion is covered in many countries. Prices also vary, in many economies they are around USD 50/tCO_2, but often even lower. In both China and the USA, various states have set up their own, more or less ambitious emissions trading schemes (see Figure 10 b)). Regardless of whether emissions trading or CO_2 pricing in the form of a tax has been established, these mechanisms offer the prospect of emissions in various sectors of the respective countries being recorded with increasing reliability. This opens up potential for cooperation, regardless of whether the prices still differ.

Figure 10: Overview – Climate targets and existing GHG pricing systems

a) GHG pricing (tax or emission trading system), coverage of emissions and climate targets by country, as of 01.04.2024



b) Regional CO_2 pricing (tax or emission trading system) and coverage of emissions, as of 01.04.2024



Notes 10 a): The chart only includes countries or higher-level institutions, not federal states, regions or similar. It only contains pricing systems from [68] with the status "Implemented". Countries sorted from top to bottom by climate neutrality target year and name. Countries with a target year for climate neutrality but no pricing system are listed in groups.

1 – ETS: Emissions trading system. Prices are current prices as at 01.04.2024. 2 – Shares refer to national or supranational total emissions. 3 – Climate neutrality includes the following targets from [69]: "Carbon negative", "Carbon neutral(ity)", "Climate neutral", "Net Zero", "Zero carbon", "Zero emissions". Chart only contains climate neutrality targets with the status "Achieved (self-declared)", "Declaration / pledge", "In law", "In policy document". 4 – 7 – Target 20X0: Countries with the same target year without national pricing of CO_2 emissions. 4 – Target 2030: Barbados, Bhutan, Dominica, Maldives. 5 – Target 2050: Ethiopia, Andorra, Armenia, Belize, Brazil, Costa Rica, Cambodia, Cape Verde, Comoros, Dominican Republic, Ecuador, Fiji, Gabon, Gambia, Georgia, Guyana, Laos, Lebanon, Liberia, Malaysia, Marshall Islands, Micronesia, Monaco, Namibia, Oman, Panama, Papua New Guinea, Peru, Solomon Islands, Sri Lanka, Suriname, Tonga, Tunisia, Tuvalu, Vanuatu, United Arab Emirates, United States of America, Vietnam. 6 – Target 2060: Bahrain, Kuwait, Nigeria, Russia, Saudi Arabia. 7 – Target 2070: Ghana, India. 8 – As of 2023. 9 – No price data available for the ETS in Mexico.

Sources 10 a): Own illustration based on [68], [69], [70].

Notes 10 b): 1 – Emissions trading system. 2 – RGGI (Regional Greenhouse Gas Initiative) is a coalition of the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont. 3 – No coverage data available for the tax in Durango, MEX.

Sources 10 b): Own illustration based on [68], [69], [70].

2.3.2 The key to success: joint institutions

In recent years, various initiatives have been launched that do not yet constitute joint institutions, but could serve as the basis for a Climate Club ↘ Background 3. The G7 and G20 in particular have increasingly put the topic on the agenda. At the initiative of the G7, an initiative for a Climate Club was launched in 2022, which now includes over 40 countries together with the G7 states and the EU Commission (as founding members) [71], [72], [73], [74], [75]. One of the aims of the Climate Club is to limit the risks of relocating production to countries with less stringent climate regulations. So far, fields of action have been defined within the framework of the Climate Club, but these have not yet been underpinned by joint commitments or institutions. Harmonization of the CO_2 pricing mechanisms is not currently on the agenda. Therefore, an instrument for CO_2 border adjustment is necessary for the transitional period until similarly effective and binding emission reduction instruments have been established for economic entities in all member states of the Climate Club, as well as for trade with countries outside the Climate Club.

Background 3: Climate Club

A Climate Club is a group of countries that voluntarily join forces to jointly implement ambitious measures to reduce GHG emissions. The aim of such an alliance is to implement reliable emission reduction pathways by creating common rules, standards and incentives, thereby helping to limit the rise in global temperatures. Cooperation could take place in emissions trading or direct or indirect CO_2 pricing, or in sectoral agreements (e.g. the establishment of lead markets for sustainable steel and cement [75]). In contrast to global climate agreements, which often represent weaker compromises, a Climate Club offers the opportunity to bundle the activities of pioneering countries in order to pursue ambitious targets and at the same time take measures vis-à-vis non-members to avoid the relocation of GHG-emitting industries to countries with less stringent requirements for GHG emissions. In this context, the term "carbon leakage" is used, as in this case the emissions are not mitigated by the strict requirements, but only shifted. These measures against non-members of the Climate Club, also known as border adjustment mechanisms (see ↘ Background 4), are intended on the one hand to prevent the relocation of emissions-intensive industries to countries with less stringent climate regulations. On the other hand, if cleverly designed, they can create an incentive for non-participating countries to also participate in climate policy measures (cf. [76]).

Despite this progress, there are still considerable challenges on the way to a functioning Climate Club. One of the biggest hurdles is the fair design of sanctions against non-members. Countries that are not part of the club could be burdened by import tariffs or other trade barriers, which could lead to political tensions and economic upheaval. Countries in the Global South in particular, which have difficulties reducing their emissions quickly due to limited financial and technological resources, could be disadvantaged. In addition, compatibility with the rules of the World Trade Organization (WTO) is questionable, especially as long as the actual carbon footprint of products cannot be priced due to the lack of a uniform recording system.

Another problem lies in the harmonization of climate protection measures. Different political and economic interests of the potential members of a Climate Club make it difficult to set common standards. While the EU, for example, sees a high CO_2 price as an effective instrument, this could meet with resistance in other countries as they have different economic structures and energy dependencies. In addition, the club's rules must be compatible with existing global trade agreements such as the WTO, which poses further legal and diplomatic hurdles.

After all, global acceptance and participation is crucial for the success of a Climate Club. A club consisting of only a few industrialized nations might not have enough influence to significantly reduce global emissions. The challenge is to get both emerging and developing countries on board and provide them with financial, technical and structural support to achieve their climate goals without jeopardizing their economic development.

3
DEGROWTH

DOES NOT LEAD TO MORE CLIMATE PROTECTION

Time and again, the discussion arises as to whether emissions can be sustainably reduced by reducing (emissions-intensive) production and consumption. Reference is often made to experiences from the recent past: during the coronavirus crisis, for example, as the restriction of consumption options due to lockdowns led to a significant reduction in global emissions (cf. Figure 2 a)). During the energy crisis, the (gas) shortages led to higher prices for fossil fuels and increased energy efficiency [77], [78], [79], [80] but also to a reduction in energy-intensive production in Europe and especially in Germany (cf. [81, Fig. 17]). This also significantly reduced emissions, which is why the climate targets were achieved in the industrial sector in 2022 [82]. Do these developments indicate that "degrowth" could be an answer to climate change?

The analysis in Chapter 2 of the study makes it clear that such a "degrowth" strategy must be evaluated against the backdrop of global developments. Germany and Europe only have direct influence on national or European decisions. The behavior of other countries can only be influenced by international negotiations, the results of which depend on common goals (e.g. climate protection), negotiating power (e.g. due to economic strength or dependencies) and the extent of unilateral efforts or offers by individual actors (e.g. financial benefits or technology transfers).

3.1 Deindustrialization and carbon leakage

Firstly, the example of energy-intensive industry will be used to illustrate why the regulation associated with the climate targets can be counterproductive for climate protection if the availability of climate-friendly energy is not ensured in a timely manner.

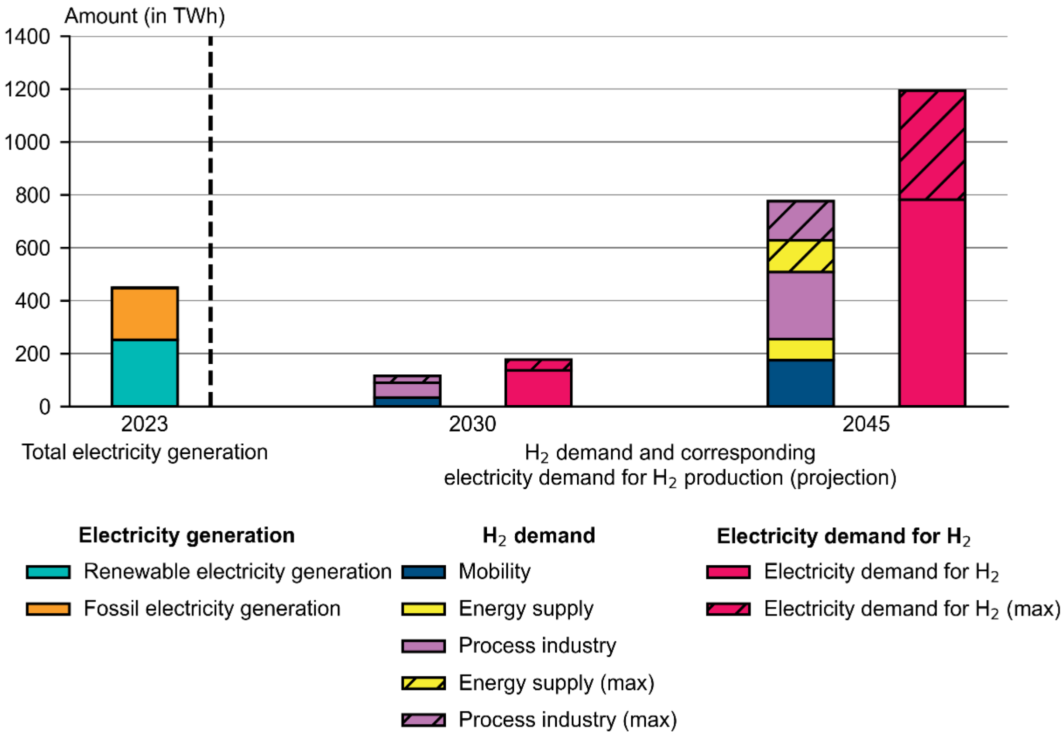
3.1.1 Without imports of climate-neutral energy: Industrial relocation and carbon leakage

The energy-intensive industries that are particularly difficult to transform – steel, parts of the chemical industry, cement, lime, glass and paper – are facing major challenges at their locations in Germany and Europe. Time and again, the debate arises as to whether and how these sites can or should be preserved. Under the current climate targets of the EU and Germany, production must be converted to climate-neutral energy carriers in the next twenty years if it is to be maintained in the EU. Due to the long investment cycles, this is a very short period of time.

With its hydrogen strategies [83], [84], [85] and other economic policy measures the German government is focusing on keeping some of the energy-intensive production in the country. Since the energy-intensive industries cannot completely replace fossil raw materials through electrification – for example because the necessary temperatures are too high or fossil gas or oil must be replaced as a raw material – climate-friendly hydrogen and derivatives based on it are needed [31] (see ↘ **Background 1**). The German government's hydrogen strategy assumes a demand of between 95 and 130 TWh of hydrogen per year for 2030, while the estimated demand for 2045 is between 360 and 500 TWh of hydrogen per year, plus 200 TWh of hydrogen derivatives [85]. Figure 10 shows the quantities of hydrogen required and the electricity generation required for this if the hydrogen is produced by electrolysis (green hydrogen ↘ **Background 1**). The figure also shows (far left) the current electricity generation in Germany, around half of which comes from renewable energies.

The numbers impressively illustrate why Germany (and large parts of the EU) will be net importers of hydrogen and derivatives in the medium term (see also Figure 2 f)). The necessary increase in the production of renewable electricity would not be affordable domestically – due to the high population density and the lower annual production of renewable energy plants compared to other countries. In July 2024, the German government therefore – rightly – adopted an ambitious import strategy for hydrogen and hydrogen derivatives [85]. The aim is to import climate-friendly hydrogen and hydrogen derivatives such as methanol, ammonia and naphtha in order to partially maintain the production of energy-intensive goods in the country.

Figure 11: Electricity required to cover the projected demand for green hydrogen in Germany

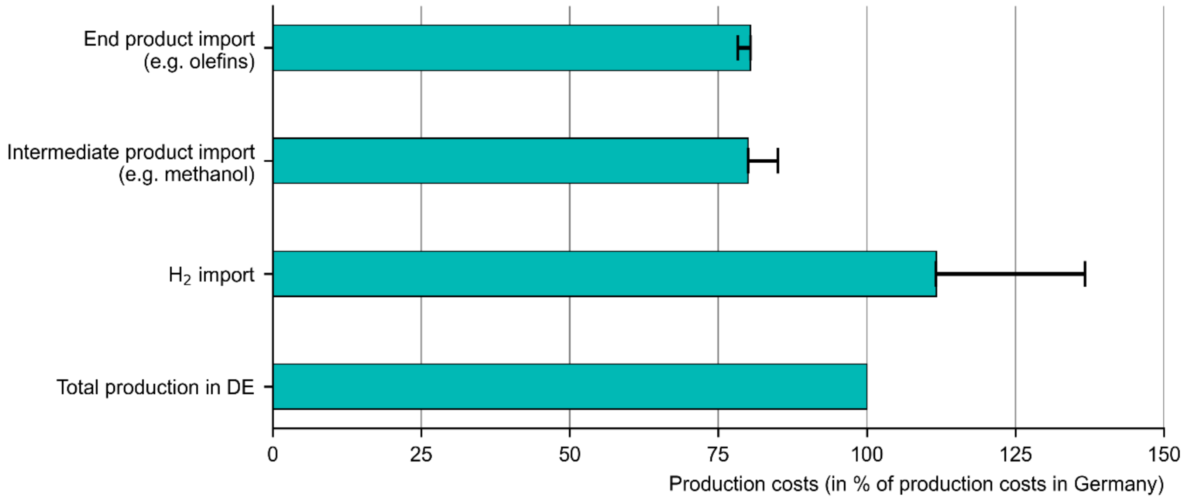


Note: Heat generation is not included. Federal government forecasts for the entire hydrogen and derivatives sector are slightly higher than the figures listed. Electrolysis efficiency: 65 %.

Sources: Own illustration based on [23], [85], [86], [87].

Figure 12 illustrates why this is a sensible strategy. Based on various studies ([31], [88]), the costs of climate-neutral production of high value chemicals are shown for four possible cases, from bottom to top: (i) the entire value chain, including the production of green hydrogen, in Germany; (ii) the import of green hydrogen from regions with excellent production conditions and the implementation of the remaining value chain steps in Germany; (iii) the import of green methanol from regions with excellent production conditions and the implementation of the remaining value chain steps in Germany; (iv) the relocation of the entire value chain, including high value chemicals, abroad. The location assumed in the studies for the cost-effective production of green hydrogen and possibly other value-added steps is a location with excellent conditions for exports (cf. Figure 2 f)). The calculations in various studies ([31], [88], [89], [90]) and for various energy-intensive products (e.g. also fertilizers, steel) are structurally very similar.

Figure 12: Production costs of climate-neutral high value chemicals by location of the individual process steps (in relation to production in Germany)



Notes: The chart is based on two studies in which different target years and export regions are examined [31], [88]. For each analysis, the production costs are normalized and shown as a proportion of the costs that would be incurred for production in Germany (= 100 %). In the case of [88] only the energy costs are shown. The bars correspond to the results in [31]. The intervals show the range of the various results in [88]. The "end product import" scenario assumes that all production steps take place at a location with excellent conditions for renewable energies and that the end product is transported to Germany. The "entire production in DE" scenario is based on the assumption that the end product and all intermediate products, as well as the hydrogen (green in the calculations), are produced in Germany. In the other scenarios, it is assumed that either the hydrogen (ship-based, which is particularly expensive) is exported to Germany from the region with the excellent conditions for renewable energies, or a hydrogen-based intermediate product such as methanol is exported.

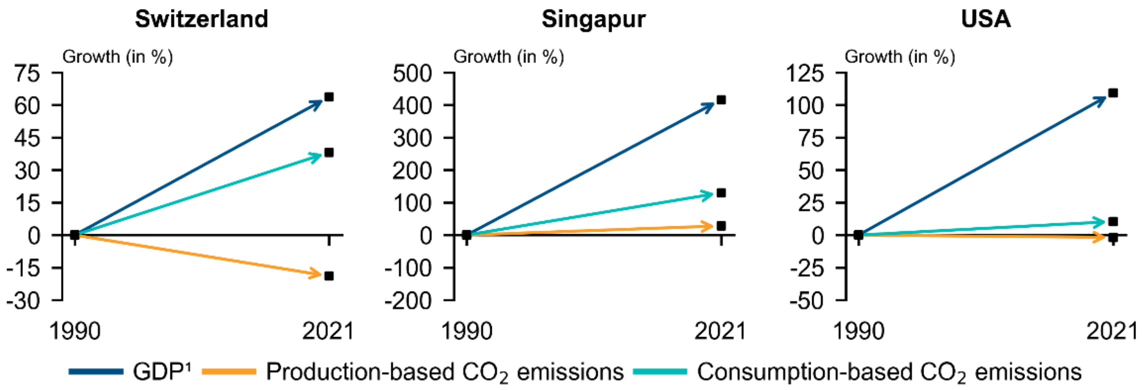
Sources: Own illustration based on [31], [88].

The central insight of the studies is that if it is not possible to import sufficient quantities of hydrogen and hydrogen derivatives, the entire value chains for the production of energy-intensive products will shift abroad, as the production costs (for the climate-friendly value chain) abroad only account for around 80 % of domestic production costs. However, the increase in production costs is almost exclusively due to the higher costs for the production of hydrogen and hydrogen derivatives. So, if it is possible to import these, it seems conceivable to maintain competitive production of the climate-neutral end products domestically. Importing hydrogen in its pure form is initially too expensive due to the still high transportation costs of pure hydrogen – as long as no pipeline infrastructure is available for import (see "Hydrogen import" bar in Figure 12). The aim should therefore be to import derivatives for which the necessary transport logistics already exist today, as the same energy carriers – produced from fossil raw materials – are already being used extensively today.

3.1.2 Relocation of energy-intensive industry is likely to counteract climate protection

If it is not possible to import sufficient quantities of hydrogen derivatives (as all EU member states have similar emission reduction requirements), it is likely that production sites will be relocated outside the EU. However, it is not to be expected that production at these locations will be climate-neutral in the short to medium term. If the entire value chain is relocated, the production of high value chemicals, for example, will take place elsewhere. Numerous co-products (i.e. products that are inevitably created simultaneously in a production process for natural or technical reasons) that are currently used in various value chains would no longer be automatically available in Germany [91]. In addition, Germany would ultimately re-import this missing product portfolio as a component of imported intermediate and end products – and thus also the associated CO_2 footprint. As a result of the relocation of energy-intensive production, the CO_2 footprint of domestic production would therefore decrease. Therefore, deindustrialization would seemingly bring us closer to the climate targets. On the other hand, the CO_2 footprint of consumption would increase, which has largely developed in line with the CO_2 footprint of production in Germany to date (see Figure 4 a)). Figure 13 illustrates such a development using Switzerland as an example. Here, GDP has risen by 60 % and production-based emissions have fallen by 20 % since 1990, which initially suggests a decoupling of CO_2 emissions from GDP. However, consumption-based CO_2 emissions have risen by 40 % in the same period. This means that Switzerland has shifted the emissions caused by its consumption to other regions of the world. A divergence in the CO_2 footprint of production and consumption can also be observed in other countries, for example in Singapore and – to a lesser extent – in the USA.

Figure 13: CO_2 footprint of production and consumption can diverge



Notes: The figure shows the percentage change between 1990 and 2021, but not the fluctuations in the period between these years. 1 – in international dollars (PPP, base year 2017).

Source: Own illustration based on [37], an update of [38], [39] – edited by OWID.

The EU is attempting to address this shift of emissions abroad ("carbon leakage") through the Carbon Border Adjustment Mechanism (CBAM). As part of the CBAM, the CO_2 footprint of imports is to be subject to a CO_2 levy, which cancels out the advantage of foreign production over domestic production. However, the implementation is associated with problems, which is why initially (and presumably for a long time) only the lower value-added stages will be affected. Carbon leakage due to the relocation of large parts of the value chain and the import of CO_2-intensive intermediate and end products instead will therefore not be prevented with the current instruments (see also [23]). Therefore, the only way to keep the CO_2 footprint of consumption reliably low is to import climate-neutral or climate-friendly energy carriers based on hydrogen. Their CO_2 footprint – in contrast to the CO_2 footprint of intermediate and end products – can be monitored on the basis of certifications. In addition, these products are already covered by the CBAM (see ↘ **Background 4**). Achieving the import targets of the import strategy should therefore have the highest priority.

Background 4: The EU Carbon Border Adjustment Mechanism (CBAM)

The EU's CBAM is an instrument that imposes a CO_2 levy on imports of certain CO_2-intensive products [92], [93]. The aim is to avoid distortions of competition and prevent production facilities from being relocated to countries with lower climate protection requirements ("carbon leakage"). Following the introductory phase of the CBAM launched in October 2023 to implement the necessary approval and reporting obligations, the comprehensive launch of the system with the obligation to surrender CBAM certificates for the import of goods subject to the CBAM will follow from 2026. These include, in particular, basic materials such as iron, steel, cement, aluminium, fertilizers, electricity and hydrogen (derivatives). The CO_2 border adjustment is initially based on estimated values for the CO_2 footprint of imports, unless the importer can prove the actual CO_2 emissions associated with the production of the imported goods. In contrast to imports, there are currently no plans to exempt exports from the EU from CO_2 costs. This could put European exporters at a disadvantage compared to global competitors if their production countries do not have comparable climate protection instruments.

3.2 Welfare state and defense capability

In addition to the difficulties described above, which the relocation of energy-intensive industries entails for effective climate protection, a strategy that relies on economic degrowth is likely to be accompanied by further social and economic policy challenges. For example, many jobs are directly or indirectly dependent on economic growth, as are the expected tax revenues. Economic growth is therefore linked to the development of people's standard of living.

3.2.1 Degrowth challenges the fulfillment of government tasks

The social security system in particular relies on tax revenues and contributions, the potential level of which is closely linked to economic growth. A shrinking economy could make the financing of pensions, healthcare and other benefits provided by the welfare state much more challenging. In many advanced industrialized countries, the share of social spending in GDP has risen in recent decades (cf. Figure 14 a)). There are several reasons for this: The ageing population, rising healthcare costs as a result of demographic developments and the advancement of medicine, the increasing use of so-called automatic stabilizers (for example, short-time work benefits) in the economic cycle, and the expansion of the welfare state. In advanced economies, there is often a strong expectation among the population that the state will guarantee social security and support. This will of the electorate is repeatedly met, although it is naturally more difficult to withdraw benefits than to introduce them.

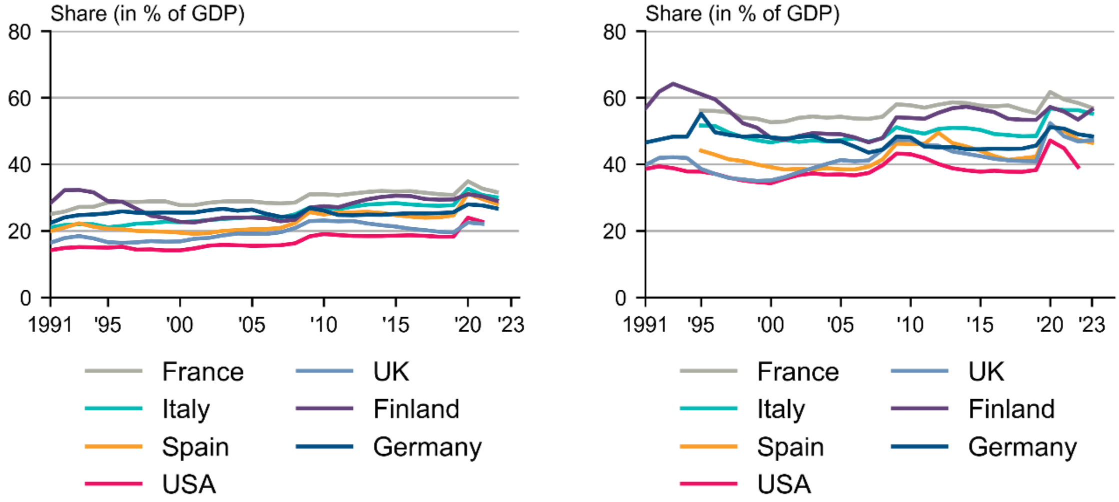
In Germany, the range of benefits provided by the welfare state has been expanded in the good economic times of recent decades. For example, benefit entitlements not covered by contributions were anchored in the pension insurance system, which are financed by an ever-increasing subsidy from the federal budget [94]. These include, for example, the mothers' pension or the pension from 63. In recent years in particular, structural reforms have repeatedly failed to slow down the increase in expenditure on social security systems.

During the coronavirus crisis, the government spending ratio (the ratio of total government spending to GDP) increased in many advanced economies and fell to varying degrees after the crisis (cf. Figure 14 b)). Germany (along with other EU member states) is one of the countries in which the government spending ratio remains at a high level – not least due to low economic growth. In the economic policy debate, despite the currently high government spending ratio and the considerable debt currently planned in the budget (new debt of around EUR 50 billion for 2025 [95]), extensive spending requirements are being called for that have no place in the public budgets. This gives an impression of the social debates that would arise in the event of a degrowth strategy: Government spending would account for an ever-increasing share of GDP, the pressure to allow more debt would rise, but nevertheless most (in part justified) concerns could not be financed. In the event of degrowth, it would not even be enough to limit the increase in social expenditure in order to create financial leeway in the budget. It would have to be significantly reduced.

Figure 14: Social expenditure and government spending ratio

a) Share of social expenditure in GDP

b) Government spending ratio in selected economies



Sources: Own illustration based on a) OECD, GCEE and b) BMF, OECD, GCEE.

3.2.2 Rising spending needs: Defense, education, infrastructures

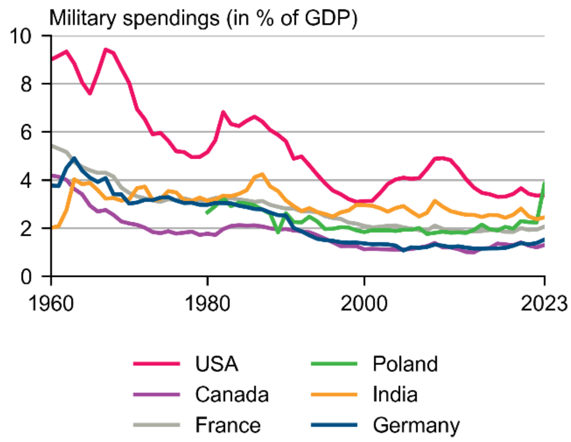
Among the many spending needs that are being discussed politically, there are some that clearly fall within the remit of the state and must be given greater prioritization. Defense spending (as a proportion of GDP) has declined in Western industrialized countries since the end of the Cold War (cf. Figure 15 a)). However, this trend must be reversed in view of current geopolitical developments and the increasing pressure from the USA on Europe [96]. However, an actual strengthening of the defense capability is likely to be difficult to implement with declining economic power. On the one hand, sufficient public funds are needed to prepare the Bundeswehr for the challenges of new geopolitical developments. On the other hand, the innovative strength of the economy is an essential prerequisite in order to keep up with the competition for the latest weapons systems and to be able to manufacture security-relevant components in Europe in the future.

By neglecting to strengthen its defense capabilities, Europe is likely to expose itself to a greater risk of future military confrontations [96]. However, a further intensification of military conflicts would shift the focus from climate protection to escalation hotspots in Europe and worldwide and push effective climate protection into the background.

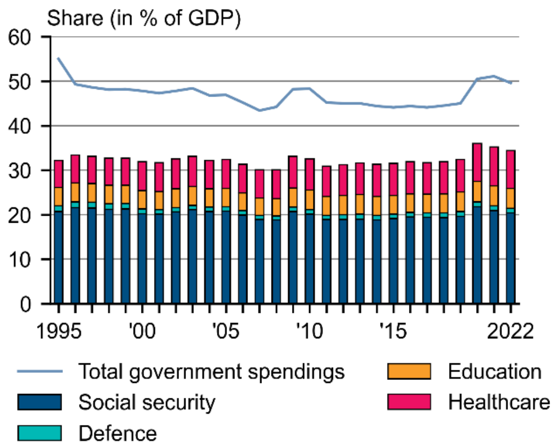
Further government spending requirements arise in the area of future-oriented expenditure, in particular for certain public investments and in the areas of research and development as well as education [97]. Figure 15 b) illustrates that the areas of expenditure discussed here alone account for a large proportion of public budgets and are likely to increase (healthcare and social security) or should increase (defense, education, research) due to structural developments such as demographic ageing. One prerequisite for this is economic growth.

Figure 15: Little leeway for future-oriented spending

a) Military spending in selected economies



b) Social, health, education and defense spending in Germany



Sources: Own illustration based on **a)** [98] – processed by OWID and **b)** Eurostat, GCEE.

3.2.3 A failure to mitigate social burdens jeopardizes acceptance of climate protection

Over the past few years, it has become increasingly clear that climate protection ultimately affects households directly in their living environment. The costs of converting the heating supply became a political issue during the discussion of the Building Energy Act (in German, Gebäudeenergiegesetz, GEG) and led to extensive relief measures being planned. The rising prices of electricity and fuel, which households cannot be spared in the course of the transformation, will hardly be enforceable without cushioning the hardships for low-income households. Sufficient state potential for measures to cushion hardship is therefore likely to be a prerequisite for the adoption and implementation of effective climate protection measures.

As part of a degrowth strategy, the social cushioning of climate policy measures is likely to be difficult to finance. This could reduce broad acceptance of climate protection, especially if, instead of cushioning the hardships of climate protection measures, cuts in the financing of pensions, healthcare and other social benefits were to increasingly dominate the political debate. Without a general acceptance of climate protection among the population, it is difficult to imagine establishing a reliable regulatory framework that provides incentives for companies and private households to invest in climate protection measures. However, it is precisely private investment that is needed to accelerate the transformation. In recent years, private sector investment has accounted for around 88 % of overall economic investment in Germany [99]. If politicians do not succeed in establishing reliable framework conditions that make climate-friendly investments more attractive than fossil fuel business models, climate protection will not succeed in Germany and beyond. In a democracy, climate protection through degrowth would therefore hardly be sustainable [100], [101].

3.2.4 Sustainable fiscal policy as the basis for growth and climate protection

Although a relaxation of the debt brake is currently often presented as a solution, it is unlikely to be a suitable means of overcoming the challenges ahead, even if majorities could be obtained. According to calculations by the German Council of Economic Experts (GCEE), if an increase in the debt ratio in Germany is to be avoided, the additional scope is only between EUR 8 and 12 billion per year [102]. However, this additional leeway is not nearly enough to make structural reforms unnecessary. An increase in debt following a relaxation of the debt brake and possible debt crises in Europe as a result would also shift the focus away from climate protection [103]. Ecological and fiscal sustainability must therefore go hand in hand. An effective climate policy over the next 20 years requires a sustainable financial policy that guarantees that the state can continue to reliably fulfill its tasks in the future.

Instead of a degrowth strategy, a combination of sustainable growth, technological progress and structural reforms is likely to be more effective in ensuring climate protection and economic stability. Germany and Europe will have to act strategically and jointly to lead Europe and cooperation partners worldwide into a climate-neutral future under the emerging framework conditions. Some elements of such a strategy are outlined in Chapter 4.

4
ALIGNING GROWTH AND CLIMATE PROTECTION:

COOPERATION AND COMPETITION

Europe was an early advocate of reducing emissions in international climate negotiations (cf. [41]), has taken extensive climate protection measures over the years (such as the introduction of the EU Emissions Trading System (EU ETS) in 2005) and has decided to achieve climate neutrality in 2050 with the Green Deal (cf. Figure 10 a)). However, a pioneering role alone is unlikely to lead to success in the necessary global reduction of GHG emissions. It could even be counterproductive if a unilateral transformation results in a loss of competitiveness for Europe and thus also reduces the potential for cooperation and international climate financing [104], [105]. Instead, Europe must get the other countries "on board" through its actions (cooperation) and at the same time strive for technological leadership in key technologies (competition). It should therefore be considered for all measures whether and through which mechanisms they contribute to actually reducing emissions worldwide. Measures that weaken Europe's influence in the world, that contribute to carbon leakage (cf. Chapter 3) or that release fossil resources which are then used elsewhere should be critically scrutinized. Climate protection can only succeed if Europe makes use of its many opportunities to decisively drive forward the reduction of global emissions on the way to achieving its own climate targets. Germany and Europe need to combine growth-oriented structural change with international cooperation in a smart way.

4.1 Role model Germany? Others will imitate what works

Europe is in a good starting position to drive forward climate protection at home and worldwide. Europe's role model function can play a role in the global context when it comes to showing other countries possible transformation paths. However, the European model will only be imitated if it is possible to achieve the internationally agreed climate targets in the EU member states as cost-effectively (efficiently) as possible and without major social upheaval [105]. Furthermore, it is not enough to rely on the role model function; it is crucial to focus on the international coordination of climate protection (cf. [104], [106] and Section 4.2). However, the successful implementation of climate protection can facilitate international cooperation on climate protection, for example by reducing the costs of implementing climate protection for imitators. A role model function can arise both with regard to the regulatory framework and with regard to the concrete implementation of climate protection by means of technological solutions.

4.1.1 Framework conditions

Framework conditions might be imitated if their effectiveness is demonstrated. Europe, for example, established European emissions trading in the energy sector and for parts of industry back in 2005, which has since been extended to other sectors [23, Ch. 10], [107], [108], [109], [110], [111]. In the meantime, emissions trading systems have also been established in various regions of the world (cf. Figure 10 a) and Figure 10 b)), often based on the European regulation, such as in China, New Zealand or South Korea [70], [112]. It can be seen worldwide that emissions trading successfully reduces emissions [108], [113]. However, rising CO_2 prices can lead to a competitive disadvantage for the companies and regions affected by them [114], which is why efforts to anchor emissions trading internationally must be an important part of the further development of this instrument. The EU's CBAM (↘ **Background 4**) can play an important role on the path to global integration of emissions trading systems [104]. Emissions trading in the EU in conjunction with a carbon border adjustment may well be suitable for the establishment of a climate club [23], [76] (↘ **Background 3**). In particular, it increases the incentive for third countries to introduce emissions trading – if designed appropriately – [115], [116], [117] and to use the instrument of border adjustment at the external borders of the Climate Club.

Another climate protection instrument that is being imitated internationally is the feed-in tariffs under the German Renewable Energy Sources Act (EEG), which have led to a massive expansion of PV and wind energy plants and the corresponding production capacities for these plants since 2000. Most recently, a similar strategy was pursued in the USA with the Inflation Reduction Act (IRA), whereby tax breaks are granted within a specified period for the expansion of capacities of certain technologies (such as electrolysis plants, wind and PV capacities). Such instruments have proven to be effective in scaling up the expansion of plants as quickly as possible. In the case of new technologies, this often leads to a reduction in costs during the industrialization of production, from which other users also benefit and which can contribute to the spread of technologies worldwide. The most prominent example of this is solar technology. However, it has also been shown that the costs for the "first movers" are high if the programs are widely adopted. As a result, the support measures are often not sustained. As subsidies are reduced, the number of new installations usually decreases, as was the case in Germany with the expansion of wind and PV. Production capacities for systems are also shifting to countries with favorable location conditions in the medium term. PV modules, for example, are now largely manufactured in China. When it comes to support measures that involve high costs for taxpayers, it is therefore not necessarily expedient to always be among the pioneers. On the contrary, it can be helpful for climate protection if different countries share the task of bringing about cost degression for important technologies [118].

4.1.2 Technological implementation

Technological solutions for the transformation of the energy system or the transformation in companies can serve as a role model and be imitated internationally. For example, energy efficiency solutions or self-supply models for companies as well as neighborhood solutions for energy supply in urban districts can create interesting role models for regions where there is currently no nationwide electricity grid. Advances in the series production of buildings and the circular economy can also shift standards worldwide.

Europe's role as a role model can have several advantages. If technologies in which European companies are technology leaders are scaled up in Europe, the feasibility and attractiveness of climate-neutral solutions can be demonstrated. Imitation in other countries around the world is then associated with lower costs for them. European activities can therefore also lead to local companies becoming leading providers of smart energy transition solutions on global markets. Competitive advantages can arise from early scaling if the technologies are widely used worldwide and the added value is fully or partially retained domestically.

Europe can play a special role model function in the implementation of a climate-friendly energy supply. The heterogeneity of European countries with their different solutions for a climate-neutral energy supply enables the member states to demonstrate many different transformation paths. Due to different preferences (e.g. for nuclear power), but also due to different geological conditions (availability of hydropower or good wind and solar locations), it is clear that the transformation of the energy supply can succeed under very different conditions. It will therefore be of great importance that these different transformation paths interact effectively and, above all, cost-efficiently in Europe.

In particular, one cannot and should not expect other countries to imitate German solutions 1:1. On the contrary, the acceptance of different national transformation paths, which are typically based on different starting conditions or preferences of the population, is a prerequisite for the success of global climate protection. Climate protection efforts will therefore encounter the least resistance if the international community agrees on common goals and an institutional framework that is as open to technology as possible, but leaves the technology paths to developments in the respective countries [119].

For Germany, the phase-out of nuclear power and coal-fired power generation means that the most cost-efficient electricity supply possible must be achieved on the basis of renewable energies, gas-fired power plants (powered by hydrogen in the long term), storage and flexibility, and that integration into the European internal market is also of great importance. In addition to the availability of hydrogen for power generation, hydrogen procurement for industry must also be successful. In order to act as a role model in this context, this dual challenge must be mastered without any significant loss of competitiveness. Figure 6 illustrates that no substantial disadvantages in electricity costs are to be expected if the power plant mix is designed cost-efficiently [47]. However, due to numerous small-scale subsidy measures Germany is currently not on the path to an efficient energy supply. Rooftop PV systems, for example, receive significantly higher feed-in tariffs than ground-mounted systems, which unnecessarily drives up the costs of the system [45].

4.1.3 Standards and certification

Another advantage of being a role model can be greater influence in standardization and certification processes. In standardization committees around the world, companies and increasingly also countries are committed to aligning international standards closely with their patent portfolios. On the one hand, technological properties are important in the development of standards. However, the standards that are ultimately established also depend on the commitment of the companies and countries in the relevant committees as well as on the already established applications of the technologies.

Germany and Europe should place a particular focus on energy transition technologies here [120], [121], [122]. If global standards are set close to the patents and product portfolios of companies in Germany and Europe, they have an important 'first mover' advantage. Calculations for the period 1997 – 2006, for example, show a benefit from standardization activities of around 17 billion euros per year, which corresponded to 0.7 to 0.8 % of GDP during this period [123].

However, German and European players are less coordinated in the committees than representatives from other nations. For small and medium-sized enterprises (SMEs) and start-ups in particular, financial and personnel bottlenecks are one of the main obstacles to participation in standardization committees. In order to influence standardization, better coordination of international activities at national and European level is of central importance. The pre-competitive phase is crucial here, in particular the anticipation, prioritization and addressing of standardization needs in strategic areas. Against this backdrop, the establishment of the High-Level Forum on European Standardization and the German Strategy Forum for Standardization in January 2023 are to be welcomed. In the strategic areas where there is great growth potential for Germany or Europe, coordination platforms should be set up in a timely manner to accompany the activities in the field of standardization and guarantee good coordination between public and private interests (see e.g. [124] for the field of hydrogen technologies).

4.1.4 Negative examples deter others

If climate policy measures are successful, they could be imitated by other regions of the world. In the case of regulatory frameworks, this would have the advantage of coming closer to a "level playing field" in terms of the economic burden of climate protection. However, the prisoner's dilemma in the provision of global public goods implies that interests in other regions of the world are also opposed to the adoption of regulations. Climate negotiations, joint institutions and financial incentives must therefore play an important role (more on this in the following section). In the case of certification procedures and the monitoring of activities, imitation by many countries worldwide can reduce the costs of implementation due to greater standardization. However, the same can also apply in reverse: if others have better regulation, consideration should be given to adapting in order to benefit from the advantages of better and, above all, common or harmonized institutions.

Those who present and implement regulation or technologies at an early stage must pay attention to the attractiveness of the solutions. Inefficiencies in implementation (e.g., over-subsidization of PV systems for private households) can create reservations about the transformation among observers and make imitation unattractive. A variety of support mechanisms that make the implementation of the energy transition costly, that can ultimately not be sustained and that erode acceptance can turn a role model function into the opposite.

4.2 International cooperation and support

International cooperation is the key to successful climate protection. On the one hand, the majority of emissions are already being caused outside Europe today and future growth in emerging and developing countries – if it is based on fossil fuels – is likely to exacerbate this effect (see Figure 1 and Figure 2). On the other hand, the transformation to a climate-friendly economy will be easier to achieve in Europe if climate-friendly business models become more attractive worldwide in relation to fossil fuels. However, considerable efforts are required to achieve this.

4.2.1 Strategic climate cooperation: joint institutions are key

International cooperation is necessary for climate protection, even across the borders of geopolitical blocs. The majority of global emissions already occur in Asia today, while energy consumption in Africa is likely to increase significantly due to population growth. A key challenge is that many countries have large reserves of fossil resources, which would be devalued by a switch to renewable energies (cf. Figure 2 e)). In autocracies, fossil resources are often a significant factor in the power structure and the maintenance of power [125]. The resulting reservations about a transformation to renewable energies – which typically breaks up the monopoly in energy supply – must be taken into account in negotiations on joint institutions.

Unilateral climate targets and national climate protection contributions, which many countries around the world have now adopted in the course of international climate negotiations (cf. Figure 2 a) and Figure 10) are a step forward, but not enough to achieve the goals of the Paris Climate Agreement. On the one hand, these voluntary commitments are not yet sufficient to achieve the containment of global warming agreed in Paris [67]. On the other hand, there is a lack of implementation of these targets. In order to achieve effective climate cooperation in the international context, reciprocal joint commitments are necessary [106]. This is an agreement to abide by rules, provided that others also abide by the agreed rules. Simply acting as a role model or even a pioneering role in climate protection is not suitable for achieving climate targets worldwide; a pioneering role could even prove to be counterproductive (see Section 3.1), for example because it weakens a country's negotiating position in the struggle for common institutions.

Various candidates for a joint commitment have been discussed in the past, which could facilitate progress in global climate protection and level the playing field worldwide. These include sectoral agreements to reduce emissions and a global CO_2 minimum price. The latter is considered to be a particularly effective means [106]. In general, such agreements or joint institutions are unlikely to be achievable globally, but will initially only comprise a "community of the willing". It would therefore be conceivable to work towards a solution that combines a common CO_2 minimum price in some countries (or another effective instrument) with a Climate Club. In this case, the club members could secure themselves with a CO_2 border adjustment mechanism in order to maintain their competitiveness and at the same time avoid carbon leakage – i.e., to ensure the effectiveness of climate protection measures.

Cooperation in the development of certification and monitoring systems for recording emissions is also of great importance for international cooperation in reducing emissions. Such cooperation initiatives and unilateral measures such as the CBAM must be considered together. Ideally, it must be possible to identify the CO_2 footprint of goods so that they can be treated differently in the CBAM. Taking the actual CO_2 footprint into account in carbon border adjustment implies that it is attractive to keep it low for goods imported into the Climate Club, as this saves costs.

Cooperation involving institutions and the regulatory framework is particularly important because the investments required to achieve the climate targets cannot be raised by the public sector alone. The greater the incentives for private investors to contribute to climate protection worldwide through joint institutions such as emissions trading, the faster effective international financing of climate protection activities can be achieved.

Strengthening emissions trading and other effective institutions that make the use of fossil fuels more expensive (e.g., sectoral agreements to reduce emissions) should increase the momentum of investments in climate-friendly business models. However, many countries around the world will be reluctant to make fossil fuels less attractive, as they often open up favorable growth prospects or generate income for the country itself from fossil fuel trading (cf. Figure 2 e)). In this case, international climate financing can both provide targeted incentives and increase interest in setting up effective institutions for climate protection. For example, international development banks could compensate emerging countries for the decommissioning of their coal-fired power plants [126], [127], [128]. Climate policy and development policy should be closely interlinked for this purpose.

Efforts to establish joint institutions could initially focus on the major emitters worldwide. China, for example, is already extensively affected by the effects of climate change and also by the local effects of the use of fossil resources (such as air pollution). Due to its high share of global emissions (cf. Figure 2 a)) and the high proportion of clean tech production (cf. Figure 7 c)), China has both a great leverage and, in principle, a vested interest in establishing effective institutions. Clever initiatives in the direction of reciprocal cooperation, which enable China to also reduce local environmental pollution [129], could therefore have a chance of success.

This is an opportunity, as joint initiatives in the area of climate protection can help to maintain channels of communication and partnerships despite diverging geopolitical or economic interests. This is of great value, as the importance of global public goods such as climate protection, health or financial stability is increasing despite current geopolitical developments. Europe can play an important role in this context. Efforts should focus on establishing mutually compatible institutions. This includes, in particular, the emissions trading system that China developed years ago based on the European emissions trading system and has now implemented. After initially only including the electricity sector, the system is now being extended to companies in the steel, cement and aluminum sectors [112].

4.2.2 Energy imports: Supporting new energy providers, leveraging synergy effects

Even in a climate-neutral world, Europe will be the only major economic area to rely heavily on imports of "molecules" (i.e., climate-friendly hydrogen or hydrogen derivatives; cf. Figure 2 f)). It is therefore necessary to trigger diversified procurement proactively and promptly. If this does not succeed, there is a risk that significant parts of the energy-intensive industry will migrate (see Section 3.1). Negotiations with individual countries on the import of hydrogen derivatives show that the potential trading partner often wants to take over a larger part of the value chain than just the production of the basic materials. However, these relocations can become a problem for the European industrial structure if important co-products that are important in the highly complex industrial value chains are missing.

In order to procure large quantities of climate-friendly raw materials and energy carriers from all over the world as quickly as possible, large quantities should therefore be put out to tender worldwide – if possible, by the EU or at least by a community of willing states. Tenders offer the possibility of structuring the rules in such a way that imports can be diversified [130]. In addition, tendering large quantities and the resulting competition among suppliers can make it easier to procure specific energy carriers and raw materials instead of having to accept the relocation of other links in the value chain. At the same time, competition among potential suppliers of climate-friendly energy carriers can reduce procurement costs for customers in Europe. The tendering of large quantities also makes it possible to generate price signals that can accelerate the transition to exchange trading [130].

Active efforts to diversify energy imports are important in order to avoid repeating past mistakes. For example, scientific advisory bodies such as the Monopolies Commission repeatedly pointed out in the 2010s that Germany should reduce its dependence on Russian gas by building LNG terminals [131], [132]. However, in view of the high costs of these measures, this has not been implemented by either private investors or the government. Once the supply of cheap energy has been realized by a few suppliers, it is often not possible to achieve greater resilience.

A similar situation could arise with imports of hydrogen and hydrogen derivatives if the diversification of the ramp-up is not proactively accompanied. Countries from the Middle East and North Africa (MENA) region, for example, are already coming into play as hydrogen exporters that can finance the necessary investments from the oil and gas export revenues of the past decades. Potential competitors that have similarly good prerequisites for the production of climate-friendly hydrogen, but less financial strength, are unlikely to be able to make competitive offers on their own. These include democracies such as Chile, Colombia and Brazil as well as (partly democratic) African countries [22], [33]. It should be in the EU's interest to enable these countries to enter the global trade in climate-friendly hydrogen at an early stage - also as part of an extensive financial commitment. This will help to reduce market power in global energy trading, especially in the long term.

Investment protection agreements can play an important role in facilitating the financing of projects. These have recently been criticized as they hedge the risks of fossil investments from the past. Looking ahead, however, they should primarily reduce the risks of investments in climate protection projects, which can already be observed today [41, Ch. IV.2]. The critical attitude towards these agreements, particularly in the EU, should therefore be urgently reconsidered.

The development of energy trade relations is accompanied by substantial funding requirements. However, if the cooperation partners ensure that the trade relations are mutually beneficial, various synergy effects can be achieved for the countries involved. For Germany and the EU, in addition to the diversification of energy imports (i.e., the reduction of dependencies), the procurement of raw materials can also be diversified and the strengthening of general trade relations with the countries concerned can be beneficial. Both leads indirectly to a reduction in dependence on countries such as China, without having to focus on restricting trade relations with them. The conflict potential of such a strategy (reducing dependencies by expanding alternative trade channels) is likely to be significantly less conflict-laden than actively withdrawing from existing partnerships.

In addition to the positive effects for the diversification of trade relations, the development of new (climate-friendly) energy trade relations also holds significant value creation potential for German and European industry. This is because both the development of value chains and services in connection with maintenance and repair are among the core competencies of European companies. Extensive exports of technology and services can therefore be expected if the ramp-up of energy imports is accelerated.

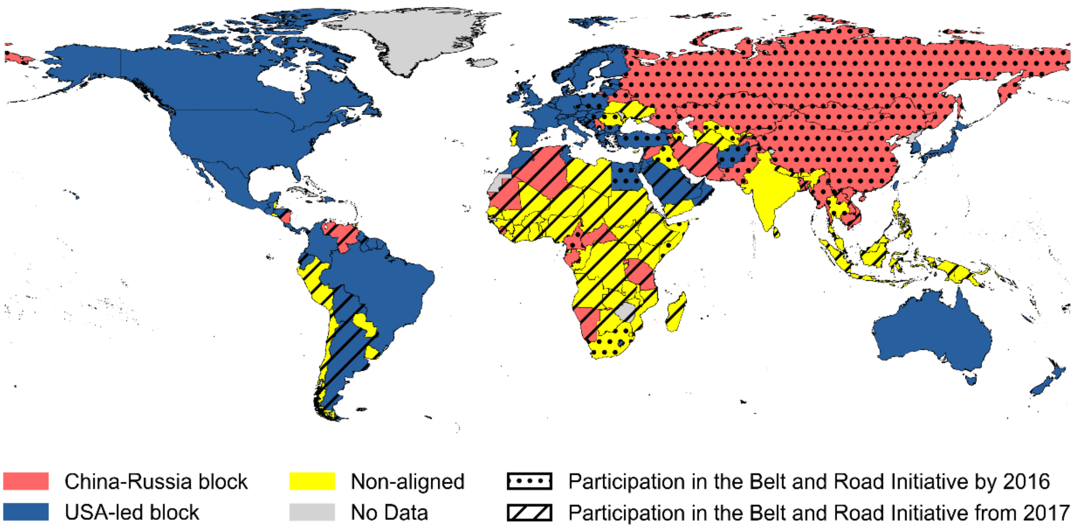
The partners can also benefit: In addition to the income from energy exports, the transformation of the energy supply in the partner country could be implemented more quickly if the projects are designed appropriately. If, for example, greater capacities for renewable energies are expanded than are required for electrolysis, growth could also be realized locally to a greater extent on the basis of renewable energies. This could also prevent a greater reliance on fossil fuels as economic performance in the partner countries increases. The possible and necessary transfer of technology to the partner countries can also encourage such a development. With the construction of the plants and their operation, it is also necessary to bring extensive expertise to the partner country and to qualify the relevant specialists.

In addition to the direct impact on the energy supply and the associated competencies, there may also be other synergy effects depending on local conditions. For example, water scarcity can be reduced by increasing the size of seawater desalination plants, which have to be built anyway for the treatment of seawater for electrolysis [133], [134]. It is also foreseeable that new trade relations based on the revenues from energy trading could increase local prosperity.

4.2.3 Geopolitics: Interdependencies create stability, but also vulnerabilities

Therefore, it cannot be a question of cooperating only with "friends" or only with other democracies, as important targets with regard to growth and climate protection would not be achieved in this way. In addition, it is not easy to divide the world into friends and enemies, or even just into geopolitical blocs. Both the bloc orientation of countries and the spheres of influence of major economies change over time and are often the result of long-term strategies. It is not least a matter of strategically influencing these developments, for example through climate protection cooperation and trade agreements.

Figure 16: Block alignment of countries and participation in the Belt and Road Initiative



Sources: Own illustration based on [135], [136], [137]. Country boundaries based on [21].

Figure 16 shows an example of the assignment of countries to geopolitical blocs based on the proportion of arms imports from either the USA/Europe (blue) or China/Russia (red). Other indicators for geopolitical classification give a similar picture [135]. It is noticeable that many states, particularly in Africa, could not be clearly categorized in the past. However, the political stability of regions and their geopolitical classification are constantly changing. Both at a military level (e.g., via arms exports) and via strategic trade partnerships, influence is constantly being exerted on the world order. For example, China has extended its "Belt and Road Initiative" to many countries in Africa and South America since 2017 (see Figure 16), which are also major producers of raw materials (see Figure 9 a)) and potential energy suppliers (see Figure 2 f)) for Europe [136], [137], [138].

Europe in particular, with its need for imports of climate-friendly energy and critical raw materials, must counter the Chinese initiatives. Europe's foreseeable dependence on imports in the future means that there is a need, but also an opportunity, to strengthen and restructure networks and cooperation worldwide. This cannot be about triggering "change through trade". Rather, it is about reducing dependencies and increasing global stability [138] and resilience by expanding trade relations with many different partners, both in energy trade and in the procurement of raw materials as well as trade relations in general.

However, the diversification of trade relations alone is no guarantee of stability in times of increasing geopolitical tensions. This is because autocracies today are willing and able to use the complex network of trade relations directly and indirectly as a weapon (weaponized interdependence) [125]. This was recently observed in the example of Russian gas and the blockade of Ukrainian grain exports. In this way, shortages can be used to trigger inflation or refugee flows and put democracies under pressure. In the course of diversifying and reorganizing trade relations, it is therefore important to pay attention to resilience and to identify and occupy important nodes in the economic network [139], [140], [141]. These nodes range from critical raw material deposits to platforms for processing payment transactions [125]. It is also important – ideally at EU level – to identify critical production capacities for which it is advisable to maintain capacities within the EU's borders. These facets of resilience are still insufficiently understood. However, the ability to fend off "economic attacks" is an important basis for growth. However, efforts to create a "resilient economy" must not overshoot the mark, as even extensive reshoring (i.e., relocating production facilities back to the domestic market) is likely to reduce growth potential and not even lead to greater resilience. It may therefore often be a better option to create more resilience by diversifying supply relationships. After all, in times of crisis, it can be helpful to have access to goods that are not available domestically via international trade channels – such as masks during the coronavirus pandemic.

In many regions around the world, Europe is perceived as an attractive (in some cases preferred) cooperation partner. However, cooperation with the EU is often complicated [142] while China (initially) usually appears to be a straightforward partner. In contrast to China's numerous trade policy initiatives, the EU has therefore found it difficult to conclude new trade agreements in recent years. Even agreements with other democracies, such as the Transatlantic Trade and Investment Partnership (TTIP), Mercosur [143] or the agreement with Australia [144], have failed due to the high expectations of Europeans to push through their own ideas (e.g. on climate protection) or due to the protectionist interests of individual member states [7], [145]. This development threatens both growth potential and success in climate protection if, on the one hand, it results in insufficient imports of energy and critical raw materials and, on the other, Europe loses access to important markets.

4.3 Securing a low-cost energy supply

For Europe, the cheapest possible energy supply is a key component for future growth. In the course of the transformation to climate neutrality, it is therefore important to coordinate the expansion of energy generation, flexibility and grid capacities in such a way that the system is as cost-effective and resilient as possible. In the political discussion, the realization times must be urgently taken into account (cf. Figure 7 a) and b)).

4.3.1 Expanding infrastructure

Rapid and extensive grid expansion in the areas of electricity (transmission and distribution grids), hydrogen (pipeline infrastructure, storage and port facilities) and mobility (charging and hydrogen filling station infrastructure) are of key importance to achieving the climate protection targets. Particular challenges for the expansion and safe operation of grid infrastructures arise in Germany due to the targeted share of renewable energies in gross electricity consumption of 80 % by 2030 and the accelerated phase-out of coal. A comparison of the target paths from the grid expansion monitoring and the status of the completion of lines shows a considerable delay in the expansion of the transmission grid [23].

Extensive expansion is also required in the distribution grids. While this has so far been driven primarily by the integration of renewable energies, new consumers (especially heat pumps and charging stations for electric vehicles) increasingly require the (medium and low-voltage) grids to be reinforced and expanded. Recently, investments in the distribution grids have risen continuously [146]. Recent studies assume a further increase in investment requirements [147], [148], [149], [150]. This makes it particularly necessary for grid operators to strengthen their equity in order to be able to finance the necessary increase in investments. This in turn can conflict with the objective of low network tariffs. Balanced solutions must be found here in order to make it possible to finance the investments.

The development of a pipeline infrastructure is necessary for the hydrogen ramp-up in Germany and Europe. The current draft for the hydrogen core network is primarily based on connecting the major industrial hydrogen consumers, potential hydrogen consumers in the electricity sector, hydrogen storage facilities and import corridors [151]. For financing the hydrogen core network at national and European level, a financing model with intertemporal cost allocation ("amortization account") can be a pragmatic way to create robust infrastructure conditions for an ambitious hydrogen ramp-up. In view of the high upfront costs in the area of electricity grid infrastructure, the Expert Commission on Energy Transition Monitoring considers it sensible to examine models for shifting the passing on of costs to network tariffs over time also in the area of electricity grids [23].

For climate-friendly mobility, the EU's Alternative Fuels Infrastructure Regulation (AFIR) provides for the expansion of charging infrastructure for battery electric vehicles and hydrogen filling stations. In order to accelerate the transition to alternative drive systems, the reliable development of this infrastructure is necessary so that a significant number of vehicles can be operated. If this does not succeed, it is to be expected that European providers will fall behind when it comes to alternative drive systems [152, p. 125 ff.].

4.3.2 Strengthening the common electricity market in Europe

The common European energy markets are the key to the cost-effective provision of energy in the EU. Fortunately, during the energy crisis, it was possible to use the markets for the efficient rationing of scarce energy and at the same time to ensure extensive energy savings and permanently effective energy efficiency efforts [77], [78], [79], [80]. At the same time, despite vehement (but often ill-founded) criticism of the merit order, the central features of the European energy market have been preserved [153], [154]. The merit order is the principle of marginal cost pricing, in which power plants are deployed according to their generation costs from the cheapest to the most expensive. The system of the European energy market has recently been questioned once again. The Draghi Report [1], [2] proposes, among other things, splitting off the financing of renewable energies from the common electricity market [2, p. 35]. However, it is a fallacy that this could make electricity cheaper. On the contrary: the challenges would increase significantly due to the lower trading volumes and lower liquidity in electricity trading and therefore also on the futures markets [155]. As described in Section 2.2 and Figure 6 it is likely to become much more difficult to install and finance the complementary technologies that are necessary for a reliable electricity supply in addition to renewable energies and which are likely to account for more than half of the generation costs (cf. Figure 6). Ultimately, these proposals amount to greater state involvement in these areas as well [155]. This can reduce the speed of transformation, especially in times of change, as ongoing discussions about the "right" path typically slow down progress.

On the contrary, important reform steps include a stronger integration of renewable energies into electricity trading and the implementation of regional price signals [23], [155], [156], [157]. These are important to ensure efficient interaction between the many decentralized players and to strengthen investment incentives in the right places in the overall system. Numerous unsuccessful attempts to design a system that establishes regional prices in addition to the existing uniform wholesale electricity price [53], [121], [158], [159] have led to a situation in the recent past in which numerous experts support price zones or a nodal pricing system (i.e. prices at individual nodes of the transmission grid) as a solution (for a comprehensive argumentation see [155], [156]). Such a price system should significantly increase the cost efficiency of the electricity supply system due to its short- and long-term incentive effect. Therefore, even in regions with higher prices, prices would not be expected to increase significantly compared to maintaining the current market design [159], [160].

4.3.3 Focusing on the costs of energy supply

When it comes to electricity supply, it will be important to keep the costs of electricity generation and grid expansion as low as possible, as these will ultimately have to be borne by consumers either through electricity prices or through higher taxes, levies and surcharges. In an investment environment in which the market prices for electricity do not reflect the relative shortages due to the lack of regionally differentiated wholesale prices and in which there is also intervention outside the market through feed-in tariffs, self-consumption regulations and other support measures, a cost-efficient transformation cannot be expected.

It can therefore be advantageous to "think from the end". Calculations show that the generation costs are particularly favorable in a system in which the renewable energies are distributed in a regionally balanced manner and are supported by a system-friendly allocation of gas-fired power plants (cf. [53], [159], [160]) and in which a certain amount of battery storage is used (for a simple illustration of generation costs, see Figure 6 and [47]). Gas-fired power plants, which will be fired with hydrogen in the future, will be needed as "long-term storage" anyway - a task that battery storage systems cannot fulfill. Once they have been built, it is cheaper to use them to a certain extent to cover short-term supply gaps. This is because only the fuel costs are incurred for their use, which would have to be compared with the investment costs of battery storage systems. Given the expected costs of climate-friendly hydrogen, this could result in a different cost-efficient generation mix than would result if battery storage systems were built on a large scale first and additional gas-fired power plants only later, as is currently emerging due to the delays in the German power plant strategy [161].

Various subsidies and price distortions are currently leading to an unnecessarily expensive electricity supply system. The expansion of many small-scale rooftop PV systems is also associated with higher subsidy requirements than if the economies of scale of larger PV systems were to be used, which are installed close to the load, e.g. on industrial roofs, parking lots or open spaces [44], [45]. A slightly less small-scale system could therefore potentially be associated with lower system costs, particularly at the distribution grid level [45], [150]. In addition, the strong growth of PV systems in particular, combined with the current framework conditions, which take little or no account of the grid status due to a lack of regional and temporal price signals, leads to an increase in hours with negative prices on the electricity exchange and thus to an increasing burden on the EEG account and to network congestion, which also drives up system costs. In order to address these problems and incentivize a system-friendly operation of all plants, regionally and temporally differentiated prices must be passed on to all players (e.g. via dynamic tariffs, which are based on – ideally regionally differentiated – wholesale electricity prices) [23], [121], [156], [162].

Against this backdrop, there should be a greater focus on expanding gas-fired power plant capacities in the near future and ensuring the availability of climate-friendly hydrogen in the medium term. If this does not succeed, a discussion about maintaining coal capacities is foreseeable, but it is unlikely that these can be operated profitably at the expected market prices [23]. This would be a challenge, as a polarized debate on the use of state subsidies to maintain fossil capacities could be expected. This should also be avoided in light of the fact that climate protection can only be successful if countries around the world are convinced to phase out coal (see Section 4.1 and 4.2).

4.3.4 Hydrogen and derivatives: solving the "chicken and egg" problem

The coordination of hydrogen supply, infrastructure and demand in particular still poses major challenges at present [163]. Both the production and use of hydrogen are dependent on a transport infrastructure, but this can only be built in an economically viable way if there is sufficient supply and demand. It is also not possible to finance the development of hydrogen production capacities without a reliable ramp-up in demand. Conversely, companies will not invest in the conversion of industrial plants or in vehicles if hydrogen is not expected to be available.

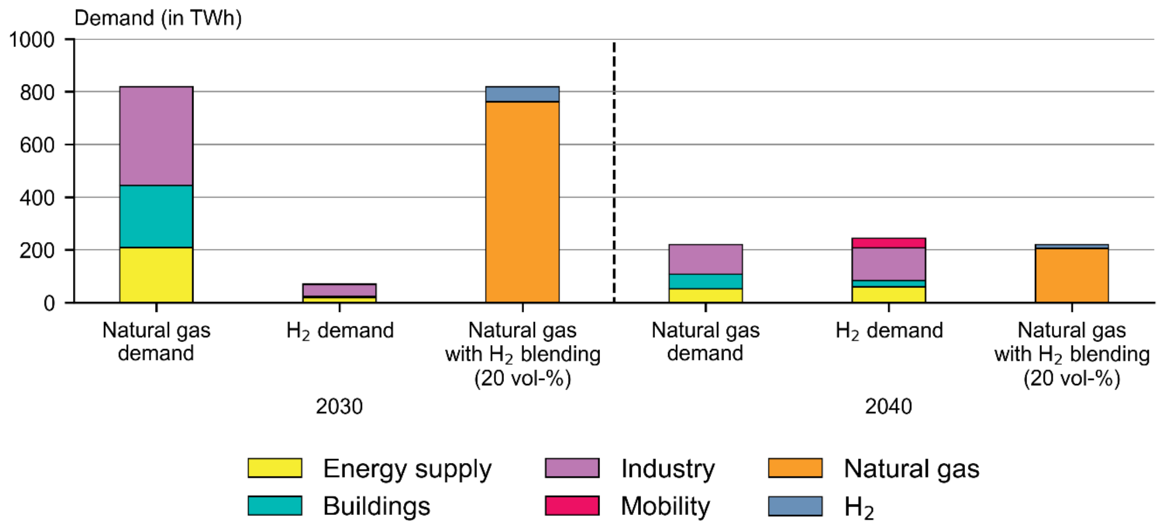
One way of addressing the multiple "chicken and egg" problem in the hydrogen ramp-up would be to ensure the availability of hydrogen through joint hydrogen (derivatives) procurement – ideally at European level or through a coalition of the willing, see Section 4.2 – and, at the same time, to promote infrastructure expansion in order to enable delivery to users. The availability of the quantities predicted in the hydrogen strategies could thus be ensured. However, the willingness to pay of potential customers in Germany is likely to be lower than the procurement costs arising from global tenders, at least in the first few years. The state would therefore initially have to cover the difference in costs between the purchase price and the willingness to pay of customers.

An allocation of the procured hydrogen (or derivatives) to the highest-bidding users by means of auctions with a minimum price could ensure that the state, as an intermediary, bears the differential costs between the purchase price and the willingness to pay of the customers to a certain extent, but that the level of funding is secured upwards. Reliable procurement of the announced quantities by means of global tenders could be expected to eliminate a significant risk for users, namely uncertainty about the availability of hydrogen. Potential users could therefore be expected to invest more in the conversion of industrial plants.

Green gas quotas or green steel quotas in various sectors of industry could additionally boost demand and increase the willingness to pay for hydrogen and hydrogen derivatives on the part of customers. However, careful consideration must be given to whether such quotas during the ramp-up phase (when hydrogen costs are still likely to be very high) could weaken the competitiveness of the industries concerned to an extent that would lead to the relocation or abandonment of activities which would have a long-term business model in Europe.

Figure 17: Potential for blending hydrogen into the gas grid

a) Predicted natural gas and hydrogen demand for 2030 and 2040



b) Allocation of the additional costs of hydrogen blending (with 10 and 20 vol-%) for the year 2030

Assumptions/**Results**	Unit	Blending with 10 volume-%			Blending with 20 volume-%		
Hydrogen price	EUR/kg	4.0	6.0	8.0	4.0	6.0	8.0
	EUR/MWh	120.1	180.2	240.2	120.1	180.2	240.2
Natural gas price	EUR/MWh	30.0					
CO_2 certificate price	EUR/t CO_2	133.0					
Costs of natural gas (incl. CO_2 costs)	**EUR/MWh**	**56.7**	**56.7**	**56.7**	**56.7**	**56.7**	**56.7**
Costs of natural gas-H_2 mixture	**EUR/MWh**	**58.8**	**60.7**	**62.7**	**61.2**	**65.4**	**69.6**
Additional costs/Surcharge	**EUR/MWh**	**2.1**	**4.0**	**5.9**	**4.4**	**8.6**	**12.8**
Share of surcharge on natural gas costs	**%**	**3.6**	**7.0**	**10.5**	**7.8**	**15.2**	**22.6**

Sources: Own illustration based on [164], [165] and own calculations.

However, for the state as guarantor (not necessarily as organizer) of the procurement of the quantities, there is a risk that the procured quantity will not be sold completely. This risk can be eliminated in the first few years by blending unsold quantities into the gas grid and passing on the costs (minimum price in the hydrogen auctions multiplied by the blended quantity) to the gas customers. Although blending into the gas grid is not the most efficient use, it can completely eliminate the sales risk if the existing gas grid can be used as a "sink" for hydrogen volumes for which no customer is initially found. Calculations show (i) that the gas grid is able to absorb excess quantities, especially in the first years of the ramp-up of hydrogen procurement (cf. Figure 17 a)), (ii) that the additional costs for gas customers would be bearable if the additional hydrogen costs incurred by blending were financed via a surcharge on the gas price (cf. Figure 17 b)) and (iii) that the reduction in emissions through the use of hydrogen in electricity generation does not depend on whether gas-fired power plants are operated entirely with hydrogen or whether a natural gas-hydrogen mixture is used first (cf. also [166, p. 43]). The latter is initially even a favorable option for the gradual conversion of gas-fired power plants to more climate-friendly gases, as existing power plants can use this gas mixture without major adaptation costs. The construction of fully hydrogen-capable gas-fired power plants is initially associated with innovation risks, which can be addressed cost-effectively if individual power plants are first tested in operation, gradually improved and only then built in larger numbers.

The hydrogen added to the gas grid could also be sold to users (such as operators of gas-fired power plants or steel producers) via a certificate system so that they could meet their green gas quotas. At the same time, the changed load distribution would reduce the surcharge for gas customers.

4.3.5 The role of blue hydrogen and negative emissions

Global electrolyser production capacities are far from sufficient to meet the predicted global demand for hydrogen (see Figure 7 c)). If the focus is exclusively on green hydrogen, the necessary quantities of hydrogen and derivatives are unlikely to be available in time or at low cost. Therefore, in addition to green hydrogen, comparatively low-emission hydrogen from other production routes will also be necessary [23].

Blue hydrogen in particular (see ↘ **Background 1**) can be an important component for scaling up the amount of hydrogen available. The technology is already well developed. However, the GHG emissions of blue hydrogen can vary considerably depending on the production technology, the system boundaries of the consideration and the emissions from natural gas extraction and transportation [25]. The recording and pricing of GHG emissions along the entire value chain are therefore an important prerequisite for the use of blue hydrogen. Due to the GHG emissions that occur during the transportation of natural gas (e.g. natural gas consumption of compressor stations; see also [167]), the production of blue hydrogen close to natural gas deposits can lead to a greater reduction in GHG emissions [25], [168]. Possible suppliers of blue hydrogen are the USA, Canada, Norway, Saudi Arabia, Qatar or Australia [36]. When considering whether supply chains based on climate-friendly blue hydrogen should be scaled up more quickly, it must also be taken into account whether the natural gas would otherwise be used in other applications without any reduction in GHG emissions.

If blue hydrogen were also to be produced in Germany, this would require the creation of a CO_2 infrastructure for sequestration and, depending on the location of the plants, also for transporting the CO_2. However, the construction of a CO_2 infrastructure is a no-regret measure in some areas, as such an infrastructure must also be planned and developed in the future for industries that are not to be decarbonized, such as the production of cement and lime or waste incineration [23], [169], [170]. The German government's carbon management strategy [171] and various statements have recently addressed the topic. Carbon Capture and Storage (CCS), Carbon Capture and Utilization (CCU) and Carbon Dioxide Removal (CDR) only make a small contribution to avoiding GHG emissions in the long term. However, the risk of failing to meet climate targets without the use of CCS outweighs the risks of CCS application [170].

4.4 Strengthening resilience and growth, allowing structural change

Growth and innovative strength are key prerequisites for mastering the extensive challenges posed by the transformation of energy supply and industry. However, estimates of the potential output growth of the German economy after the crises of recent years currently average around 0.4 % for the years 2024 to 2029 (cf. [172], [173] and Figure 18). This corresponds to around a third of the average annual potential output growth of the 2010s. The main drivers are the demographic decline in the labor volume and the current low level of investment. A growth-oriented transformation is therefore particularly important in Germany. It is important to strengthen the resilience and resistance of the German and European economies and at the same time to focus on a growth-oriented economic and transformation policy.

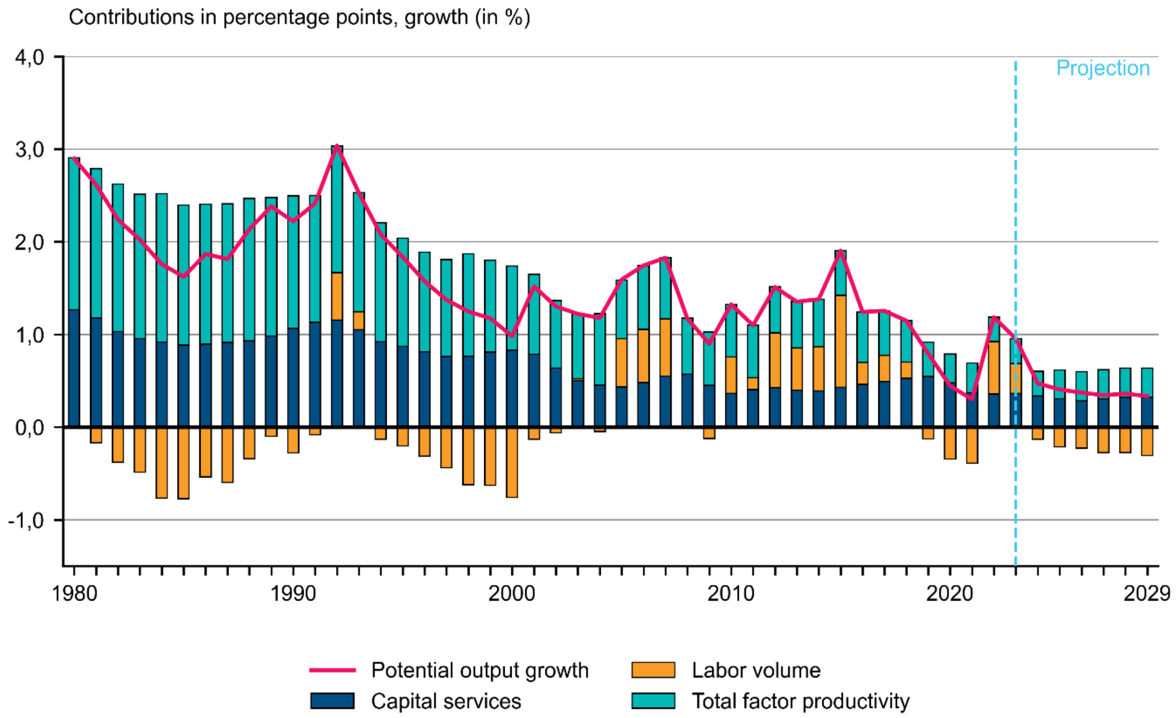
4.4.1 Increase labor volume, strengthen human capital

The declining labor volume (cf. Figure 18) poses challenges for the economic sectors to varying degrees [174]. Companies will attempt to replace the future shortage of workers by making greater use of capital. Nevertheless, an increased mobilization of workers (such as women currently working part-time, immigrants, older workers or recipients of the citizen’s benefit) should help to increase the labor volume [175]. However, this alone will not be enough to achieve robust growth. Productivity-enhancing investments in the capital stock and the strengthening of human capital are necessary on a large scale in order to revive growth and advance climate protection [175]. The outlined cost-efficient transformation of the energy supply is a prerequisite for the success of a growth strategy.

In view of the worsening shortage of skilled workers, the challenge for economic policy is likely to be less an oversupply of labor and more a change in the necessary qualification profiles. Highly qualified skilled workers are traditionally an important location factor in Germany, as are the research ecosystems in which companies are often closely integrated. In the course of the transformation, the necessary qualification profiles will change. Employees may need further training, retraining or even a change of their employer. In order to master these transformation challenges, it should be expedient to systematically support structural change with further training and retraining opportunities. It is important to identify where in-company training is not sufficient to meet the requirements of structural change.

Investment in the education system, from early childhood education to university, forms an important basis for economic growth. Public spending on education should increase significantly [97] and a greater focus should be placed on the first years of education, from early childhood education to elementary school [176], [177], [178]. A society that is becoming more diverse through immigration must develop strategies at an early stage to offer immigrants and their children equal opportunities. This is the only way to make Germany an attractive immigration country that succeeds in leveraging the potential of its population [179]. At the same time, high-quality childcare and education services can increase the potential working hours of parents.

Figure 18: Growth of the potential output in Germany



Notes: Values for 2024 and 2025 are based on the GCEE's short-term forecast. Projection from 2026 onwards. Total factor productivity (TFP) indicates which part of the potential output growth cannot be explained by an increase in labor volume or capital services, but can be attributed to improvements such as technological progress, innovations or more efficient production processes.

Source: Own illustration based on [173].

4.4.2 Steer investments to high productivity sectors

In order to boost growth, it is important to invest in areas that are likely to have a particularly strong effect on potential output. The impending structural change and the resulting expected slowdown in growth in Germany was already discussed in 2019 [180]. Changes in trade relations due to geopolitical developments, developments in the field of digitalization and artificial intelligence as well as the constraints resulting amongst others from climate targets and the conversion of the energy supply, are expected to significantly accelerate structural change. The crises of recent years have led to higher energy prices, for example, and increased the pressure to accelerate the transformation of energy systems and the digital transformation. At the same time, more and more emerging countries are becoming production locations for goods in which German industry has traditionally held a strong position. Due to the delay in adapting to these new framework conditions – whether through inertia or due to persistence and subsidies – an inefficient allocation of production factors can currently be identified, which unnecessarily dampens potential output [175].

In order to attract private investment and channel production factors into the more productive sectors of the economy, it is important to increase the attractiveness of the location. There is no single best measure; rather, it is necessary to address various aspects as part of a growth agenda, not all of which can be covered in detail in this report. Nevertheless, some areas for action are listed here with references to more detailed sources: (i) The low availability of highly skilled labor requires a focus on education and training, efforts to attract skilled immigration and the reallocation of labor from the less productive to the more productive sectors of the economy [175], [179]. (ii) The tax burden on companies should be addressed, on the one hand through adjustments to corporate taxation and improved depreciation options, and on the other hand through a reduction in non-wage labor costs [181], [182]. (iii) There is an urgent need to reduce regulatory uncertainty and bureaucracy. (iv) If an increase in the debt ratio is to be avoided, a relaxation of the debt brake can only increase the leeway by around EUR 10 billion per year [102], which, given the challenges, does not represent a substantial contribution to a solution. In public budgets, future-oriented expenditure should therefore be prioritized and, in return, the increase in social spending should be limited ([97], on pension insurance reforms [94]). (v) Infrastructure expansion in the areas of energy, digitalization and mobility should be accelerated in order to strengthen the attractiveness of the location [23], [152, p. 125 ff.]. (vi) An increase in the defense budget and its firm anchoring in budget planning should go hand in hand with strategies for the effective use of funds and an innovation agenda based on investments in the area of defense equipment [96].

The capital markets will play a decisive role in facilitating the financing of investments. However, the European capital markets are fragmented along national lines, which limits the financing options available to companies. In particular, there are major national differences in corporate reporting and insolvency law, as well as tax obstacles to cross-border investments. One key in this context is a deepening of the Capital Markets Union. This could help to diversify risks and facilitate the financing of investments in the course of the transformation [183]. This is because the financing via loans that is widespread in Germany and other European countries is unsuitable for many projects in the course of the transformation due to their risk structure [183].

4.4.3 Resilience: Strategic industrial policy, focused and European

The current geopolitical changes also make it necessary to strengthen the resilience of the European economies and to arm them in the event that economic dependencies are used as a weapon (see Section 4.2.3) and to increase their security of supply in the event of a crisis.

There is a great danger that individual EU member states will pursue national interest policies under the guise of strategic motives. This is particularly problematic if subsidies are used to keep industries in place for which the location factors have shifted in favor of other countries. Such subsidies would slow down structural change and take public funds away from important future-oriented projects. One major challenge is that it is not easy to identify areas in which state intervention can and should be justified.

With a view to security of supply and the resilience of the economy to "economic warfare", it is expedient to focus on three criteria (cf. the explanations in [184]): (i) the lack of substitutability of goods in the short term, (ii) the immediate relevance to consumption and (iii) external effects and inefficiencies that cause a supply shortfall to generate damage that exceeds the individual losses from a societal perspective. Only if all three criteria are met, the state should take measures to increase the potential security of supply in a crisis. It is not necessary to aim for a supply from its own production, but security of supply can be achieved through sufficient diversification of supply. This can be achieved, for example, through a “concentration tariff” [184] or through the forward-looking design of supply chains (e.g. in energy trading; see Sections 4.2.2 and 4.3.4). It is always important to bear this in mind: Protecting against a crisis in advance is associated with (sometimes high) costs and should only be done where major damage could otherwise occur.

For the same reasons, the question of which "domestic" production capacities are of strategic importance should be answered on a European rather than a national basis. Shifting production locations within Europe can increase the cost efficiency of production and should not be prevented by national interests. On the contrary: Europe strengthens its competitiveness and resilience if the advantages of the division of labor within Europe are exploited.

At the same time, attention should be paid to achieving a position of strength vis-à-vis trading partners. In this context, it is proposed, for example, to promote high-tech export industries that produce niche products that are difficult to replace [184]. In the long term, this could give the European economies leverage to respond to the threat to European security of supply. In addition, there should be a focus on (co-)controlling important hubs of the global economy, such as trading centers or international payment systems [139], [140], [141].

In the context of this discussion, Europe is not least trying to find an answer to the fact that governments around the world are realigning their industrial policy, with varying degrees of potential and willingness to provide state subsidies. However, it must be noted here that – unlike the USA – Europe cannot achieve self-sufficiency in important areas (cf. Figure 2 f) and Figure 9). This also means that approaches from the USA (such as funding under the IRA) should not simply be copied [118]. When it comes to energy supply, for example, Europe must ensure the import of hydrogen from partner regions around the world, while the USA could transform national production (cf. Figure 2 f)). Since Germany is particularly dependent on imports of climate-friendly energy carriers, the German government should – as stated in the import strategy [85] – promote international cooperation and the diversification of energy imports with a high level of ambition.

4.4.4 Avoiding subsidies against unfavorable framework conditions

Beyond measures that prevent the use of economic dependencies as a weapon on the one hand and expand technological leadership in high-tech sectors with unique selling points on the other, structural change towards a more efficient international division of labor should not be thwarted by state intervention. Where the international division of labor brings advantages for the EU – as is the case with the production of inexpensive PV modules in China, for example – the relocation of production should not be prevented actively and costly. Companies that fear uncertainties in the supply of modules are already independently striving for a certain diversification of supply countries [185], [186], [187].

However, it is certainly advisable to change the framework conditions in such a way that the EU's locational advantages come to the fore and ultimately have an impact. In this context, it is certainly worrying that production capacities in important CleanTech sectors in Asia are growing much more dynamically than in Europe (cf. Figure 7 c)), although Germany and Europe are leaders in CleanTech patents in many growth areas (cf. Figure 8). Both for the development of climate-neutral energy supply and with a view to the export markets, for example for vehicles, fuel cells and electrolysers, a regulatory environment and infrastructural conditions should be urgently created that allow European players to consolidate their position in international competition [152, p. 125 ff.].

For example, growth potential and technological expertise can be lost on a large scale for various technologies (climate-friendly vehicles, fuel cells, wind turbines, etc.) if no domestic markets are created due to unnecessarily complex and small-scale regulation, a lack of infrastructure or unnecessarily high electricity prices as a result of the market design [152, p. 125 ff.]. Germany and the EU should therefore create the most attractive competitive environment possible, as outlined above, instead of rashly distributing subsidies. Subsidies to existing industries tie up the (scarce) workforce in inefficient use, they tie up resources in companies for rent seeking, i.e., the search for potential to absorb subsidies, and often lead to a wait-and-see attitude in anticipation of further subsidies.

4.4.5 Clear framework conditions instead of patchwork regulation: the example of CO_2 pricing

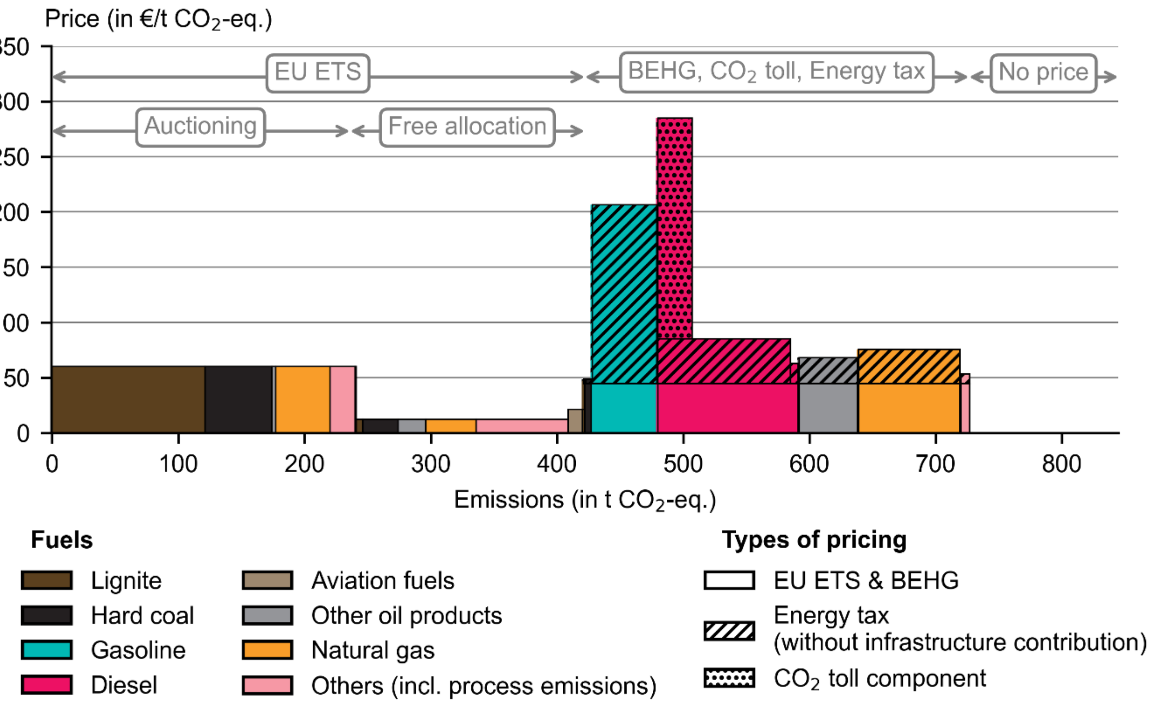
Companies make their decisions regarding the expansion or reduction of production capacities and, in connection with this, location decisions based on the expected framework conditions in an international comparison. Numerous aspects play a role in these decisions, which can be influenced by politics: Regulation, legal certainty, bureaucratic burdens, taxes, availability and prices of energy, framework conditions on the capital markets as well as reporting obligations and burdens from climate policy.

The patchwork regulation that has developed over the years is likely to steer investments in the wrong direction and also reduce investment incentives. This can be illustrated by the example of effective CO_2 pricing. The EU has succeeded in first establishing a European emissions trading system for the energy sector and parts of industry (EU ETS I) and then adopting a similar system for the heating and transport sectors (EU ETS II) in 2023. Both systems are to be successively transferred to a cross-sector emissions trading system. This approach ensures that the climate targets are achieved cost-effectively (if the appropriate emission reduction paths are adhered to) and allows companies to anticipate price developments. In Germany, emissions in the heating and transport sectors that are not covered by EU ETS I have already been priced under the Fuel Emissions Trading Act (BEHG) since 2021. The emission allowances will be allocated at a fixed price that increases over the years from 2021 to 2025, and the transition to emissions trading is planned from 2026.

However, despite the introduction of emissions trading across (almost) all sectors, the effective price per ton of CO2 currently varies considerably due to numerous exemptions on the one hand and additional regulations on the other: it is between EUR 10 and 240 per ton of CO2, although similar prices should actually apply in many areas as a result of emissions trading (cf. Figure 19 and [23]). Figure 19 b) gives an impression of how the different implicit CO2 prices, especially for heating oil, coal, but also gray hydrogen (for use in combustion engines), come about. On the one hand, the different implicit CO2 prices are problematic because they mean that emissions are not reduced first where the abatement costs are particularly favorable. On the other hand, the patchwork regulation increases the complexity of evaluating business models. This can make it more difficult to finance projects, for example.

Figure 19: GHG pricing in Germany

a) Profile of explicit and implicit GHG pricing in Germany



Notes: Recording of CO_2 pricing systems as at mid-2024, EU ETS price EUR 60 per emission allowance, 79 % free allocation, for energy taxes only the revenue shares not attributable to infrastructure financing, emission structures 2021, adjusted for atypical sector effects (aviation, etc.).

Source: Own illustration based on [23].

b) Energy taxes and implicit CO_2 pricing

		Nominal tax rate (€/UOM)	Implicit tax rate (€/t CO_2)	Without infra-structure contribution (€/t CO_2)
Natural gas (heat)	EUR/MWh (H_O)	5.50	30.23	
Heating oil extra light	EUR/1,000 l	61.35	23.03	
Heavy heating oil (heat)	EUR/t	25.00	7.94	
Heavy fuel oil (electricity)	EUR/t	25.00	7.94	
Unleaded gasoline	EUR/1,000 l	654.50	286.76	161.01
Diesel	EUR/1,000 l	470.40	179.06	39.81
Coal (heat)	EUR/GJ	0.33	3.47	
Hydrogen (combustion engine)[1]	EUR/kg	0.55	15.91	
Hydrogen (fuel cell)	EUR/kg	0.00	0.00	

Note: 1 – If hydrogen is used as a heating fuel, it is not subject to energy taxation. Use as a fuel is subject to energy taxation, unless the hydrogen is used in fuel cells. For the calculation of the implicit CO_2 tax for grey hydrogen, a conversion efficiency of the steam reformer of 70 % (without CCS) was assumed. Further upstream emissions were not taken into account. UOM = unit of measure.

Source: Own illustration based on [23].

Not shown in the overview in Figure 19 b) (but shown in Figure 19 a)) is the taxation of electricity, for which the implicit CO2 pricing depends heavily on the assumed emission intensity of electricity generation, but is currently significantly higher than that of the heating fuels under consideration in any case. The pass-through of CO2 costs of the EU ETS to wholesale electricity prices and the additional taxation of electricity on the end consumer side through the electricity tax results in a considerable double or overcharging of electricity. Due to the lack of integration of the pricing systems, this unnecessarily makes electrification unattractive as long as fossil fuels are still being used to generate electricity – which is likely to slow down the transformation.

In addition to the different effective CO_2 prices described here, there are other mechanisms that also restrict the possible business models, such as the EU taxonomy (↘ **Background 5**) in particular, but also detailed requirements under the Renewable Energy Directive III (RED III), for example. These diverse requirements often make the transformation more difficult without making an additional contribution to climate protection. In particular, policymakers should scrutinize technology-specific instruments such as the EU taxonomy, as well as small-scale regulation that distorts the relative prices of emissions without significant added value and is often accompanied by costs for the state. At the same time, standards and certification procedures should be further developed in order to record the CO_2 intensity of production and processes and to be able to consistently price GHG emissions on the basis of the CO_2 footprint and cross-sector emissions trading. A CO_2 price-based energy price reform is a central component of an effective and efficient framework for achieving the long-term energy transition and climate protection targets [23].

Background 5: The EU taxonomy

The EU taxonomy [188], [189], [190], [191], [192] is a detailed classification system that defines which economic activities are considered environmentally sustainable. The aim is to channel capital into sustainable projects and thus support the transition to a low-carbon economy. However, there are considerable challenges when it comes to classifying technologies. It is often controversial which technologies should be considered sustainable – especially in sensitive areas such as nuclear power, natural gas [193], [194], or in the production of military equipment in connection with the so-called "social" taxonomy [195], [196]. This disagreement leads to tensions between the EU Member States, some of which pursue different economic interests and environmental priorities. The taxonomy guidelines are extremely comprehensive and currently comprise over 500 pages of technical criteria and specifications. This makes application complex and requires specialist knowledge in order to interpret the regulations correctly. In addition, these lists and criteria need to be revised regularly to incorporate technological advances and new scientific findings. This represents an ongoing challenge, as the taxonomy must be constantly updated, which can lead to uncertainty among investors and companies. Another problem is that there is no international harmonization of taxonomy systems. Other countries, such as Japan, Brazil and China, have their own systems for classifying sustainable investments, some of which differ greatly from the European guidelines. This makes comparability and harmonization at a global level more difficult, which means additional effort for internationally active companies [197].

4.5 Cushioning hardship, opening up opportunities for people

Many people are rightly worried about the financial hardship that the transformation will cause them. CO_2 pricing increases the cost of living. Lower income groups often have fewer opportunities to avoid the CO_2 costs through forward-looking investments, either because they are renting or because they cannot afford to switch to climate-friendly technologies (such as a battery electric vehicle or a heat pump) [198], [199]. Others fear unemployment in the course of the transformation, for example because their job will be lost or they believe they will not be able to meet the demands of a new job. Policymakers should take these concerns seriously and address them both in terms of substance and communication.

4.5.1 Climate money

A stronger focus on the pricing of CO_2 makes it necessary to offset the cost burden that will be borne by consumers. For this reason, the 2021 coalition agreement announced a direct payment of the revenue from CO_2 pricing to citizens in the form of a per capita flat rate, but this has not yet been implemented.

Implementation would be an important step (see also [23]). In particular, people on low incomes have a significantly lower CO_2 footprint than people in the higher income groups. For the lower income groups, the climate money would therefore be even higher on average than their cost burden from CO_2 pricing [121], [198], [200], [201]. The measure would therefore – if well communicated – make a very credible contribution to the social cushioning of the transformation. In addition, climate-friendly behavior pays off, because those who reduce their emissions are less burdened by CO_2 pricing, but receive the same amount as climate money as all other citizens.

Overall, acceptance of climate protection is likely to remain high if CO_2 pricing has a steering effect, but the revenue flows back to the people: If the accrued revenues from national emissions trading were paid out in full in summer 2025, a household of four would receive over EUR 1,000 in climate money in one go [202].

However, there are still problems in at least two areas. Firstly, the revenue from CO_2 pricing has been flowing into the Climate and Transformation Fund (KTF) for several years now. However, the money from the KTF has so far not been used for climate money, but for many other purposes – from heating subsidies to subsidies for the construction of chip factories. Secondly, the establishment of the payment channel for the climate money is also making slow progress. In order to be able to pay out the lump-sum climate money in Germany in a targeted manner, the tax ID (for unique identification) and the account details are to be linked in Germany with an independent data trustee. However, the specific structure of the direct payments is still not regulated by law and the transfer of account numbers has only just begun [203].

These delays in the introduction of a climate money and the lack of consistency in the design of market-oriented approaches are increasingly jeopardizing the success of climate protection.

4.5.2 Investments

The introduction of a climate money should be accompanied by measures to ensure that lower income groups can also avoid the cost burden of CO_2 pricing in the medium term. This is because the CO_2 footprint of lower income groups is initially low in comparison, which is why they benefit net from the combination of CO_2 pricing and climate money. In the medium term, however, investments by higher income groups in climate-friendly mobility and heating systems will mean that this correlation will no longer apply. In order to prevent lower incomes as tenants and owners of fossil vehicles from ultimately bearing a disproportionate share of the costs, the state should expand local public transport where possible and take measures that lead to the conversion of heating systems in rented accommodation as well [198], [199].

4.5.3 Communication

In the coming phase of the transformation, necessary climate protection measures will be associated with hardships for industry and households, but these are unavoidable in order to achieve the climate targets. In this context, it is crucial to develop a consistent overall concept for the transformation that distributes the burdens on the stakeholders in a balanced way and to communicate this openly. Vulnerable population groups in particular should receive special protection and support. It is crucial that regulations are adopted and communicated with sufficient lead time so that companies and households can react appropriately to the upcoming changes and adapt their strategies and investments accordingly. This predictability is an important aspect to ensure broad acceptance and support among the stakeholders concerned and also to trigger forward-looking investments to avoid costs. In contrast, measures that are announced or implemented at short notice, significantly redesigned or unexpectedly terminated can weaken support in society [23].

5
POLICY RECOMMEN-DATIONS

This study has outlined the international context in which Germany and Europe have to promote both growth and climate protection (Chapter 2). Specific examples were used to show that climate protection cannot be realized without growth (Chapter 3) and key points for the alignment of growth and climate protection strategies were presented (Chapter 4).

Figure 20: Central recommendations of the study

Reliable and effective framework for energy and climate policy	Section
Strengthen emissions trading	4.1.1, 4.4.5
Give greater priority to certification and standardization	4.1.3
Allow the interplay of different transformation paths in the EU	4.1.2
Strengthen the European electricity market	4.3.2
Introduce regionally differentiated electricity prices	4.3.2, 4.3.3
Prepare the expansion of the CBAM	3.1.2, 4.1.1, 4.2.1
Accelerate the expansion of infrastructure	4.3.1
Implement social cushioning transparently	4.5
State support and specific interventions	**Section**
Ensure cost-effective climate-neutral electricity generation	4.3.3
Procure sufficient climate-neutral energy carriers	3.1.1, 4.2.2, 4.3.5
Guaranteed offtake of excess hydrogen	4.3.4
Think European when it comes to strategic industries	4.4.3, 4.4.4
Ensure security of supply and resilience	4.4.3
Reduce regulation and bureaucracy	**Section**
Reduce unnecessary and contradictory regulation	4.4.4, 4.4.5
Reduce climate-damaging subsidies	4.4.5
Standardize and coordinate reporting obligations	4.4.5
Harmonize the implementation of rules	4.1.3, 4.4.5
International climate cooperation	**Section**
Anchor global climate cooperation in binding institutions	4.2.1
Establish global trade in climate-neutral energy carriers	3.1.1, 4.2.2
Redirect and broaden trade relations	4.2.2, 4.2.3
Intertwine policy areas	4.2
Use forward guidance in global energy policy	3.1, 4.2.1, 4.3.3
Strengthen growth potential	**Section**
Increase the labor volume	4.4.1, 4.4.2
Strengthen the education system	4.4.1
Steer investments towards growth sectors	4.4.2, 4.4.3
Strengthen capital markets and a banking union	4.4.2
Adapt social security systems to growth potential	4.4.2
Acting sustainably not only in climate protection	3.2.4, 4.4.2

This chapter summarizes the main policy recommendations. First, Section 5.1 outlines some important framework conditions for an effective energy and climate policy that create a predictable environment for stakeholders. Section 5.2 identifies specific fields of action in which targeted government intervention is necessary to combine climate protection and competitiveness. It is important to understand the proposals in this order, as the transformation would exceed the state's capabilities without strengthening private investment incentives through reliable framework conditions. However, a reliable environment can only be achieved if the large number of overlapping regulations is reduced. The corresponding proposals are made in Section 5.3. Section 5.4 is devoted to international climate cooperation, which is a key prerequisite for aligning climate protection and growth. Finally, Section 5.5 lists the key elements of a growth agenda in which an effective energy and climate policy must be embedded. A summary of the policy recommendations is shown in Figure 20 each with references to the sections of the study in which they are discussed and explained in more detail.

5.1 Reliable and effective framework for energy and climate policy

The aim of the regulatory framework should be to achieve the German and European climate targets as efficiently and effectively as possible, while at the same time establishing options for international cooperation. Where possible, overarching regulations should be anchored at EU level. This increases the consistency of the rules as well as transparency towards companies and on the capital markets, thereby facilitating the financing of business models. The following elements are key components of such an energy and climate policy:

a. **Strengthen emissions trading**. European emissions trading should be further strengthened as a key instrument of climate policy. European emissions trading within the framework of EU ETS I has proven its effectiveness; it is now important to ambitiously continue the implementation of national emissions trading within the BEHG and strengthen it. The tightening of national legislation should be designed in a way that allows for an easy incorporation into the future EU ETS II or even to supplement EU ETS II if more ambitious climate targets are pursued in Germany than in the EU for a transitional period.

b. **Give greater priority to certification and standardization.** Certification and standardization should receive greater attention for important future-oriented technologies. Government coordination activities could provide start-ups and SMEs in particular with better access to pre-competitive activities. A certification system that can be linked internationally and is based on the CO_2 footprint is a prerequisite for the attractiveness and feasibility of climate-neutral business models. In contrast to certifications that are technology-specific, a CO_2-based certification increases the predictability of future revenues.

c. **Allow the interplay of different transformation paths in the EU.** The member states of the EU have different transformation paths due to different geographical conditions, but also due to the different preferences of their populations. Some continue to rely on nuclear power, others reject it and are therefore largely dependent on hydrogen-capable gas-fired power plants and battery storage when hydropower is not available in sufficient quantities. Mutual acceptance of the various transformation paths in the EU is a key prerequisite for achieving the climate targets in the individual countries and in the EU as a whole quickly and as cost-effectively as possible. As different transformation paths are associated with (different) risks, the countries can also protect each other. The less technology-specific European regulation blocks the technologies required in individual member states and the more integrated the European energy market is, the better this will work.

d. **Strengthen the European electricity market**. Greater integration of the European electricity market is crucial in order to make energy supply in the EU more efficient, cost-effective and environmentally friendly [80]. A better integrated market will make it easier to distribute electricity surpluses from renewable energies between the Member States. This increases security of supply, reduces electricity costs and enables more flexible adaptation to increasingly fluctuating energy generation. In addition, closer cooperation within the EU reduces dependence on fossil fuels and promotes the transition to a climate-neutral energy supply throughout Europe. Greater integration also creates incentives for investment in cross-border infrastructure projects and ensures more efficient use of existing grids.

e. **Introduce regionally differentiated electricity prices**. The current electricity market design does a poor job of efficiently coordinating suppliers and consumers. Wrong incentives in the uniform German price zone lead to inefficient location decisions and inefficient operation of generation plants. Investments are often not even made or can only be realized with extensive subsidies. In addition, a uniform German electricity price sends the wrong signals in the context of cross-border electricity trading, which reduces the incentives of neighboring countries for greater integration of the European electricity market [156]. Regionally differentiated prices significantly reduce inefficient operation and, by increasing the expected revenues at the right locations, reduce the necessary funding for the expansion of capacities. Due to the efficiency gains of a regionally differentiated pricing system, electricity prices should not rise significantly even in high-price zones within Germany relative to a scenario in which the uniform price zone is retained [155], [156], [159], [160]. Since the decisive factor for locations within Germany is not the intra-German comparison, but competitiveness with other countries, all federal states would benefit. There are already numerous electricity markets with nodal price systems or price zones, and Germany could benefit from their experience when implementing them.

f. **Prepare the expansion of the CBAM**. As the CBAM currently only covers the lower stages of the value chain, companies could strategically plan to relocate their production in such a way that their imports into the EU are no longer subject to the CBAM. This could lead to a shift in value-added stages that are currently integrated into German industrial production in a variety of ways, resulting in unfavorable consequential effects. However, such relocation strategies will only work if the CBAM does not actually cover higher stages of the value chain in the long term. Preparing for the expansion of CBAM can therefore make such strategic relocations riskier and therefore less attractive for the companies concerned. The preparation of an extension of the CBAM does not imply that a binding decision for this extension must already be made today. This is because an actual extension of the scope of CBAM is likely to be problematic and, not least, raise questions of compatibility with the WTO rules. Nevertheless, preparing the EU for various options for action can be expedient in order to make relocation of industry with the aim of re-importing products less attractive on the one hand and to strengthen the negotiating position on the way to a multilateral Climate Club on the other.

g. **Accelerate the expansion of infrastructure**. The transformation to climate neutrality requires a large-scale expansion of infrastructures for energy (electricity and hydrogen), mobility (charging stations and hydrogen filling stations), CO_2 transportation (for CCS options) and digitalization. The expansion of the various energy and mobility infrastructures should be prepared in a joint grid development plan in order to take into account the interdependencies between the infrastructures. The regulation of the grids must meet the challenges associated with the necessary increase in investment. In particular, the returns granted should not be set too low so that equity can be built up as a basis for financing increasing investments. At the same time, regulation should be geared towards not hindering the replacement of line expansion through digitalization or flexibilization in the transmission and distribution grids [159], [204]. For the expansion of completely new infrastructures (e.g., for hydrogen transport or mobility), state support may be necessary during the transition as long as user fees do not yet realistically make it possible to refinance the infrastructures. One option here is the concept of an amortization account, which is currently being considered in connection with the development of the hydrogen core network. European coordination of infrastructures can reduce the necessary expansion, as can a generation structure in which decentralized concepts are also evaluated with regard to the necessary infrastructure expansion.

h. **Implement social cushioning transparently**. Social hardships resulting from the rise in CO_2 prices should be addressed. In the coming years, returning the revenue from CO_2 pricing in the form of an identical per capita climate money would provide noticeable relief for lower incomes and even put them in a better net position on average. However, specific measures should also ensure that lower income groups can also benefit from investments in climate-friendly heating and mobility options. Otherwise, there is a risk that they will bear a disproportionate burden in terms of CO_2 pricing as soon as households in the upper income bracket have switched to climate-friendly systems. An institutional anchoring of social cushioning is a prerequisite for the success of climate protection and must be an integral part of the framework. Clear communication of a transparent system is central to the continued acceptance of climate protection among the population.

5.2 State support and specific interventions

In some cases, government measures are necessary in the course of the transformation. This is particularly the case if further externalities (beyond the greenhouse gas effect) need to be addressed, such as network externalities or questions of security of supply in the course of current geopolitical developments. It can also make sense to specifically promote research and development in order to accelerate certain developments. For all measures, it is important to pay attention to cost efficiency so that government activities do not have to be stopped unexpectedly due to a lack of funds. The costs to be expected if a support measure is unsuccessful should therefore be anticipated when setting up measures.

a. **Ensure cost-effective climate-neutral electricity generation.** The expansion of gas-fired power plants, which are urgently needed when phasing out coal and nuclear power, has not been triggered by the market design (e.g., due to a lack of regionally differentiated prices) and has been repeatedly postponed to date. As gas-fired power plants, which are to be operated with hydrogen in the long term, are an integral part of the targeted climate-neutral generation mix, the expansion of sufficient capacity must be triggered quickly. If regionally differentiated prices are established in wholesale electricity trading, the system-friendly choice of location could be achieved through the early announcement of a capacity mechanism that obliges producers to cover a significant proportion of demand on the futures markets [155]. The expected market prices would be higher with regional pricing in the regions where capacity is more urgently needed. In the short term, it may be necessary to make sufficient capacity available via capacity payments or a strategic reserve.

b. **Procure sufficient climate-neutral energy carriers.** In order to achieve regionally diversified imports of climate-friendly energy carriers (hydrogen and hydrogen derivatives), efforts should be made to establish joint procurement at EU level (or as part of a "coalition of the willing" among the member states) in order to be able to diversify the sources of supply by procuring large quantities. In this context, tenders are suitable for keeping exporters' markups as low as possible. In addition, competition among potential suppliers in the tenders should ensure that Europe can purchase the desired energy carriers and that individual negotiating partners do not take over a larger part of the value chain. Technology transfer to attractive partners that have not previously been global energy exporters could create additional competitors and thus spark global competition on the energy market for climate-friendly energy carriers.

c. **Guaranteed offtake of excess hydrogen**. The gas grid can serve as a backup option in order to use quantities procured in the tenders that initially find no buyers in industry or for mobility and to be able to remunerate the importer for them. Surplus quantities that have been procured but not found a customer could be blended into the gas grid. As the conversion of gas-fired power plants to hydrogen is planned anyway, blending can be seen as a first step in this direction. The additional costs of hydrogen blending could be passed on to gas customers, which would not represent a major cost burden given the relatively small quantities initially involved. As an alternative to the surcharge, certificates could be sold so that their buyers could be credited for the CO_2 reduction resulting from the hydrogen volumes. This would enable gas-fired power plants, for example, to meet specific emission reduction targets or reduce the necessary purchase of emission allowances in the EU ETS. By trading the emission reduction within the framework of financial contracts, the necessary surcharge on gas customers would then be lower.

d. **Think European when it comes to strategic industries**. In the course of the current geopolitical changes, various countries around the world are striving to locate or retain strategically important industries at home. The EU and its member states are also discussing which industries and locations should be retained locally despite more favorable production conditions abroad. While the aim of policy should of course be to improve the general economic framework conditions (including energy supply) and thus also the location conditions for companies, subsidies should only be used sparingly. The high opportunity costs of the use of funds should always be taken into account when making decisions on strategic locations. Public funds can be saved (i) by choosing the most favorable location in the EU and (ii) by achieving resilience through diversification of imports instead of domestic production. EU-wide decisions would be less susceptible to the influence of national lobby groups, which in case of doubt would claim strategic relevance for an unnecessarily large number of industries.

e. **Ensure security of supply and resilience**. Only in exceptional cases should the state take measures to increase the potential security of supply in the event of a crisis, namely when goods cannot be substituted in the short term but are directly relevant to consumption and the loss of supply is associated with significant externalities for society [184]. Even with these goods, it is not necessary to strive for supply from own production, but security of supply can be achieved through sufficient diversification of supply. Possible ways to achieve diversification are “concentration tariffs” [184] or the forward-looking design of supply chains to be expanded (e.g. in energy trading). It should always be borne in mind that hedging against crises in advance is associated with (sometimes high) costs and should only be done where major damage could otherwise occur.

5.3 Reduce regulation and bureaucracy

Building a reliable and effective regulatory framework requires not only the strengthening of effective institutions and rules, but in particular the dismantling of regulation and bureaucracy that hinders investment and contributes little or nothing to climate protection. This is likely to be more challenging than creating additional rules, as every existing rule also has its supporters (as well as its beneficiaries in some cases) and there is also little political gain in abolishing rules.

a. **Reduce unnecessary and contradictory regulation**. At both EU and national level, there is an increasing number of rules that entail high compliance costs – for the state and for companies – but make no or at least no significant contribution to achieving the targets. Overall, this regulatory environment is likely to inhibit private investment in technological progress, as the numerous measures lead to completely different marginal abatement costs in different sectors despite EU-wide emissions trading (cf. Figure 19). Furthermore, the system of objectives should be designed to be free of contradictions. As things stand today, for example, the targets for reducing energy consumption cannot realistically be achieved without accepting the relocation of energy-intensive industry (cf. [23, pp. 40–41]). Various technology-specific regulations should be scrutinized, for example those that make the use of blue hydrogen more difficult or impossible in the transition to climate neutrality or that prescribe detailed specifications for the construction and operation of electrolysis plants [122], [205].

b. **Reduce climate-damaging subsidies**. The reduction of climate-damaging subsidies has been discussed for years. The German Environment Agency has presented an extensive list on this subject, which includes around EUR 70 billion per year [206]. However, it is not easy to save this money, as every measure has its advocates and often achieves socially desirable goals, at least in part. Nevertheless, it is worth taking a closer look. For example, the commuter allowance could be realigned to eliminate climate-damaging incentives and reduce benefits for households in higher income groups.

c. **Standardize and coordinate reporting obligations**. A constant stream of new reporting obligations – as part of the Supply Chain Act, the Corporate Sustainability Reporting

Directive (CSRD) and other initiatives – is increasing compliance costs not only for the companies directly affected, but also for their suppliers. The impact on companies that are not directly affected is a particular problem for Germany with its many small and medium-sized enterprises. The focus of policy should therefore be on harmonizing reporting obligations and reducing them where possible. In addition, structures could be created, for example via associations, to support companies in their reporting.

d. **Harmonize the implementation of rules**. There are currently considerable differences in compliance with and enforcement of rules in the EU member states. However, the Aarhus Convention [207], [208], [209], for example, prevents participation rights, once established, from being abolished or reduced without further ado. While this ensures the rights of affected parties in participation processes, it also makes it more difficult to simplify approval and participation processes. On the one hand, this is problematic because competition within the EU is distorted by the different scope of participation processes in the Member States. On the other hand, this situation makes it more difficult to harmonize participation procedures, which impairs the financing of business models on the capital market, as it is more difficult to estimate future revenues and costs.

5.4 International climate cooperation

Effective international climate cooperation is the key to successful climate protection, but also a prerequisite for reconciling climate protection and growth in Europe. The further development of international climate policy from joint targets and unilateral target commitments to joint binding institutions that implement the targets is crucial. The conversion of European energy imports and the necessary diversification of imports of critical raw materials are forcing Europe to strategically realign its role in international energy and climate policy. The following elements can be part of a strategic reorientation:

a. **Anchor global climate cooperation in binding institutions**. In order to achieve effective international climate cooperation, joint commitments based on reciprocity are required [106]. One possible starting point for such agreements, be it through sectoral agreements to reduce emissions or the introduction of a global CO_2 minimum price, could be a Climate Club. Such a club has already been set up on the initiative of the G7, but binding joint commitments and institutions are still lacking. Joint institutions of selected states could initially comprise a "community of the willing" (also within the Climate Club) and would have to be secured externally with a CO_2 border adjustment mechanism (analogous to the CBAM) in order to protect the competitiveness of the participating states and at the same time avoid carbon leakage. Such an approach could be discussed within the Climate Club in order to reduce the reservations of countries that do not yet want to commit to joint institutions for climate protection.

b. **Establish global trade in climate-neutral energy carriers**. Europe has a special role as the only continent that needs significant energy imports even in a climate-neutral world. The EU should therefore initiate global trade in climate-neutral energy carriers at an early stage and also establish new energy trade relations in this context in order to diversify energy trade relations. For countries with great potential for the production of climate-friendly hydrogen and derivatives, the new role as an energy exporter offers opportunities, for example through technology transfer from the EU and the creation of skilled jobs. The EU can diversify its energy supply by establishing new energy value chains and also benefit from plant construction and service exports.

c. **Redirect and broaden trade relations.** Europe must muster the strength to ratify trade agreements that have already been negotiated and to negotiate new ones. This is important not least in order to gain access to important raw material deposits. Activities should be intensified in a targeted manner where new cooperation can be strategically initiated or the hardships of transformation for other countries are to be cushioned. It is preferable to reduce dependencies by intensifying new collaborations in the course of the transformation than by cutting back existing relationships.

d. **Intertwine policy areas.** International climate financing, energy policy, development policy, foreign trade policy, trade policy and other policy areas exhibit strategic complementarities in the upcoming transformation. It is important to overcome the departmental principle in these areas and to leverage the sometimes substantial synergies between the policy fields. This can be achieved, for example, by agreeing on cross-departmental mechanisms that are not associated with specific funding instruments but have a structural effect (such as emissions trading). On the other hand, initiatives that are coordinated across departments can address the strategic interdependence and take this into account. The import strategy for hydrogen and hydrogen derivatives sets a good example here by comprehensively coordinating and explaining the interplay of policy areas.

e. **Use forward guidance in global energy policy.** In order to strategically align Europe's role in energy and climate policy, it is important to analyze long-term global developments at an early stage and identify opportunities and risks for Europe. Important aspects may include the future growth ambitions of developing and emerging countries (Figure 2 c)) and the energy requirements necessary for this, the control of fossil resources by power elites (Figure 2 e)) or migration flows that are to be expected as a result of climate change but can possibly be mitigated with foresight through international cooperation.

5.5 Strengthen growth potential

An efficient energy and climate policy can only succeed and promote growth if structural changes are made in parallel to strengthen growth potential. In addition to measures that are directly aimed at energy and climate policy and therefore result in the lowest possible energy costs, the following measures should be prioritized:

a. **Increase the labor volume.** The declining labor volume, particularly due to demographic change, is significantly dampening potential growth and posing challenges for various sectors of the economy. Companies will try to compensate for the lack of workers by increasing their capital investment. However, it will also be necessary to mobilize part-time workers, older workers and recipients of the benefit system as well as immigration in order to mitigate the negative effects on potential output [175], [179]. In view of the shortage of skilled workers and the change in requirement profiles in the course of the transformations, the adaptation of qualification profiles will become a challenge. Highly qualified specialists will continue to be a key location factor in the future. In the course of the transformations, coordinated efforts in the area of further training and retraining (partly also by the state) are therefore essential in order to successfully master the structural change. Due to the hoarding of scarce labor by companies and the lack of reallocation of labor to more efficient companies during the crises of recent years, labor productivity is currently low [97, Ch. 1]. Obstacles to the reallocation of labor should therefore be removed as consistently as possible. This implies in particular that structural change in industry should not be unnecessarily held up by state support for companies.

b. **Strengthen the education system.** Investment in the education system, from early childhood education to university, is an important, if not the most important, basis for economic growth. Public spending on education should increase significantly [97] and a greater focus should be placed on the first years of education, from early childhood education to elementary school. A society that is becoming more diverse through immigration must develop strategies to offer immigrants and their children equal opportunities. This is the only way to make Germany an attractive country of immigration, where immigrants are rewarded for their achievements and where, in turn, the country succeeds in raising the potential of its population [179]. At the same time, high-quality childcare and education services can increase the potential working hours of parents, which will alleviate the increasing shortage of skilled workers.

c. **Steer investments towards growth sectors.** The weak growth that has already manifested itself since 2019 [180] has been further exacerbated by the effects of the recent crises. Significant productivity-enhancing investments in capital stock and human capital are required to get back on a robust growth path. An efficient transformation of the energy supply in the European and global context, as outlined in this report, is a prerequisite for success. However, an inefficient allocation of production factors is currently slowing down growth potential [175]. In order to attract private investment and channel production factors into more productive economic sectors, it is important to increase the attractiveness of the location (see the other recommendations in this section) and also to refrain from supporting companies that will no longer be competitive under the future framework conditions. In addition, adjustments to the tax and regulatory framework will be necessary in order to increase the innovative strength of the economy and the attractiveness of business models.

d. **Strengthen capital markets and a banking union.** The deepening of the capital markets union and the banking union are crucial to facilitate access to capital for future growth markets. However, European capital markets are fragmented along national lines, which limits the financing options available to companies. In particular, there are major national differences in corporate reporting and insolvency law, as well as tax obstacles to cross-border investments [183]. Greater integration and harmonization of financial markets in Europe could make it easier for companies to access financing options and help to diversify risks and facilitate the financing of investments in the course of transformation [183]. This is because the financing via loans that is widespread in Germany and other European countries is unsuitable for many projects in the course of transformation due to their risk structure [183].

e. **Adapt social security systems to growth potential.** In order to create room for state investment, the social security systems should be adapted to the expected growth potential. In particular, the expected increase in statutory pension insurance expenditure as a result of demographic developments should be curbed by means of suitable reforms [94], [94, p. 368 ff.]. In order to relieve the transfer systems, work incentives could be strengthened, which would also alleviate the labor shortage [210]. Long-term sustainable social systems relieve the burden on state budgets and create scope for future-oriented expenditure.

f. **Acting sustainably not only in climate protection.** Climate protection can only succeed if sustainable action is also taken in other policy areas. Key areas of action include effective fiscal rules, which are necessary to ensure long-term debt sustainability and prevent sovereign debt crises. It is also crucial to establish and maintain long-term defense capabilities in order to make military attacks unattractive for potential aggressors and thus make conflicts less likely from the outset. Adequate spending on education ensures that equal opportunities and the innovative strength of society are strengthened and maintained in the long term. Abandoning sustainability in any of these areas (or in other important fields of action) is likely to make crisis situations more likely, which would inevitably divert political attention away from climate protection and growth-oriented policies.

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