IRENA
International Renewable Energy Agency

REmap 2030
A Renewable Energy Roadmap

RENEWABLE ENERGY PROSPECTS:

GERMANY

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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FOREWORD

Germany is a leader in the global transition to a renewable energy future. With its forward-looking energy policy and decades of support for renewables, the country has played an important role in propelling clean, sustainable energy from niche technologies into the mainstream.

Germany's energy transition, or *Energiewende*, is an evolving effort that engages government, private industry and civil society, and that is set to continue to 2030 and beyond. The *Energiewende* has become the flagship for the ongoing global energy transition and has also inspired other countries to reinforce and grow their ambitions to increase renewable energy use.

The German energy system has already been transformed by steadily increasing shares of renewables. The next 15 years, however, will demonstrate the wide-ranging implications of the *Energiewende* and point to the solutions Germany needs to realise its ambitious long-term energy and climate goals. Those solutions will be at the forefront of integrating new technological advances in the integration of variable renewable power, as well as innovative finance and business models, and serve as a model for global energy transition.

REmap Germany provides an overview of the progress to date in the country's energy transition. It also identifies where further action can be taken. Germany's ambitious goals include securing more than half of its electricity supply and just under a third of its total final energy from renewable sources by 2030. The REmap analysis – conducted by the International Renewable Energy Agency (IRENA) in collaboration with national and international experts – suggests the country has the potential to achieve an even higher level of ambition.

Germany will, however, need to make additional efforts to maximise its renewables potential, particularly if it is to harness the vast potentials of renewables for heat and transport. The expansion of the *Energiewende* in those sectors provides a way forward. Continued integration of European energy markets is also essential for Germany and others to fulfil their renewable energy potentials.

This report demonstrates that the benefits of the energy transition on the whole outweigh the costs. Renewable energy deployment reduces human health and environmental externalities, reduces fossil fuel imports, boosts economic growth and can cut energy system costs over the long term.

This report is based on the conclusion that Germany can continue to lead the global transition to a renewable energy future. By taking the necessary steps now, at this crucial stage in the *Energiewende*, the country will ultimately succeed in its goal of building a healthy, prosperous, competitive and environmentally sustainable future through renewable energy. IRENA is honoured to be working together with Germany to define this new energy paradigm.

Adnan Z. Amin

Director-General

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EXECUTIVE SUMMARY

Germany is a world leader in its level of renewable energy deployment. Driven by a long-term renewable energy policy that dates back to the 1970s and, more recently, a nuclear power phase-out, the country is spearheading a transition to renewable energy that is commonly known as the *Energiewende* ("energy transition"). The *Energiewende* has gained broad political consensus in recent years. Its main drivers are climate change mitigation, improved energy security and industrial development.

Germany's experience continues to attract interest in the global renewable energy community and among national policy makers, and has inspired action in many countries around the world. The German Federal Ministry for Economic Affairs and Energy (BMWi) requested the preparation of this *REmap Germany* roadmap by the International Renewable Energy Agency (IRENA).

REmap is IRENA's analytical approach for assessing how, by 2030, to close the gap between current national renewable energy plans and the realistic potential of renewable energy beyond those plans. As an intergovernmental agency with broad membership, IRENA is uniquely positioned to promote widespread adoption and sustainable use of all forms or renewable energy worldwide. To date, 38 countries participate in the REmap 2030 programme. Together, these countries represent 80% of total global energy demand.

REmap Germany highlights best practice policy and technology experiences from which others can learn. It also identifies areas where the *Energiewende* can be expanded, in order for Germany's ambitious targets for renewable energy, energy efficiency and greenhouse gas emission reduction to be met by 2030. In addition, the report goes into depth on the integration of Europe's energy markets.

Germany's progress to date

Germany has seen tremendous growth in renewable power generation capacity. For many years, the policy instrument of choice was a feed-in tariff, but the country is now moving to introduce new instruments, including feed-in premium payments and an auctioning system. In the power sector, the development of renewable energy has diversified the energy mix, changed ownership structures and reduced Germany's dependence on fossil fuel imports. In addition, the renewables industry has built up a workforce of over 371 000.

Germany's renewable power share reached more than 25% in 2014, and it exceeded 30% in the first half of 2015. The country has shown the world that such a high level of renewables can be integrated without systemic problems, thanks to strong grid infrastructure and cross-border exchange links. As Germany transitions to ever-higher shares of renewable power, beyond 50% and even higher by 2030, important grid and sector-coupling options must be considered.

For Germany to reach its target of a 30% renewable energy share in total final energy consumption (up from 10% in 2010), a systemic change involving all sectors will be required, as the power sector alone is not sufficient to transition the country's energy system away from fossil fuels.

In the heating and transport sectors, targeted support policies have been less effective in increasing renewable energy technology deployment. Deployment of renewables for transportation has been limited in recent years, with liquid biofuel consumption remaining stable and sales of electric vehicles falling short of earlier forecasts. For industry, which is the second largest energy demand sector in Germany, no specific renewable energy market framework is in place.

The focus with regard to energy use in buildings should first be on improvements in energy efficiency and then on the deployment of renewable systems. Germany has taken considerable steps to improve its energy efficiency and recently introduced a national action plan for energy efficiency to accelerate improvements. However, the yearly energy productivity improvement rate stands at 1.6%, compared to the target rate of 2.1%. In addition, current renovation rates represent roughly half of the 2% per year target. The existing building stock therefore will need to be renovated at a higher rate in order to meet the energy productivity improvement goal, and policies should be considered that also support the installation of renewable heating systems in renovated buildings.

Going forward, the role that renewables will play in both the power and end-use sectors will determine at what rate Germany can continue to progress towards its greenhouse gas emission reductions and ambitious renewable energy targets.

Findings from the *REmap Germany* roadmap to 2030

For the Reference Case, this roadmap builds on the 2014 report *Energy Reference Forecasts*, prepared for BMWi by Prognos AG, the Institute of Energy Economics at the University of Cologne, and the Institute of Economic Structures Research (GWS mbh).

For REmap, which aims to determine the feasible potential of renewable energy deployment, this baseline is combined with an analysis of technology options derived from a comprehensive set of data, including reports and information provided by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), BMWi, IRENA and others.

The REmap analysis shows that in the Reference Case, Germany reaches a 27% renewable energy share in the total energy mix by 2030. The Reference Case technology deployment is driven largely by renewable power generation. Solar photovoltaic (PV) applications at the utility scale and on rooftops would increase threefold, and installed wind capacity would double between 2010 and 2030. These are outcomes of policies that are focused primarily on the power sector, but that devote less attention to renewables in end-use applications for heating and cooling, as well as the transport sector.

REmap shows the potential for additional renewable deployment utilising technologies available today. Deploying higher levels of renewable power technologies, as detailed in REmap, will ensure that Germany can realise its renewable energy target of 30%. In REmap 2030, two-thirds of Germany's total power generation is from renewables, and, even more importantly, half is from the variable renewable energy sources of solar and wind. Installed wind capacity reaches 88 gigawatts (GW), split between 72 GW onshore and 16 GW offshore. Solar PV reaches 75 GW, with more than three-quarters coming from distributed generation and over 10 GW coming from decentralised generation coupled with storage.

Importantly, REmap illustrates that there is a potential for renewables in end-use applications that is not yet fully captured by the *Energiewende*. If the potentials in heating and transport are utilised, Germany can increase its total renewable energy share beyond 30% of final energy. Increasing this share to between 30% and 37% will be cost-optimal depending on how the environmental benefits of individual technologies are valued and if costs are viewed from a business or a government perspective.

The technology options that enable these higher renewable shares are identified largely in the end-use sectors. Some of these technologies are more expensive than their fossil fuel counterparts when viewed from a levelised cost of energy perspective. However, these technologies (*e.g.*, heat pumps, electric vehicles) are also enablers. They allow end-use and power sector coupling to accommodate higher shares of variable renewable power, thereby reducing the need for other flexibility measures. They also ensure the development of heating and transport systems that are smart and sustainable, more affordable in the long-run, and a source of future knowledge and industrial growth. Germany will need to forge new ways of valuing the costs of these energy services by taking a holistic view that includes the economy-wide and energy system benefits of these services.

The end-use sectors offer significant additional renewable potential. If all of the technology options identified in REmap are deployed, the total installed heat pump stock can grow to over 6 million units, solar water heaters can exceed 10 million square metres (m^2) and the use of biomass for heating in industry and buildings can increase by 8 million tonnes per year by 2030, compared to the Reference Case. By 2030, the supply of renewable heat can more than double compared to current levels. There also are important benefits from increases in sector coupling, with the introduction of district heating systems that utilise heat pumps and solar thermal.

In the transport sector, where robust biofuel growth occurs in both the Reference Case and REmap, total biodiesel demand reaches nearly 9 billion litres and total ethanol demand reaches 3.4 billion litres, with two-thirds of this total being advanced ethanol. Electric mobility, coupled with renewable power generation, plays an equally important role, reaching 6.5 million electric vehicles by 2030. This includes not only electric vehicles and hybrids, but also e-bikes and electric vehicles used for freight transportation. By 2030, the share of the transport sector's energy consumption that will come from renewable sources will increase fourfold over today's levels, reaching more than 20%.

However, the deployment of many of these technologies is only beginning, and their potential, costs and synergies with other energy sectors is only starting to be understood. Importantly, as the share of electricity in final energy increases, and as this electricity is increasingly sourced from variable renewable sources, transition costs need to be better understood and analysed. These can include investments in transmission and distribution infrastructure, measures to ensure flexibility in the power system, and the development of district heating systems and charging infrastructure.

What are the cost and benefits of renewables for Germany, according to REmap?

Achieving this transformation will require, on average, USD 15.7 billion per year of investment to 2030 in renewable technologies (including investments for both the power and end-use sectors in both the Reference Case and REmap Options).

REmap assesses the cost of Germany's energy system from two perspectives: business and government. The business perspective annualises renewable energy investments with a national discount rate and accounts for the annual operation and maintenance costs as well as national fuel and carbon costs. It reflects how businesses and investors would perceive the investment opportunity. From this perspective, Germany would save USD 2.4 billion annually by 2030 for the REmap renewable energy system relative to the Reference Case. This makes for a compelling case for higher renewable deployment. If these investments are viewed from the government perspective, which provides a macro-economic view and includes a higher discount rate of 10% and energy prices that exclude tax effects, renewables would have incremental costs of USD 4 billion per year in 2030.

Complementary infrastructure is not assessed, due to uncertainty about what those actual transition costs could entail. For instance, some of the end-use sector coupling technologies deployed in REmap (heat pumps, electric vehicles) can offer complementary services to the grid. Understanding how these services are provided, and their costs, will be crucial in the coming years to better assess the transition costs, or the savings, that can result from significantly higher renewable shares.

In both the business and government perspectives, however, a portfolio of technology options that permits a renewable share above 30% can be realised cost-optimally, when their benefits are accounted for. At a technology level, each option has the potential to bring important benefits in better energy security, improved human health and greenhouse gas mitigation. If all REmap Options were deployed, the total fossil fuel import costs in Germany would be reduced by almost USD 30 billion per year by 2030. Improved human health, from reduced outdoor air pollution, can save USD 1-2 billion per year in 2030, and climate change benefits in REmap can be valued at USD 2-8 billion per year in 2030. The total of all benefits is USD 33-40 billion per year in 2030, much higher than the total system costs of USD 4 billion when viewed from the government perspective.

In REmap 2030, energy-related carbon dioxide (CO_2) emissions will decline from some 789 million tonnes in 2010 to 540 million tonnes in the Reference Case. The REmap Options result in an additional reduction of 101 million tonnes, to 439 million tonnes in 2030, representing a 55% reduction in CO_2 over 1990 levels for the energy sectors covered in this study.

What are the challenges and solutions?

Generating 50% of electricity from variable renewable energy will require changes in the power system. After intensive discussions, Germany has decided to undertake an electricity market reform, dubbed "electricity market 2.0", highlighting the importance of flexibility measures, including cross-border exchange, demand-side management (including smart grids/metering that incentivises customers to save energy, and other measures) and sectoral linkages between the power and end-use sectors. In particular, sectoral linkages enable important renewable energy potential and reduce the need for costly measures such as curtailment or battery storage. The use of combined heat and power (CHP) generation coupled with heat storage, heat pumps and electric vehicles all can be scheduled to accommodate the variability in solar and wind power generation.

In this context, *REmap Germany* shows that the largest potential for additional deployment of renewables beyond the Reference Case is in the heating and transport sectors. These sectors also will face the biggest challenges to deployment, especially because the policy focus in these areas is still somewhat limited, and progress is needed to realise further growth in renewables deployment.

The key factor for increasing both the energy efficiency of the building stock, and the deployment of renewable systems, is the rate at which old buildings are renovated. Even with a 2% per year renovation rate (in 2014, it was under 1.0%), and approximately 10% of the building stock being newly built to 2030, only about 40% of the total building stock in 2030 will have gone through some level of renovation. Therefore, additional efforts will need to be made to expand the rate of energy efficiency retrofits in old buildings, and to link these retrofits with increased renewable energy deployment.

The industry sector has very specific heating supply requirements, and today, renewables play only a modest role in supplying process heat. However, REmap shows that additional potential exists. For low-temperature heating applications, both solar thermal technology and heat pumps offer potential. Biomass is, and will remain, the largest renewable energy source, but it should be allocated primarily to applications that require medium- and high-temperature heat. Additionally, the possibility of further electrification of the sector for heating needs should be considered.

In the transport sector, all options need to be considered to increase the renewables share from what currently is the lowest of all sectors. Importantly, electric mobility will need to be increased, which will allow for better demand-side management of variable electricity generation. However, increased investment in charging infrastructure and incentives for electric vehicles are needed to enable this significant growth.

What does European integration mean for Germany to reach its targets?

Germany consumes approximately 20% of the European Union's (EU) energy, and the country will play a major role in helping the EU realise its regional energy and climate targets. Germany will not achieve its REmap 2030 potential without further market integration with the EU. Germany is at the centre of European energy markets and is linked closely with the electricity markets of its neighbours. Regional integration already is regarded as a core component to strengthen the EU's coupled power markets. Integrated markets offer greater flexibility and balancing potential as well as gains from using smoothing effects. The next steps are finalising and implementing the 10 European network codes, taking a co-ordinated approach to strengthening grid infrastructure at the national level and expanding cross-border trade. Finally, a larger unified European market will help to reduce equipment and project costs.

Expanding the focus of Germany's energy transition

The *Energiewende* is a visionary, long-term and evolving process. Its development will continue, but ensuring Germany's aim to build one of the world's most energy-efficient, sustainable and low-carbon energy systems will require expanding the *Energiewende's* focus beyond the power sector and making deliberate efforts to link sectors that have remained largely separate. In this way, the next step of the *Energiewende* will define what a transition to very high shares of renewables will look like and lead the way in the global energy transition.

In making this new transition, this analysis shows that realising Germany's climate targets and long-term renewable energy goals will require efforts in both improving energy efficiency and deploying additional renewable energy in both the power and end-use sectors.

Efficiency measures and the renewable heating sector are the potential Achilles' heel of the *Energiewende* in the medium term. Renovation targets need to be met, and efficiency regulations in the building sector must be harmonised with renewables targets to achieve the best technical and economic solutions. To increase the share of renewables in heating, a combination of building-type specific efficiency and technology-neutral renewable heating targets, supported with continued finance programmes, will help to achieve both goals.

The industry sector is, in large part, not yet part of the *Energiewende*. Therefore, benchmarks and targets need to be established for supplying industrial process heat based on renewable energy. The development of a dedicated programme to increase the uptake of renewables for process heat generation is missing and is required urgently. Innovative policy approaches need to ensure continued competitiveness for the sector.

The transport sector will be among the most challenging areas for the future of the *Energiewende*. The uptake of electric vehicles in Germany is progressing slowly, and specific policy measures for electrification are required that also incentivise investments in charging stations and their access and use by all. Advanced biofuels represent an important enabling technology for applications such as aviation and freight. The technologies exist to use non-food feedstocks to provide biofuels, but costs need to be driven down through economies of scale. To utilise the limited availability of biomass resources in the most sustainable and cost-effective way across competing uses, a Germany-specific bioenergy resource plan needs to be developed.

The new power market design that is being planned in Germany should create business opportunities for heating storage and demand-side management technologies as well as sectoral linkages to support grid integration of renewable power supply. Regular reviews are needed to ensure its effectiveness.

The *Energiewende* in Germany will influence international energy markets. The EU electricity market needs to finalise implementation of the 10 network codes and to facilitate investments in transmission infrastructure. The EU member states need to develop and co-ordinate mechanisms to address energy security situations, update market design to deliver secure and affordable energy supply, and foster research, development and deployment (RD&D) in transmission networks.

To date, Germany has played a remarkable leadership role in the promotion of renewables in the international arena. It now has the opportunity to show the world what the true energy system of the future will be. The country has started on a process that will continue for years to come, and will require constant evolution. In making this contribution to the German debate, it is the hope of IRENA that with the solutions outlined in this report, Germany can realise its full renewable energy potential and, in the process, continue to forge best practices, create awareness and spread knowledge worldwide, and remain a pioneer in the renewable energy field.

1 INTRODUCTION

REmap 2030 is the result of a collaborative process between IRENA, national REmap experts within the 38 participating countries[1] and other stakeholders. The current report focuses on the actual and potential role of renewable energy in Germany, the largest energy user in the European Union (EU). In 2010, Germany had a total final energy consumption (TFEC[2]) of 9.6 exajoules (EJ), equivalent to 2.6% of global TFEC. About half of Germany's TFEC was consumed in the building and services sectors, with the remainder consumed largely in the industry and mining sectors (28%) and the transport sector (27%) (AGEB, 2010; IEA, 2013).

The expansion of renewable energy has made Germany a European and international pioneer in energy, climate and innovation policy. The country's *Energiewende* ("energy transition") includes decentralised power solutions that are focused heavily on solar and wind power, the deployment of large-scale renewable energy systems such as offshore wind parks, and cross-cutting sectoral approaches, with the aim of expanding renewable energy in sectors beyond the power sector.

Germany's TFEC is projected to decrease by 20% between 2010 and 2030. In the same time period, based on current policies (or the "Reference Case", according to this study), Germany's share of renewable energy in TFEC will grow from 10.5% to 27% in 2030, below the country's target of 30%. Germany has the potential to go beyond its Reference Case developments.

According to the REmap analysis carried out by IRENA with input from external stakeholders, Germany could reach a 37% renewable energy share in TFEC by 2030 *if* the realisable potentials of all renewable energy technologies identified in REmap are deployed. The technology potentials to realise this higher share are called the "REmap Options". If only the power sector technologies are deployed, then the share would increase to 30%; the remaining technologies to increase the renewable energy share to 37% are found in the end-use sectors (buildings, industry and transport).

Depending on the technology mix, the portfolio to go beyond a 30% share may have additional costs to Germany's energy system. In the power sector, the renewable energy share will increase to 65% by 2030, an almost threefold increase over 2014 levels. The available renewable energy resources include mainly solar, geothermal, biomass, wind and hydro. The first three can be used either for power or heat generation, depending on resource availability and the technologies implemented.

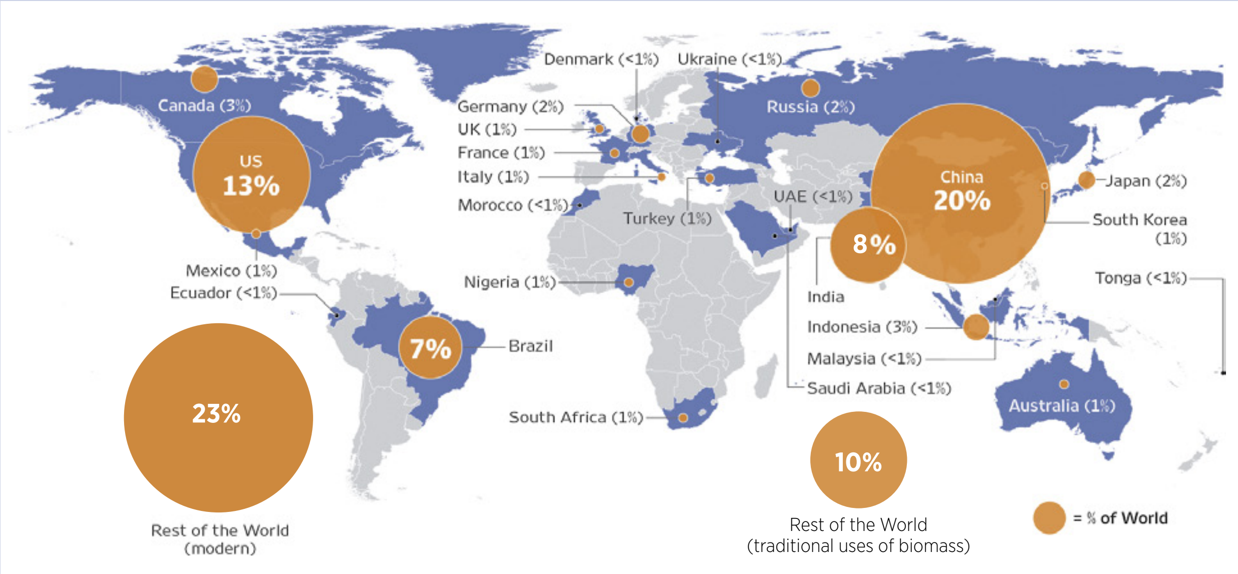
This national potential for renewables contributes to the global renewable energy share. Figure 1 provides a breakdown of total renewable energy use among the original 26 REmap countries that have developed REmap Options by June, 2014. Germany accounts for 2% of the identified renewable energy potential in the original 26-country grouping. The number of REmap countries has since expanded to 38 countries as of October, 2015.

As of mid-2015, IRENA had released six REmap country reports, providing detailed background data and the results of REmap country analyses for China, Mexico, Poland, Ukraine, the United Arab Emirates and the United States and making suggestions for translating the results into action. For each country, the reports

1 The 38 REmap countries (as of November, 2015) account for eighty percent of global TFEC. TFEC includes the total combustible and non-combustible energy use from all energy carriers as fuel (for the transport sector) and to generate heat (for industry and the building sector) as well as electricity and district heat. It excludes non-energy use. This report uses TFEC to measure the renewable energy share, consistent with the *Global Tracking Framework* report (World Bank, 2013). In this study, TFEC includes only the consumption of the industry (including blast furnaces and coke ovens, but excluding petroleum refineries), building (residential and commercial) and transport sectors. In this same year, the non-energy use in Germany was about 10% from total final consumption (TFC), which includes both the energy and non-energy use of energy carriers.

2 The REmap methodology uses TFEC; however, the EU measures renewable energy shares in terms of gross final energy consumption (GFEC). GFEC includes energy commodities delivered for energy purposes to industry, transport, households, services (including public services), agriculture, forestry and fisheries, including the consumption of electricity and heat by the energy system for electricity and heat production and including losses of electricity and heat in distribution and transmission. It excludes transformation losses. In this study, comparisons are made to TFEC; however, results for total renewable share in GFEC are also provided.

Figure 1: Contribution of individual countries to total global renewable energy use of the original 26 REmap countries in REmap 2030



Note: The total global renewable energy use of the original 26 REmap countries represents 75% of global final energy consumption.

discuss in detail the latest developments in renewable energy markets, the renewable energy policy framework, business-as-usual renewable energy use to 2030, and the realistic potential and costs and benefits of renewables beyond business as usual. Based on these findings, the reports end with policy recommendations for how countries can accelerate the uptake of renewable energy use by 2030.

Compared to most countries, Germany is unique in terms of its advanced renewable energy policy, with the so-called *Energiewende* that aims to transform the country's energy system. In view of the specific case of Germany, the aims of this report are: 1) to provide an objective overview of the *Energiewende* to inform countries about Germany's experiences and best practices, 2) to identify the role of individual sectors in realising Germany's energy transition and its ambitious renewable energy goals, based on IRENA's global assessment of countries and the existing renewable energy projections, and 3) to discuss Germany's role in the context of EU energy and climate targets.

This report begins with a brief description of the REmap 2030 methodology (section 2). It continues by explaining the current policy framework and providing an overview of the *Energiewende* up until today (section 3). Section 4 provides the details of Germany's business-as-usual ("Reference Case") and renewable energy potentials ("REmap 2030") to 2030, as well as the challenges associated with achieving higher renewables deployment. Section 5 discusses these findings in the European and international contexts. Section 6 concludes with findings from the analysis for Germany, the EU and other countries and outlines the key take-away topics of the report.

Table 1: Structure, target audience and aim of the report

Section	Section focus	Target audience	Key take-away topics
3	Germany's current policy framework; detailed summary of the *Energiewende*	Policy makers and private sector representatives outside of Germany who are interested in best practices from Germany policy making German policy makers interested in areas where renewable energy is not addressed in the existing *Energiewende* approach	• Brief history of Germany's renewable energy policy • Germany's experiences with the *Energiewende* • Other aspects of Germany's energy policy, such as energy security and climate change • Effects of higher renewable energy deployment on various aspects of the economy
4	A view to the year 2030: renewable energy potential, costs and benefits, sector and technology perspectives; discussion of challenges and solutions in achieving accelerated renewable energy uptake; in depth discussion on importance and needs for renewables in the end-use sectors	Policy makers and private sector representatives in Germany	• Renewable energy deployment if Germany were to follow business as usual to 2030 • What does the additional potential look like (by technology, sector) to reach a 37% renewables share in TFEC by 2030? • What does realising this potential imply in terms of cost and benefits and efforts required by sector? • The importance of the end-use sectors in enabling higher renewable energy deployment, and some of the challenges and needs for realising deployment of renewables in heating and transport • Summary of challenges arising from accelerated renewable energy uptake
5	Germany's role in the context of the European and international renewable energy sectors; actions needed at the European level, and Germany's role in realising higher shares of renewables; international perception of the *Energiewende*; Germany's role in international co-operation for renewables	Policy makers and stakeholders along the power supply chain in Germany, Europe and internationally	• Germany's contribution to renewables deployment in Europe and the world • Regional integration actions in Europe to realise higher shares of renewables in Germany and the EU • How the *Energiewende* is viewed by other countries • Germany's role so far in the international setting for renewables
6	High-level summary, learnings and key take-aways based on Sections 3-5	Policy makers in Germany, Europe and internationally	• Next steps for the *Energiewende* • Power sector and market design • Heating and cooling sectors • Transport sector • Regional integration and infrastructure • Sectoral linkages • Bioenergy

2 METHODOLOGY AND DATA

This section explains the REmap 2030 methodology and summarises the background data used for the analysis of Germany. The report's annexes provide greater detail on these background data.

REmap is an analytical approach for assessing the gap between current national renewable energy plans, additional renewable technology options which can be realistically deployed by 2030 and the United Nations Sustainable Energy for All (SE4ALL) objective of doubling the share of global renewable energy by 2030 (IRENA, 2014a).

As of November 2015, the REmap 2030 programme assesses 38 countries: Argentina, Australia, Belgium, Brazil, Canada, China, Colombia, Denmark, the Dominican Republic, Ecuador, Egypt, Ethiopia, France, **Germany (the present analysis)**, India, Indonesia, Iran, Italy, Japan, Kazakhstan, Kenya, Malaysia, Mexico, Morocco, Nigeria, Poland, Russia, Saudi Arabia, South Africa, South Korea, Sweden, Tonga, Turkey, Ukraine, the United Arab Emirates, the United Kingdom, the United States and Uruguay.

The analysis starts with national-level data covering end-use demand sectors (buildings, industry, transport, agriculture) as well as the supply sectors of power and district heat. Current national plans using 2010 as the base year of this analysis are the starting point. However, the energy landscape in Germany is constantly evolving during a time of *Energiewende*, or energy transition.

The German government's "Energy Concept" (BMWi and BMU, 2010) provides the long-term (to 2050) political timetable for the transition of the country's energy supply system. However, under EU law, EU member states are obligated to renewable energy commitments on the EU level as a whole by 2020. EU member states must set national targets to achieve the EU targets. These so-called "20-20-20" targets include increasing the share of renewable energy in GFEC to 20%, reducing the EU's greenhouse gas emissions by 20% from 1990 levels, and reducing the EU's total primary energy consumption (compared to projected development) by 20%.

EU member states were required to submit National Renewable Energy Action Plans (NREAP) in 2009 that detail sectoral targets and the technology mix, the general trajectory that countries will follow, and the measures and reforms that they will undertake to overcome the barriers to developing higher levels of renewable energy use. The EU and its member states have adopted a 2030 framework, but as of 2015 they were still discussing how this can be implemented effectively. Germany is one of the few EU countries that has renewable energy plans to and beyond 2030.

The REmap analysis first assesses current energy developments to 2030 (the Reference Case), then identifies a pathway for accelerated renewable energy potential known as the REmap Options. For an analysis of the Reference Case for Germany, IRENA used the report *Entwicklung der Energiemärkte – Energiereferenzprognose* ("Energy Market Developments – Energy Reference Forecasts") (Prognos, EWI and GWS, 2014), hereafter referred to as either the Reference Case, or *Energy Reference Forecasts*. This report includes policies made by the German government as of mid-2014. Since then, additional policies have been passed, mainly a reform to the Renewable Energy Act (*Erneuerbare-Energien-Gesetz*, or EEG, of 2014), and additional measures have been proposed, such as reform of the German power market and a National Action Plan on Energy Efficiency (NAPE).

In the Reference Case, Germany sees significant changes to its energy system. TFEC declines by 12% between 2010 and 2020 and then by a slightly slower 8% between 2020 and 2030, resulting in a total reduction of 20% from the 2010 level. Despite the decline in energy demand, the use of renewable energy increases in all sectors, with more than half of power generation coming from renewables. The building sector and the district heating sector see the next-highest gains in the share of renewables, and the industry and transport sectors see the least.

After the Reference Case was prepared, the potential for accelerated renewable deployment was explored. The technology options that were identified in this analyses are called the REmap Options and the case where they are included is called REmap 2030. For this analysis, IRENA used the "Target Case" from the *Energy Reference Forecasts* as well as the *Projektionsbericht* (BMUB, 2015), known hereafter as the *Projection Report*, which includes the changes found in the EEG 2014 law. Other sources included IRENA publications and analysis as well as material from other agencies, organisations and studies. The report annex provides a detailed overview of the sources used for the analysis.

The choice of an options approach instead of a scenarios approach is deliberate: REmap 2030 is an exploratory study, not a target-setting exercise.

IRENA developed a REmap tool that allows staff and external experts to input data in an energy balance for 2010, 2020 and 2030 and then to assess technology options that are consistent with an accelerated deployment of renewable energy that could take place by 2030. In addition to what is provided in the annexes of this report, a detailed list of these technologies and the related background data are provided online. The tool includes the costs (capital, operation and maintenance (O&M)) and technical performance (reference capacity of installation, capacity factor and conversion efficiency) of renewable and conventional (fossil fuel, nuclear and traditional use of biomass) technologies for each sector analysed: industry, buildings, transport and power.

Each REmap Option is characterised by its substitution cost. Substitution costs are the difference between the annualised cost of the REmap Option and the cost of a conventional technology used to produce the same amount of energy, divided by the total renewable energy use in final energy terms (in 2010 real US dollars (USD) per gigajoule (GJ)[3] of final renewable energy). This indicator provides a comparable metric for all renewable energy technologies identified in each sector. Substitution costs are the key indicators for assessing the economic viability of REmap Options. They depend on the type of conventional technology substituted, energy prices and the characteristics of the REmap Option. The cost can be positive (incremental) or negative (savings), as many renewable energy technologies are already or could be cost-effective compared to conventional technologies by 2030 as a result of technological learning and economies of scale.

Based on the substitution cost and the potential of each REmap Option, country cost supply curves were developed from two perspectives for the year 2030: government and business. In the government perspective, costs exclude energy taxes, subsidies and a CO_2 price, and a standard 10% discount rate is used which allows for comparison of the cost and benefits across all REmap countries; the government perspective shows the cost of doubling the global renewable energy share as governments would calculate it. For the business perspective, the process was repeated using national prices that include, for example, energy taxes or subsidies, a CO_2 price applied to all fossil fuels, and a national cost of capital of 6% for Germany in order to generate a localised cost curve. This approach shows the cost of the transition as businesses and investors would calculate it.

Assessments of all additional costs related to complementary infrastructure, such as transmission lines, reserve power needs, energy storage or fuel stations, are excluded from this study. However, where relevant, a discussion is included on the implications of infrastructure needs on total system costs based on a review of comparable literature.

Throughout this study, renewable energy share is estimated by comparison with TFEC. Based on TFEC, the renewable energy share can be estimated for the total of all end-use sectors of Germany, or for each of its end-use sectors (with and without the contribution of renewable electricity and district heat). The share of renewable power generation is also calculated. Further details of the REmap 2030 methodology can be found online at *www.irena.org/remap.*

This report also discusses the finance needs and avoided externalities related to increased renewable energy deployment. Three finance indicators are developed – incremental system costs, total investment needs and subsidy needs – and are defined briefly as follows:

- Incremental system costs: The sum of the differences between the total capital (in USD per year) and operating expenditures (in USD per year) of all energy technologies based on their

3 1 gigajoule (GJ) = 0.0238 tonnes of oil equivalent (toe) = 0.0341 tonnes of coal equivalent (tce) = 0.238 gigacalories (Gcal) = 278 kilowatt-hour (kWh) = 0.175 barrel of oil equivalent (BoE) = 0.947 million British thermal units (MBtu). In 2010, USD 1 was equivalent to EUR 0.752.

deployment in REmap 2030 and the Reference Case in the period 2010-2030 for each year.

- Total investment needs: The annual investment needs of all REmap Options and the investment needs required in the Reference Case. Renewable energy investment needs are estimated by multiplying total deployment of each technology (in GW) to deliver the same energy service as conventional capacity by the investment costs (in USD per kilowatt (kW)) for the period 2010-2030. This total is then annualised by dividing the number of years covered in the analysis.
- Subsidy needs: Total subsidy requirements for renewables are estimated as the difference in the delivered energy service costs for the REmap Option (in USD per GJ of final energy) relative to its conventional counterpart, multiplied by its deployment in a given year (in petajoules (PJ) per year).

External effects related to greenhouse gas emission reductions as well as improvements in outdoor and indoor air pollution from the decreased use of fossil fuels are also estimated.

As a first step, for each sector and energy carrier, greenhouse gas emissions from fossil fuel combustion are estimated. For this purpose, the energy content of each type of fossil fuel was multiplied by its default emission factors (based on lower heating values, LHV) as provided by the Intergovernmental Panel on Climate Change (IPCC, 2006). Emissions were estimated separately for the Reference Case and REmap 2030. The difference between the two estimates yields the total net greenhouse gas emission reduction from fossil fuel combustion due to increased renewable energy use. To evaluate the related external costs related to carbon emissions, a carbon price range of USD 20-80 per tonne of CO_2 is assumed (IPCC, 2007). This range was applied only to CO_2 emissions, not to other greenhouse gases. According to the IPCC (2007), the carbon price should reflect the social cost of mitigating one tonne of CO_2-equivalent greenhouse gas emissions.

The external costs related to human health are estimated in a separate step, which excludes any effect related to greenhouse gas emissions. Outdoor air pollution is evaluated from the following sources: 1) outdoor emission of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter of less than 2.5 micrometres ($PM_{2.5}$) from fossil fuel-based power plant operation, and 2) outdoor emissions of NO_x, and $PM_{2.5}$ from road vehicles. To evaluate the external costs related to outdoor emission of SO_2, NO_x and $PM_{2.5}$ from fossil power plant operation, the following parameters for respective pollutants were used: 1) emission factor (*i.e.*, tonne per kWh for 2010 and 2030 taken from the IIASA GAINS database (ECRIPSE scenario) (IIASA, 2014), and 2) unit external costs (*i.e.*, Euro-per-tonne average for the EU) (AEA, 2005).

An extended version of the REmap methodology can be found online at *www.irena.org/remap.*

3 GERMANY'S *ENERGIEWENDE*: MARKET FRAMEWORKS AND ECONOMIC RESULTS

Key Points

Energiewende: progress to date

- Renewable energy policy in Germany dates back to the 1970s, and the phasing out of nuclear power has been an important driver for renewables deployment. The nuclear phase-out was very controversial in German politics between 1980 and 2011, but the *Energiewende* has gained broad political consensus in recent years.
- Germany's climate and renewable energy policy has been triggered as a result of domestic as well as European and international climate and energy policy.
- Germany is unique in terms of its advanced renewable energy policy. The *Energiewende* aims to transform the country's energy system based on the two pillars of renewable energy and energy efficiency. Other important focuses include future grid, markets and system integration as well as support for energy sector research and development (R&D).
- The drivers for the *Energiewende* include climate protection, energy security, industrial development, employment and the phase-out of nuclear power.
- Germany's electricity feed-in tariff (FiT) policy has been effective, as it has led to tremendous growth in national renewable power generation capacities. Energy efficiency is envisaged to be accelerated by the recently introduced NAPE. Targeted support policies for the heating and transport sectors have been less effective, and no specific renewable market framework is in place for the manufacturing sector.
- In the electricity sector, the development of renewables has diversified the energy mix and ownership structures, slowed Germany's growing import dependence and expenditures, built up a workforce of over 371 000 and had impacts on national, European and international climate policy.
- Growth in renewable power in Germany has increased significantly, with the renewable share in gross electricity consumption increasing from 6.2% in 2010 to 17% in 2010, 27.8% in 2014 and over 30% in the first half of 2015.
- Despite cost increases to consumers, the *Energiewende* continues to enjoy strong public support in Germany, as 80-90% of citizens are in favour of the *Energiewende's* goals.

End-use sectors: heating, cooling, transport

- The renewable heating market, supplied mainly by biomass, has grown much slower than renewables for power generation. Growth in biomass heat slowed greatly in recent years, whereas geothermal and heat pumps grew the most rapidly and overtook solar water heaters in 2009.
- The Renewable Energy Heat Act that came into force in 2009 requires new buildings to obtain a share of their total heating/cooling demand from renewables. The Market Incentive Program aims to complement the Renewable Energy Heat Act by implementing renewables in existing buildings.
- The Biofuels Quota Act required a minimum biofuels share of 6.25% to be used in road transport starting in 2010. The act was replaced in early 2015 with the Climate Protection Quota, which specifies the minimum contribution of biofuels to reduce greenhouse gas emissions based on a reference fuel value; currently, that reduction is 3.5%.
- Biodiesel is the dominant renewable fuel for transportation. Although the use of biodiesel made from rapeseed (canola) grew significantly in 2004-2007, market volumes decreased rapidly to 2014, to less than 1% of the market volume.

Costs

- The Renewable Energy Act (EEG) required a major reform in 2014 to 1) steer development of renewables, 2) slow the rise in costs, 3) distribute the financial burden and 4) improve market integration. In 2014, the EEG surcharge for households was EUR 6.24 cents per kWh, excluding the 19% value-added tax (VAT). Energy-intensive industry that purchases its electricity from the wholesale market is partially exempt from this surcharge. In 2014, wholesale electricity prices declined to EUR 3.79 cents, from EUR 5.43 cents in 2011.
- Without the *Energiewende*, fossil fuel import costs, which represent some 3% of Germany's gross national product, would be even higher.

Energiewende: key findings and tasks for today's decision makers

- Germany's ambitious greenhouse gas emission reduction targets may not be reached without further significant efforts in all sectors.
- German decision makers are tasked with transforming into action the recently developed (July 2015) guidelines of future energy policy for the *Energiewende*, with key points addressing the mitigation of climate change, increased energy efficiency, enhanced electricity market design, energy security, CHP and financial reserves for nuclear power.

Evaluation and next steps

- Because the *Energiewende* has impacts on European economies and energy sectors, and because regional approaches can ease the energy sector transition, Germany will need to strongly support the strengthening of regional energy market frameworks and electricity market structures.
- The strengthening of the EU Emissions Trading System (EU ETS) will be required, as it is a climate policy measure that has strong impacts on energy markets and technology choice.
- As an ongoing process, the *Energiewende* requires constant monitoring, and the adjustment of market frameworks is to be expected.

Germany is unique in terms of its advanced renewable energy policy. The *Energiewende* aims to transform the country's energy system based on the twin pillars of renewable energy and energy efficiency. The *Energiewende* is a change in Germany's policy direction and detailed regulations. It is designed to trigger change in the energy system and in energy technologies – mainly through the shift from conventional to renewable energy – for smart energy use and better consumer participation coupled with the implementation of energy efficiency measures.

The *Energiewende* is a long-term and evolving process. The "Energy Concept", adopted in 2010, and earlier efforts dating back to the 1990s have resulted in the considerable success of renewable energy deployment in Germany, particularly in the power sector. More than 27% of the country's gross electricity consumption was from renewable sources by the end of 2014, and that share surpassed 30% in the first half of 2015. Nearly 15% of total generation is from variable wind and solar power.

Germany is now entering the next phase of its *Energiewende*. This phase will focus on how higher shares of wind and solar can be accommodated and how the grid infrastructure also can be expanded to ensure that the power system and its actors are more flexible to allow for the integration of electricity from renewables. As part of the continuing transition, the deployment of renewables in the end-use sectors of heating, cooling and transport, as well as the synergies between power and end-use sectors, will be key.

To date, much has been published already by German media, research organisations and other stakeholders taking part in this transition. The *Energiewende* has attracted huge interest from many other countries as well. Countries want to learn best practice technology and policy information from Germany's experiences on how to implement higher shares of renewables, and where challenges or missteps have occurred. This section summarises the most relevant issues related to the *Energiewende* that could be of interest for countries that are starting or continuing with their own energy transitions.

The purpose of this section is to present the history of Germany's renewable energy policy, to elaborate on the principles, objectives, achievements, cost and benefits of the *Energiewende*, and to identify the areas that require further attention in order for Germany to realise its renewable energy, energy efficiency and climate change goals by ensuring a secure and affordable energy system. In section 4, a quantitative assessment explores how these additional potentials can be closed from a sectoral and technology perspective and what the benefits and costs of this would look like. This section ends with a brief summary of learnings for policy makers both in Germany and rest of the world.

Much of the information in this section came from literature and experiences provided by BMWi, Agora *Energiewende* and other authoritative institutions in this field.

3.1 The *Energiewende* and the evolution of Germany's renewable energy policies

History of the *Energiewende*, its principles and goals

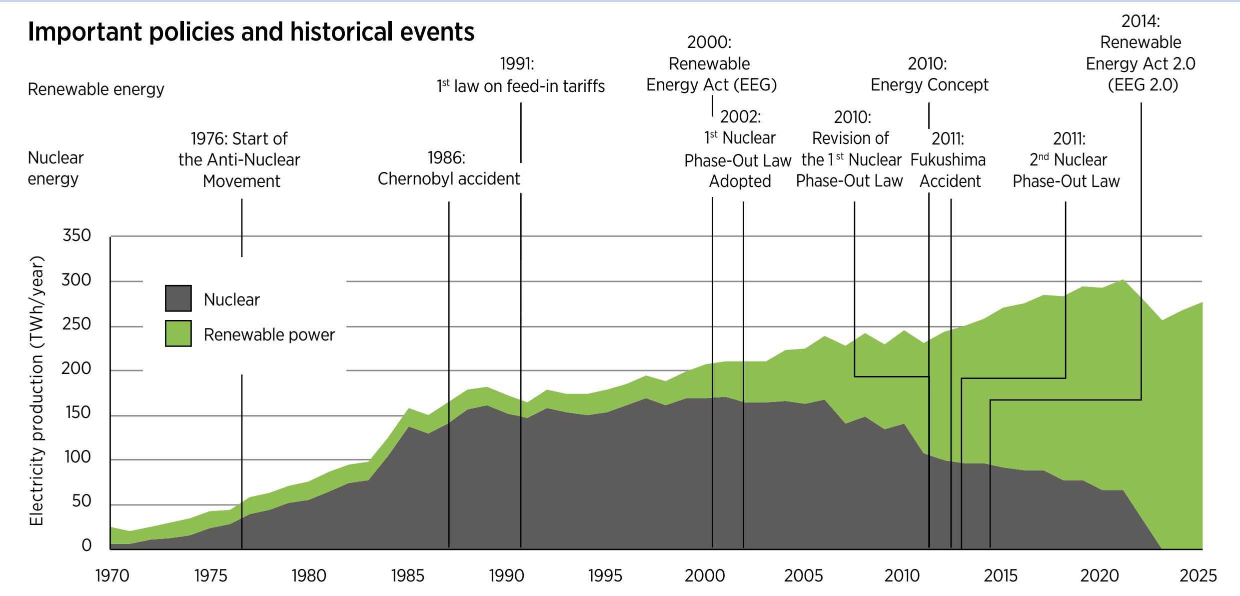
The oil crisis in the 1970s, as well as the controversial debate about nuclear power in Germany, triggered increased R&D of renewable energy technologies – especially onshore wind – in recent decades. In addition, the need to reduce CO_2 emissions to meet climate protection goals has put renewable energy (in combination with energy efficiency) at the centre of Germany's energy debate. In 2000, Germany decided to phase out nuclear power, a decision which was re-enforced in April 2011 in response to the nuclear accident in Fukushima, Japan.

The nuclear phase-out was very controversial in German politics between 1980 and 2000, but the *Energiewende* has gained broad political consensus. Germany has adopted concrete plans for gradually phasing out nuclear power by 2022, based on two pillars: energy efficiency improvements and the accelerated expansion of renewable energy.

The guiding principles of Germany's *Energiewende*, as documented in the report *Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply* (BMWi and BMU, 2010; BMWi, 2015a) are:

- Restructuring of fossil fuel power plants
- More rapid expansion of renewable energy and its integration into the energy system
- Wind energy as a central component
- Expansion of electricity grids
- Smart grids and storage facilities
- Energy-efficient buildings

Figure 2: Nuclear and renewable electricity generation and major events, 1970-2025



Source: Adapted from Agora, 2015

- European initiatives for energy efficiency
- Efficient procurement
- Cost efficiency

Figure 2 shows the important policies and major historical events related to Germany's nuclear and renewable energy development since 1970. Until the early 1990s, nuclear power generation increased, while renewable generation remained more or less constant. From 1990 onwards, however, the situation reversed, with nuclear generation remaining constant and generation from renewables growing. According to Germany's nuclear phase-out law, the country's last nuclear reactor will be switched off by 2022. A mix of onshore and offshore

Box 1: Germany's climate and energy legislation and milestones

Germany´s climate and renewable energy policy has been triggered as a result of domestic as well as European and international climate and energy policies. Important milestones that have contributed to Germany's policy decisions since 1990 include:

1991 – Germany's first law on feeding renewable energy into the electricity grid enters into force on 1 January (*Stromeinspeisungsgesetz* = Electricity Feed-in Law).

1992 – Germany is among the 154 countries to sign the United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janeiro, Brazil.

1998 – Germany signs the Kyoto Protocol, committing the country to a 21% reduction in greenhouse gas emissions.

1998 – The German Energy Industry Act (Energiewirtschaftsgesetz) comes into force and is directed towards power market liberalisation and implementing the EU directive concerning common rules for the internal market in electricity.

2000 – The Renewable Energy Act (*Erneuerbare-Energien-Gesetz*, or EEG) is adopted, serving as the basis for today's renewable energy support mainly by stipulating feed-in tariffs that enable grid operators to directly pass through costs to consumers.

2002 – Germany passes the Nuclear Energy Act, aimed at reducing dependence on nuclear energy.

2005 – The EU ETS starts, as part of the EU's efforts to fulfil Kyoto commitments on emission reductions. It covers around 45% of the EU's greenhouse gas emissions. In 2020, emissions from sectors covered by the EU ETS will be 21% lower than in 2005.

2007 – Germany decides on key points of an integrated energy and climate programme.

2008 – The German government adopts its adaptation strategy to climate change, which lays the foundation for a medium-term process to progressively identify the effects of global climate change, assess the risks, and develop and implement adaptation measures.

2009 – The EU agrees on a comprehensive climate and energy package, "Energy 20-20-20", with targets for emission reduction, energy efficiency and renewable energy deployment to 2020.

2009 – The EU renewable energy directive, as part of the Energy 20-20-20 package, is adopted. It sets mandatory national targets consistent with a 20 % share of energy from renewable sources and a 10 % share of energy from renewable sources in transport in EU energy consumption by 2020. All EU member states are required to adopt National Renewable Energy Action Plans (NREAPs), setting out Member States' national targets for the share of energy from renewable sources consumed in transport, electricity, and heating and cooling in 2020.

2010 – The German government adopts an ambitious "Energy Concept" which lays down the main strategic targets of the country's long-term energy and climate policy (to 2050).

2011 – Building on the "Energy Concept", a package of legislation accelerates the transformation of the German energy system. It includes phasing out nuclear energy by 2022, with some nuclear plants shutting down already in 2011.

2011 – The EU publishes its *Energy Roadmap 2050*, outlining an 80-95% emission reduction target by 2050, among others.

2012 – The EU adopts its latest energy efficiency directive, which establishes a common framework of measures to promote energy efficiency in order to ensure achievement of the EU's 20% by 2020 energy efficiency target and to pave the way for further energy efficiency improvements beyond that date.

2014 – The EEG requires a major reform to steer development and support of renewables while reducing costs and to distribute the financial burden through improved market integration. The reform is driven by changing market conditions, due in part to the faster-than-expected declines in the costs of many renewables, but also by European dynamics.

October 2014 – The EU sets goals for by 2030 of reducing greenhouse gas emissions by 40%, increasing the share of renewables to at least 27% and fostering continued improvements in energy efficiency.

October 2014 – Germany's BMWi releases the "Green Paper", *An Electricity Market for Germany's Energy Transition*, to provide the basis for decisions to be taken in 2015.

December 2014 – The German government agrees on the NAPE, which aims to increase energy efficiency, combining economic incentives, regulation, and improved information and advisory services.

July 2015 – Building on feedback received for its "Green Paper", BMWi releases a "White Paper" that advocates an "electricity market 2.0".

wind, solar PV and bioenergy will replace nuclear, maintaining secure and carbon-free power generation for the country. Renewable energy is one of the main pillars of the *Energiewende*.

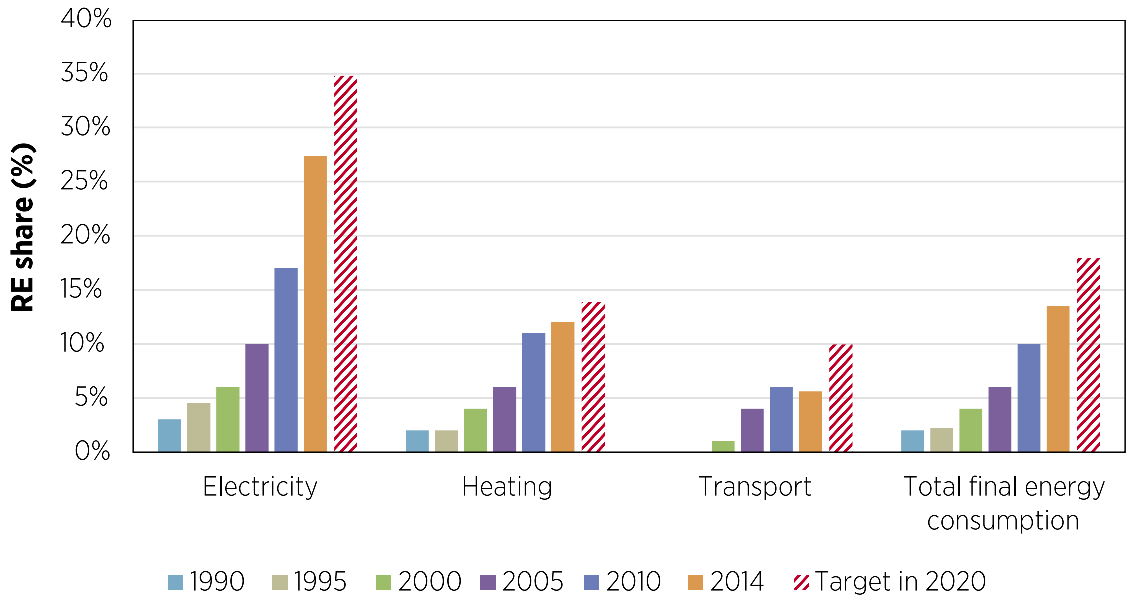
Germany's "Energy Concept"

In its "Energy Concept", adopted in September 2010, the German government formulated guidelines for an environmentally sound, reliable and affordable energy supply and, for the first time, mapped a road to the age of renewable energy (BMWi and BMU, 2012). The "Energy Concept" was followed by a specific action plan (*Maßnahmenkatalog*) published in June 2011, which contains a set of targets and measures.

A core element of these measures is the implementation of pivotal political objectives for Germany's future energy system: Germany is to become one of the world's most energy-efficient, sustainable and low-carbon energy systems, maintaining a secure and reliable power supply while enjoying competitive energy prices and a high level of prosperity. Other aims are to have a high level of energy security, effective environmental and climate protection, and an economically viable energy supply which is necessary for the country to have a competitive industrial base in the long term.

Germany wants to strengthen its competition and market orientation in energy markets, to secure sustainable economic prosperity and future jobs, and to support technical innovation. The challenges of sustainable energy provision derive in part from long-term global trends: over time, the world's rising demand for energy will lead to a pronounced increase in energy prices. Under business as usual, Germany's dependence on energy imports also would continue to increase. Energy use currently is responsible for 80% of greenhouse gas emissions. For these reasons, Germany aims to transform its energy supply structures in the medium-to-long

Figure 3: Renewable energy share of Germany's final energy consumption, 1990-2014 and targets for 2020



term to achieve energy security as well as climate protection targets (BMWi, 2010).

Germany aims to increase the share of renewable energy in electricity generation to 80% by 2050, up from 27.4% in 2014. The renewables share in heating and cooling was 12.2%, and in transport 5.6%, in 2014. The target for renewables in TFEC is 60% by 2050, compared to 12.3% in 2013. Germany is on track to meet its 2020 target of an 18% renewables share in TFEC.

With regard to energy efficiency, Germany aims to reduce its total primary energy demand by 20% by 2020 and 50% by 2050, compared to 2008. To reach these targets, the energy intensity improvement rate will need to increase to 2.1% per year, up from about 1.6% between 2008 to 2014. The "Energy Concept" also aims to double the yearly rate of building renovations from about 1% of the building stock per year to 2% by 2050.

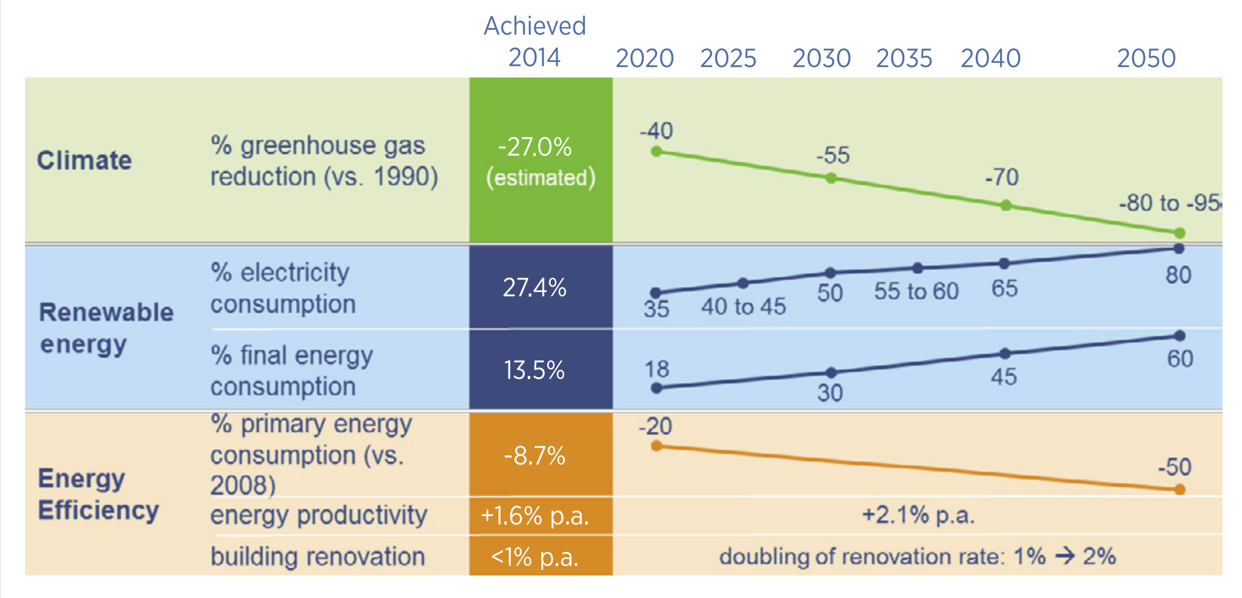
Long-term strategy for future energy supply

The "Energy Concept" is about designing and implementing a long-term overall strategy for the period to 2050. The aim is to provide a long-term orientation while also preserving the flexibility required for new technical and economic developments. Renewable energy sources are to account for the biggest share in this future dynamic energy mix, as they steadily replace conventional energy sources. The goal is a market-oriented energy policy that is free of ideology and open to all technologies, embracing all paths of use for power, heat and transport (BMWi, 2010).

Formulating an integrated, all-around strategy will be decisive. In the area of electricity, for example, the expansion of renewable energy must be combined with enhanced energy efficiency, strengthening market price signals for producers and consumers, the expansion and optimisation of grids, construction of new storage facilities, maintaining a single price zone, intensifying European co-operation and delivering on climate protection goals. For buildings, implementing efficiency measures, in particular, has enormous potential. Only if this is fully tapped can the full effect of using renewable energy for heating be realised (BMWi, 2010 and 2014).

As the share of renewable energy increases, the trends in energy costs depend crucially on cost-efficient deployment of renewable technologies. In this light, Germany aims both to achieve its expansion targets for renewables and to step up the pressure for innovation and to lower costs even. Innovation and the reduction of technology cost through economies of scale is an

Figure 4: Renewable energy, energy efficiency and climate targets in Germany



Source: Based on BMWi, 2014b, with updates for 2014 by IRENA

important way to enable energy-intensive sectors to remain internationally competitive and to contain costs to consumers.

Climate protection targets

Implementing the long-term 2050 strategy requires a development path that is clear to all stakeholders. In line with the government agreement, greenhouse gas emissions are to be cut by 40% by 2020 and by at least 80% by 2050, compared to 1990. Germany is on track to reach its Kyoto Protocol targets, but more efforts will be required to reach the *Energiewende*'s long-term greenhouse gas emission targets (see Figure 4). In 2013, Germany achieved a 23.8% reduction in emissions compared to 1990.

Key findings from the "Energy Concept" scenarios

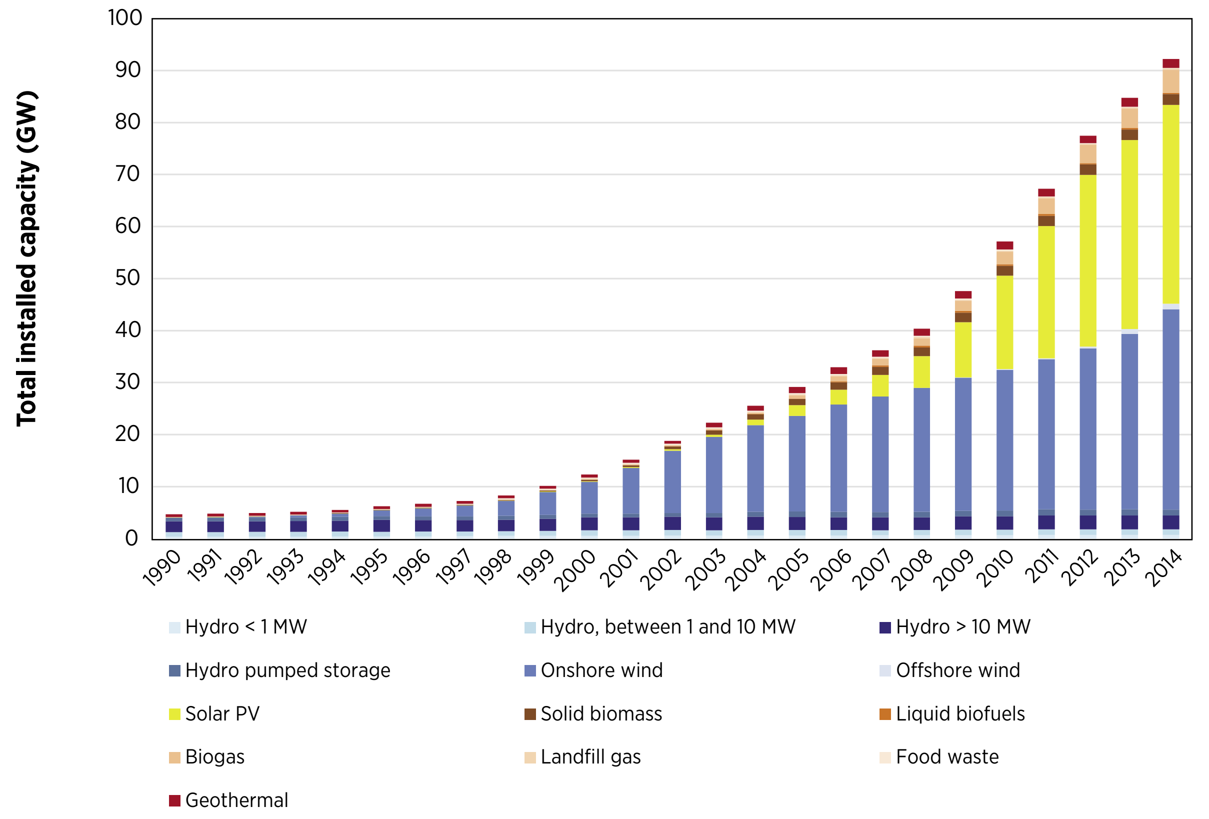
On behalf of the German government, external experts drew up a number of scenarios for the "Energy Concept" to indicate not only the challenges facing future energy policy, but also solutions, required policy measures, and environmental and economic impacts (EWI, 2010).

The outcome shows that the path to an age of renewable energy is possible. It is likewise clear that efforts are required in all fields and that the conditions must be created for a radical restructuring of the energy supply. The findings of the "Energy Concept" scenarios should not be regarded as forecasts. Rather, they are rough roadmaps or a compass that, if certain conditions are met, can signpost the way to the destination. All scenarios assume the need for additional investment up to 2050 to achieve the ambitious climate protection targets.

The expected volume of investment is in the order of EUR 15-20 billion per year to 2050 (BMWi and BMU, 2012). These investments will lead to reductions in energy imports and to energy cost savings. Additionally, the leading position of German companies in the field of environmental and energy technology would be reinforced (BMWi, 2010). New investments are necessary not only to realise the *Energiewende* targets, but also to replace the country's ageing capacity.

The energy scenarios have shown that wind energy will play a key role in electricity generation by 2050. This calls for a massive expansion of onshore and offshore wind capacity. If the growing share of renewable energy is to be integrated effectively, it is crucial that the expansion of grids in both Germany and Europe is co-ordinated closely for better integration of Germany's market with its neighbours. Moreover, Germany's role in a European

Figure 5: Cumulative installed capacity of renewable power, by source, 2000-2014



Source: Based on BMWi, 2014b

electricity market will entail both considerable imports and exports of electricity (BMWi, 2010).

Renewables for power generation: the Renewable Energy Act and its impact

So far, Germany's focus on renewables has centred mainly on the power generation sector. Measures regarding energy use in end-use sectors (buildings, industry and transport) have related mainly to energy efficiency.

Germany´s renewable power market has grown considerably since the introduction of the FiT in 1990, and especially after the FiT's reform into the Renewable Energy Act (*Erneuerbare-Energien-Gesetz*, or EEG) in May 2000. The investment security created by these conditions induced enormous growth in all fields of renewable energy and resulted in a distributed ownership structure. Implementation of the EEG led to major growth in onshore wind and solar PV. This sub-section provides an overview of the development of Germany's renewable power market with regard to cumulative installed capacities, annual new build capacities and market growth rates.

Figure 5 shows the growth in Germany's cumulative installed renewable power capacities. The total installed renewable power capacity increased by a factor of 7 between 2000 and 2013, from 12.3 GW to 85 GW. Onshore wind and solar PV dominate the market, followed by various forms of bioenergy.

Germany's onshore wind market has been growing by between 1500 megawatts (MW) and 2000 MW annually for more than a decade, making it a reliable and predictable industry. By the end of June 2015, total installed capacity reached 39.2 GW, reflecting net additions of 1.1 GW in the first half of 2015 (DWG, 2015). Infrastructure, professional training and financing have developed to meet the needs of the wind industry, creating a strong economic base with high public acceptance. However, in some cases, renewable energy projects have faced public resistance from people living in neighbourhoods that are directly affected. This is particularly the case for onshore wind projects in forests; for the repowering of older wind farms (as small turbines are replaced by large-scale turbines with hub heights over 150 metres) as well as bioenergy projects that result in increased truck traffic.

Hydropower has started to reach the limits of its potential in Germany, and bioenergy has seen strong growth in wood and other biomass resources. Whereas the onshore wind market has matured with single-digit growth rates, the solar PV market has experienced double-digit growth for more than a decade. Solar PV's growth has decreased since 2013, however, at the expense of onshore wind.

Offshore wind is growing faster than in previous years. According to 2015 estimates, Germany will overtake the UK as the country with the largest installed offshore wind capacity. In 2015, Germany will install an expected 2.1 GW of new offshore wind capacity, a fourfold increase over 2014 levels of around 0.5 GW. Germany will make up around 50% of the estimated 4 GW global market for offshore wind in 2015 (GlobalData, 2015). On 25 July 2015, Germany achieved a renewable power generation share of 78% around mid-day, including 0.5-2.1 GW of offshore wind capacity (Fraunhofer ISE, 2015a).

The EEG has promoted renewable energy mainly by stipulating a FiT and by requiring that transmission system operators connect, fully integrate and compensate for the supply of renewable energy fed into the power grid. Transmission system operators do not pay for renewable energy, but rather they fully pass the costs on to consumers. The key elements of the EEG are shown in Table 2 (BMWi, 2014a).

However, Germany is now taking initial steps to introduce renewable energy auctions over the period 2015-2017, with three auction rounds scheduled for each year. In the first round, held in April 2015 for solar PV, bids were related to a minimum installed capacity of 10 kW and a maximum capacity of 10 MW. The auction prices seem to better reflect the actual costs faced by project developers. For instance, FiT levels in Germany generally were considered too low in recent years for solar PV, which has resulted in a sharp decline in solar PV installed capacity since 2013, compared to previous years.

Table 2: Key points of the EEG

Grid access

- Renewables have priority access to the grid
- Renewable electricity has priority in transmission and distribution
- Transition towards an integrated renewable energy market:
  - In addition to the market price, a fixed premium is paid for every kWh from renewables sold on the market
  - With the feed-in premium (FiP) system, renewable energy operators have an incentive to sell electricity on the market when the price is high

Payment

- Tariffs are differentiated by source and size of plant
  - Advantages: no over-support for cheap technologies; support for developing new technologies

Financing/budgets

- Shared costs and independence from government budgets:
  - The EEG levy, part of the final electricity paid by consumers, covers the difference between the market price achieved and the tariff (in the FiT system), including the premiums (in the FiP system)
  - Specific electricity-intensive industries which are exposed to international competition pay only a reduced levy

Financing/budgets

- Annual degression of all tariffs to organise the transition towards a self-sufficient renewables market

In Germany's 2015-2017 solar auctions, each bidder must provide a bid bond worth EUR 4 (USD 4.47) per kW to be installed in order to be considered in the auction. This deposit is reduced to EUR 2 (USD 2.23) per kW if the bidder already has a building permit, as this eases the after-auction work and decreases the auctioneer's risk of not having a signed contract. Lowering the bid bond also can facilitate the participation of smaller players. The Federal Network Agency, Bundesnetzagentur (BNetzA), sorts the bids from the lowest to highest price, and projects are selected until the auction volume has been filled. Bids beyond the auction volume do not receive the right to remuneration for their output and get their bid bond back (IRENA, 2015a).

Streamlining the EEG for the future

After 14 successful years, the EEG required major reform. The experiences gathered since the EEG started in 2000 are unique worldwide and have not only shaped new policy design in Germany, but influenced other countries as well. The German renewable energy law had a huge impact on the development of both the national and international renewable energy industries. As a result, costs for wind and solar PV have dropped due to economies of scale, global competition and the pressure mounted by each decreasing FiT. The frequent evaluations and adjustments of the EEG in 2000-2014 aimed to create better co-ordination, precision and efficiency, as well as improved market integration to achieve the *Energiewende* objectives.

However, the cost reductions were faster and larger – especially for solar PV (see Box 1) – than the EEG process had envisaged. Therefore, in 2014, a major revision of the EEG took place in order to achieve the following objectives:

- steer development of renewables reduce costs
- distribute financial burden, and
- improve market integration.

The following key areas have been reviewed, and changes have been implemented:

- *Better co-ordination to steer renewable capacity development:* The "target corridor" fixes a technology-specific amount of additional capacity to be installed annually. The EEG amendment of 2014 sets those target corridors and flexible degression rates. BNetzA collects and publishes data on monthly capacity additions of all new renewable power plants. The degression rate depends on capacity additions of the past 12 months. The binding target corridors set annual capacity additions for all technologies. If additions exceed these targets, degression rates

Table 3: Overview of remuneration

Corridor		Remuneration in EUR ct/kWh	Degression
Hydropower	-	3.50-12.52	-0.5 %/year from 2016
Landfill, sewage and mine gas	-	3.80-8.42	-1.5 %/year from 2016
Biomass	100 MW (gross)	5.85-23.73 (dependent on fuel and size)	-0.5 % every three months from 2016
Geothermal		25.20	- 5.0 %/year from 2018
Wind energy onshore	2,400 -2,600 MW (net)	Standard tariff: 8.90, for at least 5 years; Minimum 4.95	-0.4% every quarter from 2016
Wind offshore	-	Initial tariff: 15.40 for min.12 years; Option: 19.40 for min. 8 years if installed before 2020 Minimum 3.90	Standard tariff: - 0, 5 ct/kWh in 2018, 1 ct/kWh in 2020 - 0,5 ct/kWh/year 2021; Option: - 1 ct/kWh in 2018
Solar PV	2,400-2,600 MW (gross)	9.23-13.15 (and tenders for ground-mounted PV)	-0.5 % per month

Source: BMWi, 2014d

are increased (= lower FiT); if additions do not reach the targets, degression rates are reduced (= higher FiT).

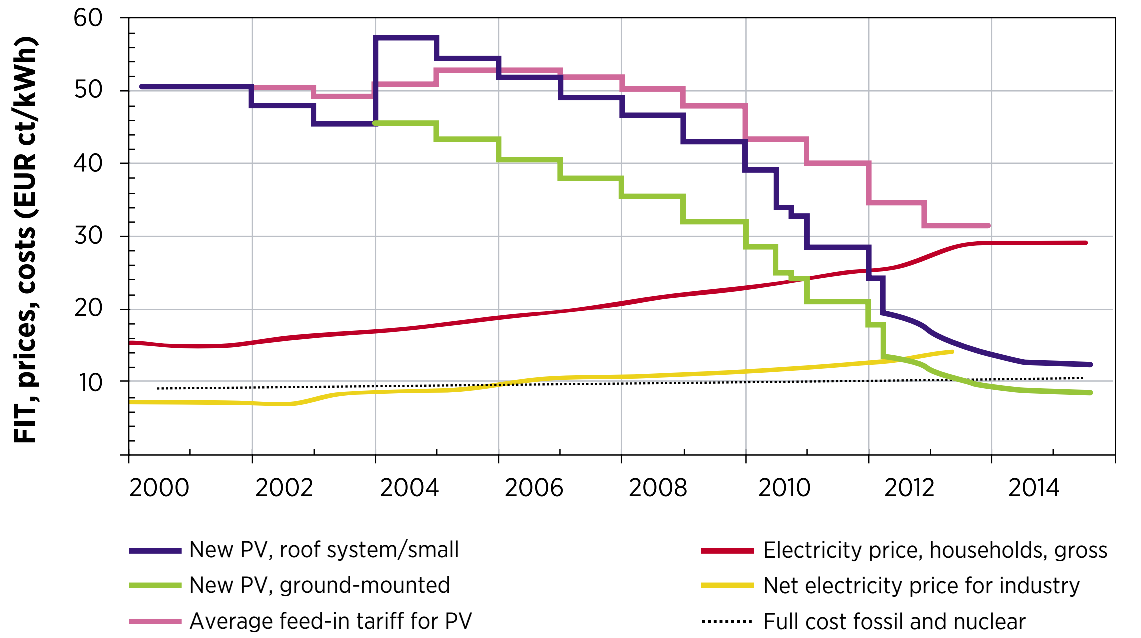
- *Planning:* Definition of technology-specific target corridors for additional installed capacity, steered through degression of tariffs (see table 3).
  - *Solar PV:* The annual capacity corridor is 2400 MW to 2600 MW, with an overall cap of 52 GW of installed capacity. If this capacity is reached, FiT support will expire. The new degression rates (BMWI, 2014c) started on 1 September 2014, and tariffs can be reduced on a monthly basis.
  - *Onshore wind:* As with solar PV, the annual capacity corridor is 2400 MW to 2600 MW, but it is based on net capacity additions, *i.e.,* after balancing net capacity growth through repowering of old machines. The new degression rates (BMWi, 2014c) are proposed to start on 1 January 2016; tariffs can be reduced every three months, and the level can be adjusted every three months.

Box 2: Reductions in solar PV FiT costs since June 2006

Falling solar PV system prices are reflected in Germany's FiT rates. The FiT for small rooftop systems was reduced from just over EUR 50 cents per kWh to below EUR 15 cents per kWh by the end of 2013 – representing a 70% decrease. The constant reduction of FiTs closely reflects the decreasing system prices over the years. With monthly instead of annual digression rates, the actual cost development can be followed closer to the market.

Figure 6 shows the FiT for solar PV power as a function of commissioning date and average solar PV power remuneration for all installed systems. The calculation was done by Fraunhofer ISE with data from BMWi, German grid operators and IfNE (Ingenieurbüro für neue Energien). Since mid-2013, the FiT for large-scale PV systems has been below average electricity prices for Germany industry,, and small rooftop systems get a FiT below household electricity prices.

Figure 6: EEG remuneration and system prices



Source: Fraunhofer ISE, 2015b
Note: Fossil and nuclear include external costs.

- *Biomass*: The annual capacity addition is 100 MW.
- *Offshore wind:* There is no annual expansion target, but rather an overall target of 6 500 MW by 2020 and 15 000 MW by 2030.

- *Precision:* Support remains technology-specific, and further subdivision of FiTs has been done, for example for location-specific wind power rates to take the pressure off regions with the best wind resources, which already have a high density of wind farms, and to achieve a more even distribution across Germany.
- *Distribution of financial burden and reflection of international competition of energy-intensive industries:* To diversify and distribute the costs of the EEG levy further, the levy has been extended to also cover self-supply with solar PV for private generators. An increased number of households switched from 100% feed-in electricity to self-consumption of solar power and therefore reduced the amount of purchased electricity. This leads to a reduced volume of electricity units used for cost sharing. In addition, a "Compensation Regulation" (*Besondere Ausgleichsregelung*) has been implemented to reduce the EEG levy for electricity-intensive companies and railroads and other affected businesses in order to safeguard the international competitiveness of companies.
- *Market:* Obligatory direct marketing linked to the payment of a FiP instead of a FiT.
- *Improved market integration:* In order to integrate renewables into the existing market, "direct marketing" of produced electricity for large renewable energy plant operators has been made obligatory. Thus, renewable energy operators need to set up systems to sell renewables-based electricity independent from the FiT. This obligatory direct marketing is in force for all new plants above 500 kW of installed capacity since 2014 and will be expanded to all new plants above 100 kW by 2016.

Renewable electricity and infrastructural changes

Only a decade ago, the German power sector was dominated by dispatchable and large-scale thermal and hydro power plants. The *Energiewende* triggered a paradigm shift by introducing new renewable technologies, particularly wind and solar PV. By the end of 2014, Germany was covering nearly 30% of its electricity demand on average with renewables, and the total renewable power capacity was 88 GW – exceeding the country's peak demand.

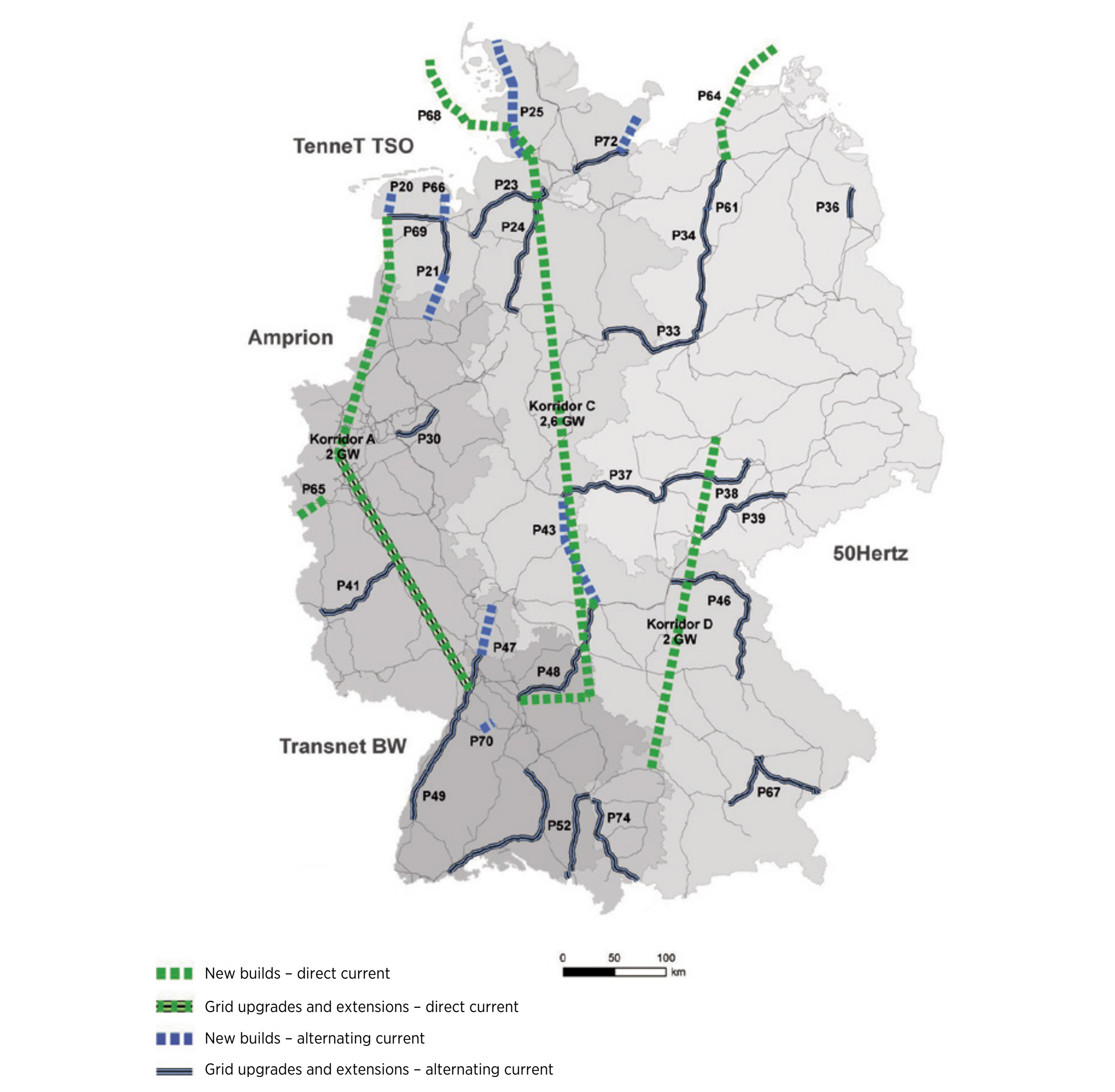
Wind and solar PV technologies show different generation characteristics and require technical upgrades, restructuring and deployment of distribution and transmission network infrastructures; smarter and more-dynamic system awareness and management capabilities; and more-flexible supply- and demand-side technologies, including storage.

Coal- and gas-fired power plants have become increasingly flexible, and a wide range of new "flexibility options" (demand-side management, grids, storage, power-to-heat, etc.) is progressively entering the energy system (BMWi, 2015b; Agora, 2015a). However, the required deep and co-ordinated technological development of the power system is to be guided by an adopted power market design which needs to be developed in parallel (BNetzA, 2013).

Because new renewable generation technologies are more location-constrained, integrating them on a large scale requires restructuring and expanding the transmission network infrastructure. Germany's four transmission system operators are responsible for developing this infrastructure. Each year, these operators (50Hertz, Amprion, TenneT and TransnetBW) establish power system scenarios, representing the likely developments in electricity generation, consumption and associated network infrastructure over the next 10 years. The network-related scenario results formulate the Electricity Network Development Plan (see figure 7) and the Offshore Network Development Plan, where all optimisation, expansion and reinforcement measures are summarised.

To avoid negative environmental and social impacts, potential impacts are taken into account in a very early stage of grid expansion planning, and the transmission system operators must consider several alternative routes for each transmission corridor. A public process then discusses the proposals and assesses them for their environmental compatibility. In the end, a planning approval decision is reached with the routes that have the least impact on people and the environment.

Figure 7: 2013 Network Development Plan to 2023



Source: BNetzA, 2014

BNetzA also produces an environmental report listing all possible environmental effects.

Transmission projects that are designated in the Federal Requirements Plan Act as spanning federal, state or national borders are dealt with in a Federal Sectoral Planning process, in which BNetzA decides which corridors are best for the new transmission lines. The exact future route of a new transmission line in a corridor is decided on in the Planning Approval Procedure. Routes are chosen that have the least impact on people and nature (BNetzA, 2013).

By 2015, only 463 kilometres of power lines had been added, and BNetzA identified the need for 1883 kilometres of additional lines. Thus, only one-quarter of required grid expansion has been realised. As curtailment levels of wind generation rise, the delayed network expansion has significant consequences for the German renewables target. Although decision-making procedures have been mostly streamlined, public and political opposition often persist, slowing network infrastructure development and potentially requiring further technological innovation. For example, a connection from the north-eastern state of Saxony to the south-eastern state of Bavaria to transmit wind power to industrial areas in order to replace nuclear electricity sparked an intense debate. An agreement could only be reached between the federal government of Germany and Bavaria, as the transmission line is to predominantly use underground cables.

The role of storage, and which type of storage technology, is another area that has received attention from both policy makers and the renewable energy industry. Options include heat/cold storage, balancing variable renewable energy generation with CHP capacity (with heating capacity becoming storage), district heating and cooling, pumped hydro and battery storage. Expensive battery storage on the transmission network does not need to be the first choice in realising higher renewables shares, as household-size storage technologies are becoming mainstream and are expected to be deployed further. Existing heat storage technologies can easily offer the flexibility required in the future. Linking the power generation sector with developments in the end-use sectors – in particular storage capacity from electric mobility, heat pumps and CHP – will also be key. In periods where electricity from variable renewables cannot be exported further, peak shaving (curtailment) will be another important option.

The role of coal in the *Energiewende*

Germany's electricity trade balance was neutral in 2000. In 2013, net exports increased, reaching 34 terawatt-hours (TWh) per year, representing approximately 2% of total generation. This was mainly because renewables have pushed conventional energy carriers out of the system. Wholesale prices have decreased, and Germany is now able to export much more electricity to its neighbours. At the same time, total power generation from coal and lignite has increased because of the increase in these net exports, with the mix in conventional generation shifting from natural gas to coal.

There are several reasons behind the new coal plants. The capacity coming into operation today was planned between 5 to 10 years ago. The assumptions behind investments in the past were likely different from those that would be made today, when utilities face financial difficulties. In the mid-2000s, the first phase of the EU ETS was an important driver behind investment certainty for new coal plants (across all of Europe). The increase in coal capacity can also be attributed to the failure of subsequent phases of the EU ETS, where an oversupply of allowances resulted in a drop in the CO_2 price.

Furthermore, investors found it important to invest in new capacity in order to replace capacity that was reaching the end of its life. The choice was made to favour coal plants (flexibility at that time was considered to be less important) over natural gas. Finally, utilities found investing in renewables less profitable in the mid-2000s, as this was outside the scope of their traditional business models. The overall increase in coal capacity was not a reaction to the nuclear phase-out (Jungjohann and Morris, 2014).

These developments have resulted in higher greenhouse gas emissions for Germany. Although coal is the most carbon-intensive fossil fuel, it is not the only source of emissions. Coal accounts for only about one-quarter of Germany's total primary energy supply. Oil and natural gas dominate the heating and transport sectors, and they too contribute to the country's greenhouse gas emissions. A holistic approach to emissions mitigation that goes beyond the power sector will be required if Germany is to realise its climate targets.

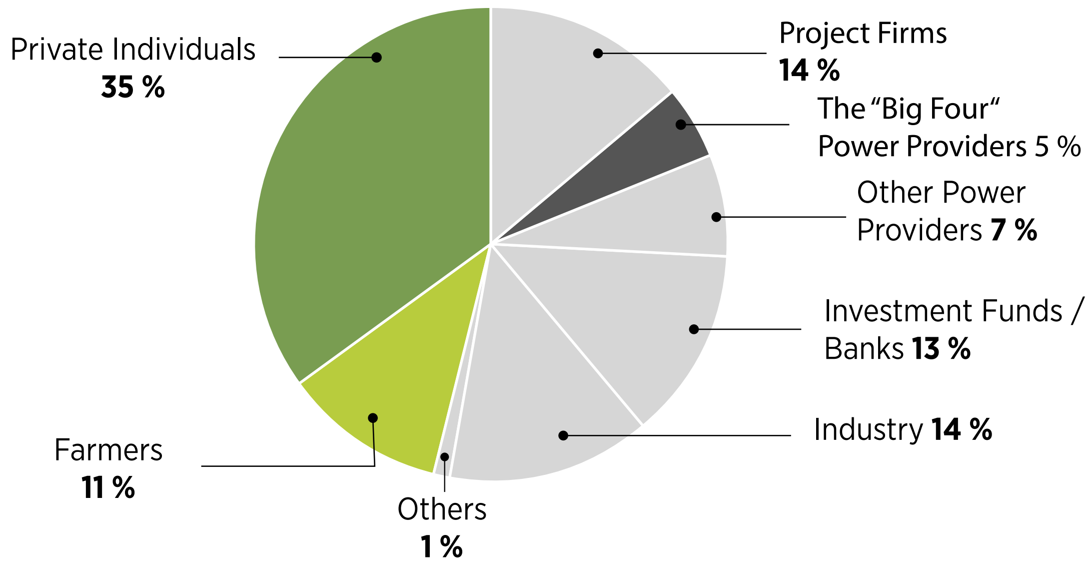
Non-energy related aspects of the *Energiewende*

As discussed earlier, strong opposition to nuclear power was a decisive driver of the *Energiewende*. Increasing environmental awareness was another. Other aspects of the *Energiewende*, discussed below, go beyond directly energy-related issues.

The *Energiewende* has created an efficient and renewable energy sector with a rather decentralised structure. This includes both large-scale industries with a focus on more than one sector, as well as small and medium-sized enterprises (SMEs). Today, Germany's renewable energy sector consists of many players with a huge variety of job profiles, from engineers, scientists, financial experts, salespersons and lobbyists to craftspeople, administrators, and business developers, such as electricians and plumbers.

Beyond the motivation to reduce the environmental impacts associated with electricity generation,

Figure 8: Ownership structure of renewable power capacity in Germany



Source: BEE, 2014

the economic rationale was a key incentive for local communities to become involved in renewable energy. Substituting imported fossil fuels or final energy with renewables creates opportunities at the local level to establish links in the renewable energy value chain, resulting in socio-economic benefits in the respective regions. According to an analysis from the Institute for Ecological Economy Research (Heinbach *et al*., 2015), planning and installation, as well as the operation of renewable energy facilities, became important value-added at the local level. The production of plants and related equipment accounted for about one-third of the total municipal value added and is thus an important factor for German manufacturing industries.

Furthermore, the increased use of renewable energy has led to diversification of the power mix and affected the ownership structure of power plants in Germany. Figure 8 shows the ownership structure of the country's renewable energy sector. Thanks to the FiT system, which enabled SMEs to contribute across the entire value chain of the renewables sector, the *Energiewende* has taken on a rather decentralised character. Renewable energy therefore is deeply rooted in German society.

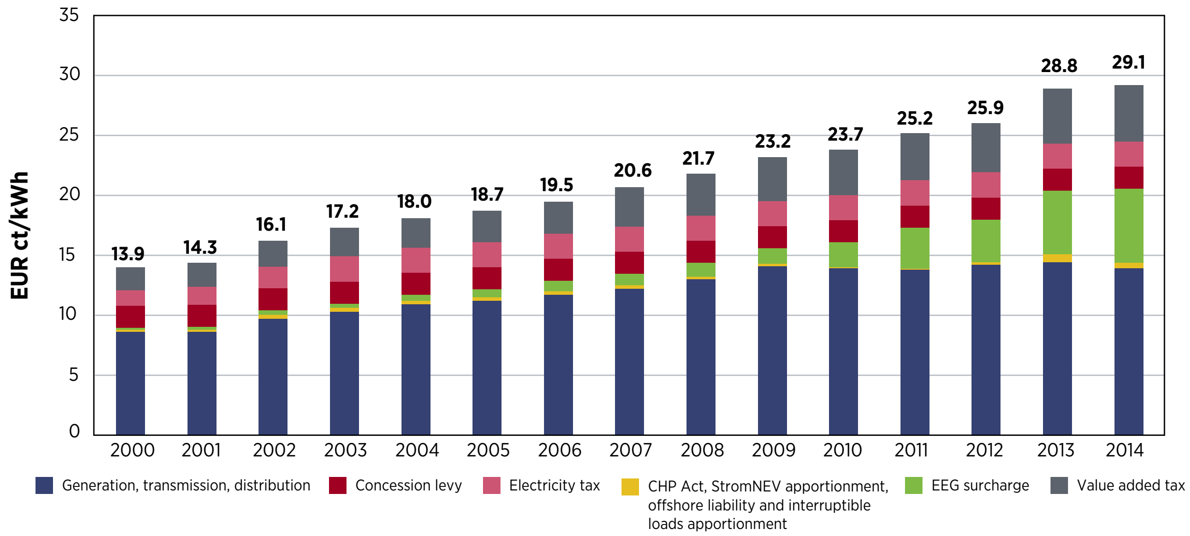
By 2017, Germany will have switched away from the FiT system, to auctions. The first round of bids was held for solar PV in 2015. This policy change may have impacts on the decentralised character of the country's renewable energy sector. To take part in the auctioning process, a renewable energy project has to be pre-developed and licensed. This may be an entry barrier for smaller companies, as pre-development costs can be significant. As a result, today's structure may change in the future.

3.2 Tariffs and costs of the *Energiewende*

Electricity tariff for household consumers

In 2014, the EEG surcharge for households reached EUR 6.24 cents per kWh, excluding the 19% VAT. Energy-intensive industries, which consume some 20-25% of Germany´s total electricity demand, are partially exempt from this surcharge if they face international competition and have high electricity costs compared to the total value-added of their end products. The special equalisation scheme was introduced in 2004 to minimise the impact of the EEG surcharge on the global competitiveness of large electricity-consuming enterprises and the intermodal competitiveness of railroad companies (BMWi, 2014a). As a consequence

Figure 9: Cost components of household electricity tariffs in Germany



Source: BMWi, 2014b; some changes made by IRENA
Note: red coloured sections indicate taxes, green section indicates EEG surcharge

of the ever-increasing high volume of renewable electricity competing with fossil and nuclear fuel power generation, wholesale prices declined to EUR 3.79 cents in 2014, from EUR 5.43 cents in 2011 (Agora, 2014b).

The retail electricity price for private households has many components in addition to the EEG surcharge (see figure 9). Electricity prices averaged nearly EUR 29.1 cents per kWh in 2014. Of this total, EUR 13.9 cents (just under half) was related to generation, transmission and sales. The remaining 52% was taxes, fees and levies, which totalled EUR 15.2 cents per kWh. The largest component of this portion is the EEG surcharge, followed by a VAT of EUR 4.65 cents per kWh. An average household (consuming 3 500 kWh per month) paid around EUR 85 per month for electricity in 2014. The EEG surcharge comprised around EUR 18 of the total. Household electricity prices have more than doubled (in nominal terms) since 2000, rising from EUR 13.9 cents to EUR 29.1 cents per kWh. This rise has been fuelled primarily by prices for generation, transmission and sales; the EEG surcharge; and the VAT (BMWi, 2014a).

The increase in prices for generation, transmission and sales and the rise in the EEG surcharge have pushed up electricity prices by roughly equal amounts since 2000. Increased generation costs at conventional power plants were responsible for most of the price hikes until 2009, when they were replaced by the rising EEG surcharge. All price components are now taxed at a 19% rate. The tax increase has added EUR 2.7 cents per kWh to household electricity prices since 2000 (BMWi, 2014a).

In 2015, the trend towards higher EEG surcharges changed for the first time since 2000. With decreasing costs, especially for solar PV, the EEG successfully drove down costs not only in Germany but worldwide. Thus, countries that start new renewable energy programmes now benefit substantially from lower renewable energy costs. However, renewable energy costs are country-specific and are also related to the existing energy policy framework: reliable and stable policies lead to lower renewable energy financing, and rapidly changing policy frameworks lead to higher costs for renewables.

The EEG surcharge and its calculation

The EEG guarantees a specific fixed tariff (*i.e.*, the FiT) for each kWh of renewables fed into the grid of the system operator. Transmission system operators are requested to sell the entire volume of renewable electricity under the EEG to the stock exchange market. Alternatively, the plant operator can sell its electricity directly, and this electricity is promoted on the market premium (BMWi, 2014c). The difference between the FiT payment to the renewable plant operator's remuneration or bonus payments and the income of the transmission system operator from the stock market results in the overall additional costs of the EEG electricity.

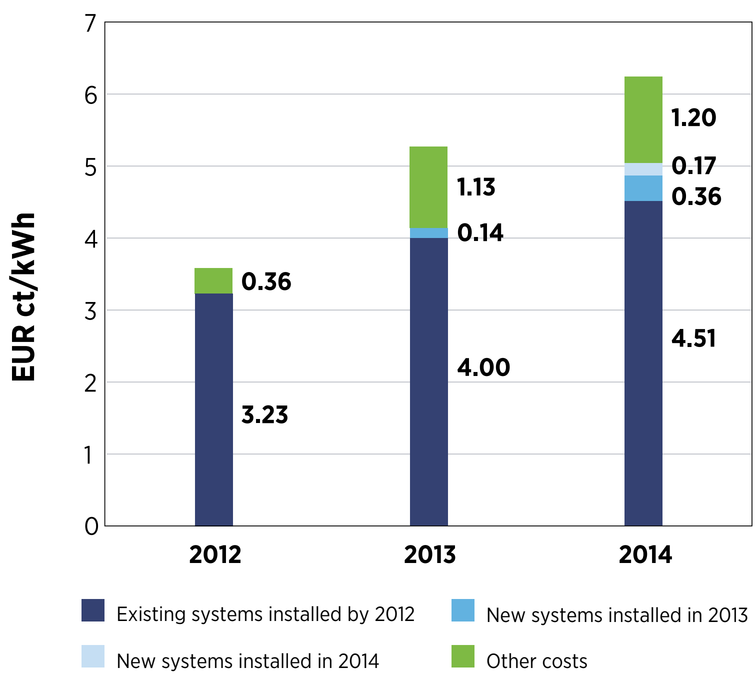
These total costs have to be paid by all energy companies and shared across all electricity consumers. However, not all industries are included, especially electricity-intensive companies that face international competition, railways and electricity producers for their own consumption. The production costs of the EEG – *i.e.*, the difference between the compensation payments and the revenues from the exploitation of renewable energy stream in the stock market – are transferred to all energy supply companies and, subsequently, to customers.

The EEG amendment that took effect on 1 August 2014 requires operators of newly built plants to market the electricity produced. For this purpose, operators receive a market premium from the transmission system operator. The market premium compensates the difference between the fixed EEG payment and the average exchange price and represents an important component of the "EEG differential costs".

Every 15 October, transmission system operators calculate the EEG surcharge for the coming year. The surcharge is based on forecasts made in accordance with the Equalisation Scheme Ordinance (AusglMechV) (BMWi, 2014a). Hence transmission system operators predict future payments to the operators of renewable energy systems for the coming year and exclude them from the forecasted marketing revenues. The difference between the projected production costs of renewable energy and the sector-related additional costs arises. The so-predicted differential costs will be allocated in the form of the EEG surcharge per kWh on electricity consumers. Deviations from the forecast are taken into account in the following year at the new forecast and definition of EEG apportionment.

Before calculating the EEG surcharge, the transmission system operators first have to determine the aggregate EEG surcharge. In addition to the forecasted differential

Figure 10: Breakdown of the EEG levy based on time of installations, before and after 2013



Source: BMWi, 2014e

costs of renewable energy in the subsequent calendar year, they include a liquidity reserve to cover future forecast errors and an account settlement charge to offset past forecast errors.

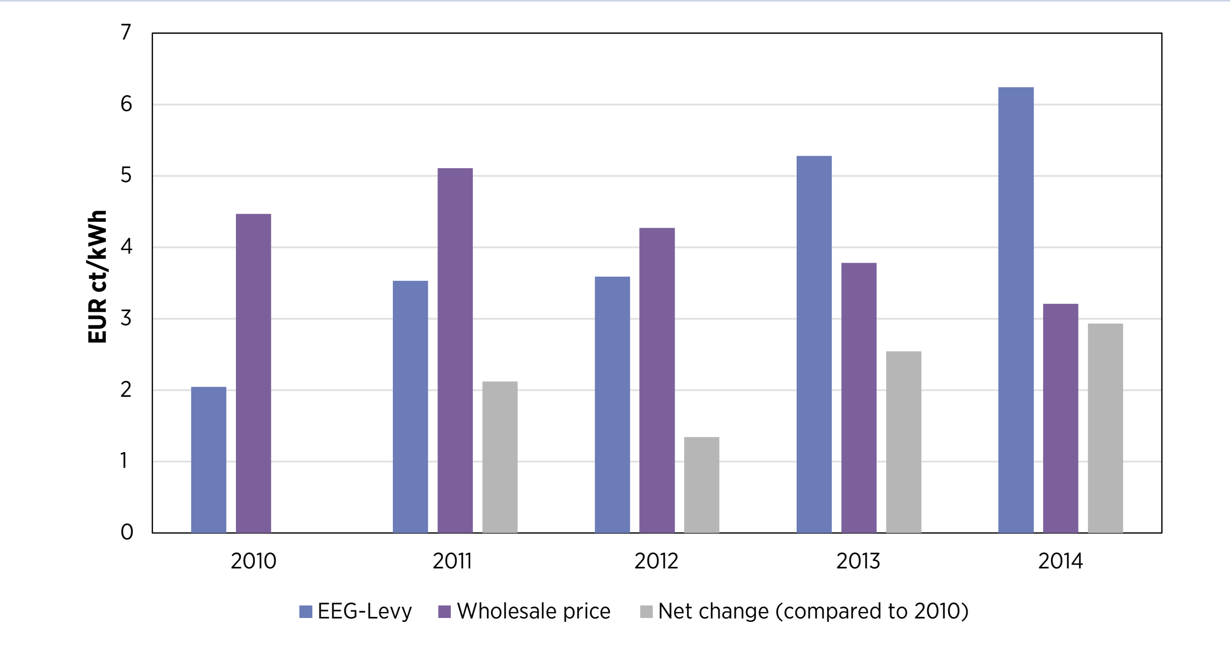
The market price and EEG surcharge are closely related. For example, in 2011, the market price was EUR 5.11 cents per kWh, while the EEG surcharge was EUR 3.53 cents per kWh. The sum of the market price and the EEG levy is EUR 8.64 cents per kWh. Due to high volumes of renewables-based power generation, the overall market price decreased significantly to EUR 3.78 cents per kWh in 2013, and the EEG surcharge increased to EUR 5.83 cents per kWh. The total of the two, however, was only slightly higher than in 2011. Thus, the market price was 27% lower than in 2011, but the EEG levy increased by 50% – even though the actual EEG tariff costs increased only 14%.

Figure 10 shows the relation between FiT expenditures for existing and new installations, respectively, and the development of the stock market price for electricity and the EEG levy. By 2014, the stock market price decreased further to EUR 3.21 cents per kWh, or EUR 0.57 cents per kWh lower than the previous year (see figure 11). In addition to the increasing use of renewables, other factors contributing to the decrease in market prices of electricity include a coupling of the EU power markets, overcapacities of fossil fuel power plants, and stable/lower demands due to economic crisis in some EU member states (BMWi, 2014f).

The aggregate EEG surcharge grew steadily from 2001 to 2014, due mainly to an increase in EEG payments to plant owner/operators. Much of the rise in the aggregate EEG surcharge was fuelled by the solar PV boom, during which at least 7 GW of capacity was added each year between 2010 and 2012. However, falling prices at the power exchange pushed up subsidy requirements as well. After all, every drop in proceeds from selling EEG electricity at the exchange translates into a direct increase in differential costs. Due to the positive development of the EEG account in 2015, the aggregate EEG surcharge will decrease for the first time. On the settlement day of 30 September 2014, the EEG account had a positive balance of EUR 1.4 billion. In the previous year, in contrast, a deficit of EUR 2.2 billion had to be compensated (BMWi, 2014a).

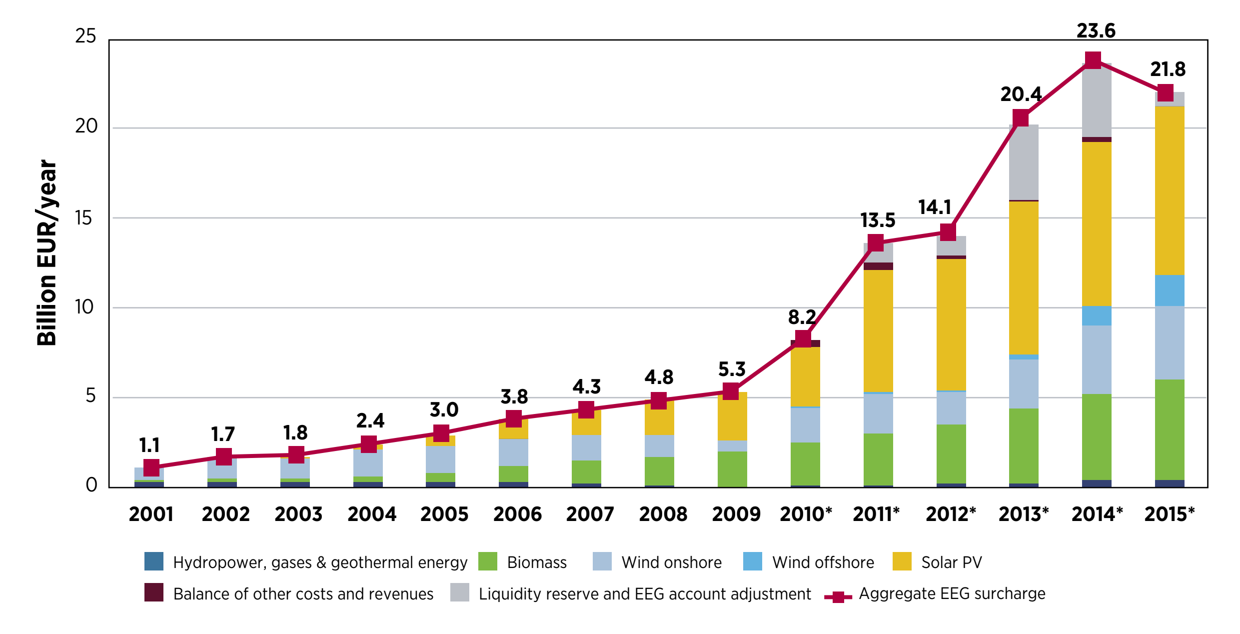
Because the 2014 reform of the EEG law focuses on the most mature technologies (onshore wind and solar PV), the EEG surcharge is expected to increase only moderately in the years to come. It should reach a maximum of EUR 7.5 cents per kWh in 2022-2023 and then decrease

Figure 11: Average power wholesale price and EEG levy



Source: based on BMWi, 2014e

Figure 12: Development of the EEG surcharge



Source: BMWi, 2014b

**Transmission system operators' forecast of EEG surcharge in accordance with the Equalisation Scheme Ordinance (AusglMechV), published on www.netztransparenz.de.*

Note: Calculated EEG differential costs of all electricity suppliers for 2001 to 2009 based on transmission system operators' annual statements and the average value of EEG electricity. The item "Balance of other costs and revenues" includes expenditure by transmission system operators on profile service, exchange listing admission, trading platform connectivity, interest charges, EEG bonus, cost of retrofit due to 50.2 Hz issue as well as revenues from paying the minimum surcharge due to privileged final consumption, revenues from offshore capacity auctions and revenues according to Section 103 subsection 6 EEG in connection with Section 75 EEG.

when consumers no longer must pay for the oldest (and most expensive) renewable capacity installed in the 2000s. The main reason for the continued increase through 2023 is the development of offshore wind, a relatively expensive emerging technology (twice as costly as onshore wind) (Agora, 2015b).

According to the German Association of Energy and Water Industries (BDEW, 2015), electricity prices in 2014 declined slightly. However, a three-person household that consumes 3 500 kWh per year now pays EUR 84 monthly, compared to EUR 54 in 2005. Considering price trends of the past decade, the recent decline does not compensate for the electricity price increase. However, there was no public outcry against these price increases for several reasons:

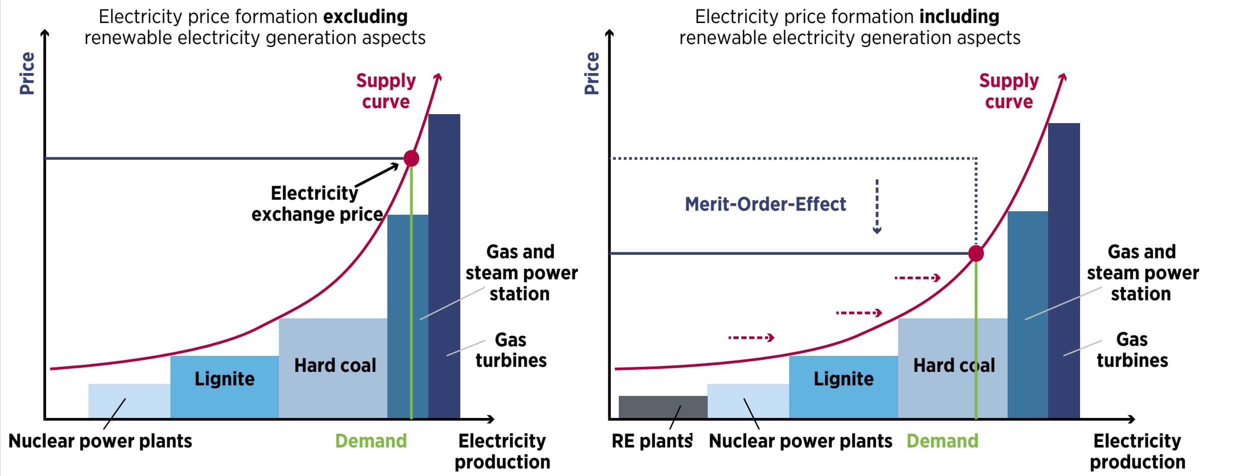
- The liberalised power market in Germany allows consumers to switch to providers that offer cheaper electricity. The difference between the most expensive and the cheapest tariff is as high as 40%[4]. Hence, households can entirely or partly compensate for the tariff increase of their current utility by switching providers.
- The average electricity demand of a German household is around 10-15% below that of the average European household, and has been decreasing continuously since 2006 (BDEW, 2013).
- There is broad support for renewable energy in Germany, and a majority of consumers are willing to pay for a transition to renewables.

A mix of tariff change and increased energy efficiency can reduce the monthly cost even when the overall average tariffs increase. Therefore, consumers have room to manoeuvre to react on price increases, which compensates public pressure and outreach.

After the German power market was liberalised, many new players entered the market; however, many new players have since disappeared from the market as

4 As detailed on *http://www.verivox.de/strompreisvergleich/*

Figure 13: Schematic description of the merit-order effect



Source: BMWi, 2014b

well. However electricity prices differ by region. In September 2015, a household in Hamburg, for example, could choose among 53 different tariffs, ranging from EUR 872 to EUR 1255 per year[5] for the same amount of electricity (3500 kWh per year).

Effects of renewable generation on wholesale electricity prices

Electricity supplied from renewable energy sources tends to lower power prices. This is an outcome specific to the German market design and may not necessarily happen in other jurisdictions. It reduces demand for conventional electricity and therefore displaces power stations that have higher variable costs in line with their merit order (priority of use of power stations on the basis of short-term marginal costs), and thereby ensures that prices are determined by power stations with relatively low variable costs (BMWi, 2014a).

This results in decreasing electricity prices at the wholesale level. Although this reduces power generators' revenues, it also benefits suppliers and electricity consumers, especially if they buy their electricity directly from the power exchange. The merit-order effect, in other words, does not describe savings for the economy as a whole, but rather shows a shift in cost distribution (see figure 13). The impact of the merit-order effect on individual manufacturers and economic players depends, among other things, on whether the power supply agreements are short- or long-term and whether electricity purchases at the power exchange are optimised.

Whether final customers also profit from falling costs, and to what extent, is among other factors that depend crucially on the electricity suppliers' procurement and market behaviour, and this is therefore difficult to verify. Rolling procurement strategies on the futures market over a period of up to three years can lead to time shifts in the merit-order effect (BMWi, 2014a).

3.3 Market design and electricity pricing

This sub-section summarises recent changes and proposals for reforming the German electricity market and electricity pricing to allow it to better cope with increasingly high shares of renewable energy. This issue has been debated heavily in Germany in recent years. During a broad consultation process involving government authorities, associations, trade unions, companies, research establishments and individual citizens, BMWi prepared a "Green Paper" in October 2014 that was open for comment until March 2015 (BMWi, 2014a). The feedback received resulted in the preparation of a "White Paper" released in July 2015 (BMWi, 2015b). This paper suggests the creation of "electricity market 2.0" (an electricity-only market) backed up by a capacity reserve; capacity markets are not suggested. The "White Paper" also includes proposals on how to set

5 Sample research of the author with Verivox search engine.

Table 4: Overview of measures for Germany's electricity market reform

Component 1 – "Stronger market mechanisms": These measures strengthen the existing market mechanisms. The required capacities can thus refinance themselves, and the electricity market can continue to ensure security of supply.
Measure 1 Guaranteeing free price formation on the electricity market
Measure 2 Making supervision of abuse of dominant market positions more transparent
Measure 3 Strengthening obligations to uphold balancing group commitments
Measure 4 Billing balancing groups for each quarter hour
Component 2 – "Flexible and efficient electricity supply": These measures optimise the electricity supply at both European and national levels. They thus ensure a cost-efficient and environmentally compatible use of capacity.
Measure 5 Anchoring the further development of the electricity market in the European context
Measure 6 Opening up balancing markets for new providers
Measure 7 Developing a target model for state-induced price components and grid charges
Measure 8 Revising special grid charges to allow for greater demand-side flexibility
Measure 9 Continuing to develop the grid charge system
Measure 10 Clarifying rules for the aggregation of flexible electricity consumers
Measure 11 Supporting the wider use of electric mobility
Measure 12 Making it possible to market back-up power systems
Measure 13 Gradually introducing smart meters
Measure 14 Reducing the costs of expanding the power grid via peak shaving of renewable energy facilities
Measure 15 Evaluating minimum generation
Measure 16 Integrating CHP generation into the electricity market
Measure 17 Creating more transparency concerning electricity market data
Component 3 – "Additional security": These measures provide additional security of supply.
Measure 18 Monitoring security of supply
Measure 19 Introducing a capacity reserve
Measure 20 Continuing to develop the grid reserve

Source: BMWi, 2015b

out a future grid that has strong market mechanisms, flexibility and security of supply. This sub-section builds on a summary of the "White Paper" and also presents facts based on other authoritative literature addressing electricity market design and electricity pricing issues.

Table 4 provides an overview of the measures, which can be broadly grouped in three core areas: stronger market mechanisms, flexible and efficient electricity supply, and security of supply. Some of the measures build on existing structures to allow market players to meet their supply commitments, while others strengthen existing market mechanisms. The measures also set out broad goals of greater European electricity market integration. The "White Paper" was intended to be discussed during the remainder of 2015 and to be followed up by legislation supporting its vision.

Market design

Germany has 4 transmission system operators, 900 distribution system operators and 800 parties responsible for balancing. Each transmission system operator and distribution system operator has its own network charges. The regulator decides on the revenues of network operators. Germany has four markets: 1) Planning: Forward market, 2-3 years ahead; 2) Optimisation: day-ahead market, 24 hours ahead; 3) Correction: intraday market, 15 minutes ahead; 4) Residual: balancing market.

The German power system is characterised by significant overcapacities. The country had 83 GW of peak demand in 2013, but around 160 GW of installed capacity. Today, the system has 100 GW of conventional power generation capacity, more than enough to meet demand. This will decline to 77 GW in 2025. Future market design will become increasingly important as higher shares of renewables are introduced to the system.

According to the "Green Paper" the German electricity market operated based on the following: 1) submarkets, 2) the pricing signal, to which electricity production and consumption align, 3) the transmission system operators, which use balancing capacity to balance out any unanticipated differences, 4) the system of balancing groups and imbalance settlement controls synchronisation, 5) as a result of the interaction between these two mechanisms, the electricity market that provides remuneration for energy and capacity, and 5) transmission system operators that rectify bottlenecks in the grid by expanding and upgrading the power grid, and, on an interim basis, by using redispatch measures (*i.e.*, congestion management).

To accommodate higher shares of renewables, one option discussed in recent years is so-called capacity markets[6]. Several studies suggest selecting a strategic reserve that sets aside sufficient reserve capacity (*i.e.*, a given amount of firm generation capacity) for situations where capacity cannot meet the demand. Power plants that set aside this reserved capacity receive a remuneration. Similarly, commercial and industrial users can reduce their demand and also receive a remuneration. All of this is paid by all electricity consumers as a capacity fee. Examples of capacity markets exist in PJM Interconnection, New York and in New England. In principle, storage system operators and electricity consumers who are willing to temporarily cut back on their consumption could conceivably also profit from such payments. In the last two years, various proposals have been drawn up on precisely how to design such a capacity mechanism for Germany.

Advocates of capacity markets suggest that electricity-only markets do not provide sufficient incentives to invest in new capacity, as price peaks would come late and are not easy to forecast. Capacity markets typically are considered to be more costly and/or to result in higher costs throughout their operation. According to capacity market advocates, this may not be true, especially when considering the costs that arise from uncertainty of a newly designed electricity market that has not yet been operated. Finally, it is suggested that capacity markets can ensure a flexible system at both the generation and demand sides, and that flexibility should be promoted explicitly in such market design.

The outcome of the consultation in Germany, however, favoured an electricity-only market, the so-called "electricity market 2.0". Three main arguments support this choice. An electricity-only market can deliver security of supply where power plants and flexibility options can be financed through market mechanisms. Furthermore, remuneration of capacity is possible since "electricity market 2.0" also would reward capacity (*e.g.*, on the balancing markets). There is a high risk that a capacity market will be an irreversible intervention to the competitive electricity market and would entail high costs and risks. Finally, the power sector transformation that Germany is aiming for can be hampered by capacity markets, with negative impacts on integration of renewables, capacity turnover, price signals and the environment (*i.e.*, higher emissions).

Remuneration of capacity is one key issue that is discussed. "Electricity market 2.0" will not only incentivise the electricity generated, but explicitly the capacity. This will be achieved through different means. Conventional capacity will still be able to trade in the spot markets and, more importantly, in the long-term futures markets. In long-term contracts, a price is established by the market, and the buyer often agrees to pay a premium against the security of supply. For conventional capacity, further remuneration will be possible when acting as balancing capacity. Finally, during price peaks, capacities that are less used (often conventional generation) will be able to cover their fixed costs.

In the "electricity market 2.0", flexibility measures aimed at guaranteeing security of supply will be key. Flexibility supports not only security of supply, but also renewables integration by synchronising production and consumption. The measures include flexible conventional and renewable generation, trade, flexible demand and coupling of sectors (heating, cooling, transport),

6 In cases where capacity markets were applied, the main objective was for peak demand, not for flexibility.

reduction of must-run and flexible renewables, and peak plants replacing baseload.

Advocates of both sides highlight the importance of demand-side management in accommodating higher shares of renewables. This is especially important because the potential of dispatchable renewable sources like hydropower, biomass and geothermal is limited in Germany. Hence, achieving ambitious renewable energy targets will require drawing on variable renewable energy sources of wind and solar PV to large extent. Demand-side management has a number of advantages. If operation hours manufacturing industry plants can be re-arranged, it can help companies to cut production costs. It also reduces the investment in back-up power capacity.

In terms of ensuring flexibility, there is 6.4 GW of storage capacity on the German grid, with expansion planned to 8.6 GW. Interconnector capacity with neighbouring countries was 29 GW as of 2013, but this is projected to grow to 31.3 GW in 2025. Meanwhile, some studies note that the overall need for balancing energy has been falling for years (Steinbach, 2013), which is probably because of the merger of balancing zones from four to one, a one-time event.

The role of storage, and which type of storage technology, is another area which has received attention from both policy makers and the renewable energy industry. Options for energy storage include heat/cold storage, balancing variable renewable energy generation with CHP capacity (with heating capacity becoming a storage), district heating and cooling, pumped hydro and battery storage. Expensive battery storage technologies on the transmission network do not need to be the first choice in realising higher shares of renewables, as household-size storage technologies that are becoming mainstream will be further deployed. Existing heat storage technologies can easily offer the required flexibility. Linking the power generation sector with developments in end-use sectors – in particular storage capacity from electric mobility, heat pumps and CHP – will also be key. In periods where electricity from variable renewables cannot be exported further, peak shaving will be another important option.

Overall, the new market design will be built on the 20 measures described in Table 4. Germany is now working to realise all of these options and is focusing on the development of innovative technology, market design, finance and business models.

Zonal versus nodal pricing

There are two types of pricing in electricity markets. Zonal pricing is typically used in the European spot markets, and it applies merit order to dispatch power from one location to another. Germany also applies zonal pricing. The output of consultation in Germany shows strong preference towards retaining zonal pricing. It basically involves a large bidding zone and allows easy access to the internal market as well as competitive bidding from generators. It helps to increase renewable energy capacity expansion and market integration (Zerres, 2015).

Several studies also discuss drawbacks of zonal pricing. For instance, there could be insufficient capacities in the network to transmit the contracted power. This would require the system operator to adjust the generation and consumption in order to change the physical flows in the network and to mitigate congestion. Given also that there is a uniform price within each pricing area, there is a risk that sufficient price signals to market participants regarding scarce transmission capacity will not be received (Bjorndal, Bjorndal and Cai, 2014).

Nodal pricing, on the other hand, could potentially give an optimal value for each location and produce feasible flows within the network. Therefore, it is considered to give clearer market signals. The Electric Reliability Council of Texas (ERCOT) has developed from seven zones to nodal pricing. This has reduced reserve needs and resulted in a better use of transmission capacity. Zerres (2015) discusses some characteristics of nodal pricing, such as: localisation of congested elements, economic signals on congested elements and the potential risks from market players exercising market power.

The difference that nodal pricing can add to new power market design with the aim of accommodating large-scale renewables has already been discussed. In the case of the undergoing transition in the United States to nodal pricing, the associated implementation costs were recovered within one year of operation. A power market design based on nodal pricing initially provides customers with a single price across the region. As end-users become more price-responsive and as regional congestion increases, further levels of prices can be provided to retail customers. This would avoid the need to adjust overall system or contracting structures (Neuhoff and Boyd, 2011).

Germany applies a single price zone, meaning that the same prices are guaranteed even if the grid is congested. A similar model is applied in Austria. It is often the case that a country has a single price zone, such as in the Netherlands, but some countries are split into more zones (as in Sweden). If the building of new transmission lines in Germany is delayed, this may result in 2-4 bidding zones in the future. Intensifying European co-operation also will be important in retaining a single price zone for Germany.

Market and price coupling

Market coupling is a necessary intermediate step towards realisation of the fully integrated internal electricity market. Market coupling is used to manage capacity congestion between adjacent power spot markets by optimising the capacity allocation. It also allows the matching of power exchanges' orders and the implicit allocation of the available cross-border capacities received from the transmission service operators. Currently, market coupling is established in different regions within the EU, and different types of market coupling models exist in EU member states and Norway. However, they all have in common the integration of cross-border transmission capacity allocation in the price-setting mechanism.

North-Western Europe (NWE) price coupling is a project that aims to establish price coupling of the day-ahead wholesale electricity markets in the region, increase the efficient allocation of interconnection capacities and optimise overall social welfare. The project started on 4 February 2014 and covers the Nordic-Baltic region (Nord Pool), Great Britain and the Central-Western Europe (CWE) region.

The Baltic States and Poland are coupled to the Nordic market. The same applies for the Austrian market: Austria is not directly involved, but Austrian prices are determined at the same time as German prices, since they are part of a single bidding area. Overall, 15 countries will be coupled. Price Coupling of Regions (PCR)[7] will be used to facilitate the NWE initiative, thereby optimising area and cross-border trades in a region that accounts for three-quarters of total European electricity consumption.

In June 2015, 12 neighbouring countries in Europe signed a declaration – led by Germany – to start considering energy security as a European issue, rather than as a purely national one (BMWi, 2015c and 2015d). There are three key points of the declaration:

- The signatories have agreed to place greater focus on making supply and demand more flexible by using strong market signals and price peaks; they have agreed to refrain from introducing legal price caps and to eliminate barriers that impede greater flexibility.
- The signatories will further reinforce their grids, and they will not restrict cross-border electricity exchange, even in times of electricity scarcity.
- In future, the signatories will place greater focus on assessing their generation adequacy as a regional group, and, to this end, they will develop a common approach.

Benefits of market coupling include the optimal use of interconnectors, facilitating congestion management, reduction of price volatility, price convergence of market areas in case of sufficient border capacity, smoothing effect on negative or positive price spikes resulting from extreme weather conditions (*i.e.*, cold wave, storm front) on other market areas, and higher security of supply through market integration (EPEX-SPOT, 2013).

3.4 Renewable heating and cooling in the building sector

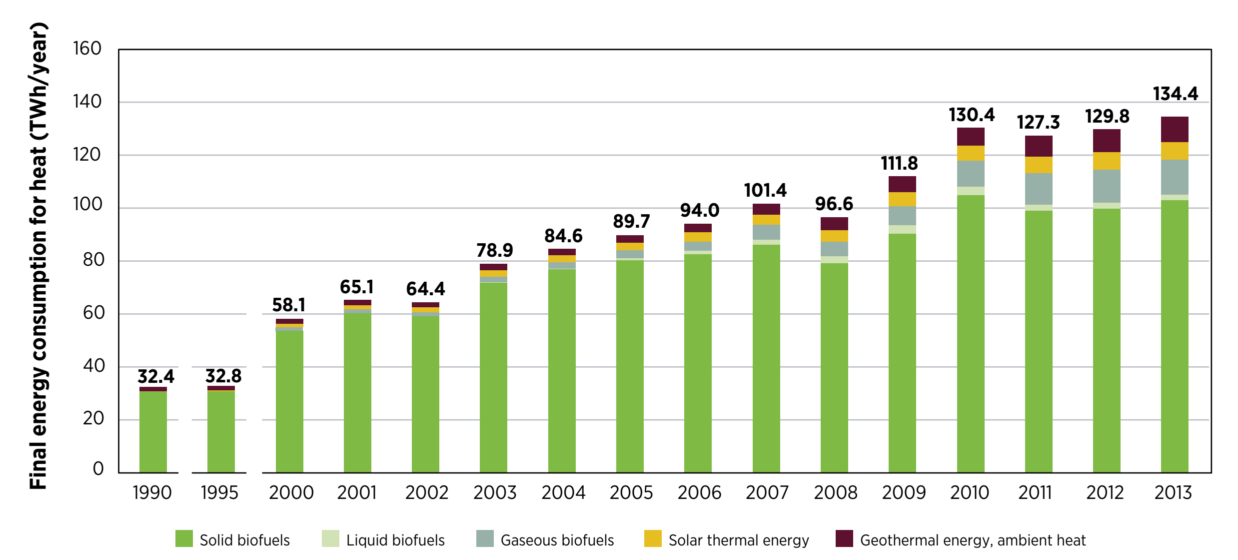
Market development

Germany's renewable heating market grew steadily until 2010. Since then the capacity has remained stable. However, overall growth has been significantly slower than in the power sector. The total share of renewables in Germany's heating and cooling market is 11%.

Biomass accounts for as much as 85% of the total heat supply from renewables and therefore provides the largest share of renewable energy capacity today (see figure 14). Its growth slowed significantly in recent years,

7 PCR, or "Price Coupling of Regions", is the initiative of seven power exchanges (APX, Belpex, EPEX SPOT, GME, Nord Pool Spot, OMIE and OTE) to develop a price coupling algorithm embedded in a common system solution (PMB), with the goal that this infrastructure, including the algorithm, will be used for European Price Coupling (EPEX SPOT, 2014; Nord Pool Spot, n.d.).

Figure 14: Development of renewables-based heat consumption in Germany



Source: BMWi, 2014b

however, whereas geothermal heat pumps grew fastest and overtook solar thermal collectors in 2009.

The market for heat pump heating in Germany has grown consistently since 2006. This is due in part to the improved economics of combining heat pumps with renewable electricity production technologies, especially solar PV. The total number of heat pumps in Germany reached some 1 million in 2014, up from about 360 000 units in 2000. This represents 7.5% annual growth.

The market for solar heating in Germany reached a peak in annual additions (1.3 million m^2 per year) in 2008 and has dropped since 2009 (1.1 million m^2) as a result of reduced solar PV costs and changed market support regulations. The total installed area in 2014 was 17.2 million m^2.

Renewable Energy Heat Act

The building sector is the largest energy user in Germany, accounting for more than 40% of total final energy demand, followed by the industry sector (which accounts for a quarter) and the transport sector (which accounts for the remaining 35%). The building and manufacturing sectors use fuels for water, space and process heating (as direct heat or steam generation). Fuels are also used for cooking in households.

The Renewable Energy Heat Act (“EEWärmeG”) was enforced in 2009 and requires new buildings to source a share of their total energy demand for heating and cooling systems from renewables, such as geothermal heat pumps, solar PV or solar thermal installations (BMWi, 2014a). The proportion varies by technology:

- Minimum 15% of total heating and cooling demand must be met by solar thermal energy, or
- Minimum 30% of the total demand when biogas is used, or
- Minimum 50% of the total demand when solid biomass, geothermal, district heating, waste heat or co-generation is used.

Hence the requirements of the Renewable Energy Heat Act are fulfilled if at least 15% of the total heating and cooling demand of a building is delivered by solar thermal energy. In addition, the law requires public buildings to use renewables for heating and cooling when undertaking renovations with lower targets: 25% if biogas is used, and 15% for any other technology.

Market Incentive Program

The Market Incentive Program (MAP) supports installations of renewable heating and cooling technologies in existing industrial and commercial buildings and thus complements the Renewable Energy Heat Act, which considers only new buildings. Both the German Development Bank (KfW) and the Federal Office of Economics and Export Control (Bundesamt für Wirtschaft und Ausfuhrkontrolle – BAFA) offer financial support for renovations of heating systems under the MAP.

The target of MAP is to increase the renewable heating and cooling share from around 10% to 14% by 2020. Several measures are linked to requirements of the EU Energy Efficiency Directive and were implemented in 2011 (BMWi, 2015d).

The details of this assistance are laid down in funding rules. The "Guidelines on support for measures for the use of renewable energy sources in the heat market" are reviewed as necessary to bring them in line with the latest technology and market developments (BMWi, 2014a).

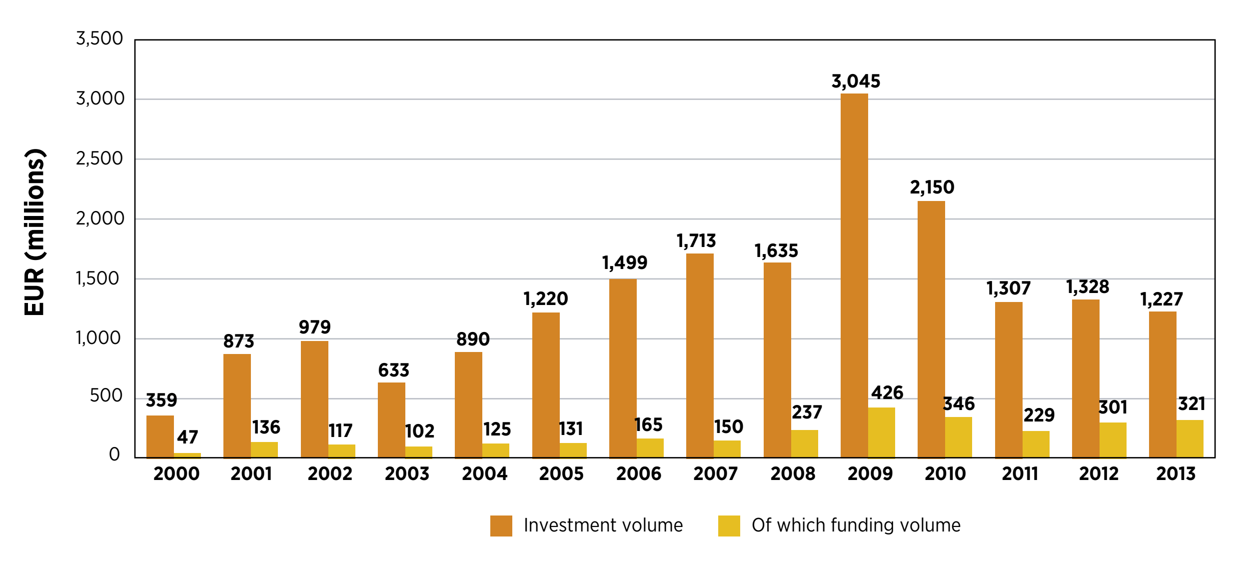
MAP provides two kinds of support, depending on technology and size:

- investment grants are made through BAFA for small installations, primarily in existing buildings; such applications come mainly from private investors in the single-family or two-family homes segment, or
- Reduced-interest loans with repayment grants may be given under KfW's Renewable Energy programme (premium variant) for larger heating solutions and for heating grids and storage solutions. Investments of this kind are made mostly for commercial or local government use.

From 2000 to 2013, investment grants totalled some EUR 1.3 billion for more than 1.1 million solar thermal units and some EUR 590 million for around 340 000 small-scale biomass heating systems. The resulting investment totalled some EUR 9.6 billion in the solar segment and EUR 4.9 billion in the biomass segment. Efficient heat pumps have been eligible for assistance since 2008. From 2008 to 2013, some 86 000 investment grants totalling roughly EUR 210 million were approved. The resulting volume of investment totalled some EUR 1.5 billion.

The KfW Renewable Energy Premium programme approved some 16 300 reduced-interest loans with repayment grants from 2000 to 2013. The total volume of loans granted came to around EUR 2.7 billion, and the volume of repayment grants totalled some EUR 640 million. This assistance is provided, for example, for solar thermal plants with large collector areas, biomass plants with relatively high outputs, deep geothermal plants, and local heating grids and heat storage facilities

Figure 15: Renewable energy support in the heating sector under MAP, 2000-2013



Source: BMWi, 2014b

Funding volume = KfW and BAFA financial support supplied from renewable energy sources. All in all, the MAP, with about EUR 321 million in funding, resulted in EUR 1.23 billion in investment in 2013 (see figure 15) (BMWi, 2014a). Since then, the MAP guidelines have been revised and entered into force in April 2015.

3.5 Renewable energy in the manufacturing sector

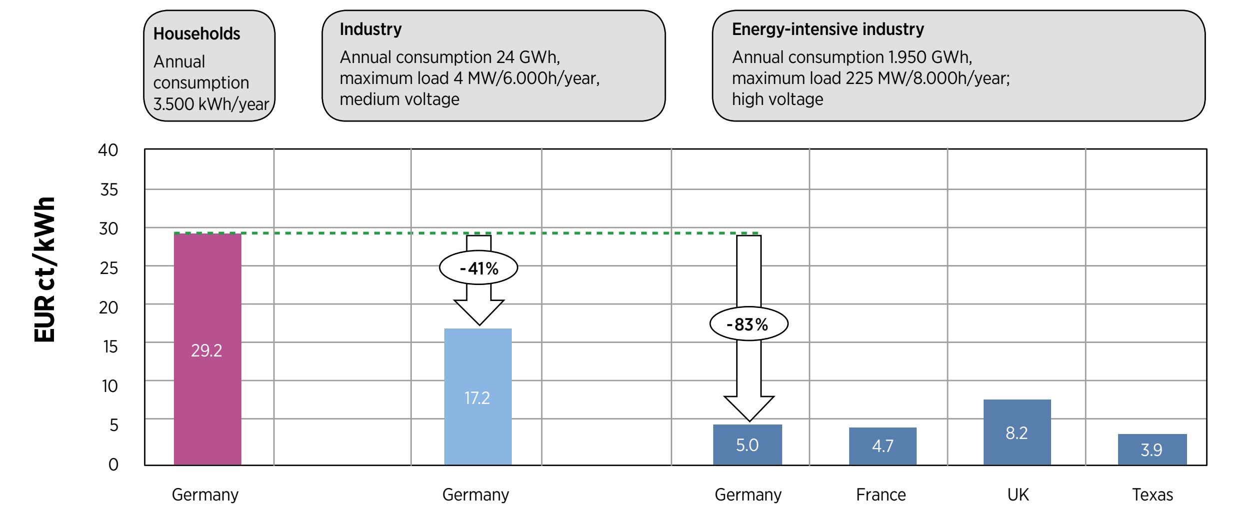
Germany has the largest industry sector in Europe. The industry sector represents the backbone of Germany's economy and accounts for just under a quarter of the country's TFEC. Within the industry sector, the chemical industry is the single largest energy user. The situation for energy-intensive industries varies due to differentiated need for electricity, process heat with different temperature levels and energy commodity feedstocks.

So far, German industry has been more interested in energy efficiency than in renewable energy. Hence, the potential for renewables in the sector has been largely neglected, as is the case in most countries. However, Germany's industry can benefit greatly from increased deployment of renewables, particularly from security of supply and independence from volatile fossil fuel markets.

Although Germany's household electricity prices are relatively high, the electricity costs for energy-intensive industries are among the lowest in the world. To preserve international competitiveness, industries such as steel, cement and aluminium enjoy exclusions from almost all energy-related taxes and levies (*e.g.*, the EEG). These industries purchase electricity directly on the wholesale market and therefore benefit directly from declining prices. In 2014, about 2 000 companies in Germany – representing 20% of the country's energy demand – benefited from these exclusions. Wholesale prices have decreased as a result of the EEG, which is a benefit for the manufacturing industry. Figure 16 compares electricity prices in Germany with those in several other countries and regions that employ energy-intensive industries. Figure 17 compares the average electricity prices for industrial consumers in various countries, with and without taxes and levies.

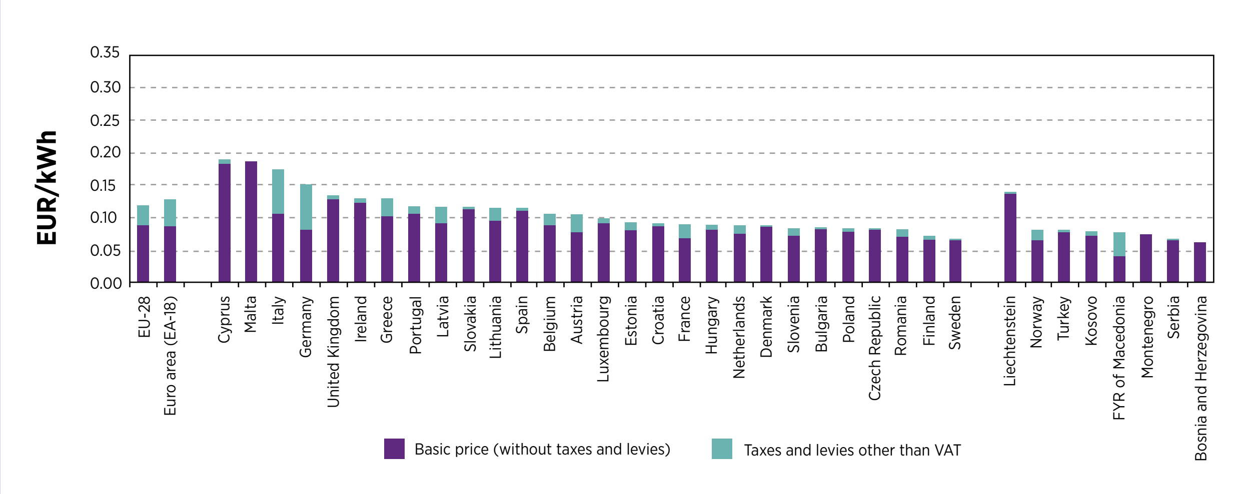
Due to support programmes for on-site co-generation, some industries actually earn extra income because they operate/own CHP and/or power generation plants that also sell surplus power to the market. BASF, one of the largest chemical companies in Germany, operates its own power plants. According to BASF´s annual report 2013 (BASF, 2014), the company generates all of the electricity demand at its headquarters, located in Ludwigshafen, from a gas turbine. While most of BASF's operations are excluded from EEG surcharges because it is identified as an energy-intensive industry, other branches might not be excluded. However, they benefit

Figure 16: Average electricity prices for households and industrial consumers, selected countries, 2013



Source: Agora, 2015b

Figure 17: Electricity prices for industrial consumers, selected countries, second half of 2014



Source: EUROSTAT, 2015

Note For industrial consumers with annual consumption of between 500 and 2 000 MWh
Basic price = Energy and supply and network costs

from reduced stock market prices due to high volumes of renewable electricity in Germany.

In terms of costs for CO_2 under the EU ETS, the German industry sector receives free allocation as part of the benchmarking rules for CO_2 emissions trading for sectors that are subject to trade risks (according to the third phase of the EU ETS) until 2020. This regulation aims to protect industries that compete globally and that might lose cost-competitiveness.

Under the ETS scheme, all CO_2-emission rights that are allocated to the industry – free of charge – can still be traded. Thus, an investment in energy efficiency and renewable energy reduces CO_2 emissions, and the (unpaid) emission rights can be sold from the industry under the ETS trading scheme. This represents an additional option for the industry to benefit from renewables and strong CO_2 reduction targets.

3.6 Renewable energy in the transport sector

Market development

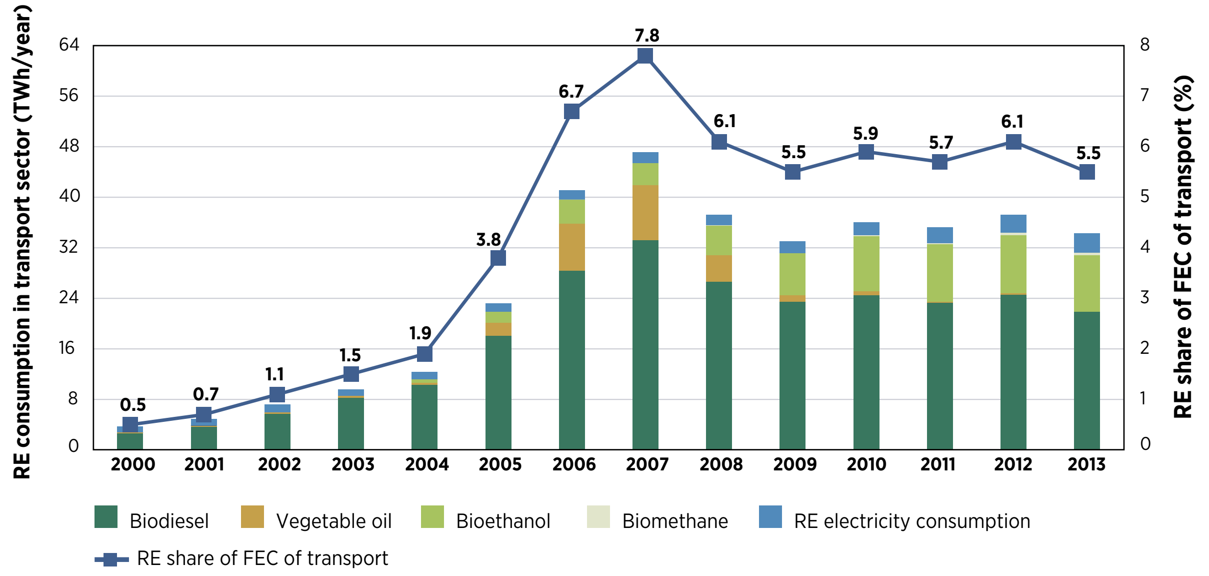
The transport sector is the second largest energy user in Germany following the building industry sector. Vehicle ownership in Germany is among the highest in the world, with one out of every two people owning a car. Germany has a long history of developing an automobile industry, and the sector is among the most competitive and innovative in the world, employing nearly 1 million people.

In 2013, the renewable energy share in Germany's transport sector reached 5.5%. Liquid biofuels – especially biodiesel – are the dominating renewable fuel in the transport sector. The use of plant oil – mainly canola (rapeseed) – grew significantly between 2004 and 2007, but market volumes then decreased rapidly between 2007 and 2014, to less than 1% of the total.

In addition to liquid biofuels, Germany is one of the few countries that uses biogas in its transport sector. It is the world's third largest user of biogas in transport after Iceland and Sweden. Biogas accounts for about 1% of total bioenergy use for transportation. In Berlin, a quarter of the vehicles used by the members of the Bundestag run on biomethane. In Munich, half of the total compressed natural gas supplied in filling stations is biomethane.

Figure 18 shows the development of biofuels in the German transport sector between 2003 and 2013. The total biofuel share has decreased since the peak year 2007 (7.8%), due mainly to implementation of the biofuels quota.

Figure 18: Renewable energy use in Germany's transport sector, 2000-2013



Source: BMWi, 2014b

Biofuels Quota Act

The Biofuels Quota Act sets a minimum level of biofuels use in road transport in Germany. In 2010, the quota was set at 6.25%, based on energy content. All quotas are minimum obligations: between 2009 and 2014, providers could choose which mix to use to fulfil the quota as long as they did not fall below the specific sub-quotas. Due to public and political concerns about the sustainability of biofuels, the initially planned quota of 8% for 2015 was frozen at 6.25% from 2010 to 2014 by the law on amendments in the promotion of biofuels passed in 2009.

Climate Protection Quota

As of 2015, the biofuels quota replaced by the climate protection quota, which specifies the minimum net contribution of biofuels to reduce greenhouse gas emissions. Furthermore the quota for fuel suppliers changed from annual sales to total greenhouse gas reductions. The methodology for the estimation of total emission reduction from biofuels use needs further R&D. The issue of how the differences between the German and European targets will be harmonised is still under debate.

The climate protection quota was initially set to 3% for 2015, 4.5% for 2017 and 7% for 2020, but it has since been changed to 3.5% for 2015, 4% for 2017 and 6% for 2020. Non-compliance with the quota is sanctioned with EUR 0.47 kilogram of CO_2-equivalent (CO_2-eq).

Electric mobility

As of May 2015, Germany had a fleet of 32 900 electric vehicles (EVs) and over 90 000 hybrid-electric cars, representing a share of 2.7% of Germany's total vehicle fleet of 44 million cars. The German government plans to increase the total number of EVs to 1 million by 2020 and 6 million by 2030. In order to stimulate the market, EVs (including fuel-cell power cars) registered between 18 May 2011 and 31 December 2020 are excluded from the vehicle tax for a period of five years.

In 2014, only some 8 522 EVs and 27 435 hybrid vehicles were sold in Germany (KBA, 2015) – representing only some 1.7% of all vehicles sold in the country that year. To reach the 2020 target – which represents about 2.5% of the German car-fleet – the market volume must increase by a factor of at least 20 to around 150 000 to 200 000 EVs per year.

3.7 Energy efficiency

Energy efficiency is a major cornerstone of the *Energiewende*. Germany's strategy to increase energy efficiency is laid out in the National Action Plan on Energy Efficiency (NAPE). A mix of economic incentives, regulations, and improved information and advisory services is intended to harness further efficiency potentials of private households, companies and the public sector at their own initiative.

Exploiting energy efficiency potential as a means to improve the global competitiveness of German industry and to trigger innovation is a central part of the country's energy efficiency strategy. Energy savings are to be established as an investment and business model. Energy management systems and energy audits will play an important role in identifying efficiency potentials.

In the building sector, if installation of renewables is not allowed, higher energy efficiency standards apply. In this case, the energy demand of the building must exceed the energy performance standards for new buildings by at least 15%. Germany has stringent new regulations for new buildings as well as support schemes through banks such as KfW.

The energy efficiency target in the transport sector is to reduce final energy demand by 10% in 2020 and by 40% in 2050, compared to 2005 levels. With regard to electricity consumption, the "Energy Concept" includes a reduction target of 10% for 2020 and 25% for 2050, both over 2008 levels.

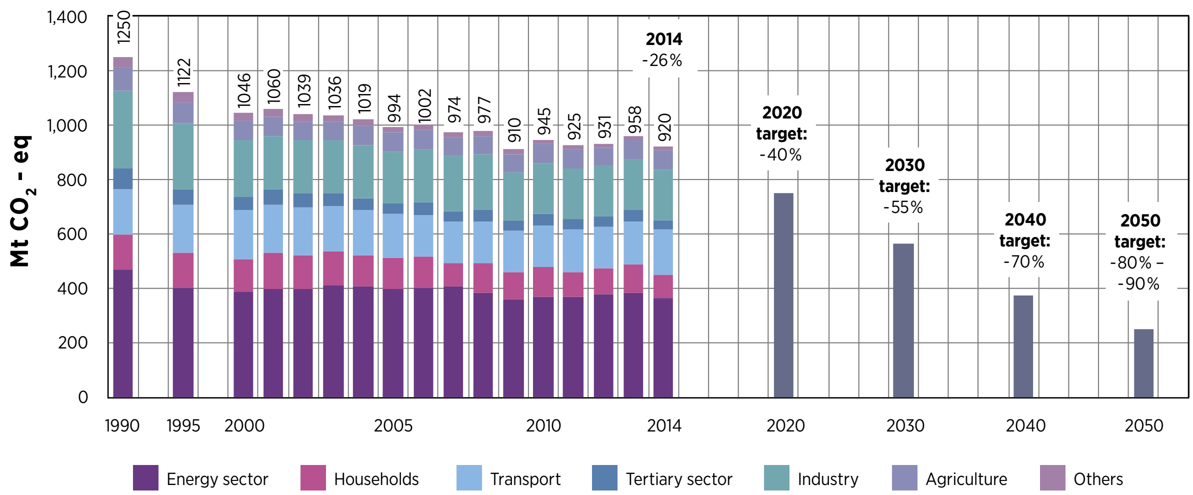
Energy scenarios of the International Energy Agency (IEA), Global Energy Assessment (GEA) and IPCC, as well as various other projections from scientific institutions such as the German Aerospace Center (DLR), calculate energy productivity improvements that range from 1% to as high as 2.5% per year.

3.8 Climate change

Germany's greenhouse gas emission reduction targets are very ambitious, and the *Energiewende* is embedded in the wider EU climate and energy policy structure. The aim is to reduce emissions by 40% by 2020 and 55% by 2030, compared to 1990 levels. Germany is the largest energy consumer of all EU member states; hence, its emissions reductions effort plays an important role within the EU.

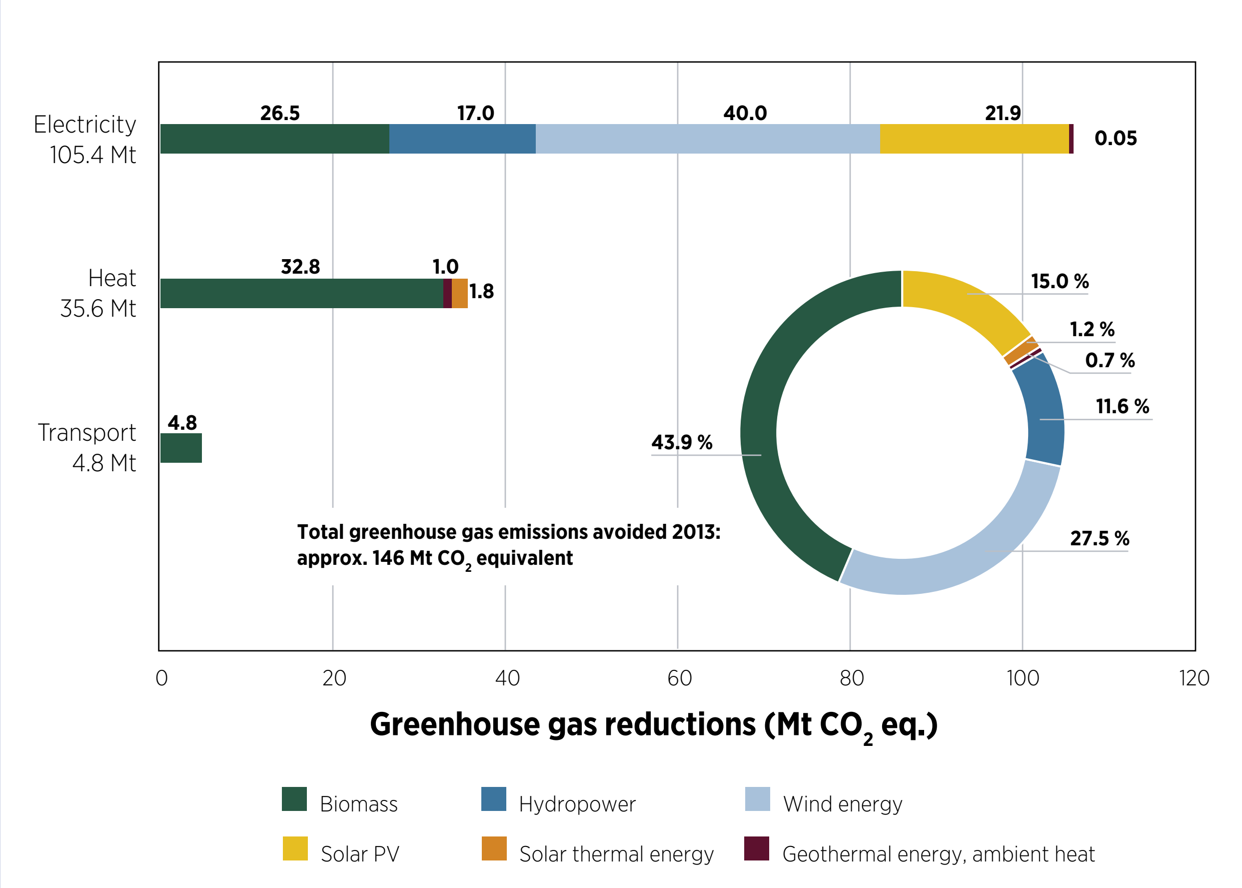
In 2013, Germany's use of renewable energy sources avoided nearly 146 million tonnes of CO_2-equivalent

Figure 19: Germany's greenhouse gas emissions by sector, 1990-2014 and targets for 2020-2050



Source: Agora, 2015b, AGEB, 2015; UBA, 2014;

Figure 20: Net balance of greenhouse gas emissions avoided by renewables in Germany, 2013



Source: BMWi, 2014b

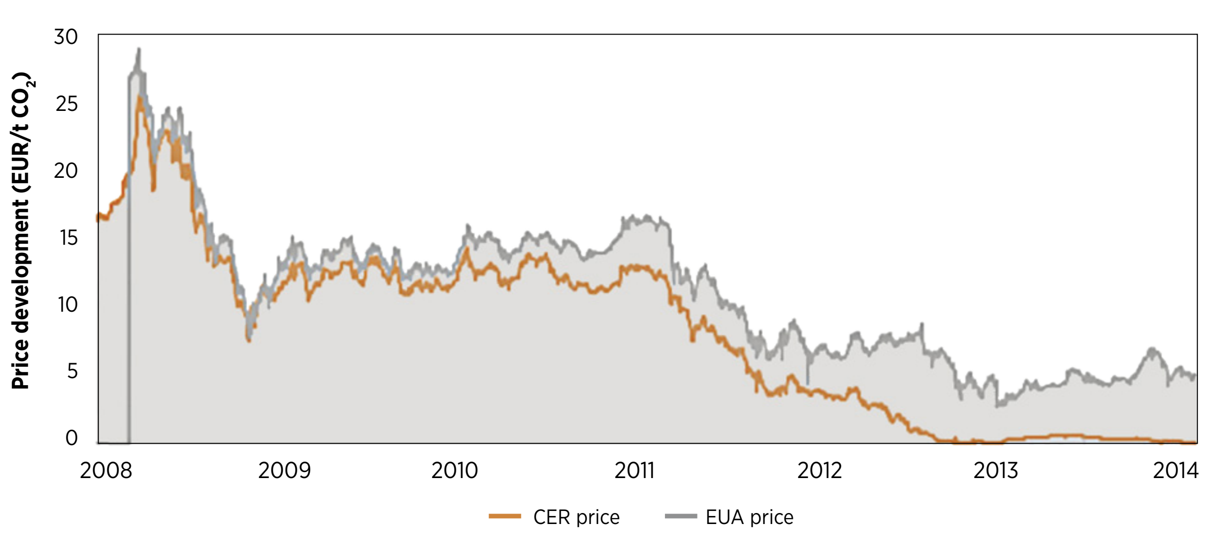
greenhouse gas emissions. The electricity sector accounted for over 105 million tonnes of CO_2-eq, including around 84 million tonnes for renewable electricity that qualifies for EEG compensation. Emissions avoided amounted to nearly 36 million tonnes of CO_2-eq in the heat sector and about 5 million tonnes in the transport sector. Coal for power generation is still the largest emitter (449 million tonnes of CO_2-eq in 2014). The majority of the savings are in the power sector. Figure 19 shows the development of Germany´s greenhouse gas emissions by sector from 1990 to 2014, as well as the targets for 2020-2050.

Figure 20 summarises the greenhouse gas emissions avoided in the electricity, heat and transport sectors. The figures depend on the nature and scale of the renewable energy supply and on the substitution relationships.

CO_2-equivalent emissions from electricity generation In Germany declined from 319 million tonnes in 2000 to 294 million tonnes in 2009, then increased to 317 million tonnes in 2013. The increased CO_2 emissions are due to rising electricity exports, especially from coal power plants. In the year 2000, the electricity trade balance was neutral. In the year 2013, there was a net export of 34 TWh. During the same period, the production of renewable power rose by 114 TWh while the production of nuclear power declined by 72 TWh. Thus, renewables in Germany not only replaced the nuclear power generation from eight reactors phased out since 2011, but put significant market pressure on coal and natural gas power plants.

At the national level, the BMUB (Federal Environment Ministry) supports effective climate protection measures through various programmes and projects in municipalities, in industry, for consumers, and in schools and educational facilities. In the first half of 2015, the BMWi discussed measures for further emissions reduction.

Figure 21: Price development of Clean Development Mechanism offsets and EU Emissions Trading System credits, 2008-2014



Source: Carbon Market Watch, 2015

Note: Clean Development Mechanism = CER price
EU Emissions Tranding System Credits = EUA price

The goal of the EU ETS is to put a price on carbon emissions that is sufficiently high to promote investments in sustainable low-carbon technologies and to reward companies that produce more efficiently. By putting a price on carbon emissions, it becomes more attractive to use renewable energy than heavily polluting coal, for example. Moreover, companies that produce more efficiently gain a competitive advantage because they do not need to buy as many allowances and hence have lower costs than their more polluting competitors (Carbon Market Watch, 2015).

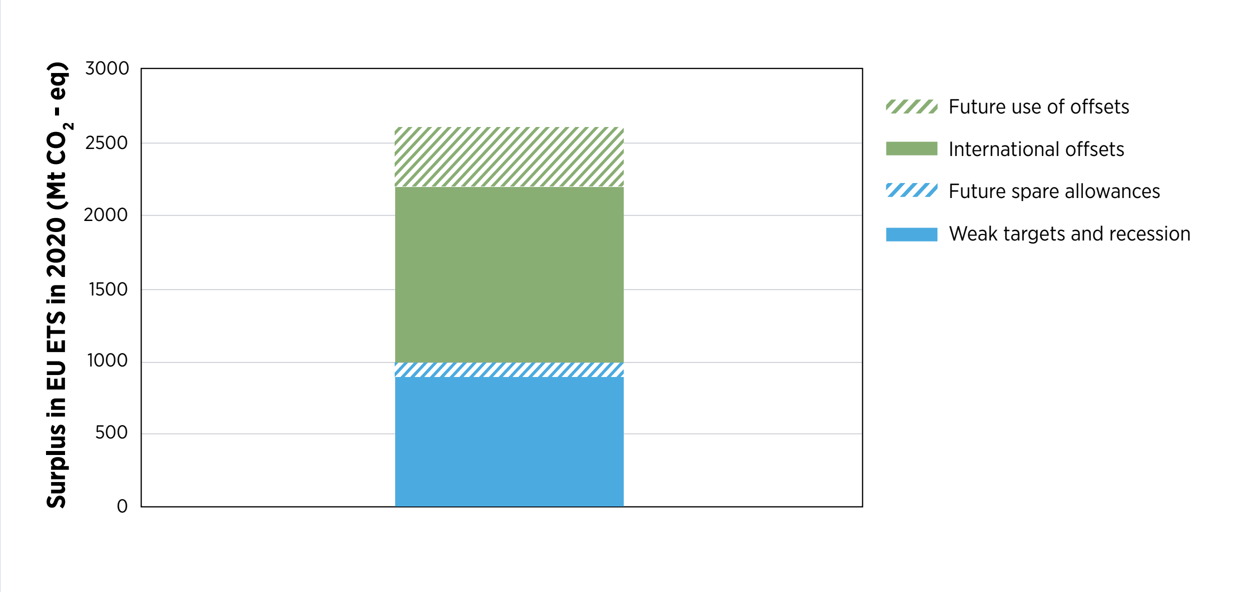
The carbon price averaged around EUR 7 per tonne of CO_2 in the first half of 2015 (the low was EUR 6.01 and the high was EUR 8.01 per tonne); however, this was far too low to spur investments into efficient technologies or to encourage the use of renewable energy. The low carbon price threatens Europe's longer-term climate objective by locking in long-lived and carbon-intensive infrastructure (Carbon Market Watch, 2015).

The low carbon price is also responsible in part for the development of new coal power plant projects between 2005 and 2008 in Germany, as these costs did not contribute to putting economic pressure on coal. Figure 21 shows that the carbon price (for Certified Emissions Reductions – CER, and EUA) plunged from almost EUR 30 per tonne of CO_2 in 2008 to as low as EUR 5 per tonne in 2014.

The huge collapse in the carbon price is the result of a continued imbalance between the supply of and demand for carbon permits. The main reasons for this are (according to Carbon Market Watch, 2015):

- Even without economic crisis, the yearly emission limits of the system were set higher than business-as-usual emissions, thereby allowing companies covered by the EU ETS to even increase their emissions.
- The surplus was further exacerbated by the possibility of using international offset credits in the EU ETS. In 2013, the accumulated use of offsets amounted to 1.2 billion. Offsets currently constitute more than half of the more than 2 billion excess allowances in the carbon market (see figure 22).
- EU emissions declined as the economic crisis affected industrial production and electricity

Figure 22: The build-up of surplus in the EU Emissions Trading System up to 2020



Source: Carbon Market Watch, 2015

consumption. However, even if economic growth returns to pre-recession levels, emissions are unlikely to return to high levels. From 1990 to 2011, the EU's economy grew 45%, while emissions decreased by 18.3%.

3.9 Supply security as a driver for the *Energiewende*

Germany's "Energy Concept" of 2010 aims to achieve an "environmentally sound, reliable and affordable energy supply" (BMWi and BMU, 2010). A high level of energy security, effective environmental and climate protection and the provision of an economically viable energy supply are necessary for Germany to remain a competitive industrial base in the long term.

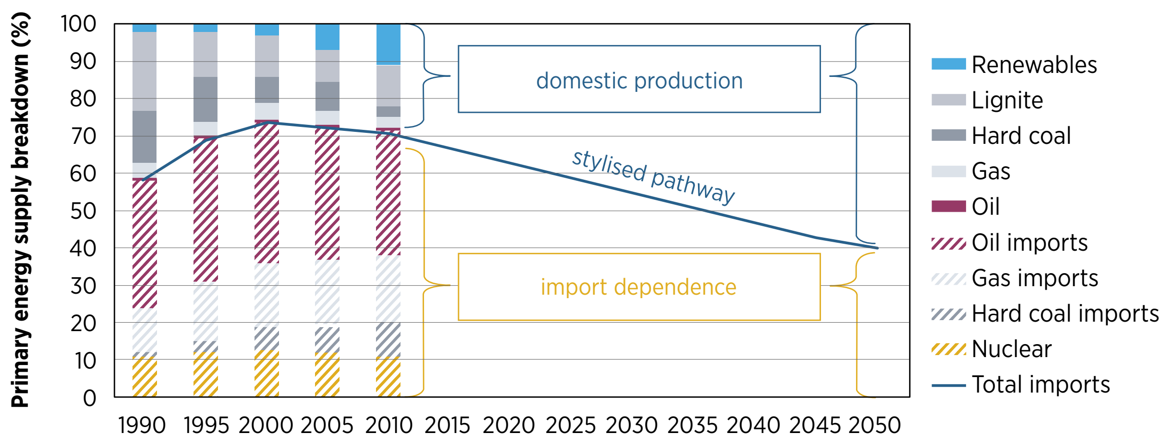
In 1990, almost 60% of the country's primary energy consumption was imported, a share that increased to more than 70% in 2000. Although fossil fuel import shares increase further in the long-run, renewable energy deployment reduces the overall import dependence of energy consumption in Germany (starting after 2000). For fossil fuels, Germany relies primarily on imports (apart from lignite).

Dependence on natural gas imports, together with ambitious greenhouse gas emissions reduction targets and a decision to close down nuclear plants following the Fukushima incident in Japan, have left renewables as the preferred power generation option. Strengthening the security of supply has also been a key driver of the *Energiewende*. Similar discussions are ongoing across many of the Organisation for Economic Cooperation and Development (OECD) countries, and the experience of Germany is often considered.

The production cost of fossil fuels is rising as less-accessible fields are exploited. Global energy demand is expected to increase by one-third by 2035, and, accordingly, demand for fossil fuels (oil, natural gas, coal) is on the rise. As a consequence, global fossil fuel prices may increase further.

Costs for fossil fuel imports in Germany are an increasing burden to the economy. In 2011, these costs reached EUR 85 billion, equivalent to 3.3% of the gross national product, up from 0.8% in 1995. A rise of USD 10 per barrel of crude oil translates into an added EUR 6.5 billion in annual import costs for Germany. Analysis by IRENA has found that fossil fuel import bills in 2013 for Germany were over USD 110 billion for oil and USD

Figure 23: Import dependency as a share of primary energy supply



Source: BMWi, 2013

50 billion for natural gas (IRENA, 2015b). The largest source for imported oil and gas is Russia, followed by the Netherlands and Norway.

Without the *Energiewende*, import costs would be even higher. Germany saved EUR 31 billion in import costs in 2011 (and EUR 36 billion in 2012) due to domestic renewable energy sources (accounting for at least EUR 7 billion of the savings in 2011) and energy savings through energy efficiency measures (IRENA, 2015b).

Renewable energy brings down average dependence on energy imports, as illustrated in Figure 23. The stylised pathway assumes a 60% share of renewable energy in final energy consumption by 2050, the target of the "Energy Concept", all produced domestically (note that assessments usually model some degree of biomass imports). Fossil fuels may also come from domestic production.

The blue and green lines in Figure 23 show that import costs are growing steadily nevertheless. However, renewables and energy efficiency bring the rising line down at least a little (blue line). For a large industrial nation, even EUR 30 billion in savings accounts for only a small reduction. The additional energy savings of 1% per year sums up to a reduction of EUR 2.4 billion per year. So this contribution of energy efficiency would still be double the contribution of renewables of EUR 1.2 billion per year in avoided energy imports between 2007 and 2011.

3.10 *Energiewende* progress and achievements

The monitoring process regularly reviews implementation of the measures contained in the *Energiewende* and progress towards the achievement of its various goals. As mentioned earlier, the *Energiewende* is an evolving process. Continuous monitoring and evaluation of its impacts and costs is key for its long-term success.

Table 5 shows the achievements of the *Energiewende*, based on the first progress report released at the end of 2014 (BMWi, 2014f). The rest of this sub-section summarises the impacts of the policies explained in the sub-section.

Germany's power sector (and its infrastructure) is doing extremely well in terms of renewables. In comparison, the end-use sectors of heating, cooling and transport require significant improvements for further deployment of renewables. The NAPE will accelerate energy efficiency improvements and help Germany reach its climate change goals in the short term. However, energy efficiency alone will not be enough. The gap needs to be closed through faster deployment of renewables in the end-use sectors, and through continuation of efforts in the power generation sector coupled with efforts to ensure an effective and affordable power market.

Table 5: Achievements of the Energiewende to date

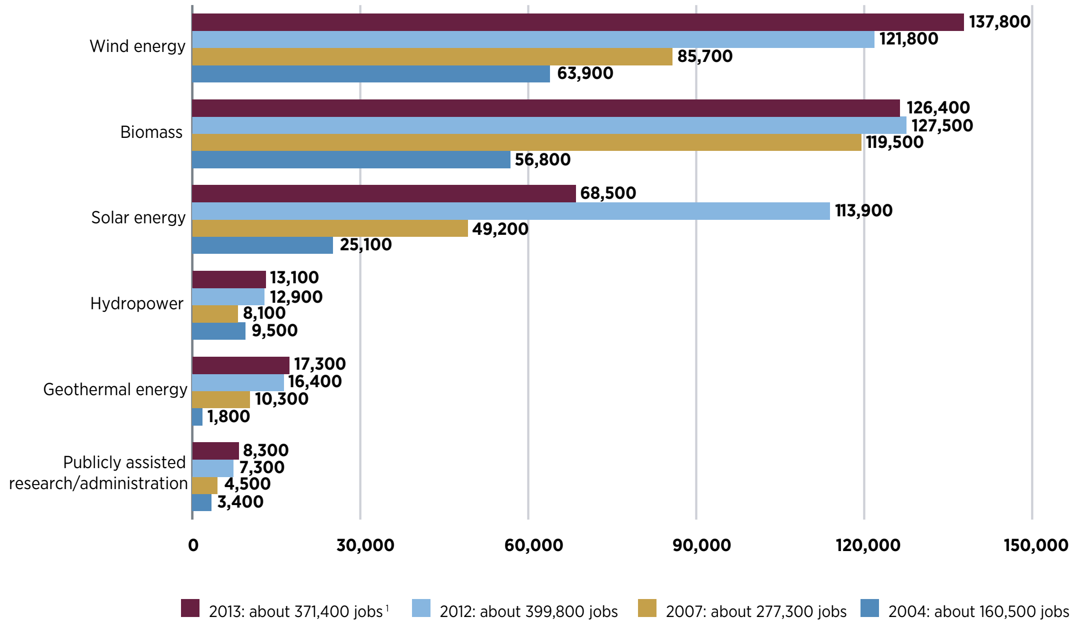
Policy focus	Achievements in 2013/2014
Renewables in power generation	27.4% renewables share in power generation. Well on track.
Grid infrastructure	The quality of the grid system is among the best in the world. It has proved to accommodate a 25% renewables share without any major problems.
Power market design	The "Green Paper" that discussed the next steps in power market design and pricing has been followed by a "White Paper" that suggests "electricity market 2.0", backed up by capacity reserve and continuation of a zonal pricing mechanism.
Renewables in heating/cooling	The renewable energy share dropped to 9.1%. Buildings biomass dominated, but heat pumps are growing. Negligible renewable energy uptake for industrial process heating. Significant efforts are required.
Renewables in transport	The renewable energy share is 5.5%. Liquid biofuel consumption has decreased compared to the mid-2000s and remains stable. EV sales are far below the 1 million target. Significant efforts are required.
Energy efficiency	The 2020 energy efficiency target could be missed if no further action is taken. The NAPE is expected to close the gap, but further measures will need to be implemented.
Climate change	Greenhouse gas emissions increased in 2013 due to higher electricity production from hard coal, to electricity exports and to weather factors. Without action, the 40% target by 2020 will be missed.
Costs	Total FiT subsidy costs dropped and will be reduced further in 2015. In 2017, the country will transition from FiTs to an auctioning system. EUR 16 billion was invested in renewables in 2013/14.
Socio-economic benefits	371 400 jobs in 2013. EUR 9 billion in fuel costs was avoided with renewables.

According to the progress report (BMWi, 2014f), Germany's efforts to increase the use of renewables in the electric power sector are well on track. The total cost of subsidies under the renewable energy incentive scheme dropped for the first time. Accordingly, the renewable energy surcharge itself is to be reduced for the first time.

The progress report also details other important results. These include (BMWi, 2014f):

- Germany has made significant achievements in energy efficiency. In 2014, primary energy consumption declined following a slight increase in 2013.
- Germany is pursuing ambitious climate change mitigation targets. Initial successes already can be observed. However, emissions have been rising again recently, due mainly to more electricity being generated from hard coal, to higher net electricity exports and to weather factors.
- The electricity market is going through a phase of transition. In Germany, the quality of grids is still very high, and the energy supply system is among the most reliable in the world.
- The European markets for energy are meant to converge further. In October 2014, the European Commission agreed on a climate and energy package for 2030. The EU ETS needs to be quickly and sustainably reformed. With its energy transition, Germany is setting a good example.
- The German government is systematically gearing research to its transformation goals for the energy supply system. Energy efficiency and renewable energy sources are priority areas for funding. European co-operation in energy research is gaining in importance. Industry-focused energy research keeps German industry competitive.
- With regard to the macro-economic impact of the *Energiewende*, investment in the context of the transformation of the energy supply system remains high. Renewable energy and energy efficiency are helping to save on fossil primary energy sources. The *Energiewende* is promoting the development and export of innovative energy technologies from Germany. It also is

Figure 24: Employment in Germany´s renewable energy sector



Note: Employment numbers are calculated on the basis of investment in renewable energy plants, the cost of operating these plants, estimates of foreign trade by manufacturers in the industry, estimates of intermediate products and services supplied by companies in the industry as well as industrial intermediate products and services supplied by other sectors. This total is added to employment resulting from public and non-profit funding in this sector, including employees in the public sector (BMWi, 2014b)

strengthening the growth of the German economy and making itself felt on the labour market.

The *Energiewende* has had significant socio-economic impacts. Whereas around 160500 people worked in the renewable energy sector in 2004, this number had risen by a factor of 2.3 to 371400 by 2013, in only nine years (see Figure 24). This includes 230800 jobs related to investments for renewables including exports, 63500 jobs related to O&M, 68800 jobs related to the provision of biofuels and 8300 jobs from publicly funded research/administration. About 261500 of the jobs counted in 2013 were attributable to the Renewable Energy Sources Act. Compared to 2012, total employment from renewable energy sources has decreased by 28400 (UNIDO and GGGI, 2015).

3.11 Future of the *Energiewende*: the German government's plan

The German government reached an agreement on future energy policy for the *Energiewende* in July 2015. The plan reconfirms the commitment to Germany´s national climate targets and aims to ensure that the implementation will be done economically and socially. The key points of the plan include (Gabriel and Baake, 2015):

- Mitigating climate change: The national climate target of cutting carbon emissions 40% by 2020 remains in place. To achieve this, Germany needs to cut an additional 22 million tonnes of CO_2 emissions by 2020, to be attained by a combination of measures including:
  - Lignite power station units with a total capacity of 2.7 GW (or 13% of installed lignite capacity) are to be gradually shifted into a capacity reserve and then closed down after four years.
  - In addition to the capacity reserve, the lignite industry agrees to provide (if necessary) an additional reduction of 1.5 million tonnes of CO_2 a year from 2018. The legal form in which this commitment will be cast has yet to be decided.

- The target attainment in the context of the capacity reserve and the implementation of the commitment by the lignite industry will be reviewed in the context of monitoring in 2018.
- The reform of the CHP Act means that CHP production will contribute a further reduction of 4 million tonnes of CO_2. This reduction will come mainly from the replacement of existing coal-fired CHP installations with natural gas-fired CHP and from moderate funding for new installations.
- The remaining 5.5 million tonnes of CO_2 will be attained from 2016 via efficiency measures in the building sector, in municipalities, in industry and in the railway sector, and will be supported with public funding of up to EUR 1.16 billion a year until 2020 from the Energy and Climate Fund.

- The electricity market and energy security: The "White Paper" sets out the details of the next stage of the electricity market, which aims to guarantee security of supply at the lowest possible costs by a re-design of the power market framework.
- Capacity reserve as additional security: Taking a "belt and braces approach", the capacity reserve safeguards the next stage of the electricity market. After all, security of supply is of key significance for an industrialised country like Germany. Some lignite-fired power plants will be temporarily taken into the reserve before they are closed down. In doing so, Germany will be making an important contribution towards mitigating climate change and will support a socially and economically acceptable process of structural change.
- CHP: Municipal companies are key players in the implementation of Germany's energy reforms. Given the low market prices for electricity, CHP installations find it difficult to pay their way. The government will help existing installations whose economic viability is at risk, promote the conversion from coal-fired to gas-fired CHP, and moderately increase the funding rates for new installations.
- Grid expansion: The expansion of the power grid is the bottleneck holding back the *Energiewende*. Due to public concern about the expansion of new overhead powerlines, underground cables will be given priority over overhead power lines in the case of new direct current (DC) routes. This will not change the fundamental need to build new power lines, particularly from north to south. The reason is that cheap renewables-based electricity from the north also needs to get through to consumers in the south.
- Financial reserves for nuclear power: The energy utilities are responsible for bearing the costs of decommissioning nuclear power plants and disposing of the radioactive waste. To ensure that utilities remain capable of this in future, the German government will carry out a stress test to assess the financial reserves. Furthermore, the government aims to adopt legislation before the end of 2015 to counteract any possible reductions in the assets held to meet liabilities. Finally, a commission to draft recommendations will be set up by the end of November 2015 showing how the funding for dismantling and disposing of the radioactive waste can be secured.

With this plan, Germany´s government will scrap plans to raise emissions charges for older coal-fired power stations. The levy was proposed in March 2015 as a way of pushing power producers into make deeper cuts in carbon emissions and to impose penalties on the oldest and most polluting power plants (Vasagar, 2015).

3.12 Learnings from this section

Policy focus	Achievements
Germany's *Energiewende*	Germany has a long history of energy and climate policy development experience. The level achieved today is advanced and best practice for the world. Germany is leading in renewables deployment for power generation, showing that a 25% renewable energy share can be integrated without major problems, also thanks to the country's strong grid infrastructure.
Costs of *Energiewende*	Germany has contributed greatly to the decrease in costs of solar PV and other renewables. Households are paying an EEG surcharge, whereas the manufacturing industry is exempt from this. Subsidy costs are now going down. There is a transition from FiT to auctioning system.
Market design and electricity pricing	The consultation round of electricity market and pricing design has been completed, with the suggestion being an electricity-only market backed up by capacity reserve. By early 2016 the Electricity Market Act will come in force.
End-use sectors	As opposed to the power sector, renewables in end-use sectors need to accelerate significantly if Germany's long-term climate change and renewable energy targets are to be met.
Energy efficiency	Germany has done a lot to improve its energy efficiency, but more efforts are needed to meet its long-term targets.
Climate change	Germany has set one of the most ambitious long-term greenhouse gas emission reduction targets in the world. There is good progress, but realising the targets will depend on how fast renewables and energy efficiency are deployed in end-use sectors.
Next steps	The *Energiewende* has not ended; it is an evolving and long-term process. A 10-Point Energy Agenda will be implemented to accelerate progress and to continue with the energy transition to realise renewable energy, energy efficiency and climate change goals and to ensure a secure and affordable energy system.

4 A VIEW TO 2030: REFERENCE CASE, REMAP, CHALLENGES AND SOLUTIONS

Key Points

A view to 2030: the Reference Case and REmap 2030

- The Reference Case is based on the recent *Energy Reference Forecasts* report (Prognos, EWI and GWS, 2014) and its "Referenzprognose" case, but it excludes changes in the power sector resulting from the EEG 2014 law. The REmap Options are based largely on the "Target Case" of the above-mentioned report. However, the power sector and part of the end-use-sectors are updated using the BMUB (2015) *Projection Report*, which includes the amendments in EEG 2014. Additional REmap Options analysis for the end-use sectors includes IRENA's own analysis and sources, as well as other external sources.
- Germany is the largest energy consumer in Europe. In 2010 (the base year of this analysis), the country consumed 9.3 EJ of final energy (or 9.5 EJ if net consumption in blast furnaces and coke ovens is included), of which 44% was in buildings, 28% in industry and 28% in transport. Electricity accounted for 21% of TFEC, and 52% was consumed in buildings, 42% in industry and 6% in transport. These shares are based on the bounds of the REmap analysis coverage.
- Germany has increased its renewable energy share in gross electricity generation from 3.1% in 1990 to almost 28% in 2014. At the end of 2014, Germany had 93 GW of renewable energy installed capacity, with around half owned by citizens and farmers. Germany has set renewable electricity consumption goals of 35% by 2020, 50% by 2030 and 80% by 2050. The total renewable energy share in TFEC will increase from 10.5% in 2010 to 27% in 2030 under the Reference Case. Pursuing REmap 2030 will increase the share to as much as 37% in 2030. If only the power sector REmap Options are considered, the renewable energy share would reach 30% (Germany's target for that year); the additional REmap Options in the end-use sector and district heat increase the share further to as much as 37% – however with additional costs.
- If measured in terms of GFEC, the renewable energy share will increase slightly less compared to TFEC, to just 26.9% in the Reference Case and 36.8% in REmap 2030.
- The results of the Reference Case show a significant increase in renewable energy between 2010 and 2030. Renewable power generation leads this trend, reaching 52% of gross generation by 2030 and 71% of power generation capacity. Pursuing REmap 2030 will increase this share to 65% of gross power generation. Electricity's share of TFEC will increase from 20% in 2010 to 23% in the Reference Case, and to 25% in REmap 2030.
- Renewables will become the largest source of primary energy in REmap, but they will still lag behind fossil fuels when aggregated.

The role of all sectors

- The end-use sectors see gains in the Reference Case, but more significant gains in REmap 2030, highlighting the importance of increasing renewable energy use in end-use sectors and the district heating sector. Power technologies make up 54% of the additions in renewable energy use in the Reference Case; however, this changes in the REmap Options, where end-use and district heat make up 65% of the increase in renewable energy additions.
- Solar energy increases from 6% to around 15% of total renewable energy use by 2030 in REmap, half from solar PV and half from solar thermal. Wind is the largest source of power generation, but bioenergy remains

the largest contributor in total renewable energy use, followed by wind, solar, geothermal (including ambient energy) and hydro.

- Important technology options identified in the industry sector include increased use of solar thermal and heat pumps for the production of low-temperature process heat.
- The building sector sees increases in solar thermal for water and space heating, in air-to-air and geothermal heat pumps, and in communal heating sourced from geothermal heat-pumps and solar thermal.
- The transport sector sees increases in biofuel, mainly biodiesel but also a limited amount of advanced ethanol and biogas.
- Significant increases are seen electric mobility in REmap, with over 6 million vehicles on the road by 2030; this includes around electric vehicles, but also significant numbers of electric two-wheelers and some light-freight vehicles.

Costs and benefits

- The REmap Options result in an incremental system cost of around USD 4 billion annually by 2030. However, benefits resulting from reduced heath costs will total USD 1-2 billion per year, and benefits from CO_2 reduction amount to USD 2-8 billion per year. The resulting effect on the economy as a whole could be between USD +1 in additional cost or up to -6 billion in annual savings by 2030 depending on how these benefits are valued.
- Investments in renewable energy will increase from USD 8.8 billion per year in the Reference Case to USD 15.7 billion per year in REmap 2030, an increase of USD 6.9 billion per year in renewable energy investments.
- The REmap Options will require an incremental subsidy need of USD 0.8 billion in 2030, which would be on top of existing renewable subsidies in the Reference Case. Because REmap considers many emerging technologies, particularly those used in the end-use heating and transport sectors, subsidies are necessary to support technological learning and deployment.
- Energy-related CO_2 emissions based on the REmap sector coverage will decline from around 789 million tonnes in 2010, to 540 million tones in the Reference Case, and further to 439 million tonnes in REmap – a reduction of 19% over the Reference Case, 44% over 2010 and 55% over 1990.
- Energy intensity will decrease from over USD 4 per megajoule (MJ) in 2010 to USD 2.5 per MJ in REmap 2030, equalling a 2.5% annual improvement rate in the 2010-2030 period.

Challenges and the essential role of the end-use sectors

- Challenges to achieving the REmap deployment levels include important implications for integrating higher shares of variable renewable energy through power market design and grid integration, and the role that storage will play.
- Heating energy demand is critical; however, low building stock turnover and slow renovation rates can limit the needed uptake in both energy efficiency improvements and renewable heating systems. Coupling renewable systems with renovation and district energy systems will be key.
- The transport sector will see higher growth in electric mobility, but a dual focus on supporting vehicle ownership and complementary infrastructure is necessary. A view beyond the passenger vehicle segment is also necessary to see how trucks and public buses can benefit from electric mobility.
- Bioenergy supply and sustainability poses another challenge due to the unknown path for the development of advanced biofuels.
- The industry sector presents difficulties due to the demand for process heat, but important options exist that include deploying state-of-the-art biomass CHP and the potential for low-temperature solar thermal and heat pumps. However, support for these technologies is needed.

This section discusses findings relating to energy use developments to 2030 based on the Reference Case and REmap 2030. It provides an overview of findings at the sectoral and technology levels, of costs and benefits, and of the roles of renewable energy and energy efficiency. Section 3 outlined in-depth the *Energiewende* up until today, discussing the current energy situation in Germany, progress in recent years, policies by sector and areas where the *Energiewende* can still be expanded. This section provides an overview of energy system developments in Germany to 2030 based on two cases: a Reference Case based on business-as-usual assumptions, and an accelerated renewables case called REmap 2030. Annexes A, E and F provide details on the sources for the base year, Reference Case and REmap Options, as well as the assumptions and background data.

4.1 Reference Case to 2030

Box 3: The dynamics of the Reference Case to 2030

Germany is unique among most countries in that it already has very ambitious renewable energy and energy efficiency efforts, as well as greenhouse gas emission reduction targets. In this analysis, determining what could be considered a Reference Case for 2030 is difficult because the *Energiewende* is an evolving process, under constant deliberation by political parties both within Germany and between its neighbours and the EU, and influenced by advances in technology and other industry interests. Major changes to the main law governing the energy transition, the EEG, in 2010 and 2014, and upcoming changes proposed in the "electricity market 2.0", have important effects on what is considered the Reference Case and a Target Case in 2030.

This analysis has used primarily two sources for energy demand and supply in 2030 (Prognos, EWI and GWS, 2014; BMUB, 2015), but it also has complemented the analysis with other sources. For this reason, the Reference Case best represents the most likely development based on policy and market dynamics as of 2014, and REmap 2030 reflects changes agreed through mid-2015, with additional renewable energy deployment based on IRENA and other analysis.

The Reference Case represents the business-as-usual developments in energy efficiency and renewables (see box 3). Whereas for many countries "business as usual" assumes little change in the energy system supply structure, Germany has aggressively instituted policies aimed at a rapid increase in renewable energy. The results of the Reference Case show a significant increase in renewable energy between 2010 (the base year of this analysis[8]) and 2030 (see Figure 25). Renewable power generation leads this trend, reaching 51% of gross electricity generation by 2030 and 71% of net power system capacity. In the end-use sectors, the highest share of renewables is reached in the building sector, which sees an increase from 14% in 2010 to 36% in 2030. Industry's share reaches 22% in 2030, and the transport sector achieves just over a doubling, at 12% renewables by 2030. In the total energy system, renewable energy as a share of TFEC increases from 10.5% in 2010 to 27% in 2030.

The largest driver for this renewables shift is a significant uptake in the amount of renewable power generation. Combined with the phase-out of nuclear power and lower coal-fired power generation, the share of renewable power generation increases significantly from 17% in 2010, and around 28% in 2014, to 51% by 2030.

Figure 26 shows the development of electricity generation to 2030 under the Reference Case. Total power generation declines from 630 TWh per year to 600 TWh per year, with exports to neighbouring European countries increasing from 18 TWh per year to 44 TWh per year (from 2.9% of total generation in 2010 to 7.3%

8 The REmap analysis uses 2010 as the base year for all country analyses and benchmarks progress based on this year. The choice of 2010 was made to adhere to the SE4ALL methodology and to allow tracking for country development over the 20-year (2010 to 2030) time frame. As discussed in previous sections, Germany has made significant progress since 2010, but for consistency with REmap and SE4ALL, this section compares results to 2010 and provides some more recent year values to detail progress.

Figure 25: Reference Case developments, 2010-2030

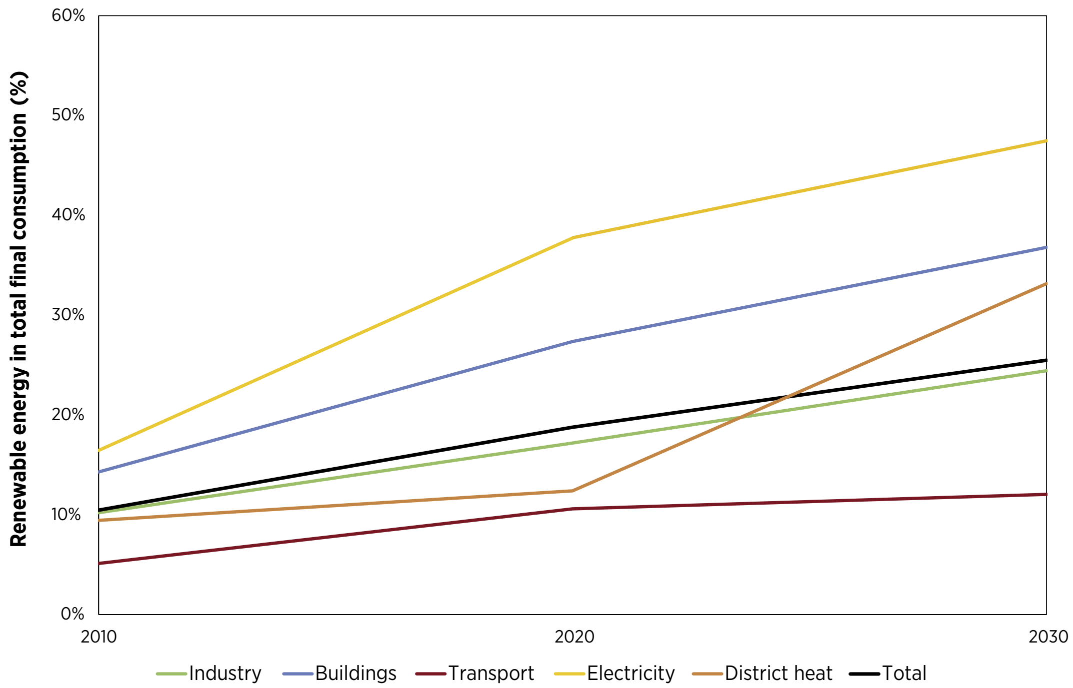
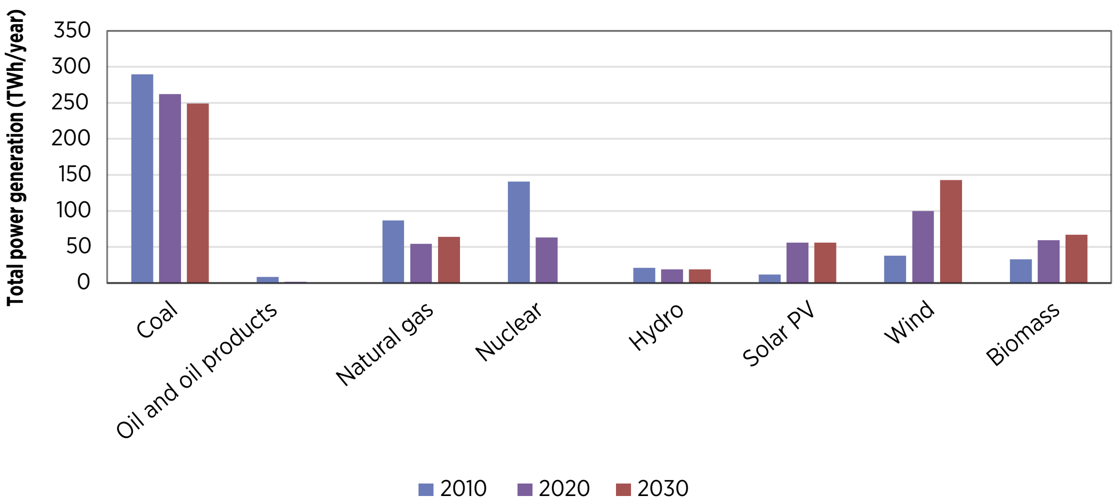


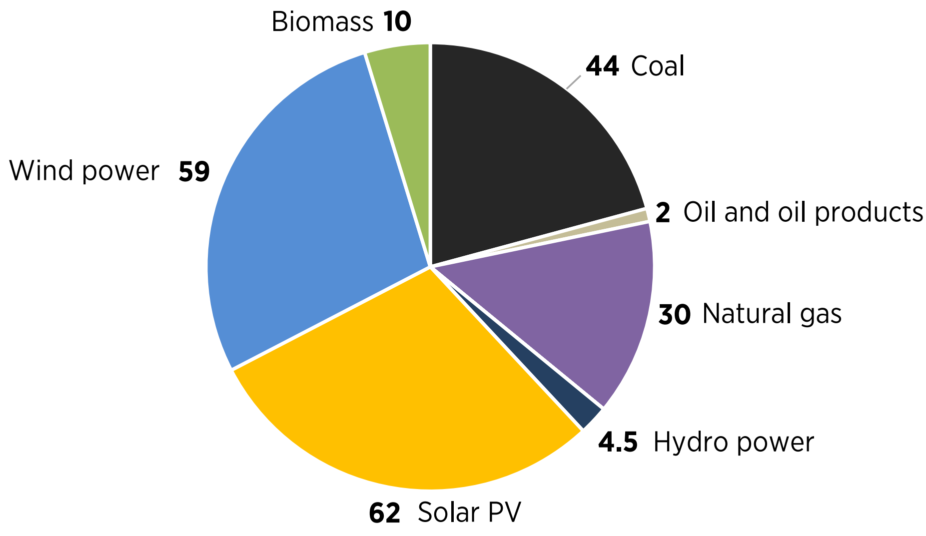
Figure 26: Reference Case power generation developments, 2010-2030



in 2030). All fossil and nuclear sources decline, with the decline in nuclear power the most pronounced (a reduction of 141 TWh per year), followed by coal (41 TWh per year), natural gas (15 TWh per year) and oil (8 TWh per year). Coal still produces 249 TWh per year in 2030, the largest contributor to total power generation, followed by natural gas at 72 TWh per year. Nuclear power is entirely phased out by 2030, and oil-based power contributes less than 1 TWh per year by then.

Renewable energy makes up for the declines in conventional generation. Wind power production leads with an

Figure 27: Breakdown of total power generation capacity in 2030 Reference Case



increase of 105 TWh per year to total 143 TWh per year in 2030. Solar PV production increases by 44 TWh per year to total 56 TWh per year, and biomass production (including CHP) increases by 27 TWh per year to total 60 TWh per year. Because the domestic hydropower resource is fully utilised, there is no growth in hydropower generation. Geothermal and concentrated solar power (CSP) are not expected to provide any measurable production.

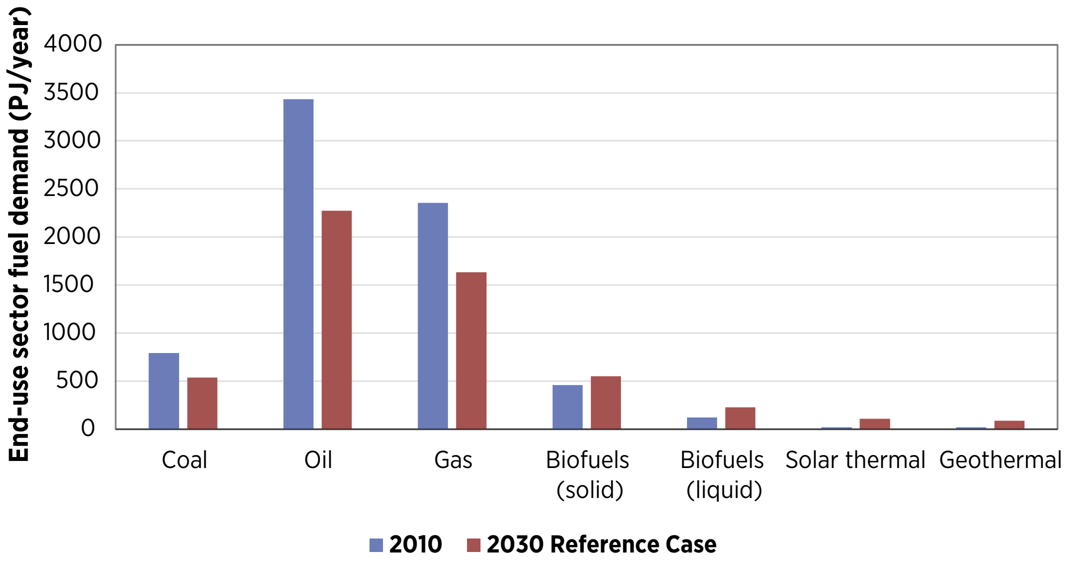
Total system power capacity increases alongside the share of renewable power due to the lower capacity factors (full load hours) of renewable technologies. In 2010, Germany had around 155 GW of power system capacity; by 2030 this will increase to 215 GW. Over 70% of the power system capacity will be renewable, with the largest single source being solar PV with 62 GW, followed by wind with 59 GW, coal with 44 GW, natural gas with 30 GW, biomass with 7 GW and hydro with 5 GW (see Figure 27).

The share of electricity consumption in TFEC will increase over the 2010-2030 period. In 2010, 20% of final energy consumed was electricity; this will increase to 23% in 2030 in the Reference Case. All end-use sectors see increases in electricity use as a share of their TFEC: in the industry sector from 28% in 2010 to 32% in 2030; in the building sector from 25% to 30%; and in transport from 2% to 4%.

In the end-use sectors, renewable energy use sees modest gains while fossil fuel use sees significant declines (Figure 28). As energy efficiency improvement reduces fuel use in the building sector, and as high vehicle fuel consumption standards reduce transport fuel demand, all fossil fuels see decreases. End-use fuel use, when excluding electricity and district heat, declines from 7.2 EJ per year in 2010 to 5.5 EJ per year by 2030. Oil use, largely in transport, declines by over 1 EJ per year during the period, and natural gas declines by 0.7 EJ per year, with most of the reduction in the building sector.

Renewables buck these trends, and all renewable sources see increases. In the building sector, which achieves the highest renewable energy share of any end-use sector at 28% (excluding electricity and district heat), heat derived from renewable heat pumps (geothermal, air-to-air) increases from 19 PJ per year to 86 PJ per year by 2030. Solar thermal use for water and/or building heating increases from 18 PJ per year to 106 PJ per year, while biomass-based heat increases more modestly from 318 PJ per year to 375 PJ per year, but still makes up the largest renewable energy source in the building sector. Fossil fuels still provide the majority of the energy supplied for heating, with 826 PJ per year of natural gas consumed, followed by 360 PJ per year of oil products such as heating oil, and limited amounts of coal at around 20 PJ per year.

Figure 28: Energy use in end-use sectors, excluding electricity, 2010-2030



In the transport sector, the use fossil fuels still dominates, with over 1 800 PJ per year of diesel and petrol consumed. By contrast, the use of biofuels, mostly biodiesel, sees almost a doubling from 121 PJ per year to 228 PJ per year, supplying around 11% of sector fuel demand. The sustainability and sourcing of biofuels is important. Some of the biomass supply challenges and land-use needs are addressed later in this section.

In the manufacturing industry, the use of biomass for heating, including process heat applications, increases from 140 PJ per year to 174 PJ per year. Industry achieves a renewable fuels share of only just over 10%. Natural gas is the largest source of energy, at 720 PJ per year, followed by coal at 430 PJ per year.

The district heating sector plays an important role in Germany. District heat is produced and used in cities and towns primarily for heating, but it also provides industry with a source of low-temperature process heat. In the industry sector, around 6% of the total final energy demand is supplied via district heating, while the share is higher in the building sector at around 8%. These shares are expected to remain flat over the 2010-2030 time frame, meaning that demand for district heating follows the overall trend in Germany's TFEC. Germany aims to increase the share of renewables in district heating from 10% (in 2011) to 14% by 2020. Plants for the production of district heat can include CHP but also heat-only plants. Total district heat consumption comprises around two-thirds of total generation. Natural gas will provide over one-third of production, followed by coal. Biomass CHP will increase to over one-fifth of total district heating generation in 2030.

4.2 REmap 2030

The Reference Case presented in this report represents Germany's plans as of mid-2014. Since that time, however, the German government has made some adaptations to the *Energiewende*. Importantly, the EEG was reformed in 2014, and the rates of onshore and offshore wind and solar PV deployment were adjusted. These changes are reflected in the REmap 2030 case, and REmap Options are considered based on additional studies and IRENA analysis.

In REmap 2030, TFEC will decrease by around 100 PJ per year over the Reference Case, from 7.7 EJ to 7.6 EJ per year in 2030. This decrease is the result of the deployment of electricity-based technologies – such as heat pumps and electric vehicles – in the end-use sectors. These technologies have 2-4 times the efficiency of a combustion technology typically used to deliver the same energy service. The renewable energy share in TFEC will increase even further, to almost 37% in REmap 2030. This is 7 percentage points higher than the 30% goal set by Germany for 2030. This higher share is driven by the higher uptake of renewable technologies in end-use sectors. Additional deployment of renewable power technologies plays a rather limited role (mainly small additions to meet possible new electricity demand from end-use sector electrification technologies such as heat pumps and electric mobility).

Gross electricity generation in 2030 will increase by 25 TWh per year compared to the Reference Case, explained by the additional electricity demand for heat pumps, electric vehicles, etc. The power generation sector achieves a 65% renewable energy share in REmap 2030, far exceeding the German minimum target of 50%. However, the largest increases from REmap Options are seen in end-use applications for heating, cooling and transport fuel. The use of renewables to provide heating in buildings and industry doubles over 2010 levels and increases 30% over the Reference Case. In total, almost 1.2 EJ of renewable energy for heating would be used in REmap 2030, including district heat use generated from biomass and heat-pumps. In the transport sector, the use of liquid biofuels increases from 228 PJ per year to 373 PJ per year in REmap 2030. A general overview of the results of REmap compared to the various German targets is shown in Table 6.

Additional renewable energy potentials

Germany has considerable renewable energy potential that is not fully utilised by 2030. This sub-section provides an overview of some of the renewable sources that are considered as additional potential beyond the Reference Case. It details both power and end-use technologies in terms of their potential; the following sub-section discusses the costs of deploying these technologies.

Wind

Wind is projected to become the single largest renewable power generation source in Germany in REmap 2030. Total wind capacity will reach almost 90 GW, of which 16.5 GW is offshore wind plants. The capacity in

Table 6: Short-, medium- and long-term targets of Germany Energiewende, and REmap results

	2011	2012	2013	2014	2020	2030	2030	2040	2050
	Achievements				German target		REmap results	German target	
Greenhouse gas emissions									
Greenhouse gas emissions (base year = 1990)	-25.6%	-24.7%	-24.1%	-27.0%	min. -40%	min. -55%	-55%[1]	min. -70%	min. -80-95%
Renewable energy									
Share of renewable electricity	20.4%	23.7%	25.4%	27.4%	min. 35%	min. 55%	65%	min. 65%	min. 80%
Share of renewable energy in gross final energy	11.8%	12.8%	13.1%	13.5%	18%	30%	37%	45%	60%
Energy efficiency									
Primary energy demand (base year = 2008)	-5.4%	-6.5%	-7.3%	-8.6%	-20%		-30%[2]		-50%
Power demand (base year = 2008)	-1.8%	-1.8%	-2.4%	-4.6%	-10%		-[3]		-25%
Electricity share from CHP	17.7%	18.0%	17.8%	17.3%	25%		21%		
Energy productivity improvement rate	1.7%	1.2%	1.4%	1.6%	2.1%		2.5%		
Time frame	2008-2011	2008-2012	2008-2013	2008-2014	2008-2050		2010-2030		

1 REmap sector coverage does not include all CO_2 emissions and CO_2 equivalents; see sub-section "CO_2 emission developments"

2 Base year = 2010

3 Due to electrification in end use sectors, decline in power demand is reduced but remains negative.

Source: BMWi, 2014b; Agora, 2015b; IRENA analysis

REmap is consistent with recent market developments and the reformed EEG 2014. By contrast, the Reference Case of the *Energy Reference Forecasts* (Prognos, EWI and GWS, 2014) estimates a total onshore wind capacity of 48 GW by 2030, only 9 GW higher than the 39 GW of total installed capacity in mid-2015 (DWG, 2015). This would imply a yearly installation rate of just 0.7 GW. In 2014, the reformed EEG adjusted the rate of deployment for onshore wind to around 2.5 GW per year, following the recent historical trend of around 2 GW per year. In REmap 2030, this deployment level is maintained and 72.3 GW of onshore wind is deployed by 2030.

Offshore wind is being discussed intensively in Germany. In 2014, there were three times as many wind turbines operating in the North Sea (67 turbines) as in the Baltic Sea (22 turbines). In total around 90 turbines were in place, operating with a capacity of roughly 385 MW. More than four times as many turbines were already under construction as of mid-2015 or were ready to be connected to the German power grid in 2015. By the end of 2015, around 3.2 GW of capacity was expected to be online.

In addition, a large number of projects are under development for the coming years. In recent years, debate has begun to question the planning for offshore sites given the transmission infrastructure needed to deliver electricity to areas in the south of Germany. As a result, the potential of onshore areas with lower wind speed or forests with turbines utilising higher hub heights is being discussed.

Germany has a 2020 target of 6.5 GW of offshore wind by 2020 and 15 GW by 2030. The Reference Case assumes that only 11 GW is deployed by 2030, and REmap 2030 assumes the target of 15 GW and exceeds it slightly for a total of 16.5 GW.

The technical offshore wind potential is very high, with an estimated capacity of 70 GW or 280 TWh a year (assuming 4 000 full load hours a year). This represents about 46% of Germany's 2014 total electricity demand. This technical potential, however, is not considered to be fully sustainable.

Solar PV

Total installed solar PV capacity has grown rapidly from 2 GW in 2005 to 17 GW in 2010, 24.8 GW In 2011 and around 35 GW in 2014. Projected capacity for 2030, under the Reference Case, is 62 GW, suggesting a doubling between now and 2030. REmap 2030 assumes limited additional growth in grid-connected solar PV, as the EEG 2014 reduced the corridor of growth and stops support to grid-connected PV with premium payments and interconnection. However, additional deployment will be seen as PV systems coupled with batteries become a mainstream option for households and businesses. In REmap 2030, 11 GW of solar home systems that include various forms of battery storage will be installed. In total, 75 GW of solar PV will be in operation in REmap 2030, encompassing utility and rooftop applications. Solar PV will become the second largest source of renewable electricity generation behind wind energy.

Solar thermal

Recent policies have targeted solar thermal technology, seeking to increase the use of solar thermal heat for buildings and water. In the Reference Case according to the *Energy Reference Forecasts*, there is a fivefold increase in solar thermal heat in the building sector, to 106 PJ by 2030. Many studies have explored the potential for much higher deployment of solar thermal in the home building segment. One study identified the potential of solar thermal space and water heating to supply 15-35% of yearly energy demand in single-family homes (Wüstenrot, 2014). The study identified over 200 PJ of solar thermal potential that can substitute fossil fuel heating. Single-family buildings are particularly apt for solar thermal systems because heating energy makes up the largest share of their energy needs, and roof area and storage is available for the necessary modules.

REmap assumes an additional 56 PJ per year of solar thermal heating supply in the building sector, with two-thirds going to heating and one-third to water heating. The result is 164 PJ of solar thermal heat, with just under 6% of the building sector's energy demand met through solar thermal systems.

Additionally, some district heating systems can be coupled with solar thermal to provide a share of their heating. In REmap 2030, a small quantity (2 PJ per year) of solar thermal heat is delivered via these district systems. This analysis is supported by literature that shows small contributions of solar thermal heat provided in district energy systems by 2030 (Schumacher, 2015).

Potential also exists in the industry sector, where solar thermal can provide low-temperature (up to 150 °C) process heating, particularly for the food processing (breweries), some chemicals, machinery and equipment manufacturing sub-sectors. REmap 2030 assumes the addition of 25 PJ per year of solar thermal heat, meeting around 2% of the industry sector's energy demand (less than half of the technical potential of approximately 60 PJ, which also include processes operating at temperature levels of 150-300 °C) (Lauterbach, 2014).

Biomass

Biomass is the largest renewable energy source in Germany's energy mix because of its ability to provide electricity, heat and biofuels. Biomass, including solid and gaseous resources, is used in the building sector to provide space heating and is used in industry for low-, medium- and high-temperature process heat, mostly when part of a CHP system, as well as for district heating. By 2030, bioenergy is estimated to supply 688 PJ of heat, a more than one-quarter increase over 2010 (502 PJ). Most will continue to be consumed in buildings, followed by the industry sector and district heat. REmap 2030 assumes a slight increase in bioenergy use in building heating applications in the form of pellets, and in district heat resulting largely from better utilisation of wastes and residues. No additional biomass is consumed in the industry or power sectors, as these sectors already have reached their full potential.

In the transport sector, liquid biofuels are projected to grow from 228 PJ to 373 PJ, according to the Target Case of the *Energy Reference Forecasts*. Most of this increase is seen in the form of biodiesel for road vehicles, but the second largest addition will come from a new advanced biofuel: biokerosene for the aviation sector. In total, biodiesel use increases from 157 PJ per year to 292 PJ per year. Conventional ethanol sees no growth and supplies around 22 PJ per year by 2030. A small amount of advanced ethanol is produced, with the addition of around 5 PJ; because around 45 PJ per year is already assumed in the 2030 Reference Case, total advanced ethanol use thus will total around 50 PJ per year in REmap 2030, twice as high as its conventional forms.

Today biogas is used in the transport sectors of Sweden, Germany and Iceland. Although its contribution in Germany is small, estimated at 1.5 PJ in 2012, additional potential exists. Use of biogas in transport will increase to 2.3 PJ per year in 2030 In the Reference Case and to 7.5 PJ per year in REmap 2030 – significant growth over 2010 levels but still small compared to the transport sector's total energy demand.

Total biomass supply potential for Germany is assumed largely exploited by 2030. On a primary level, IRENA has estimated the supply to be between 1.6 EJ and 2.3 EJ per year. In REmap 2030, primary bioenergy demand reaches 1.5-2.0 EJ, constituting full utilisation of the median estimate of supply potential. The REmap study does not assume any imports of biomass.

Heat pumps

Heat pumps are an important enabling technology that can provide heating and cooling using local environmental (ambient) energy, either in the form of geothermal, aerothermal or hydrothermal sources. The technologies are highly efficient and, when powered by an increasingly clean and renewable power system, offer significant environmental benefits. In the Reference Case, heat pump use in the building sector increases fourfold, from 19 PJ to 86 PJ per year of delivered heat. In REmap 2030, additional potential is deployed in buildings to bring this total to 114 PJ per year. Importantly, heat pumps also are assumed to be deployed in small quantities in the industry sector to provide around 22 PJ per year of low-temperature heat, as well as in district and communal heating systems to provide 84 PJ per year of heat.

Other

The transport sector is experiencing a shift to hybrid- and full-electric vehicles. Although sales in Germany have been sluggish (see section 3), the government and industry have plans to accelerate uptake. The Reference Case assumes very little deployment, with just around 11 PJ of additional electricity needed for EVs (around 1 million vehicles). REmap 2030 assumes significant acceleration of various types of battery-electric and plug-in hybrid vehicles (see Table 7), which requires an additional 39 PJ of electricity demand (Anonymous, 2015). Overall, REmap 2030 assumes an additional 1.8 million passenger vehicles (60% of which are battery-electric) for a total of around 2.8 million in 2030. Light-freight electric vehicles see significant growth, to around 100 000 units, and an important emerging segment of battery-electric two-wheelers (mostly e-bikes)

Table 7: Electric vehicle deployment in REmap 2030

	2010	Reference Case	REmap 2030
Electricity demand in transport sector (PJ/yr)	60	82	93
Electricity demand from plug-in hybrid / electric vehicles (PJ/yr)	<1	11	50
Plug-in hybrid / electric vehicles on road (million units)	<0.01	1	6.53
Plug-in hybrid passenger road vehicles (million units)		0.2	1.72
Plug-in hybrid light-freight road vehicles (million units)		0.02	0.05
Battery-electric passenger road vehicles (million units)		0.6	1.86
Battery-electric light-freight road vehicles (million units)			0.04
Battery-electric two-wheeler passenger road vehicles (million units)		0.1	2.86

could see as many as 2+ million active units in Germany by 2030.

A determination of vehicle numbers depends on electricity consumption per passenger or freight kilometre and on the average year activity in kilometres per vehicle. The EV technologies are based on projections for Germany (DLR, 2011). These numbers could vary due to changes in technology and the efficiency or unit activity of vehicles, as well as changes resulting from the relative breakdown of the share of plug-in hybrid versus battery-electric, or of small battery-electric versus two-wheelers, or freight vehicles.

4.3 Energy system findings

The breakdown of renewable energy use by source and sector for the 2010 base year, Reference Case and REmap 2030 are shown in Figure 29. Renewable energy use will double in absolute terms from 2010 to 2030 in the Reference Case, reaching 2 045 PJ in 2030. However, because of an overall decline in TFEC during the period, the renewable energy share will more than double. In REmap 2030, total renewable energy use increases even further to reach 2 776 PJ.

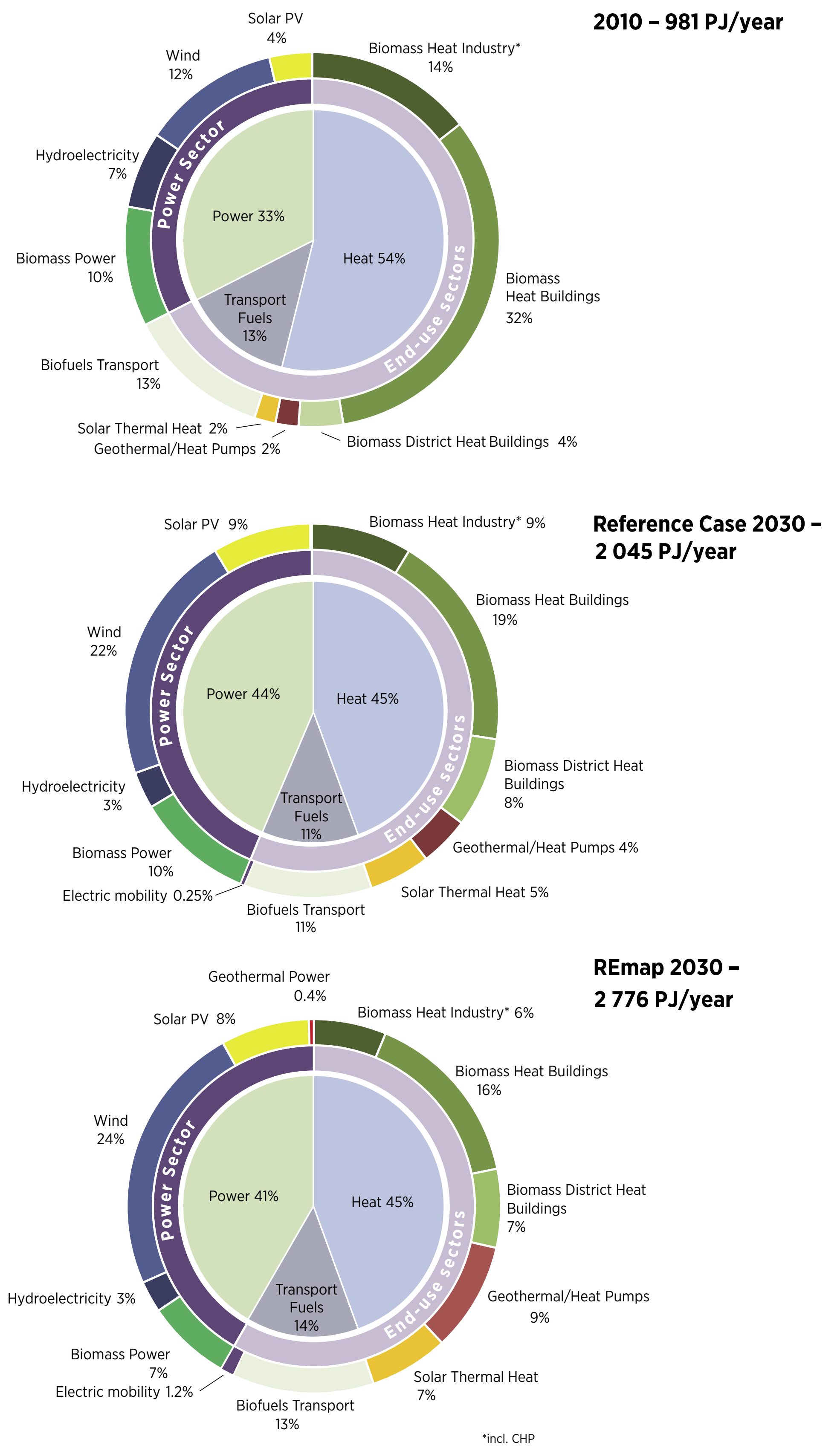
In the power sector, the continued importance of wind energy is evident, as it alone makes up almost one-quarter of all renewable energy in REmap 2030. Solar PV also grows considerably, doubling its share of renewable energy use. Wind and solar PV combined move from comprising 16% of total renewable energy use, and half of renewable power, to comprising a third of the total.

Bioenergy is reduced from comprising just under three-quarters of renewable energy use in 2010 to comprising half of renewable energy use by 2030, but it still remains the largest renewable energy source due to its ability to be used as fuel for power and heat generation as well as for transportation. Despite this decline in share, total bioenergy demand will increase because the absolute amount of renewable energy increases 2.75 fold over the period. Other sources of renewable heat include strong growth in solar thermal, increasing from 2% to 7% of the renewable contribution, and an increase in geothermal and ambient sources of heat (largely heat pumps) in the building and district heating sectors, with their contribution increasing from 2% in 2010 to 4% in the Reference Case, and then further to 7% in REmap 2030.

Figure 30 shows the total contributions of each renewable energy resource in final energy by source and also provides perspective on the additions found in the Reference Case and REmap Options. In REmap 2030, biomass is followed by wind, solar, geothermal (including ambient energy) and hydro. However, significant change is noticed over 2010, where bioenergy provided around double the renewable energy use of all other renewable sources combined. In REmap 2030, non-bioenergy sources will exceed the contribution provided by bioenergy. Importantly, wind, solar and geothermal/ambient energy show the greatest relative growth over 2010.

Figure 30 also presents the contributions in terms of final energy. Electricity produced by a source is attributed to a general category that also may include final energy supplied for heating or transport fuels. The

Figure 29: Renewable energy overview: share of renewable energy by source, 2010-2030



Note: Electric mobility and heat pumps shows share of renewable electricity consumed by these technologies.

Figure 30: Renewable energy additions in total final energy consumption by resource, 2010-2030

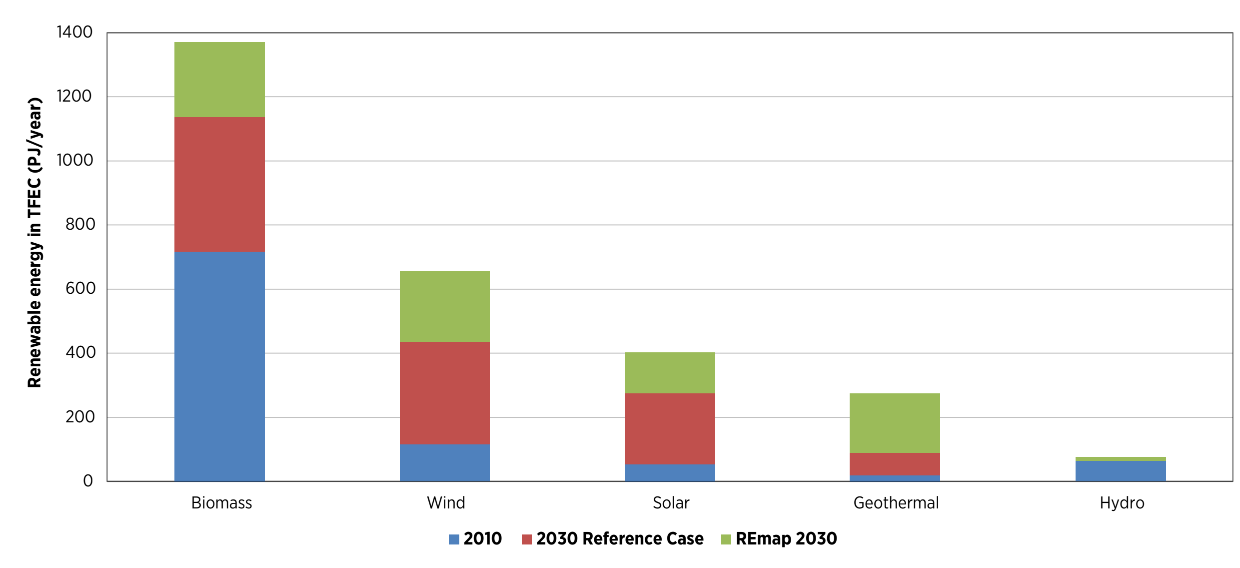
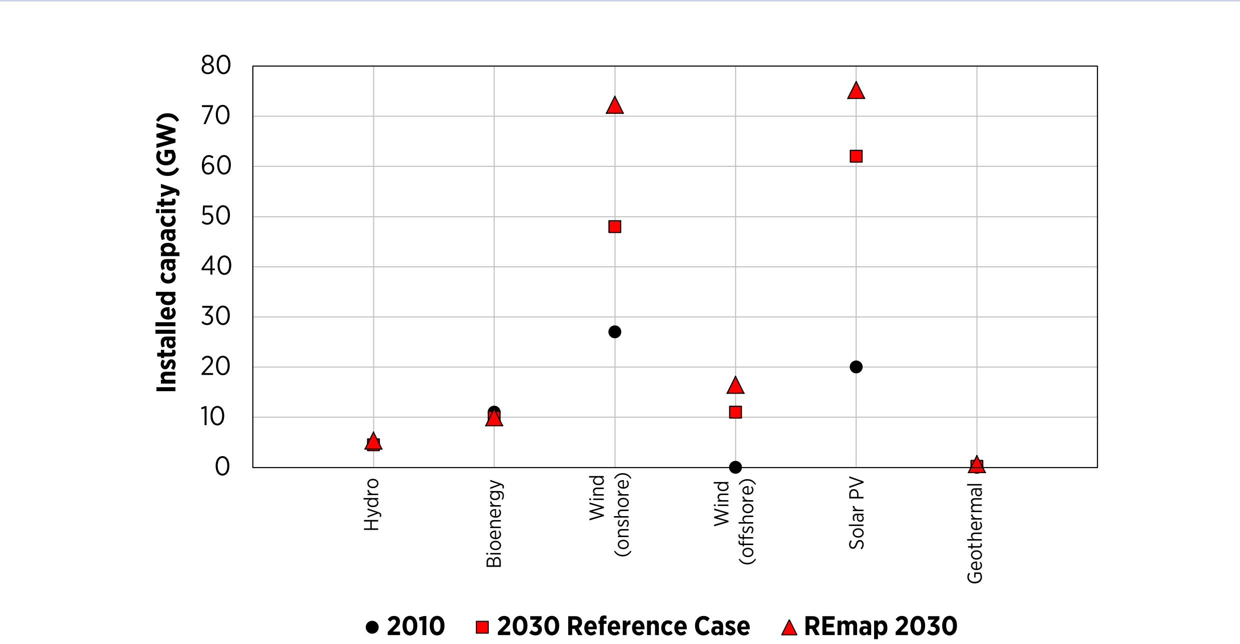


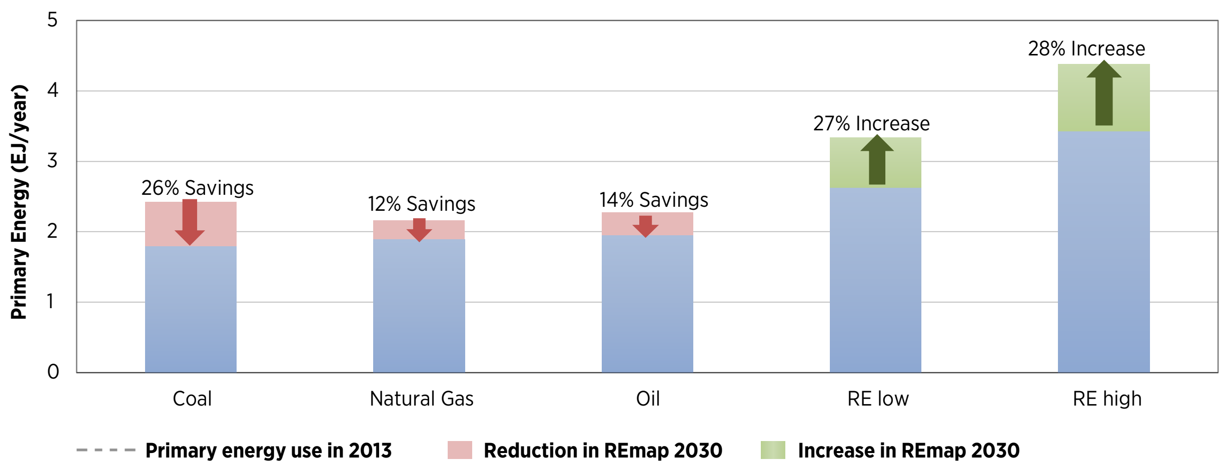
Figure 31: Renewable power capacity in 2010, the 2030 Reference Case and REmap 2030



electricity contribution adjusts for own-use and transmission and distribution losses, and then allocates the electricity consumed to the renewable energy source of production. Because the share of electricity in final energy in Germany reaches only 25% by 2030, presenting contributions of resources in final energy terms emphasises the use of fuels for heating and transport applications, which make up 75% of final energy.

Power sector technologies play an important role in both the Reference Case and REmap Options, and figure 31 shows how power capacity develops to 2030. The Reference Case sees significant growth in renewable power technologies, mainly in onshore and offshore wind and solar PV. Section 4.2 on "additional renewable energy potentials" detailed the additions found in REmap in gigawatt terms, but the figure shows where

Figure 32: Effects of REmap Options on primary energy in 2030



additional potential still exists between the Reference Case and REmap Options.

The potential is explained in part by the reform of the EEG in 2014, which revised upwards offshore and onshore developments. The EEG revision also reduced the amount of grid-connected solar PV in 2030, so this lower amount was assumed for the Reference Case. The additions that were expected in the *Energy Reference Forecasts* due to improving market developments were assumed to be deployed, but mostly in home or community systems that promote own-use of produced electricity, often enabled by local electricity storage. This trend is starting to be seen in Germany, with the numbers of solar home systems with storage installed increasing significantly in 2015.

REmap measures energy use on a final level in order to be consistent with the methodology of SE4All. However, it is important to understand the effect of the REmap Options on primary energy, which allows for an understanding of primary-level fuel use and CO_2 emissions. Based on primary energy use, the REmap Options result in significant fuel savings (see Figure 32). Reductions in total coal use amount to 26%, followed by a 14% reduction in oil and a 12% reduction in natural gas (see Table 10 for import cost effects). Renewable energy becomes the single largest primary energy source according to both the low and high renewables calculation methodologies[9], increasing 27-28% over the Reference Case.

Table 8 illustrates how all renewable energy use increases between 2010, the Reference Case and REmap 2030. It also shows how the renewable energy shares develop over time, and presents shares according to both TFEC and the EU's gross final energy consumption.

The table indicates significant increases in renewable power technologies over the period. However, it also provides a perspective on growth in renewable energy use in the heating and transport sectors. In addition, the REmap Options column provides a perspective on where additional potential for renewable energy exists between the Reference Case and REmap 2030. The largest additional potential for power technologies are in wind and solar, but important additional potential exists in the end-use sectors, specifically for solar thermal heat, district energy systems, heat pumps and advanced biofuels. The following sub-section discusses the increasing importance of renewable technologies used in the end-use sectors and details some of these technologies.

9 The "high" renewable energy calculation uses the U.S. Energy Information Administration's partial substitution method, whereas the "low" calculation uses the IEA's physical energy content method. These do not represent different cases, or levels of renewable energy consumption, but rather differences in converting renewable electricity and heat into primary equivalents.

Table 8: REmap 2030 overview

		Unit	2010	Reference Case 2030	REmap 2030	REmap Options (change between Reference Case and REmap 2030)
1. Electricity						
Power capacity	**Renewable energy**	**GW**	**56.5**	**132.7**	**177.0**	*44.3*
	Hydropower	GW	4.5	4.5	5.4	*0.9*
	Wind (onshore)	GW	27.0	48.0	72.3	*24.3*
	Wind (offshore)	GW	-	11.0	16.4	*5.4*
	Bioenergy, including biogas (power only)	GW	2.7	3.1	3.1	*0.0*
	Bioenergy, including biogas (CHP)	GW	2.3	3.9	3.9	*0.0*
	Solar PV (utility-scale)	GW	5.0	15.5	16.4	*0.9*
	Solar PV (rooftop)		15.0	46.5	58.9	*12.4*
	CSP	GW	0.0	0.0	0.0	*0.0*
	Geothermal	GW	0.0	0.2	0.6	*0.4*
Electricity generation	**Renewable energy**	**TWh**	**103.4**	**285.9**	**376.6**	*90.7*
	Hydropower	TWh	21.0	19.0	20.2	*1.2*
	Wind (onshore)	TWh	37.8	107.0	160.0	*53.0*
	Wind (offshore)	TWh	-	36.0	56.0	*20.0*
	Bioenergy, including biogas (power only)	TWh	17.6	30.0	30.0	*0.0*
	Bioenergy, including biogas (CHP)	TWh	15.3	37.0	37.0	*0.0*
	Solar PV (utility-scale)	TWh	3.5	16.8	17.8	*1.0*
	Solar PV (rooftop)	TWh	8.2	39.2	51.6	*12.4*
	CSP	TWh	-	-	-	*0.0*
	Geothermal	TWh	0	1	4.0	*3.1*
2. Heat						
Solar heating (buildings)		PJ	18	106	164.0	*58.0*
Solar heating (industry)		PJ		0.2	25	*24.8*
Biomass heat (buildings)		PJ	318	375	431	*56.0*
Biomass heat, including CHP (industry)		PJ	140	174	174	*0.0*
Biomass district heat, including CHP (and renewable waste)		PJ	44	153	171	*17.8*
Geothermal heat, including heat pumps (buildings)		PJ	19	86	114	*28.3*
Geothermal heat, including heat pumps (industry)		PJ	-	-	22	*22.0*
Geothermal heat, including heat pumps (district heat)		PJ	0	0	84	*84.4*
Total		**PJ**	**538.7**	**893.8**	**1,185.1**	*291.3*
3. Transport						
Biofuels total		PJ	121.0	228.0	373.0	*145.0*
Conventional ethanol		PJ	32.6	22.8	22.8	*0.0*
Advanced ethanol		PJ	0.0	45.6	49.8	*4.2*
Biodiesel (including jet fuel)		PJ	87.2	157.3	292.9	*135.6*
Biogas		PJ	1.2	2.3	7.5	*5.2*

Electric vehicles (plug-in hybrid, EV, two-wheeler, bus)	million	0.0	1.0	6.5	*5.5*
4. Ratio of electricity generation					
Gross power generation (excluding export)	TWh	610.8	545.9	568.5	*22.7*
Generation ratio of renewables	%	17%	52%	65%	*14%*
5. Total final energy consumption					
TFEC (excluding BF/CO)	PJ	9 311	7454	7 353	*-101*
All renewable energy	PJ	981	2 045	2 776	*731*
Renewable heat and fuel	PJ	660	1 122	1 558	*436*
Renewable power	PJ	321	923	1 218	*295*
Ratio – renewables/TFEC (excluding BF/CO)	**%**	**10.5%**	**27.4%**	**37.8%**	***10.3%***
BF/CO	PJ	201	123	123	*0*
Ratio – renewables/TFEC (including BF/CO)	**%**	**10.3%**	**27.0%**	**37.1%**	***10%***
6. Gross final energy consumption					
GFEC	PJ	9 760	8 009	7 914	*-95*
Ratio – renewables/GFEC (excluding BF/CO)	**%**	**10.6%**	**26.9%**	**36.8%**	**10.1%**

Note: BF/CO = blast furnaces and coke ovens

4.4 Sector findings

Figure 33 illustrates how the growth in renewable energy changes the relative energy make-up by resource and sector. In 2010, over two-thirds of the total final renewable energy consumed was in the end-use or district heat sectors, whereas only one-third came from renewable power technologies. In the district heating sector, the renewable share will exceed 50%, a significant increase over the 10% share today. However the findings are consistent with studies that also show that over 50% of the sectors energy supply can be renewables by 2030 (BINE, 2014).

In REmap 2030, the power sector's share in renewable energy use increases to 42%. However, the largest share of renewable use will continue to be consumed as fuel or heat in the end-use sectors. In absolute terms, renewable energy use will double between 2010 and the 2030 Reference Case. In REmap 2030, renewable energy use will increase 2.7 fold over 2010.

Figure 34 illustrates how renewable energy technologies contribute by resource and sector in relation to the share of renewable energy in TFEC. In the Reference Case, the main source of new renewable use is in the power sector, with around 54% of net additions coming from power technologies, largely wind and solar, followed by biomass. This situation reverses itself in the REmap Options, with 65% of net additions coming from renewable energy sources in the end-use heating (buildings and industry) and transport and district heat sectors.

If the additions in the Reference Case and the REmap Options for renewable power generation are included, Germany can meet its target of a 30% renewable energy share in TFEC. The additional options in the end-use heating and transport sectors and district heat sector can then increase the renewable energy share further to 37%.

Figure 35 shows that attaining a renewable energy share of 30% is possible through a combination of increases found in the Reference Case and REmap Options for power generation. The figure puts the growth in these sectors in perspective by elaborating on what the technology uptake means in physical terms between 2010 and 2030. The units presented are representative of averages, but the unit numbers can vary depending on the assumption made for unit capacity or size. The most important power technologies are the addition of significant numbers of wind turbines (both onshore and offshore) and solar PV systems. There is also significant growth in the number of technologies used for heating, with the highest deployment of solar water heaters, biomass heating units and heat pumps. In the transport sector, if assuming no biofuel imports, there would

Figure 33: Renewable energy consumption by resource and sector in 2010, the Reference Case and REmap 2030

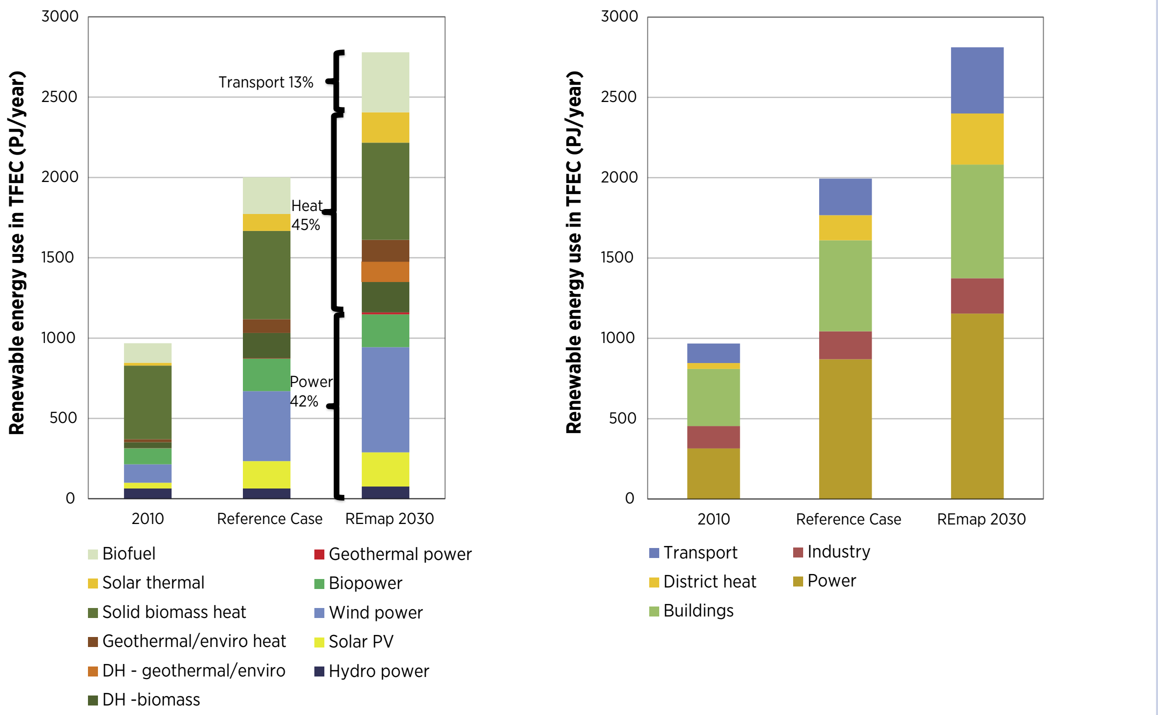


Figure 34: Contributions of renewable technologies to increasing renewable energy share, by resource and sector, in 2010, the Reference Case and REmap 2030

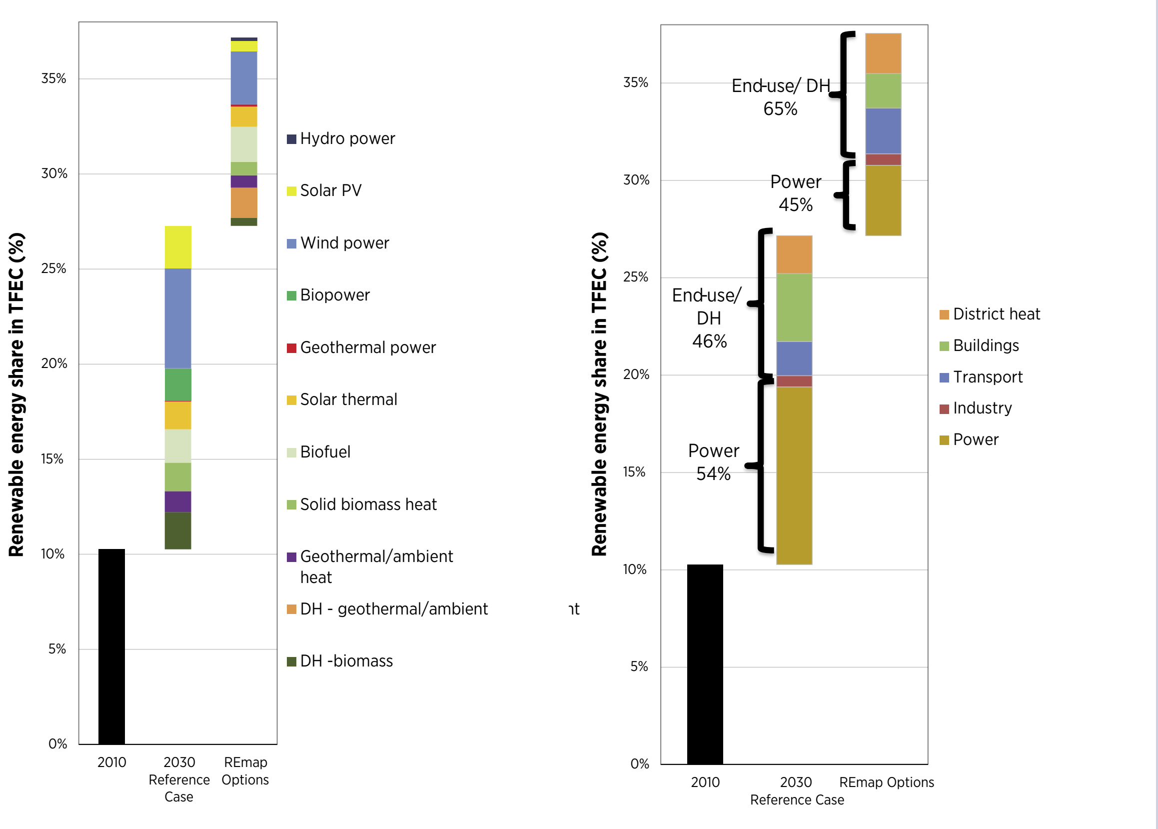
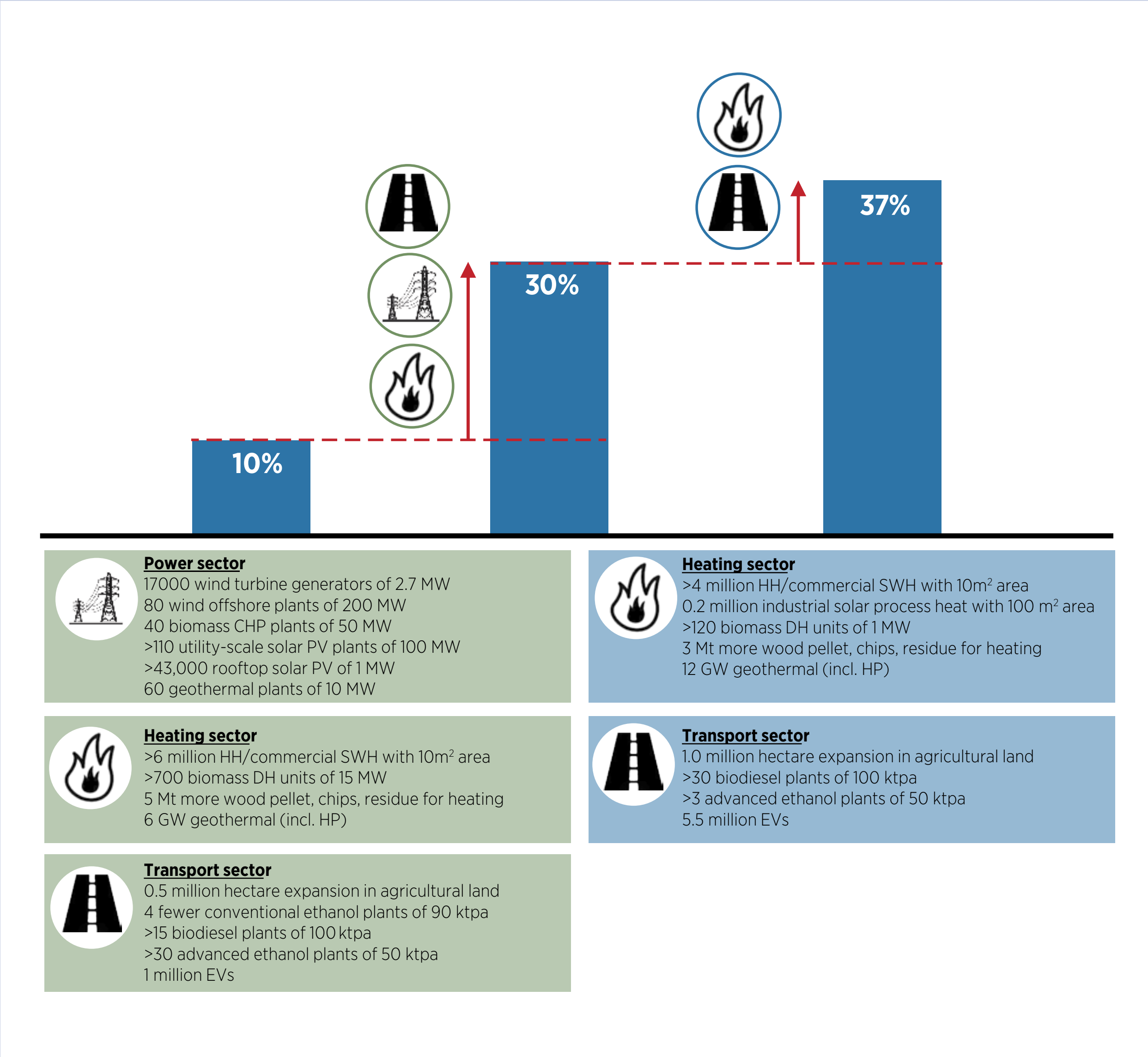


Figure 35: Technology and sector effort required to go beyond a 30% renewable energy share in total final energy consumption, 2010-2030



be a need for increased agricultural land to produce advanced biofuels and biodiesel; however, there would be a reduction in the land and biofuel plants used to produce conventional ethanol.

As REmap 2030 shows, Germany has the potential to increase its renewable energy share further, to over 37% of TFEC. One perspective is to consider the increase from 30% to 37% as being driven by additions in the end-use and district heating sectors (and the renewable power generation capacity that would be required to supply electricity for electrification in end-use applications). The notable technology options include additional heat pumps used in buildings and district heat, solar thermal for buildings as well as minor additions in industry. There is an additional potential of liquid biofuels (biodiesel and advanced ethanol) and significant growth in electric vehicles.

4.5 Cost and benefits of REmap Options

The previous two sub-sections provided an overview of the potential of accelerated renewable energy uptake. This sub-section outlines the associated costs

Table 9: Cost of substitution by sector and for the total energy system

	Business perspective (national prices)	Government perspective (international prices)
	(USD/GJ)	(USD/GJ)
Industry	2.0	15.1
Buildings	1.9	11.4
Transport	-2.0	-3.8
Power	-11.6	3.5
District heat	-2.8	10.6
Average of all	**-4.0**	**5.5**

and benefits of higher renewables deployment. REmap utilises an internally developed REmap tool to calculate the costs and benefits of the REmap Options.

The renewable technology options are assessed on a sectoral level, and the competitiveness of the portfolio of options is presented in table 9. If viewed from a business perspective, a perspective that businesses or investors would have, renewables are generally cost-competitive in all sectors except the buildings and industry sectors. The average cost of deployment beyond the Reference Case in Germany's entire energy system by 2030 is -4.0 USD per GJ of final renewable energy.

This business perspective gives a general view of which technologies and sectors would be attractive to investors based on national policies that effect energy pricing, subsides and CO_2 prices. As such, the effects of government policy relating to energy taxation and CO_2 pricing contribute to the general competiveness of renewables in this business perspective. For instance, the *Energy Reference Forecasts study* (Prognos, EWI and GWS, 2014) estimates a carbon price of USD 40 per tonne of CO_2 by 2030, and REmap assumes that by this time, all fossil fuels will internalise this cost in end-user prices. If this carbon price were to be removed, the portfolio of REmap Options, when viewed from the business perspective, would increase to USD +0.1 per GJ, instead of a saving of USD 4.0 per GJ.

REmap also assesses costs from the perspective of governments, which can be view as a macro-economic

Box 3: The REmap tool

The REmap analysis for Germany utilises an internally developed tool that incorporates the *Energy Reference Forecasts* (Prognos, EWI and GWS, 2014) for the Reference Case, as well as additional technology options known as the REmap Options. The tool allows for localised inputs for commodity, fuel price, renewable and conventional technology cost and performance. The tool then allows IRENA to enter additional renewable energy options in the end-use sectors of industry, buildings and transport, as well as for power and district heat generation. These additional options are then compared to a type of conventional generation that the renewable energy technology would substitute.

The result is a cost supply curve that plots the average incremental cost of substitution of each technology, beginning with the lowest cost, and moves horizontally along the x-axis in percent of renewable energy in the country's TFEC. In subsequent analyses, additional findings are calculated, including investment, subsidy and energy system cost calculations (excluding infrastructure), externality assessments and CO_2 impact assessments.

More information on the tool and methodology can be found in section 2 of this report and on the IRENA website.

perspective. The financial indicators in table 10 are calculated from this perspective. From the government perspective, the cost of the REmap Options is +5.5 USD per GJ. There are several reasons for this higher substitution cost. One is that the government perspective assumes a standard 10% discount rate for capital investment, compared to 6% in the business perspective. This makes technologies with high capital costs more costly to finance. Another factor is the effect of taxes on fossil fuels, which are excluded from the government perspective. These taxes generally are applied for transportation fuels and natural gas, and are high in Germany. In general, biofuels taxes are less, or they are subsidised; therefore, from the business perspective, which includes those effects, they are more cost-competitive relative to the conventional fuels that they substitute. Also important is the effect of the CO_2 price, which applies in REmap 2030 to all fossil fuels, but not to renewable energy. The government perspective removes the effects of the CO_2 price on fossil fuels and therefore increases the cost of substitution.

As summarised in Table 10, the REmap Options identified in Germany result in an incremental cost of substitution from a government perspective. The result is an incremental system cost of USD 4 billion per year in 2030. This cost excludes benefits related to reductions of air pollution (or the related improvement in human health) and CO_2 emissions from fossil fuel combustion. If such externalities are included, and depending on how these are valued, full deployment of the REmap Options could result in estimated reduced health costs of USD 1-2 billion per year by 2030. These avoided external costs result from a reduction of health complications due to air pollution from fossil fuel power plants and fuels used in the transport sector. If the benefits of avoided CO_2 emissions are taken into account, an additional USD 2-8 billion per year could be saved by 2030. The result of these externalities is a reduction in cost to Germany's energy system as a whole of up to USD 6 billion per year by 2030, outweighing the higher energy system cost of USD 4 billion in 2030.

Table 10 also shows that total investments in renewable energy technologies needed to attain the REmap renewable energy share would require USD 15.7 billion in investment per year, of which USD 6.9 billion would come from the REmap Options and USD 8.8 billion from investments taking place in the Reference Case. If viewed from the perspective of total energy system investment needs, an additional USD 4.5 billion per year would need to be invested in the energy system over the Reference Case, meaning that the renewable energy technologies in the REmap Options are more

Table 10: Financial indicators for REmap Options, 2030

	Billion USD/yr
System cost and benefits (in 2030)	
Incremental system cost	4
-Reduced health externalities	1-2
-Reduced CO_2 externalities (low at USD 20/tonne, high at USD 80/tonne)	2-8
Costs/benefits	+1 to -6
Incremental subsidy needs in 2030	0.8
Investment needs (average between today and 2030)	
Reference Case	8.8
REmap Options	6.9
Total investment needs for all renewables	15.7
Fossil fuel import cost savings (in 2030)	
Crude oil	18.4
Oil products	3.1
Coal	2.2
Natural gas	6.1

capital-intensive due to their generally higher capital costs. This means that if the REmap Options require on average USD 6.9 billion per year in investment, USD 4.5 billion will be new capital investment, whereas USD 2.4 billion per year will be a redirection of investment from conventional fossil technologies into renewables.

In this figure, investment in complementary infrastructure is not assessed, due to uncertainty on what those actual transition costs could entail. For instance, some of the end-use sector coupling technologies deployed in REmap (heatpumps, electric vehicles) can offer complementary services to the grid. Understanding how these services are provided, and their costs, will be crucial in the coming years to better assess transition costs, or savings, which can results from significantly higher renewable shares.

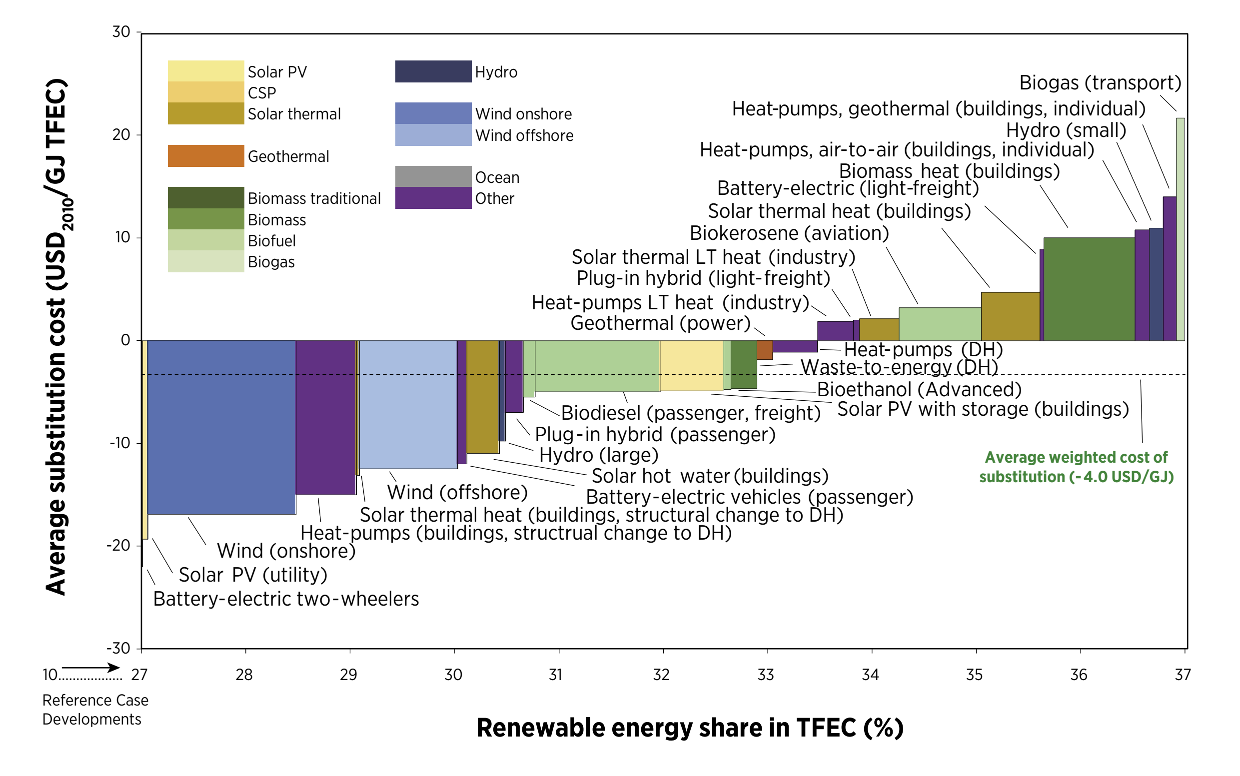
The table also shows an that incremental subsidy of USD 0.8 billion would be required to make REmap Options with positive substitution costs "competitive" with fossil technologies. The technologies that require a subsidy lie mainly in the end-use sectors rather than in the power sector, and include those for heating in buildings and industry (solar thermal). It is important to note that, by 2030, many renewable energy technologies will not require a subsidy, and will result in lower energy costs.

Finally, the table shows how the REmap Options affect fossil fuel imports. IRENA analysis (2015b) shows that Germany is highly dependent on these imports, importing 97% of its oil, 88% of its natural gas and 43% of its coal in 2014. The analysis also calculated the effect that increased renewables could have on future imports. The results show that Germany could reduce its import bill for fossil fuels by almost USD 30 billion annually by 2030 due to the REmap Options. The majority of this reduction, around USD 21 billion per year, comes from reduced imports of crude oil and oil products, with a sizable reduction of some USD 6 billion per year coming from reduced natural gas imports.

Cost supply curves

In this sub-section, the Options are aggregated into a cost supply curve and are ranked in terms of their cost-effectiveness. The cost supply curve displays an

Figure 36: REmap Options cost supply curve, in the business perspective



approximate representation for the realistic potential of renewable energy technologies – the REmap Options – that can be deployed by 2030 on top of the Reference Case.

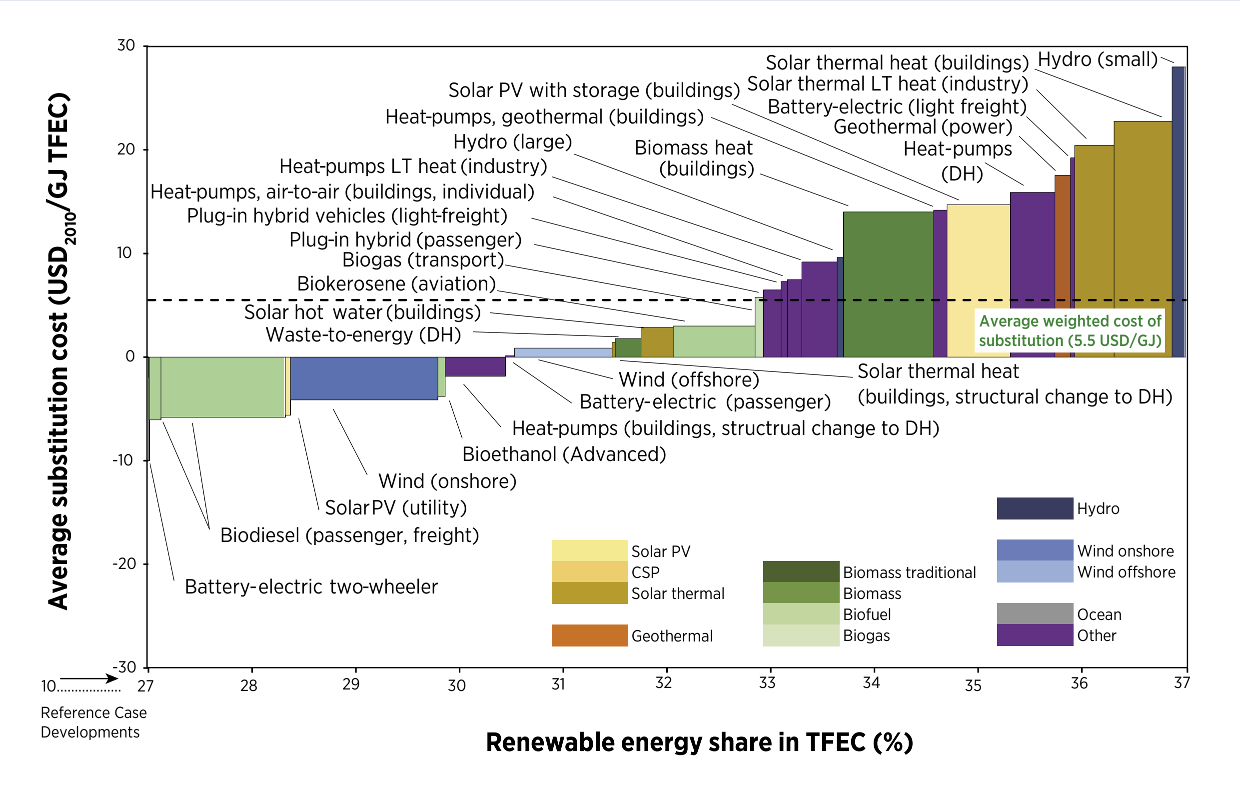
The cost supply curve is not used to develop the REmap 2030 case, but it is a representation of the REmap Options that have been selected. The REmap Options are a portfolio of technologies for accelerated renewable energy deployment in all sectors.

The results of the analysis are shown in Figure 36 and Figure 37, illustrating the business perspective and the government perspective. The former reflects factors likely to influence private investment decisions, and the latter reflects factors more relevant to government decisions on policy and spending (see section 2 for more on the two perspectives). The business cost supply curve is used to examine the economic cost and financial savings potential of increased renewable energy uptake, and the government cost supply curve is used when considering R&D needs, or when comparing renewable potential and costs across regions or globally. It also provides insight into cost differences between Germany and global markets resulting from policy decisions such as energy taxation and carbon pricing. In addition, it reflects what governments may consider when evaluating technology choice.

In the figures, the renewable energy use, *i.e.*, potential (in PJ as a share of TFEC), is shown on the x-axis. This potential remains the same in both perspectives and is based on the results detailed earlier in this section. If the figures showed developments between 2010 and the Reference Case, the share would increase from roughly 10% to 27%; however, the curve starts where the Reference Case share ends at 27%, and the REmap Options result in an increase of an additional 10% of TFEC, to 37%.

The differences between the two curves relates to the y-axis, *i.e.*, the cost of substitution. The key drivers that

Figure 37: REmap Options cost supply curve, in the government perspective



Note: Assumes a 10% discount rate, see section 2 for discount rate selection methodology and text related to this figure for discussion on discount rate effects on cost of substitution.

result in the difference in substitution costs between the curves include changes in commodity prices due to the removal of taxes and CO_2 price effects in the government perspective (which results in higher substitution costs). Also, assuming a higher discount rate in the government perspective results in a higher substitution cost for technologies that have higher capital costs, which are mostly the renewable energy technologies.

In both curves, Germany can reach its target of 30% renewable energy in TFEC with technologies that have a negative cost of substitution. This means that energy system costs would be lower than in the Reference Case. In the business perspective, the share could reach 33.5% until the substitution cost turns positive, and in the government perspective it could reach around 30.5%. However, the interpretation is not that simple, since each technology can be viewed separately and has increasing increments of costs as well as deployment increases. For instance, the average substitution cost of solar thermal heating in buildings is positive, but some deployment could occur at lower cost than the alternative, and other deployment at higher cost. The curve therefore should not be viewed as a progression from left to right. A cost-optimum would occur in the 30-37% percent range if only viewed from an energy service cost perspective. When including additional benefits, however, the portfolio of technologies would result in significant savings as shown in Table 10.

On average, the technologies with positive substitution costs would require a subsidy to be competitive in the market. However, this subsidy perspective is just for one year (2030), and these technologies could result in lower energy services costs in later years, depending on how fossil fuel prices evolve. Additionally, this subsidy can be viewed as an investment in technological learning and can result in significant cost reductions, as has been observed with solar PV. Some of the more costly technologies also have important sector linkage benefits, such as heat pumps, and facilitate a system with increasingly high shares of variable renewable energy.

Individual drivers for the competitiveness of each technology differ. A large determinant is the type of fuel it replaces, and, in the case of coal, whether it has a CO_2 price (such is the case for the business perspective). On a sectoral level, the power sector results in savings in the business perspective and is generally competitive in the government perspective, in the case of onshore wind and utility-scale solar PV. In transport, biofuels generally perform well in terms of costs, due to the price of oil in 2030 and (for the business perspective) to the additional effect of energy taxation. Electric mobility is very cost-competitive when the effects of fossil fuel taxes on fuels in the business perspective are included, but when these are removed electric mobility results in higher costs, due in part to the high cost of electricity in Germany. Many technologies used to provide heating in buildings are competitive in the business perspective, including the structural change from individual to district heating using heat pumps and solar thermal systems. The technologies in the industry sector are generally more expensive in both perspectives, due largely to the lower cost of natural gas for industry consumers.

It is important to note that all the substitution costs in the government perspective exclude any benefits resulting from reduced externalities. As detailed in Table 10, when external costs are quantified, the portfolio of REmap Options results in modest to significant savings to Germany's economy as a whole.

CO_2 emission developments

Table 11 provides an overview of CO_2 emissions resulting from combustion for energy services within the scope of sectors contained in the REmap analysis. Because the scope of the REmap analysis does not include all energy consumption, this analysis does not include all CO_2 emissions in Germany or non-CO_2 greenhouse gas emissions. For this reason, REmap represents approximately 82% of the total greenhouse gas emissions from the energy sector today, a share that is assumed to remain the same throughout the analysed period.

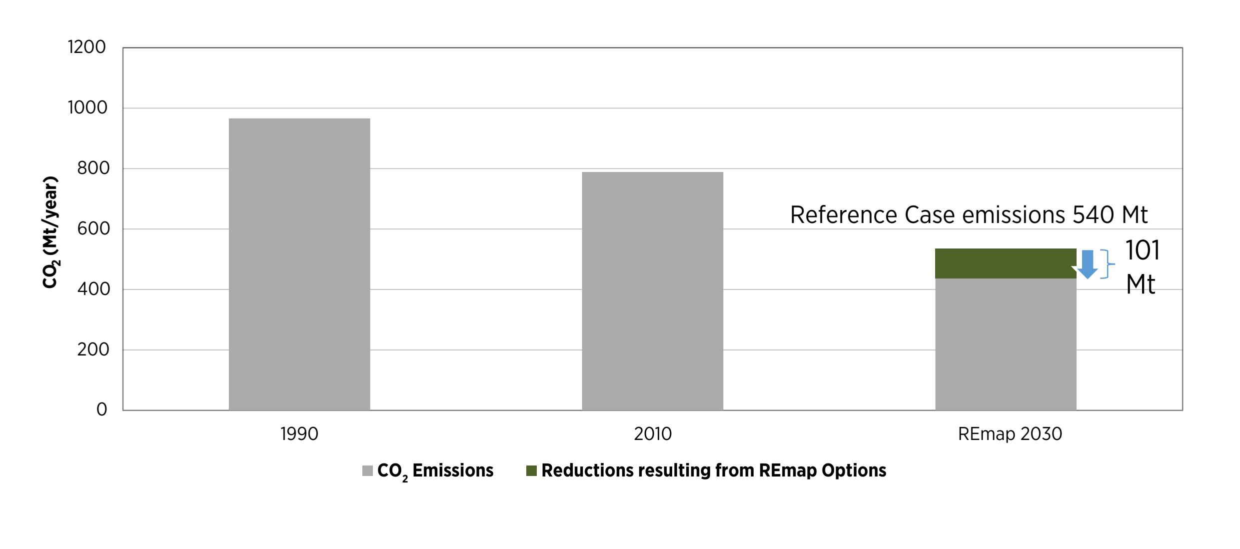
According to this metric, CO_2 emissions totalled around 966 million in 1990 and around 789 million tonnes in 2010 (see Figure 38). By 2030, under the Reference Case, emissions will fall to 540 million tonnes, a reduction of around 44% from 1990 levels. The REmap Options would result in a further reduction of 101 million tonnes by 2030, resulting in emissions of 439 million tonnes, a 55% reduction from 1990 levels. This is the outcome of accelerated efforts to deploy renewables in end-use sectors as well as additions of wind and solar capacity beyond the Reference Case.

Table 11: Development of CO_2 emissions in Germany, 1990-2030

(in million tonnes of CO_2 per year)	1990	2010	Reference Case 2030	REmap 2030
Power and district heat generation				71
Industry				3
Transport				15
Buildings				12
Total avoided CO_2 emissions				**101**
Reduction under REmap 2030 compared to the column year	-55%	-44%	-19%	*N/A*
Fossil fuel emissions from combustion for energy services[1]	**966**	**789**	**540**	**439**

[1] *According to the UNFCCC classification scheme, the sectors and emission sources covered in REmap include over 95% of the energy industries and transport, and all of manufacturing/industry and other sectors. Excluded from the REmap emissions are energy-other, fugitive emissions, industrial processes, solvents, the agriculture sector, and land-use change and forestry. Additionally, non-CO_2 greenhouse gas emissions are excluded.*

Figure 38: CO_2 emissions from fossil fuel combustion in 1990, 2010 and REmap 2030

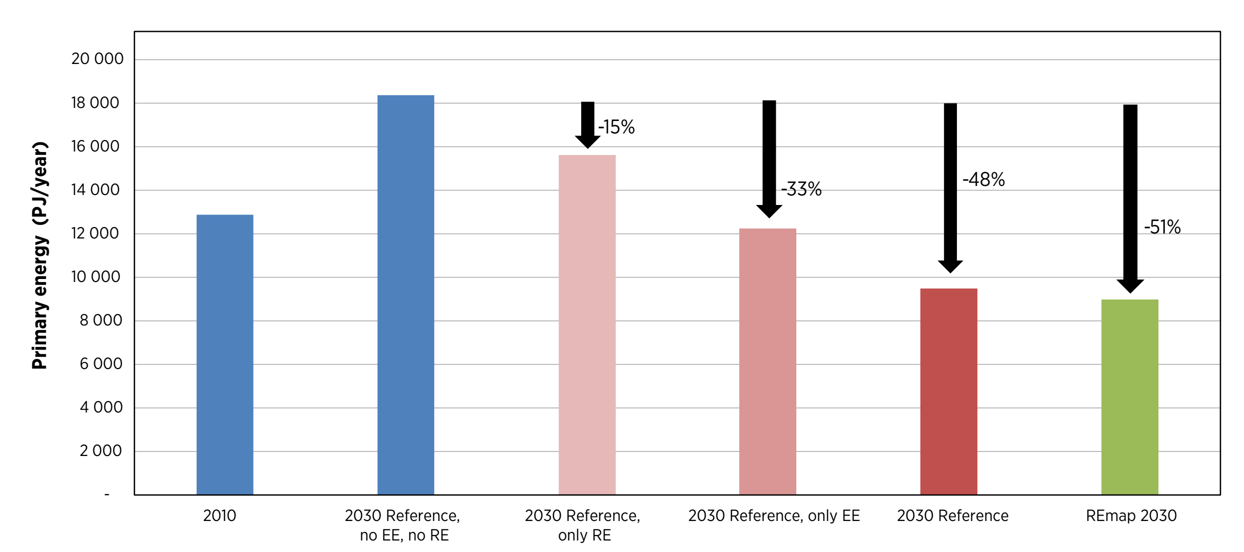


Effects on employment

It is also important to understand whether accelerating renewable energy deployment results in socio-economic benefits such as job growth. The global REmap report released in 2014 (IRENA, 2014a) included a global assessment of the effect of the REmap Options on direct employment. It shows a positive correlation between higher renewable energy deployment and job creation. However, the analysis remains at a global level and cannot be differentiated to specific countries yet.

Some external analyses have looked at the effects of the *Energiewende* on employment in Germany. One recent study (UNIDO and GGGI, 2015) looked at the results of the business-as-usual and low-carbon scenarios of the EEG 2010 targets, which are somewhat aligned with a 2030 goal of a 30% renewable energy share in TFEC. The study found that the "clean energy investment strategy" employed in the low-carbon scenario will generate positive gains in employment. Gains over the period to 2030 depend on assumptions in labour productivity growth, but even the first year of the low-carbon scenario results

Figure 39: Effect of renewable energy and energy efficiency technologies on primary energy use, 2010-2030



in estimated net job creation of 68 000 jobs in Germany, or an increase of around 0.2% of the employed workforce. The study found that positive job benefits would result as Germany undertakes its transition to building a clean energy economy.

Renewable energy and energy efficiency synergies

Although indicators and accounting methods for renewable energy and energy efficiency differ, from a technology point of view there are important overlaps between the two areas. A number of renewable energy technologies offer savings in primary energy demand and also increase the share of renewable energy in TFEC. In the case of Germany, these include electric vehicles, heat pumps, and renewable power technologies such as solar PV and wind. Use of these types of technologies improves technical efficiency, a discussion that is beyond the scope of this report. However, IRENA and the Copenhagen Centre for Energy Efficiency (C2E2), the two hubs for the renewable energy and energy efficiency objectives of the SE4ALL respectively, have prepared a working paper on the topic that is available on the IRENA website[10] (IRENA and C2E2, 2015). This sub-section discusses how renewable energy and energy efficiency complement each other and drive reductions in primary energy consumption.

10 *www.irena.org/remap*

Figure 39 shows the effect of renewable energy in reducing primary energy demand. In 2010, primary energy use in Germany totalled nearly 13 EJ. Over the 2010-2030 time frame, if no efficiency improvements take place and no renewable energy is deployed, growth in economic activity would increase primary energy use to approximately 18 EJ (the "no EE/no RE" case). However, Germany has aggressive plans for both energy efficiency and renewable energy. Taking these into account, primary energy use declines to just above 10 EJ in 2030 the "2030 Reference" case. In REmap 2030, with the deployment of renewable energy technologies, primary energy demand declines to below 10 EJ. This represents a decline on the order of around three percentage points, from 48% savings when compared to the "no EE/no RE" case, to 51%.

4.6 Challenges and solutions to accelerate renewable energy uptake

Germany has done well in integrating higher shares of renewable power into its electricity system. In 2014, the share of renewable energy – increasingly variable sources such as wind and solar – in power generation exceeded 25%. This was achieved without any major problems. Factors contributing to this achievement include the strength of Germany's grid infrastructure, flexible operation of conventional power generation systems, balancing markets, forecasting, electricity trade with neighbouring countries and improvements in local-level distribution systems.

Yet the successes achieved thus far in the power sector are not sufficient to take Germany's renewable energy share to 30% of the total energy mix – the country's 2030 target. The Reference Case results show this: the share actually remains lower than 30%. The higher share can be achieved but will require the deployment of renewables in both the power and end-use sectors.

As the analysis shows, the largest additional potential is in the end-use sectors, which can take Germany's renewable energy share to 37%. Making this jump will be challenging. Biomass will play an important role, but resource availability will remain a major barrier. Another major challenge lies in the power sector, as half of all electricity generation in REmap 2030 originates from variable wind and solar PV. This sub-section discusses these challenges as well as potential solutions, paying particular attention to the role of sectoral linkages.

Power sector challenges and solutions

Higher shares of variable renewable energy will require more flexibility and balancing. Germany had an active discussion in late 2014 and early 2015 around two competing market designs – a capacity market and an energy-only market – in order to pave the way for realising higher shares of renewables. The total volume of traded electricity at the day-ahead markets represented 40% of total generation (EC, 2014). Liquidity in the German wholesale markets was high and will grow with higher shares of renewables (BNetzA, 2014). In mid-2015, the government announced an agreement to place around 4 GW of coal power capacity into a strategic reserve, and to maintain an energy-only market.

The discussions also focused on the types of flexibility measures that will be required to meet the demand not covered by variable renewables. To achieve a high degree of flexibility for renewable grid integration while maintaining a resilient power supply, several different measures are required. In addition to current practices such as cross-border exchange and grid expansion, these include demand-side management and possibly storage, with various technologies for each voltage level. However, there is considerable debate about when (and if) large, utility-scale electricity storage will be necessary by 2030, with many studies showing a need for storage only at renewable energy shares higher than the 65% achieved in REmap. REmap does indicate growth in small, home-based storage, particularly when coupled with solar PV.

The importance of linkages between the power, heat and transport sectors arises as well (Energynautics *et al.*, 2014). The need for grid expansion can be slowed through specific policies that support "systems thinking" and that accelerate the interconnection of the power, heating and gas sectors while expanding e-mobility as an additional option for demand-side management and for accessing (limited) storage capacities in the long term.

Demand-side management can take the form of enabling electricity users to have the flexibility to use power when supply is high, for instance when wind and solar PV are producing at their peak on windy or sunny days. But demand response also can occur through electrification of the heating sector, for example by time-shifting the supply of heat in the building sector to account for peaks in electricity supply. A common method of implementing such sectoral linkages is to use heat pumps that can operate on a flexible schedule to supply heating or cooling services.

One study that explored this synergy in Germany found that high levels of heat pump deployment in systems with high levels of wind energy penetration result in a reduction of the overall energy system cost and of CO_2 emissions (Papaefthymiou *et al.*, 2012). The study estimated that by 2030, high levels of heat pumps would result in USD 40-65 million per year in system savings, compared to a case of limited heat pump deployment. In REmap, significant additional heat pump potential is considered, both in the building and industry sectors as well as in local district heating networks. Another form of sectoral linkage is the coupling of electric vehicles with smart charging, thereby offering demand-side flexibility. The EV charging process can be controlled based on market price signals or supply.

Curtailment is not much of an issue in Germany today, but it may be in the future if grid expansion is delayed or if cross-border exchange reaches its limits. Curtailment may result in financial losses, although a moderate level of curtailment (peak shaving) also can help reduce investments required for grid expansion. Planning and development of the national transmission grid, as well as cross-border exchange (hence, the integration of

European power markets) will be important to minimise curtailment. Storage is another option, but its deployment will depend on the choice of technology (*e.g.*, storage through sector linkages, as described above, or battery storage) and its cost-competitiveness, as well as at what renewable energy share significant storage will be necessary.

Changing residual load patterns (including net exports) will have an impact on how power plants will develop to meet that demand. According to a study prepared for Agora (Fraunhofer IWES, 2015), baseload power plants that operate with capacity factors of more than 7 000 hours essentially could be halved in the 2013-2030 period. In comparison, mid-merit (1750-7 000 hours) and peak load (<1750 hours) capacities (peaker plants) would increase in the same period, which is also in line with results of the analysis that show an increase in natural gas-fired capacity but a decrease in generation.

Role of storage

Storage is an important means to support a reliable, efficient, cost-effective and clean power sector by facilitating the deployment and integration of renewables. Especially in Germany, which already has high shares of variable renewable energy and the potential to reach higher levels by 2030, storage technologies can provide new opportunities and play a significant role in strengthening the power system.

The various forms of storage include pumped hydro, compressed air energy storage, batteries, flywheels, thermal, power-to-gas and power-to-heat. However, electricity storage currently is one of the most expensive flexibility options. Its deployment should follow that of other flexibility options, such as grid expansion, interconnections and demand-side management. Yet the importance of storage will likely become clear when Germany begins to reach very high levels of renewable energy after 2030. The Fraunhofer Institute for Solar Energy Systems, when estimating the storage required to achieve 100% renewable energy in Germany by 2050, concluded that this storage would amount to 24 GWh of stationary battery applications, 60 GWh of pumped hydro, 33 GW of electrolysers and 670 GWh of heat storage (Henning and Palzer, 2013).

A subsidy programme to couple battery storage systems with solar PV provided loans to 10 000 systems in 2013 and 2014. The latest figures suggest that 12% of solar PV systems in Germany are now coupled to an energy storage system, and, in REmap 2030, as much as 11 GW of solar home systems will have battery storage. So far, energy storage has played no role in integrating renewables at the level of the transmission grid. More technology and policy attention will be required in the coming years to identify the most cost-competitive and effective opportunities for energy storage in Germany's power system. However, no additional utility-scale storage is likely up to the 2030 time frame, beyond the storage that is already being deployed in solar home systems and the potential to use battery storage in the electric vehicle fleet, which could total 6 million under REmap 2030.

Using the storage potential in the EV fleet represents a form of sectoral linkage. Another example exists in the heating sector, through the use of heat pumps with heat storage and direct resistance heating. Heat stored in such a system is then released by the end-user when needed. Such thermal storage facilities are designed to store heat sufficiently for about two hours or longer.

Biomass challenges

Half of the total final renewable energy use in REmap 2030 is from biomass. Biomass has only a low contribution to total renewables use for power generation, given the availability of other technologies. However, it is an essential technology for heating and particularly for use in the transport sector, where alternatives for some transport modes like heavy transport, shipping and aviation are limited.

Total biomass demand in Germany is close to its supply potential, and importing from neighbouring countries is not a preferred option. This creates concerns about sustainability and the affordability of supply. Pathways with the lowest greenhouse gas emissions and the largest economic benefits must be developed. Conflicting aims regarding the food supply or use of feedstocks as well as possible impacts on biodiversity and indirect land-use effects must be minimised.

Total agricultural area required for ethanol and biodiesel production in 2010 was around 1 million hectares, or less than 10% of Germany's total arable land of 12 million hectares (another 5 million hectares of grassland also is available). Realising the REmap 2030 potential in the transport sector will require land expansion to around

3 million hectares in 20 years, despite a significant increase in advanced biofuels from woody biomass. Earlier studies by the Federal Ministry of Food, Agriculture and Consumer Protection showed that such land could be available, but there is currently intensive political debate over the extent of land expansion that is possible while still maintaining sustainability (BMEL, 2009).

Some of this land will be for crops to be used for biofuels production for aviation, where no other technology potential exists. To increase renewables use in the manufacturing industry, biomass will also be needed for some medium- and high-temperature applications. For other competing uses of biomass across the heating, power and transport sectors, a supply-and-demand plan needs to be made to ensure that non-biomass and other low-carbon technologies are deployed first, and, in a subsequent step, the sustainable and cost-effective pathways of biomass are deployed as necessary to realise Germany's long-term energy and climate targets. The findings of this roadmap can serve as a basis for a biomass plan for Germany to 2030.

4.7 The essential role of end-use sectors in accelerating renewable energy uptake

Figure 40 shows the breakdown of Germany's current TFEC by sector. An estimated 70% of the total final energy demand was consumed as fuel or district heat in the industry, transport and building (residential, service and commercial) sectors, and 19% was for electricity. The remaining 10% was non-energy use as raw material for chemicals production.

In 2013, end-use fuel demand was approximately 7.6 EJ (AGEB, 2015). In the Reference Case, this is estimated to decline by a quarter, to 5.8 EJ, in 2030. The Reference Case also estimates that about 16% of this total demand will be sourced from renewables, leaving 84% still sourced from conventional fuels.

The *Energiewende* so far has focused largely on the power sector. However, the REmap analysis suggests that more than half of Germany's total final renewable energy use in REmap 2030 could be related to heating and transportation. The challenge of accelerating renewable energy uptake in Germany by 2030 and beyond lies in these two end-use applications. To create a more sustainable heating supply a systemic perspective is necessary. Therefore an integrated energy concept for heating, cooling, electricity and mobility will be necessary. In additional because the deployment of many of these end-use heating and transport technologies is only beginning, understanding how their potential, costs and synergies with other energy sectors is one area where further analysis and research is needed. Therefore this sub-section starts by discussing the challenges to enabling this shift, as well as the relevant best practice and policy actions that are required, which differ by sector.

Building sector

Current building energy use and building stock

Germany's building sector is characterised by large variation in owners, users, technology type and plant size. The sector accounts for 40% of the country's final energy demand (including non-energy use). Two-thirds of the total is for residential buildings, and the remaining one-third is for service and commercial buildings (AGEB, 2015).

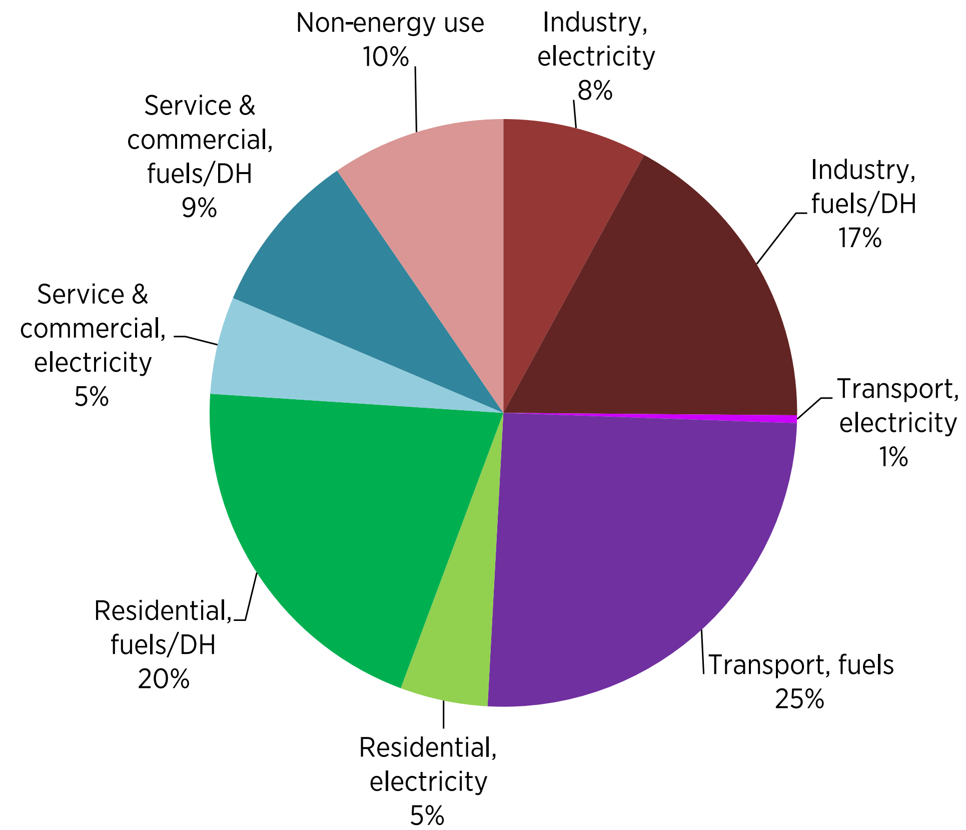
Space heating accounts for around 70% of energy demand in the residential sector. Hot water represents around 10-15%, and the remaining 15-20% is electricity for lighting and appliances. Germany has no significant cooling demand in the residential sector. For commercial and service buildings, the share of electricity use in total energy demand is higher, at around 25% (EPISCOPE, 2012; FIW München, 2015; AGEB, 2015).

The residential building stock in Germany is about 19 million buildings, and the country has about 40 million households. Two-thirds of the buildings (around 12 million) are occupied by one household, and one-third are multi-family buildings. Of the single-family dwellings, two-thirds (around 8 million) are stand-alone, and one-third (around 4 million) are linked with another building. Energy use per square metre is highest for single-family, stand-alone buildings and lowest for multi-family buildings (LSN, 2014).

About 75% of Germany's residential buildings were built before 1990. About 10% of buildings were built between 1990 and 2000, and about 15% were built after 2000 (LSN, 2014).

There is a large difference in the total heating energy demand between old and new buildings. The inefficient

Figure 40: Breakdown of Germany's total final energy consumption, including non-energy use, 2013



Source: AGEB, 2015

old building stock has low energy efficiency. A newly constructed building requires only 10% of the energy for heating that the average existing building does. Renovation can reduce energy needs by one-half to three-quarters in old buildings (ARGE, 2012; FIW München, 2015). Most building types have the potential to reduce their energy demand per square metre by 30-50%. If advanced technologies are used, a 60-80% reduction seems possible (IWU, 2015).

The fuel mix of buildings varies greatly depending on when they were built. Oil heating is significant in older, single-family houses, representing around 40% of the total demand. Other buildings are heated mainly with natural gas. In recent years, the use of heat pumps has increased, but they remain only a small share of heating systems (EPISCOPE, 2012). District heating represents less than 4% of the total heating demand of single-family houses, but up to 15% for multi-family buildings. District heating is especially common in cities in eastern Germany, in Hamburg and in parts of the Ruhr area (LSN, 2014).

Energy demand in service and commercial buildings is supplied mostly by fossil fuels, with around one-third from natural gas and one-fifth from oil products. Electricity supplies most of the remainder (40%) (AGEB, 2015). By 2030, the share of electricity use in these buildings will increase to almost 50%, fossil fuels will decrease from one-half to around one-third, and renewable sources will increase from below 10% to around 20%.

Expected developments in the future

Future energy demand for heating will depend on how the energy efficiency and fuel mix of the building stock will evolve. There are uncertainties about the future heating market, stemming from the uncertainty in energy prices, the availability of policy support and the development of regulatory frameworks. These uncertainties also are influenced by the investment decisions needed for long-term infrastructure related to heating.

Demolition rates in Germany for residential buildings are low, less than 1% per year. Only a small number of houses is withdrawn from the market. An average of below 40 000 dwellings, or 0.1% of the entire housing stock, has been demolished in each of the last 10 years in the entire country (DB, 2010).

It is expected that by 2050, 70-80% of today's building stock will remain in place (CPI, 2011). This means that 20-30% of the building stock in 2050 would be new, characterised by high energy efficiency and more likely to use renewables[11]. In 2030, the share of new buildings in the total stock would be less, at around 10%.

The rate of thermal retrofitting, the primary means for increasing a building's energy efficiency, is 1.0% per year. Realising a 2% target by 2030 would mean 30% renovation of the existing building stock. When including the 10% of new building stock, this would entail renovating 40% of the total building stock to an efficient level of heating by 2030. Existing buildings offer great potential for reducing heat demand, but their development is capital-intensive and improvements need to be carried out across many different building types. Furthermore, the technologies in place typically are improved only when a building is transferred to a new owner or when equipment stops functioning; hence, regulations often have limited impact. Half of Germany's households own the flats/houses that they live in. High shares of rentals contribute to the low renovation rates – the so-called landlord-tenant problem for efficiency. Moreover, owners are not necessarily aware of the opportunity and costs of renovation.

Only new buildings, which have the lowest share of the building stock, can meet the highest standards for efficiency and renewable heating shares. Of the new buildings built in recent years, around one in four has a heating system based on renewables. In 2014, the share was even higher, at 38.7% (DESTATIS, 2015). Gas-based heating accounts for the rest of the heating systems in new building stock (EPISCOPE, 2012). For the remaining 60% of old, inefficient building stock in 2030, the challenge to realise higher shares of renewables is large.

For service and commercial buildings, the total heated floor area is expected to decrease 5.2% by 2030, due largely to a declining workforce. By 2030, the relative energy required per square metre is also expected to decline by one-third over 2011 levels, an improvement of 2.7% per year – due largely to energy efficiency retrofits in existing buildings. However, some replacement of building stock with newer buildings is also expected. Service and commercial buildings typically have shorter lifetimes and higher renovation rates than residential buildings do. For this reason, the improvement of building thermal envelopes and efficiency heating systems occurs at a faster rate than for residential buildings (Prognos, EWI and GWS, 2014).

Also important is the rising demand for cooling and ventilation, which by 2030 is expected to increase by 88% over 2011. These changes will result in a decrease in the relative share of energy used for heating and an increase in the share used for cooling and ventilation. However, heating will remain the largest source of energy use in the sector in 2030.

Building renovation targets

Germany is making progress towards realising its renovation target of 2% per year. However, the current trend is below the target. A significant effort is required to shift current heating market trends for Germany to realise its energy transition to 2030.

Heterogeneity of the existing building stock and operations has been a major challenge for Germany to realise its targets. This also has resulted in complexity of the regulatory framework for the heating market (FVEE, 2015). A recent study by Institut Wohnen und Umwelt (IWU, 2015) provides a detailed overview of Germany's building stock, which is helpful in setting and implementing renovation targets. As a first step, outlining the following parameters is necessary for developing such targets:

- age of the building stock, broken down by building type
- establishment of building type clusters

11 An estimated 5% of the German building stock is under specific protection regulations, such as memorial or historical factors that restrict the possibility for façade insulation, etc.

- size of the building (to be reflected in building type clusters)
- status quo of renovation across the building stock
- ownership structure.

Once the energy status of individual buildings is described, the next question is how to meet future efficiency and/or renewable heat targets in view of the existing heating systems in use. Technology options need to be tailored by building type and heating system design.

Differentiated objectives to meet the complex market structure of Germany will be key, but renewable energy targets also can be clustered to address the individual energy demand and characteristics of buildings. Existing regulatory instruments that address the heating and cooling markets can be simplified as well. Their effectiveness should be monitored periodically and, where relevant, revised. Developing improvement pathways for neighbourhoods that have buildings with similar characteristics is another approach. There also is a need to continue to provide funding for renovations. Considering Germany's building ownership characteristics, putting obligations on building owners to assess renewable energy options when upgrading heating equipment will be helpful (FVEE, 2015; UBA, 2014; AEE, 2015).

The MAP provides funding for renewables, but funding rates are low for heat pumps and deep geothermal energy projects in particular (see section 3.4 for more information on the Market Incentive Program). Only about 9% of the heat pumps sold in 2012 received financial support. For both technologies, the permitting conditions are too complicated, and there is a need to simplify and speed up the MAP procedures. Even though heat pumps are an environmentally friendly renewable energy technology, investors still need to pay the EEG surcharge for operating these systems. Such burdens can be reduced if electricity from rooftop solar PV self-generation is used to power the pumps (GtV and WFG, 2013).

Policies and targets should not be limited to the development of individual technologies, but rather they should address the entire heating system by expanding the necessary infrastructure in the heating and cooling

Table 12: Examples of best practices for energy efficiency and renewable energy in the building sector

Country	Description
Energy efficiency	
Australia (Sydney)	The draft Energy Efficiency Master Plan aims to reduce building energy use and will be implemented alongside the city's Renewable Energy Master Plan and Trigeneration Master Plan.
Italy	An incentive covers up to 40% of investments in energy efficiency in existing buildings, small-scale high-efficiency systems and/or renewable heating technologies.
Luxembourg	Grants are available for projects that improve energy savings and increase the use of renewables in existing and new high-performance structures.
Switzerland	Building energy codes include "nearly zero energy" standards from 2020 onwards and a 10% renewable energy requirement for heating system retrofits.
United States (California)	The revised building code requires all new residential and commercial buildings to be "net zero energy" by 2020 and 2030, respectively. The PACE financing programme has supported energy efficiency improvements in buildings and rooftop solar PV installations.
Renewable energy	
Austria	Solar water heaters are being installed on buildings nationwide.
China	Subsidy programmes exist for solar water heaters in the residential sector, at both the urban and rural levels.
Denmark / Sweden	Financial policy instruments exist for biomass-based district heating and CHP.
UK	The renewable energy heating incentive encourages a switch to heat pumps, solar thermal and other renewable heating systems.

Source: REN21, 2015; IRENA

market. Because of the unique characteristics of the building sector – with low turnover rates and investment decisions that lock in the energy supply for decades – it is imperative that a strategy be developed and deployed that will yield higher renewable energy shares in building space heating.

On a global scale, there are numerous technology and policy examples of policy makers using regulations to advance energy efficiency and renewable energy in combination (REN 21, 2015). Some of these can provide useful examples for Germany as well (see Table 12).

The potential for renewables in buildings

Renewable heating options include air-to-air and geothermal heat pumps (in combination with renewable electricity), biomass (pellet) heating systems, biogas and solar-assisted hot water systems. With the exception of biomass, renewable heating systems are best suited for low-temperature heating rather than for the traditional radiators that operate with hot water.

The choice of renewable energy technology to be deployed depends mainly on whether a building is located in an urban or a rural setting. In urban areas, buildings often are linked, and heating systems typically are connected either to a natural gas or district heating network. One renewable energy option is to store and inject biogas into the gas network. Another option is to focus on renewables (solar, heat pumps or biomass) in the district heating network. Alternatively, buildings may partly or fully disconnect themselves from the network and implement decentralised heat pumps, biomass boilers, etc. Rural areas of Germany, where households generally make their own investment choices, have seen considerable deployment of biomass boilers and heat pumps.

For older buildings, the first step should be to increase energy efficiency, with the second step being the introduction of renewables. But these two measures need not be exclusive of each other: while the building is being renovated for better efficiency, efforts also can be made to install renewable heating systems.

Demand for space heating in Germany is limited to the cold period between October and April. This is when solar water heating is generally less available. By comparison, heat pumps, solid biomass, biogas and district heating can be deployed throughout this period. Natural gas can serve as backstop if there is limited availability of renewables for any reason.

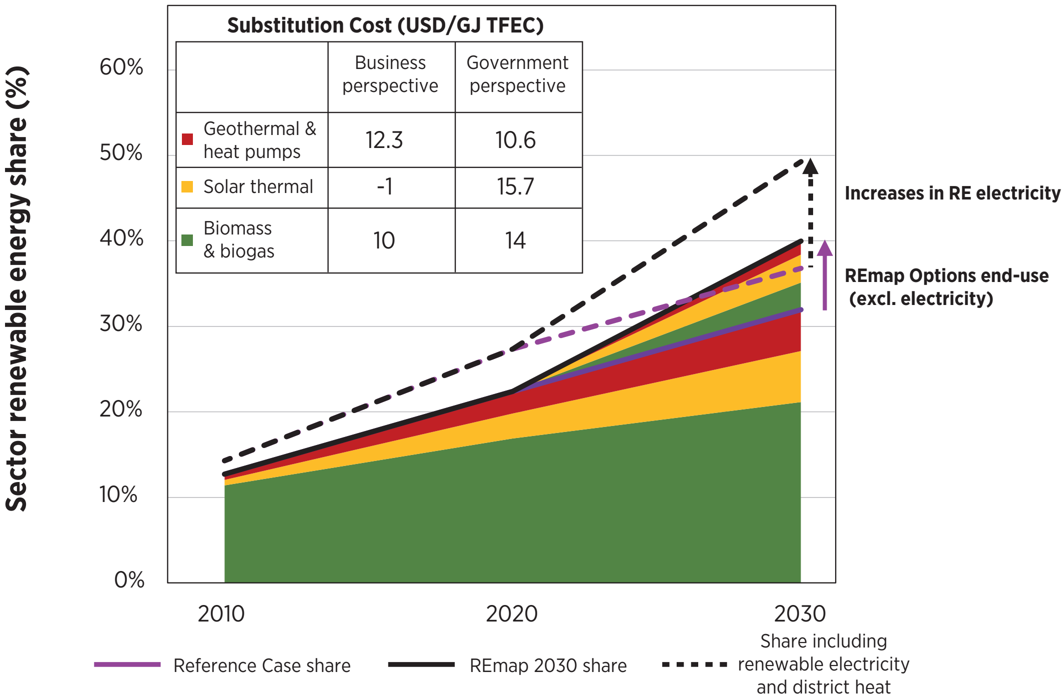
In comparison, demand for hot water is more evenly distributed throughout the year. This makes the integration of thermal systems for heating easier and more cost-effective. In 2010, 8.2% of buildings in Germany have a solar thermal hot water system, 1.6% have rooftop solar PV and an estimated 0.8% have both systems installed (BEI, 2010). However since 2010 the share of roofs with Solar PV has increased substantially and the percentage of rooftops with solar PV is likely over 2.0%. Users of solar heating systems in Germany are generally satisfied; however, surveys show that solar thermal has a somewhat negative image in the country due to incorrect installation practices and to lower returns on investment than expected. Investment return perspectives also vary depending on whether a property is used for renting or for habitation by the owner. These difficulties can be overcome, however, as experiences with other renewable technologies such as solar PV and biomass heating have shown (Wüstenrot, 2014).

Seasonal heat storage systems have been demonstrated in Germany but the scale of application is still small. Large storage volumes (such as lagoons, gravel, water, geothermal probes or aquifers) have lower losses and much lower specific investment costs due to the favourable ratio of surface area. For some technologies, costs still pose a problem, and low-temperature heating options work only for new-built city quarters or large utility buildings.

In the future, the role of low- and high-temperature storage for linking power and heat sectors will be increasingly important. The combination of a heat pump with a low-temperature storage system makes it possible to continue the current mode of operation of heating systems, and also provides a flexibility option. In 2013, Germany lifted the ban on night storage heaters, and they can be used starting in 2019 (Die Zeit, 2013).

There is considerable experience with seasonal storage systems in Denmark and the Netherlands, which provide best practice examples. Certain areas of Germany have sandy soils that are similar to soils in the Netherlands that provide a suitable environment for storage systems. And Denmark, which has a lower solar intensity than

Figure 41: Technology breakdown and substitution costs of renewable energy shares in Germany's building sector



Substitution Cost (USD/GJ TFEC)

	Business perspective	Government perspective
Geothermal & heat pumps	12.3	10.6
Solar thermal	-1	15.7
Biomass & biogas	10	14

Note: The substitution cost presented here may by a technology average if multiple types of similar technologies for the same sector are included in the REmap Options.

Germany and a limited biomass supply, has successfully deployed biomass and solar heating systems.

In principle, district heating systems can be combined with waste incineration, biomass boilers and solar heating. Denmark has made good progress with such a strategy (Sorensen, n.d.). The main parameters for implementation are the availability of infrastructure, the density of the population and the building stock. Investment needs and the time required for related infrastructure represent bottlenecks, although smaller systems can be easier to implement, both technically and economically. Planning needs to consider these potentials and to utilise them where the opportunity exists.

Costs of renewables today

The costs of renewables typically are mentioned as the main challenge to their uptake for heating applications. However, investment decisions frequently do not consider the full range of costs and benefits. Investors (building owners or designers) often make choices based on existing knowledge by comparing renewable energy options with the available capital, without considering life-cycle costs and socio-economic benefits. In these cases, the decision favours fossil fuel technologies, or renovation is not undertaken at all. Depending on the technology, renewable-based heat may have lower running costs, although initial installation costs could be higher (GtV and WFG, 2013 ; FVEE, 2015).

Experience shows that fuel switching from inefficient gas and oil heating systems to renewables can be cost-effective. Despite higher initial investment costs, when a period of 20 years is considered (the typical lifetime of heating equipment), renewable energy technologies have an investment payback of 13 years, at the latest, following installation. Pellet boilers, an alternative to old oil heaters, have a payback period of about five years. Solar water heaters combined with gas or oil systems have similar payback periods. Heat pumps amortise the investments in a slightly longer payback period of 10 years on average (AEE, 2011).

A study by DENA (2007) illustrates the cost savings of different renewable energy and energy efficiency options in a single-family house built in 1970 that employs a heating system that is not renovated, is un-insulated and uses a standard heating boiler. Assuming an oil price of EUR 60 cents per litre, a renovation that includes a solar-combi water heater and insulation would save more than EUR 900 annually. If the heating system is retrofitted with a heat pump system or a pellet boiler, the annual savings increase to between EUR 2 625 and EUR 3 125.

REmap 2030 insights for the building sector

- The Reference Case takes Germany's renewable energy share from 13% to 32% between 2010 and 2030 in the building sector. These shares exclude renewable electricity and district heating. This is an important achievement. REmap 2030 tells us that 40% of the heat demand of all buildings in Germany can be supplied with renewables – a significant increase. To realize this however the share of renewable systems in new builds must be very high and deployment must also increase in existing buildings.
- Realising this will require diverse actions in different age segments of the building stock. By 2030, an estimated 10% of the building stock will be newly built. Renewable energy uptake in these new buildings needs to be significantly higher than the rate today – *i.e.*, greater than 40%. If renovation rates reach the 2% per year target, then an estimated 30% of the building stock will be renovated by 2030. These buildings would need to achieve the same (high) level of renewable energy uptake as new buildings today. The greatest effort is required in the remaining 60% of buildings that would undertake no (or limited) renovation in this period. As the equipment in these buildings (typically oil-based) is retired and replaced, it would need to be substituted with biomass-based boilers

Action plan and technology options: residential and commercial buildings

- Develop a long-term transition policy for energy efficiency and renewables in the building sector that creates a secure environment for investments.
- Strive to meet targets for building renovation rates and the expansion of renewable energy, especially by expanding renewable share targets to existing buildings.
- Link energy efficiency measures and renewable system deployment, for example through the use of systems such as solar water heaters, heat pumps and their gas-hybrid alternatives. These technologies offer both efficiency improvement and delivery of renewable energy services.
- Consider biomass heating if a building's heating system constraints, or location constraints, do not allow for low-temperature renewably sourced heating or district heating; however, local air pollution impacts and resource availability constraints need to be considered.
- Consider developing geothermal low-temperature heating systems, particularly in the commercial and services sector where there are needs for both heating and, increasingly, cooling and air ventilation.
- Support solar (assisted) water heating systems in new dwellings and/or solar water heater retrofits during renovation.
- Consider support for seasonal storage systems as well as diurnal and weekly storage.
- Consider demand-side technologies as well as electricity-based heating sources, allowing for flexibility to adapt to power generation from variable renewable energy sources.
- Deploy sensible heat storage technologies in large commercial buildings and regional networks, and focus on RD&D for distributed latent heat and thermo-chemical storage in residential buildings that creates linkages with variable renewable power generation.
- Plan for efficient and renewables-sourced district heating in newly built areas and consider expanding the network (as part of building renovation) in cities where infrastructure exists.

or low-temperature heating systems (i.e., heat pumps, solar thermal/combi). Some of this uptake is assumed to take place already in the Reference Case.

- REmap Options in 2030 include heat pumps, pellet boilers and solar water heaters. Their cost-competitiveness depends on the price of biomass, on capacity factors and on the type of fuel they replace. As demand for biomass increases, so can its feedstock cost. Pellet boilers can replace oil-based boilers in old buildings. The price of wood pellets can be higher than the price of residential heating oil, and therefore the substitution costs are high. One reason that biomass heating is expensive is because demand for bioenergy feedstocks is reaching the limits of its supply, thereby increasing feedstock prices. Solar thermal that substitutes natural gas-fired boilers is cost-competitive in the business perspective. When taxes and subsidies are excluded from natural gas prices (the government perspective), solar thermal results in a positive substitution cost. Heat pumps substitute for natural gas as well. Although they are more efficient than a condensing gas boiler by a factor of three, they are not cost-competitive because they operate with expensive electricity.

Transportation

Germany's vehicle fleet reached 60.4 million by the end of 2014. The country's 39.3 million passenger vehicles comprise two-thirds of the total fleet. Germany has one of the highest rates of vehicle ownership in the world. The average age of the vehicle fleet is nine years (KBA, 2015).

Compared to other end-use sectors, the transport sector is relatively complex, with different transportation segments displaying different levels of energy intensity and varying fuel type requirements and quality. Road transportation accounts for 83% of Germany's transport energy demand. The remaining 17% is split between aviation (14%), railways (2%, nearly all electricity-based) and navigation (1%). The share of renewables in the transport sector is the lowest of all sectors in Germany, at 4.5%. Realising the REmap 2030 share of 20% will therefore be a significant challenge.

Domestic focus on renewable energy policy for the transport sector is less than other sectors. European agreements play the main role in determining policy for both energy efficiency and renewables. Germany has around 125 000 electric vehicles and is adding some 30 000 annually (KBA, 2015). German auto manufacturers are very active in EV production, and the country has a wide range of such vehicles. However, it is far from reaching its target of 1 million EVs by 2020, unless significant acceleration occurs. Cost is an important barrier to uptake, but other factors also limit market ramp-up, such as the availability of charging points as well as limitations on the use of bus lanes or parking spaces.

Electric mobility requires a dual policy focus, one to accelerate ownership and another for infrastructure. According to the electricity market "White Paper", the increased use of electric mobility will depend on the development of charging infrastructure, for which Germany lags behind other European countries. This requires improving the existing rules for infrastructure investment and clarifying the energy law that categorises the recharging points. Finally, EV users should be able to recharge and pay at each point.

Electric mobility is also an option for freight transport, such as trucks. Electric highways are being discussed, although this requires additional infrastructure (similar to railways) on major highways, including in neighbouring countries as well as, in some instances, for travel to distribution centres (Siemens AG, 2015).

Biofuel deployment grew in the 2000s, but consumption today is stagnant, and arguably the trend has now reversed. Germany is one of the few countries in the world where biogas is used for transportation (other large users are Sweden and Iceland), but this remains at a small scale. German auto manufacturers have stressed diesel as a key solution. However, the potential gap between test fuel efficiencies and actual fuel efficiencies, as well as other concerns announced in 2015, highlights the importance of proper testing procedures. Unlike in other end-use sectors, oil prices play a major role in the cost-competitiveness of alternative fuels and the recent drop in oil prices has contributed stagnant growth in biofuels.

Railways have been an important part of passenger and freight transport in Germany, but there are indications that this trend is changing. Goods transport by rail is declining. With the liberalisation of long-distance bus transport, passenger bus transport is showing rapid growth at the expense of trains.

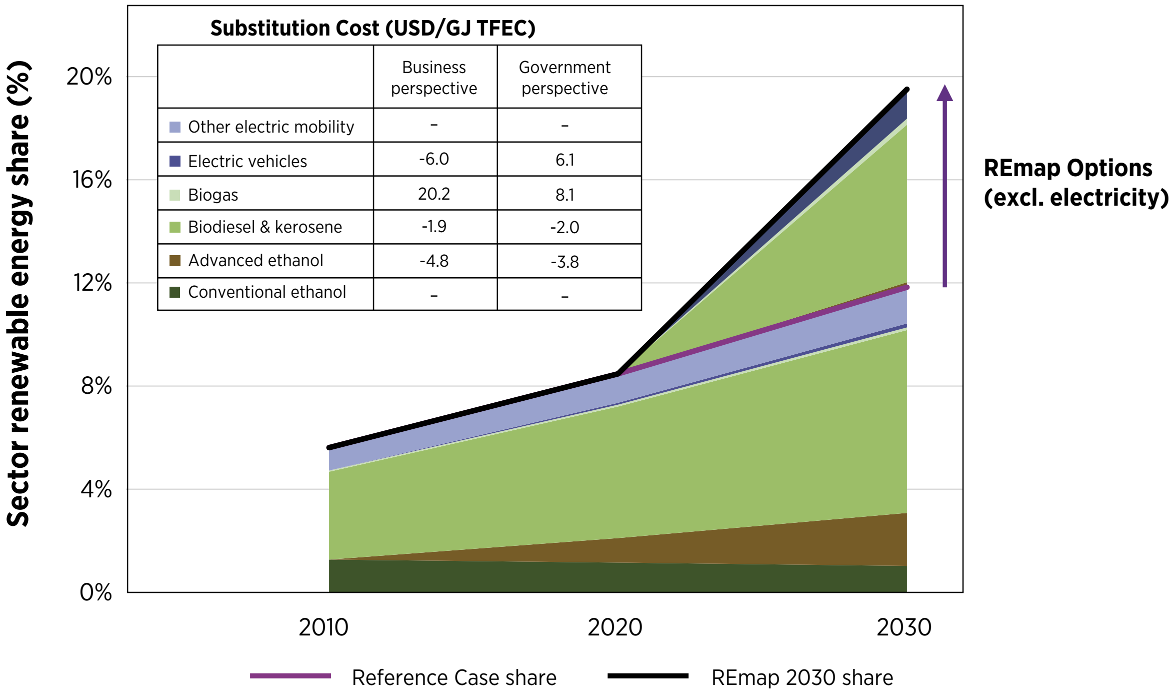
There is no government policy to introduce alternative fuels in the aviation sector. Lufthansa and Air Berlin/Etihad are among the two largest airline companies in Germany. They have put in place some voluntary initiatives to promote the use of biomass-based fuels for aviation. The German government is supporting pilot projects to produce biokerosene. The actual challenge for the international aviation sector will be how to start to achieve carbon neutral growth from 2020 onwards. An international policy framework would be the best way to avoid regional market distortions and competitiveness in the sector.

Given the relatively low deployment of renewables in Germany's transport sector and the many challenges that the country faces today around this deployment, specific policies are required that address different segments of transportation and related technologies.

REmap 2030 insights for the transport sector

- Under the Reference Case to 2030, biofuel use increases to supply around 10% of the transport sector's energy needs, reflecting strong growth in biofuels for both motor fuel and aviation fuel. The REmap Options assume this level of growth based on an accelerated scenario of the *Energy Reference Forecasts* that is driven by efforts to realise Germany's targets and that is supported by EU policy action to promote biofuels with high life-cycle greenhouse gas emission reductions. Therefore, most of this new biofuel is met with biodiesel. Biogas also is considered in REmap 2030, given that Germany is one of the three countries worldwide that uses this fuel in the transport sector. Biogas has the potential to substitute for natural gas in public passenger vehicle fleets as well as for conventional fuels in trucks. Its demand grows six-fold, but its share remains at around 0.3%.
- Costs for biofuels depend greatly on production volume, feedstock supply costs and taxes. REmap assumes that by 2030, increasing volumes of advanced biofuels will be able to compete on cost with gasoline and diesel when crude oil is priced at around USD 120 per barrel. When viewed from the business perspective, additional policy impacts increase the competitiveness of biofuels. Specific policy choices – including lower taxes and/or CO_2 price effects on biofuels due to CO_2 emissions reduction – further increase the competitiveness of biofuels.
- Electric vehicle growth is limited in the Reference Case. As recent sales have shown, the uptake in EVs is below the German target of 1 million EVs on the road by 2020. Significant uptake is necessary both in the short term as well as in the longer term to 2030, if Germany aims to achieve some 6 million EVs by then. REmap assumes that the longer-term aim of 5-6 million EVs is met within this period, consisting of plug-in hybrid and battery-electric vehicles for passenger transport as well as a smaller number of light-freight vehicles.
- The cost of switching to EVs depends largely on the ability of manufacturers to reduce battery costs as well as associated infrastructure needs for electric charging (the latter is excluded from this cost analysis). In REmap 2030, EVs continue to be slightly more expensive than internal combustion engine vehicles, even though battery costs will have declined considerably.
- From a government perspective, which assumes no tax on motor fuels, the switch to EVs results in higher costs. But because of the lower cost of electricity compared to motor fuel when viewed from a business perspective, which includes taxes on motor fuels, the switch is attractive to consumers. Consideration of road maintenance taxes and cost associated with rapid-charging could affect the electricity price and the economics of a switch to electric vehicles. Plug-in hybrids will be marginally more expensive because hybrid engine systems cost more than pure battery drives, and they also require some use of higher-cost motor fuel. However, with the added benefit of longer range, plug-in hybrids will still offer a compelling option for users who want short-distance electric drives as well as extended-range drives enabled by the motor fuel engine. Light-freight vehicles also will adopt electric drives; however, because trip distance needs between charges are longer, these vehicles will have to employ larger battery storage, increasing their relative cost of substitution compared to internal combustion engine-only vehicles.

Figure 42: Technology and cost breakdown of renewable energy shares in Germany's transport sector



Substitution Cost (USD/GJ TFEC)

	Business perspective	Government perspective
Other electric mobility	–	–
Electric vehicles	-6.0	6.1
Biogas	20.2	8.1
Biodiesel & kerosene	-1.9	-2.0
Advanced ethanol	-4.8	-3.8
Conventional ethanol	–	–

Note: The substitution cost presented here may by a technology average if multiple types of similar technologies for the same sector are included in the REmap Options.

Action plan and options: transportation

- Expand charging infrastructure not just in cities, but along main highways and in suburban regions.
- Focus on low-cost battery development as a key enabling technology, and aim for a leading global production position.
- Continue R&D for electric mobility technologies – particularly for freight transport – including electric highway systems, nodal charging, rapid recharging and high-capacity battery development.
- Support the development of electric bus systems.
- Consider strengthening and modernisation of the rail system.
- Consider better integration of high shares of variable renewable energy in the power sector, and electric vehicle battery capacities.
- Develop and implement sustainable biofuels for the aviation sector, where no other low-carbon technology alternative exists.
- Further support of research of advanced biofuel production technologies based on waste and residues, and through support for RD&D of commercial-scale production plants.
- Aim for a European biomass market that can ensure the supply of affordable and sustainable biomass feedstock and products to realise its potential for transportation.

- Despite this significant increase in EVs, their contribution to total renewable energy share remains low, at around 1.5%. This is because EVs are about twice as efficient as the internal combustion engines that they substitute for, and because their contribution to renewable energy use in the transport sector is determined by the share of electricity supplied with renewables.

Manufacturing industry

The German manufacturing industry is the largest in the EU and is the backbone of Germany's economy. The country's industry sector is characterised by both energy-intensive and small-scale sectors (see Figure 43). Energy-intensive sectors include chemicals and petrochemicals, basic metals, and pulp and paper making. The energy use of these sectors comes from only a few power plants. Small-scale sectors include food and tobacco, machinery and equipment manufacture, automotive, etc. These sectors rely on many smaller power plants (often on-site) for their energy needs.

Industrial energy demand is in part concentrated in certain locations, but also widely distributed. Concentration occurs in places like the harbour of Hamburg (refining and petrochemical industry), Ludwigshafen (BASF), the Ruhr area (chemical, petrochemical and steel plants, as well as aluminium smelters), Wesseling (refineries) and Salzgitter (a steel plant), among others.

It is imperative to maximise energy efficiency before renewables are deployed. This is especially the case in the chemical and petrochemical industry, as well as in refining – where significant efficiency potentials exist when outdated processes are replaced with the latest technologies and heat cascading is optimised. The average age of the manufacturing industry's capital stock is at least 20 years, and the demand for energy is decreasing. This creates both an opportunity and a challenge.

The lifetimes of industry plants range between 40 and 60 years, depending on the sector. This means that by 2020 and 2030, some plants can be replaced with new ones. This creates an opportunity to implement the benchmark best practice technologies as well as to install renewable energy equipment to deliver process heat when new plants are built. However, retrofitting only portions of the equipment to extend plant lifetimes is a typical practice in the manufacturing industry, as this may be more economic compared to greenfield investments. This may limit the integration of renewables.

Several best practice examples can be found in countries that have large industries and that are not experiencing growth in total energy demand, such as Japan, the Netherlands, Sweden and Switzerland. For example, Japan is leading in industrial energy efficiency, and Switzerland is particularly active in industrial solar heating. Sweden has a high level of integration of industrial and space heating, and the Netherlands has a high level of industrial heat integration, such as in Rotterdam harbour. These best practices can be employed in Germany's manufacturing industry as well, to improve energy efficiency.

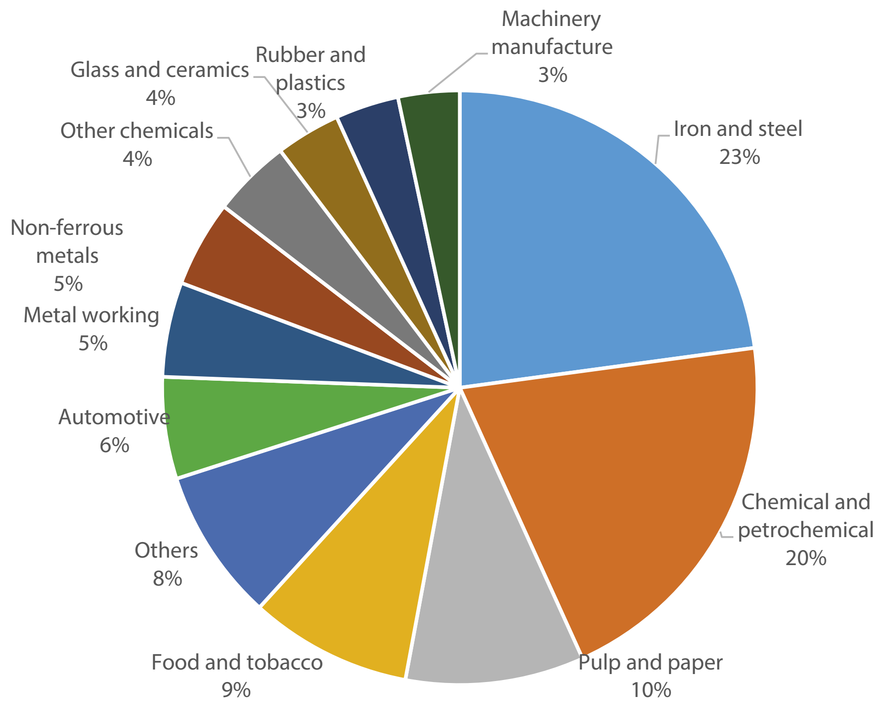
So far, Germany has given very limited policy attention to the role of renewables in the manufacturing sector. Given the sector's considerable energy use, deploying renewables for process heat can make a major contribution to the country's total renewable energy share and diversify the sector's energy supply. The manufacturing sector is different from other end-use sectors because it produces goods for consumers and needs to maintain competitiveness. This requires affordable energy sources and security of supply.

Renewables deployment in the manufacturing sector is driven by the temperature level of process heat in production plants. Figure 44 provides a breakdown of German manufacturing industry's total heat demand for processes that operate below 500 °C (including hot water and space heating) (Lauterbach, 2014). The processes displayed in the figure account for about one-third of the total industrial heat demand in Germany. The remaining two-thirds is high-temperature process heat related to basic metal and non-metallic mineral production as well as the chemical and petrochemical sector.

In view of the potential role of renewables in the manufacturing sector, industrial energy use in Germany can be broadly categorised into three areas: iron and steel production, chemical and petrochemical production, and pulp and paper production. Together, these account for more than half of the country's total final industrial energy use.

For steel production, the temperature level of heat use is very high (>1000 °C). The only alternative is newer

Figure 43: Breakdown of industrial energy use in Germany, 2013



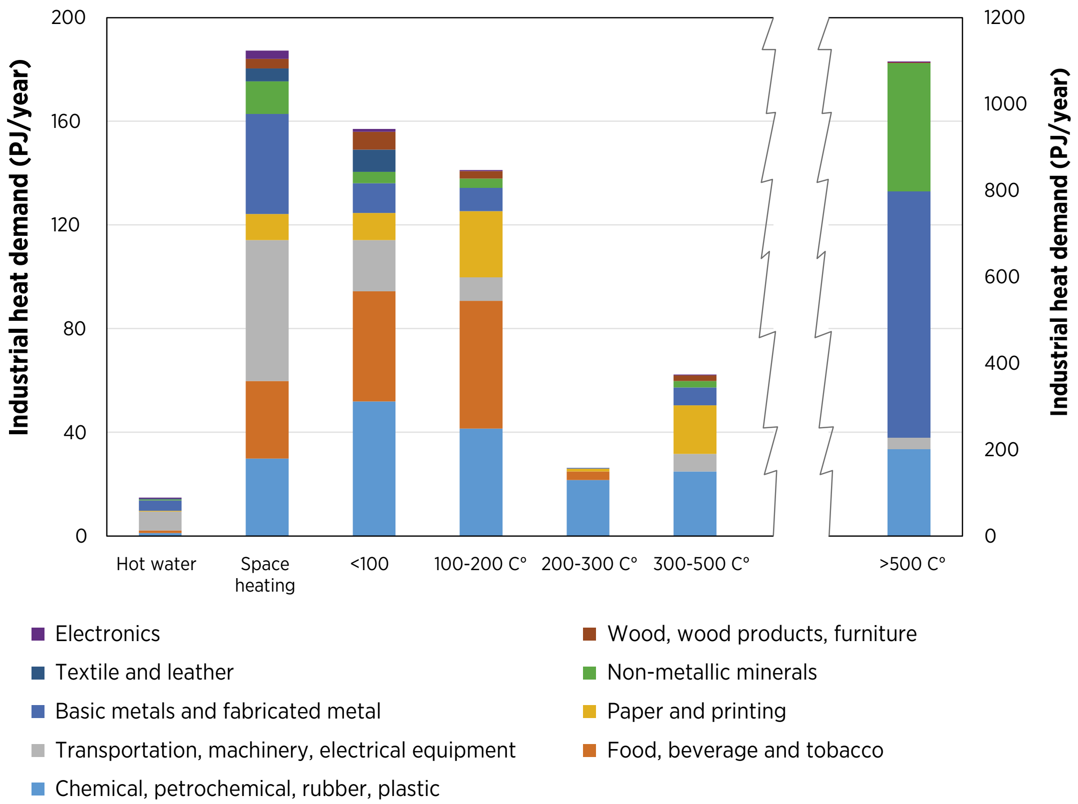
steel production processes, such as electricity-based processes or hydrogen that can be injected into blast furnaces. Electricity-based processes offer both better energy efficiency and, depending on how the electricity is supplied, a source of renewable energy. Hydrogen can be sourced from renewable feedstocks. These processes are still under development and are not expected to be commercialised before 2030. If commercialised earlier, however, they can make a significant contribution to the sector's renewable energy share. Both electricity and hydrogen offer storage potential and can contribute to accommodating higher shares of variable renewables in the power system.

Chemical plants play an important role in Germany's manufacturing industry in terms of the total energy they require. Biomass is the only source of renewable carbon for the production of chemicals and polymers. Thus, deployment of renewables in this sector will be important. However, most chemical production processes require the integration of material and energy flows. Hence, integration of new capacity with new sources of renewable energy will not always be easy unless new plants are invested in. As new plants are invested in, in both chemicals and other sectors, implementing renewables capacity in stand-alone and smaller-size manufacturing plants offers an early opportunity for renewables deployment over the coming decade.

For the pulp and paper sector, the first step is to maximise energy efficiency improvements, and subsequently to utilise the potential to integrate with local district heating networks, since much of the process heat is low-temperature. Heat cascading is potentially interesting and is another source of renewable energy.

For certain high-temperature processes – such as steel making and other metals processing, cement making and other ceramic materials, and certain high-temperature processes in the chemical and petrochemical industry – renewable electricity or biomass are the only options today. These processes currently do not use significant amounts of renewable energy, and the cost of renewable heat and international competitiveness are cited as barriers. A renewable label for commodities produced with renewable energy may create an incentive for a switch. The availability of a

Figure 44: Breakdown of industrial heat demand in Germany, 2009



Source: Lauterbach, 2014

storage area for biomass is important. Seasonality of feedstocks needs to be accounted for to ensure security of supply. If the energy demand of individual plants is lower, reliance on large volumes of biomass is also reduced.

All other demand for process heat – in food and tobacco production, the manufacturing of automotive and machinery equipment, metal working, etc. – is low- to medium-temperature heat. This opens up the potential for renewable energy technologies beyond biomass, such as solar thermal, geothermal and heat pumps. The German manufacturing industry can utilise this wide range of renewables while maintaining its cost-competitiveness.

The use of solar thermal for process heat has large potential in REmap 2030 – especially for small-sized plants that use low-temperature heat. Such plants have low energy requirements and operate fewer hours than large, energy-intensive plants. Solar thermal energy can be integrated into such processes more easily. However, upfront costs remain a major barrier and can be between 20% and 40% higher when integration costs are considered – especially when systems are retrofitted. By comparison, biomass can be integrated with negligible costs. Solar thermal uptake can benefit from innovative business models, such as energy service company (ESCO) models, that can overcome these costs. The development of a market for industrial solar heat supply systems of scale and sufficient temperature is a priority, in combination with heat storage systems.

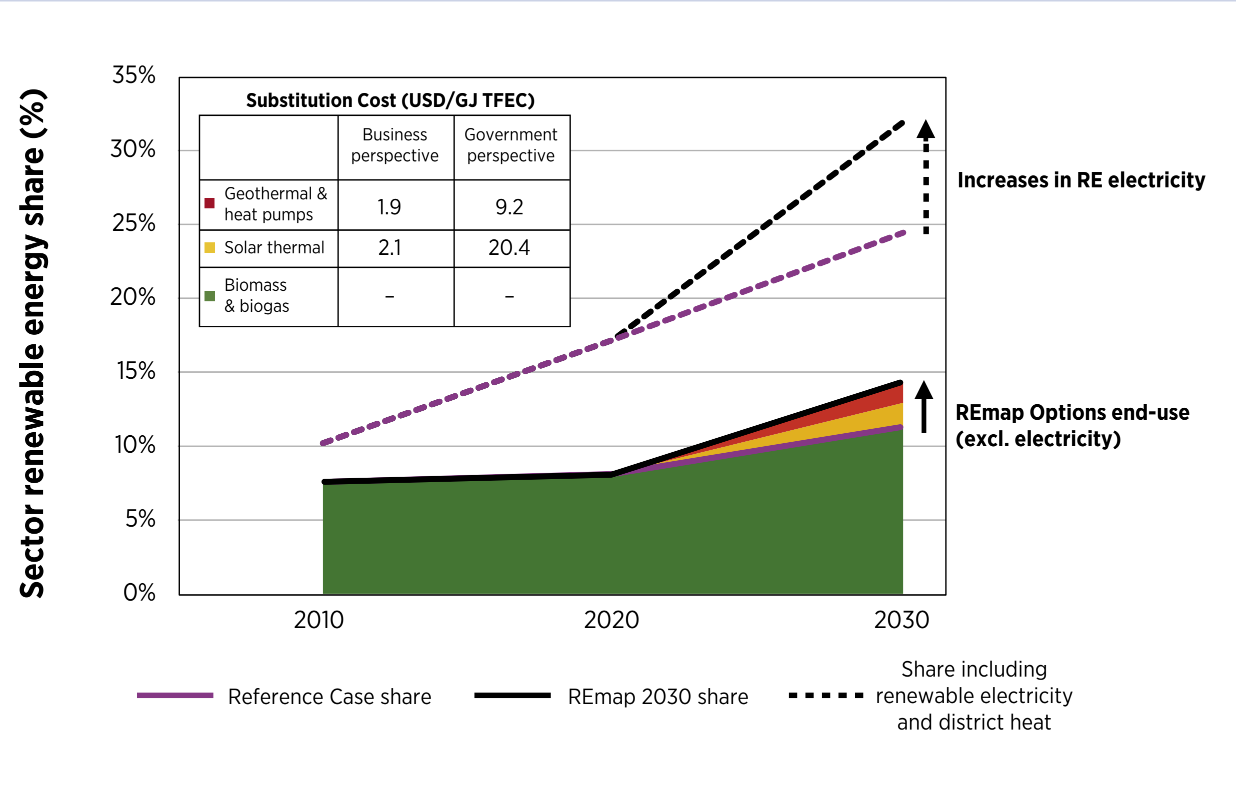
Industrial processes also require electricity for motor drives and some processes, such as cooling. CHP can serve both needs. Traditionally, maximisation of CHP has been a target, but this strategy is increasingly uneconomic in an environment of very low electricity wholesale prices that result from overcapacity caused by renewables deployment policies, and where carbon prices are lacking. If CHP is economic, however, it can provide a heat storage environment to accommodate higher shares of variable renewables for power generation. A rethinking is needed on how to provide industrial heat in a sustainable way.

Industrial production plants also may have large potential to contribute to demand-side management. Examples of this are seen in the United States, where industrial production is synchronised with variable renewable power supply.

REmap 2030 insights for the industry sector

- Germany's industrial renewable energy use is dominated by biomass. This will continue in the Reference Case to 2030. The industry sector's renewable energy share can nearly double from 7.6% in 2010 to 14.4% by 2030 (excluding renewable electricity and district heat). To achieve this, renewable energy technologies other than biomass, such as solar thermal and heat pumps, will be required.
- These technologies have great potential for low-temperature applications and together can represent about 3% of the sector's total energy demand for heating. This would represent about 200 000 industrial solar process heat units, each with about 100 m^2 area. Biomass-based heating will account for 11%.
- When renewable electricity and district heating are included, the renewable energy share of the sector more than doubles in REmap 2030, from 14.4% (excluding electricity and district heat) to 31.2%. This indicates the importance of developing electricity-based heating and cooling processes in the manufacturing industry to realise higher shares of renewables, especially when power is sourced with high shares of renewables, as is the case in Germany.
- REmap shows that, from a business perspective (including taxes and subsidies), solar thermal

Figure 45: Technology and cost breakdown of renewable energy shares in Germany's manufacturing industry



Note: The substitution cost presented here may by a technology average if multiple types of similar technologies for the same sector are included in the REmap Options.

and heat pumps will be nearly cost-competitive with natural gas-based heating in 2030. From the government perspective, however, solar thermal is more expensive because it is compared to gas prices that exclude any retail taxes. Heat pumps remain cost-competitive because they are supplied using internationally priced electricity that also excludes any subsidy and tax.

- Even with high deployment of biomass and accelerated uptake of other renewable energy technologies, the industry sector's renewable energy share remains low. Of the three end-use sectors, it sees the least growth in renewables. Energy efficiency will be key to reducing the sector's rising fossil fuel demand and related greenhouse gas emissions in the short to medium term. Breakthrough technologies that offer both better efficiency and renewables will be alternatives to conventional energy carriers in the long term.

Action plan and options: manufacturing industry

- Incentivise CHP that employs state-of-the-art technology and prioritise biomass, depending on resource and storage availability.
- Include renewable energy technologies as part of the retrofitting of existing plants.
- Support the development and deployment of low-temperature renewable heating technologies, such as solar thermal, geothermal and heat pumps.
- Synchronise the use of industrial production capacity with variable renewable power supply, as a means of demand-side management.
- Develop and implement new industrial production processes sourced with renewables, such as electricity- or hydrogen-based processes for applications where no other low-carbon technology alternative exists.

4.8 Learnings from this section

Reference Case	• Much focus today is on power sector technologies, but the Reference Case shows that increasing the renewable energy share in TFEC will be difficult without action in the end-use applications of heating and transport. The result is a renewable energy share of 27% in 2030.
REmap 2030, potential cost and benefits	• Even with high levels of deployment in the Reference Case, additional action is possible even in Germany via growth in renewable power technologies and, importantly, end-use technologies. • Action needs to be taken now to invest in systems and technologies to enable a higher renewable share in all sectors from 2030 onwards. • With accelerated renewable energy, coupled with energy efficiency measures, significant declines in CO_2 can be realised that enable Germany to meet its 2030 greenhouse gas emission reduction targets. • Even with large growth in solar PV and wind, biomass still plays an important role because it can be used for heat and liquid biofuels. Land-use and sustainability of supply/logistics will be a challenge. • Generally, when quantifying the benefits to human health and the environment, these savings are higher than any cost increase in energy services seen, with much higher renewable energy (system costs).
Challenges and solutions	• Challenges need to be addressed, such as attention to power market design. Storage will be necessary for heat and in some decentralised applications. • Demand-side management can mitigate the need for storage and increase power system flexibility. • The findings of this roadmap can be the basis for a biomass plan to deploy sustainable and cost-effective bioenergy pathways, coupled with other low-carbon technologies.
End-use sectors	• Sectoral linkages will play a key role, with an increasing need to link the power, heating and transport sectors. A sustainable heat supply depends on how it will be synchronized with the electricity and mobility sector. • It is easier to install capacity in the power sector than in the end-use sector for heating, which relies heavily on building renovation requirements and industry heating needs. • The coupling of power and heat sectors is already increasing. Prospects and consequences need to be better understood.

5 EUROPEAN AND INTERNATIONAL-LEVEL PROSPECTS

Key Points

Germany´s role in the European renewable energy sector: past, present, future

- Germany is the single largest energy consumer in the EU, accounting for approximately 20% of EU energy demand.
- Renewable primary energy production in Germany increased by a factor of nearly three between 2003 and 2013 – by far the largest growth in the EU.
- Germany generates more than one-quarter of Europe's wind power.
- Solar PV market segments in Germany are spread across utility-scale, industrial, commercial and residential projects – an important asset for a resilient solar PV industry.
- Germany hosts most solar PV installations within the EU. Other leading European markets over the past three years were the UK and Italy. Although Germany topped the list for new solar PV installations for more than a decade, new players have arisen, inspired by the German success story.
- According to the EU Renewable Energy Directive, Germany needs to increase its renewable energy share to 18% by 2020. Germany's national renewable energy action plan to 2020 outlines how this target will be met. To reach this target, Germany needs to maintain stable growth in renewable energy production over the next five years.
- Germany can and must play a leading role in implementing increased shares of solar PV and wind power in the system by addressing grid integration requirements. Germany is geographically located in the centre of the EU and plays a major role both in cross-border trade and integration of electricity markets, thereby creating a business case for all stakeholders.
- Grid development requires long-term anticipation and consideration. The European Network of Transmission System Operators for Electricity (ENTSO-E) expects 220 GW of extra wind and solar PV plants by 2022. A large share of this capacity is assumed to be installed in Germany.

Germany´s *Energiewende*: the global context

- Since the late 1990s, Germany has played an important role in the development of the wind industry, in terms of technology development, cost reductions via economies of scale, and creating a stable market for wind power installations.
- During the past 15 years, streamlined policy measures in Germany successfully drove down costs and helped other countries to learn, improve and reform renewable energy frameworks to optimise the cost performances of local renewables industries. A survey found that renewable energy investment costs are up to two times higher in Japan than in Germany.
- Germany's average global solar PV market share, during a period with the largest cost reductions, has reached approximately 40%. Thus, the German FiT – the leading driver of the solar PV market – has contributed greatly to the achievement of grid parity in many countries.
- During the past decade, Germany installed one-quarter of all grid-connected solar PV generators and contributed significantly to cost reduction, standardisation and technology development via economies of scale, due to stable market conditions.
- Germany's ongoing *Energiewende* is inspiring many countries. Although Germany is still in the top five of renewables deployment, more countries from both the industrialised and developing worlds are investing in renewable energy.

- The *Energiewende* just started. Germany aims to re-design its power market to reflect the new realities of a power system that has large shares of solar and wind electricity. Whereas the *Energiewende* in the power sector is already at an advanced stage, the transition of the heating sector is at a very early stage, and the transition of the transport sector has not even started.
- Germany played a vital role in the founding of IRENA and has supported the international distribution of detailed information about renewable energy via a variety of organisations.

The outside view: the *Energiewende* and international perceptions

- Germany introduced the first FiT worldwide in 1991. Since then, close to 80 countries and/or regions have introduced such a scheme.
- Distributed ownership of renewable energy in Germany has led to high acceptance of renewables within the country and played an important role in shaping the international perception of renewables in industrialised countries.
- In recent years, several surveys have been published about international perceptions of Germany's *Energiewende*. All surveys found that communication of the *Energiewende* – its motivations and implementation – needs further improvement.
- Perceptions of the *Energiewende* differ. Brazil, China and South Africa are among countries with a positive view of the transition, whereas countries that are concerned about their fossil exports to Germany, and that are directly affected – such as Poland and the Czech Republic through increasing loop-flow grids – tend to have a more negative view.

Room for improvement: where Germany can focus

- Aside from in a few global leaders such as Austria, Denmark and the UK, the need for renewable heating and cooling policies in the building sector is overlooked.
- Germany´s renewable heating sector lags behind those in Denmark, France and Norway. Germany´s renewables policy for transportation is weaker than that in the United States.
- The consequences of Germany´s exports of lignite- and coal-based electricity need to be addressed by various policies, including a reform of the EU ETS.

This section provides an overview of Germany's role in the renewable energy sector with respect to its neighbours, across the wider EU, and in the global context. The section discusses the role of regional co-operation with regard to infrastructural changes (especially power grids) as well as harmonisation of power market designs. The impact created through Germany's international co-operation efforts are also discussed. The section documents both positive and negative experiences in order to draw conclusions and learnings for future (renewable) energy policies, in line with the findings of section 4.

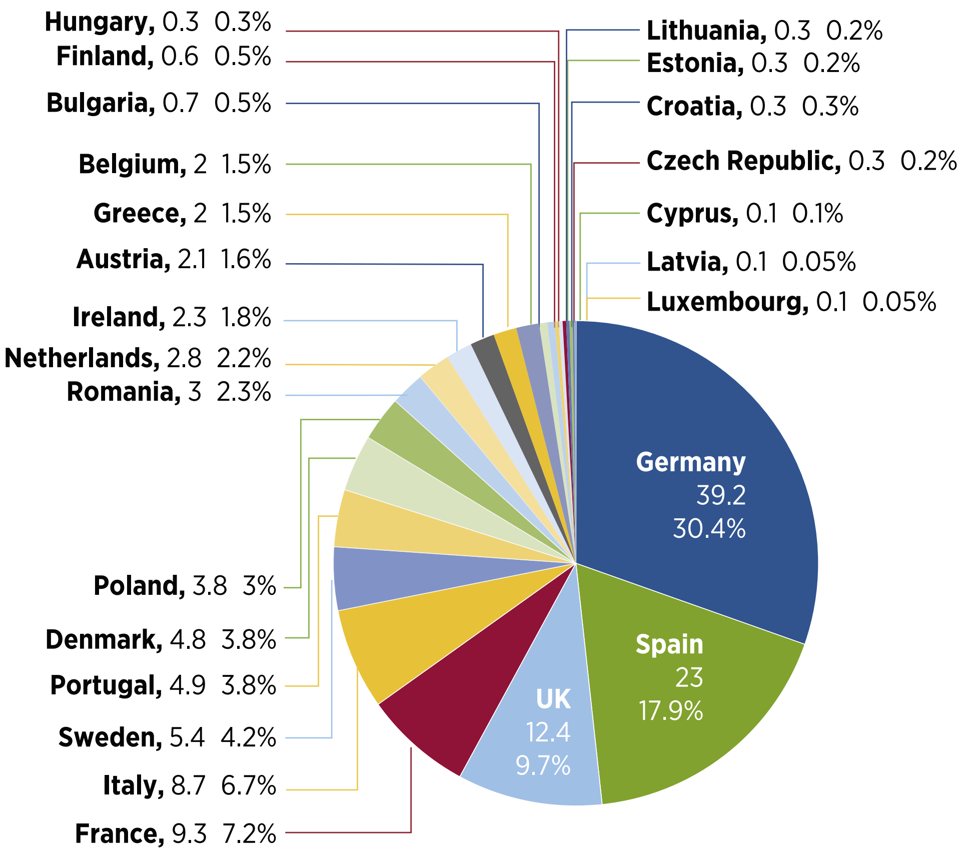
5.1 Germany's role in the EU: past and present

The *Energiewende* has influenced climate and energy policy throughout the EU and beyond. The energy policy has enabled SMEs and citizens to take part in building up decentralised solar, wind, and biomass-based power generation capacities as well as renewable heating technologies. Distributed ownership has led to high acceptance of renewable energy within Germany, which has played an important role in shaping the international perception of renewables in industrialised countries. Germany also has played a leading role in the development of the renewable energy industry within the EU. Germany hosted the most installations for onshore and offshore wind as well as solar PV in the past decade. This sub-section provides a brief overview of key statistics and renewables developments.

Renewables development: the role of Germany's wind sector within the EU

Germany has contributed greatly to the industrial development of the renewable energy sector. Since the late 1990s, the German wind industry has played a

Figure 46: Wind power installed capacity shares in Europe, by country, 2014



Source: EWEA, 2015

leading role, in terms of technology development, cost reductions via economies of scale, and creating a stable market for wind power.

Although Germany remains an important wind market for Europe, other countries have built important wind markets as well. According to the European Wind Energy Association (EWEA, 2015), annual new installations of wind power in the EU have increased by 9.8% over the last 14 years, from 3.2 GW in 2000 to 11.8 GW in 2014. By the end of 2014, the total cumulative installed wind capacity in the EU was 128.8 GW, a 10% increase over 2013.

Germany has the EU's largest installed wind capacity, followed by Spain, the UK and France. Fifteen other EU countries have gigawatt-level wind power capacity, including Poland and Romania, and eight others have more than 4 GW each of installed capacity. Germany and the UK accounted for 60% of all new installations in 2014, up from 46% in 2013 (EWEA, 2015). Germany (at 39.2 GW) and Spain (23 GW) had the largest cumulative installed wind capacity in Europe in 2014, representing roughly half of the region's total installed capacity (see Figure 46). The UK, France and Italy follow, with 12.4 GW (9.7% of total EU capacity), 9.3 GW (7.2%) and 8.7 GW (6.7%), respectively. Poland, with 3.8 GW (3% of cumulative capacity), is now in the top 10, ahead of Romania (3 GW, 2.3%), and the Netherlands is 11th, with 2.8 GW (2.2%) (EWEA, 2015).

In 2003, Germany produced more than half of the EU´s total wind power. The share has now decreased with the growing wind market in other European countries. Germany remains a large producer, accounting for a quarter of Europe's total wind electricity production (EWEA, 2015).

Renewable energy industry development: the role of Germany's PV sector within the EU

Germany has the largest installed solar PV capacity in the EU. The leading markets over the past three years were Germany, the UK and Italy. Germany topped the list for

Table 13: Wind power installed capacity in Europe, by country, 2013 and 2014

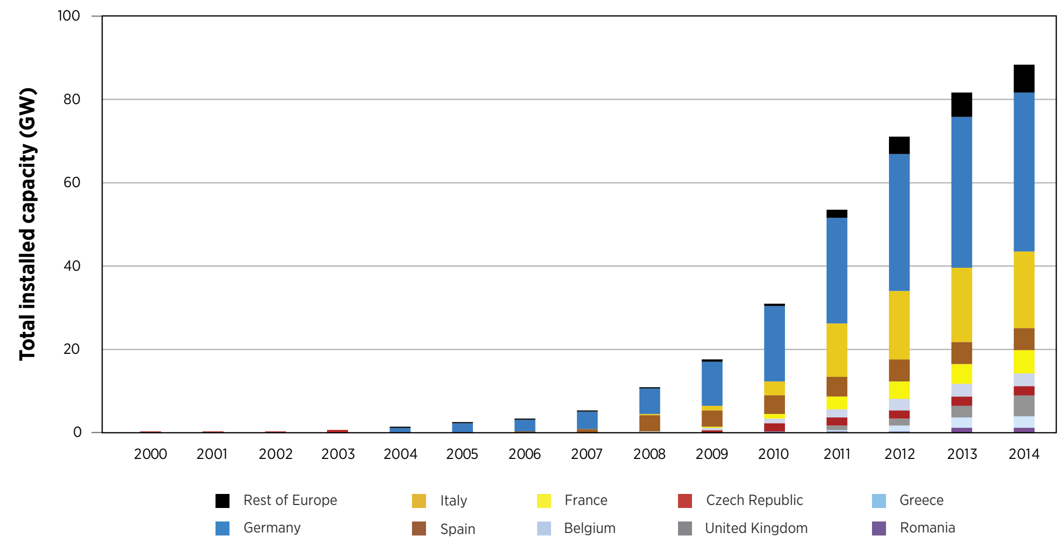
	Installed 2013	End 2013	Installed 2014	End 2014
	EU capacity (MW)			
Austria	308.4	1,683.8	411.2	2,095
Belgium	275.6	1,665.5	293.5	1,959
Bulgaria	7.1	681.1	9.4	690.5
Croatia	81.2	260.8	85.7	346.5
Cyprus	-	146.7	-	146.7
Czech Republic	8	268.1	14	281.5
Denmark	694.5	4,807	67	4,845
Estonia	10.5	279.9	22.8	302.7
Finland	163.3	449	184	627
France	630	8,243	1,042	9,285
Germany	3,238.4	34,250.2	5,279.2	3,9165
Greece	116.2	1,865.9	113.9	1,979.8
Hungary	-	329.2	-	329.2
Ireland	343.6	2,049.3	222.4	2,271.7
Italy	437.7	8,557.9	107.5	8,662.9
Latvia	2.2	61.8	-	61.8
Lithuania	16.2	278.8	0.5	279.3
Luxembourg	-	58.3	-	58.3
Malta	-	-	-	-
Netherlands	295	2671	141	2,805
Poland	893.5	3,389.5	44.3	3,833.8
Portugal	200	4,730.4	184	4,914.4
Romania	694.6	2,599.6	354	2,953.6
Slovakia	-	3.1	-	3.1
Slovenia	2.3	2.3	0.9	3.2
Spain	175.1	22,959.1	27.5	22,986.5
Sweden	689	4,381.6	1,050.2	5,424.8
UK	2,075	10,710.9	1,736.4	12,440.3
Total EU 28	**11,357.3**	**117,383.6**	**11,791.4**	**128,751.4**

Source: IRENA Statistical Database

new solar PV installations for more than a decade, but new players have since arisen, inspired by the German success story (SPE, 2015).

In 2014, the UK took the lead in Europe with an official figure of 2.4 GW of solar PV connections installed (real installations may have been higher based on recorded module shipments in the country). Germany installed 1.9 GW, significantly below its record of 7.6 GW in 2012. France installed close to 1 GW, driven by tenders granted in the past and by the growing distributed market. Besides these top-three countries, Italy is in a transition period with less than 400 MW installed despite a good regulatory framework. In markets driven by net metering, the evolution was rather negative in Belgium and Denmark, while the market in the Netherlands increased in 2014. Portugal and Austria installed more than 100 MW that year (SPE, 2015).

Figure 47: Solar PV installed capacity in Europe, by country, 2000-2014

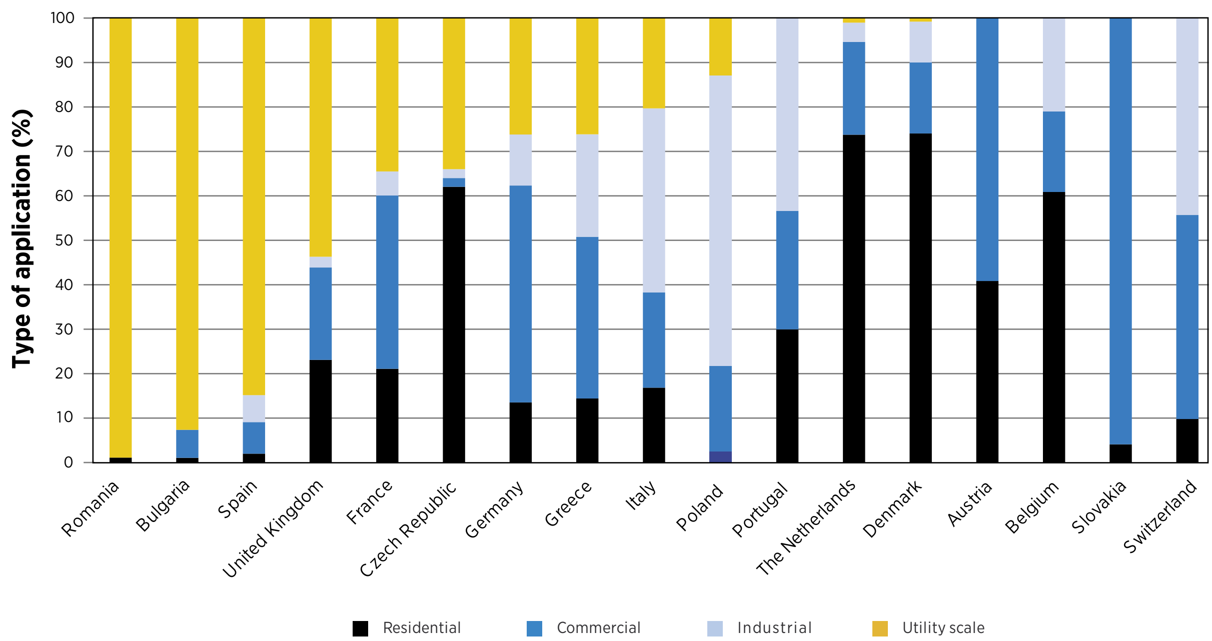


Source: SPE, 2015

Germany has reached a phase of solar PV market consolidation. The industry is undergoing significant restructuring, and policies have shifted towards more market integration. Germany was one of the first countries where solar PV became mainstream and had a direct impact on utilities and their business models.

Figure 47 shows the evolution of installed solar PV capacity in Europe since 2000. The ramping effect of support policies is illustrated clearly: the period 2006-2011 saw the effectiveness of FiTs to initiate markets, reaching a peak in 2011 and followed by a period of transition in 2012-2014. Despite its slowdown in new

Figure 48: Solar PV cumulative installed capacity in Europe, market segmentation by country, 2014



Source: SPE, 2015

additions, Germany remains the leader in total installed solar PV capacity, with 40 GW out of the 88.6 GW in the EU.

The European solar PV market remains varied, with diverse segmentation from one country to another (see Figure 48). The market segmentation has been split to distinguish between utility-scale systems, commercial and industrial rooftop systems, and residential applications. However, since the size of system depends largely on the respective support schemes in the countries, the segmentation has no standard definition among markets (SPE, 2015)

Germany's market for solar PV is distributed between utility-scale, industrial, commercial and residential projects and represents a diverse mix, since focusing on only one market segment is risky. A change in the solar policy – *e.g.*, against utility-scale PV, as happened in some countries such as Czech Republic – can lead to a collapse of the entire solar PV industry. A solar industry with distributed market segments is more resilient to policy changes.

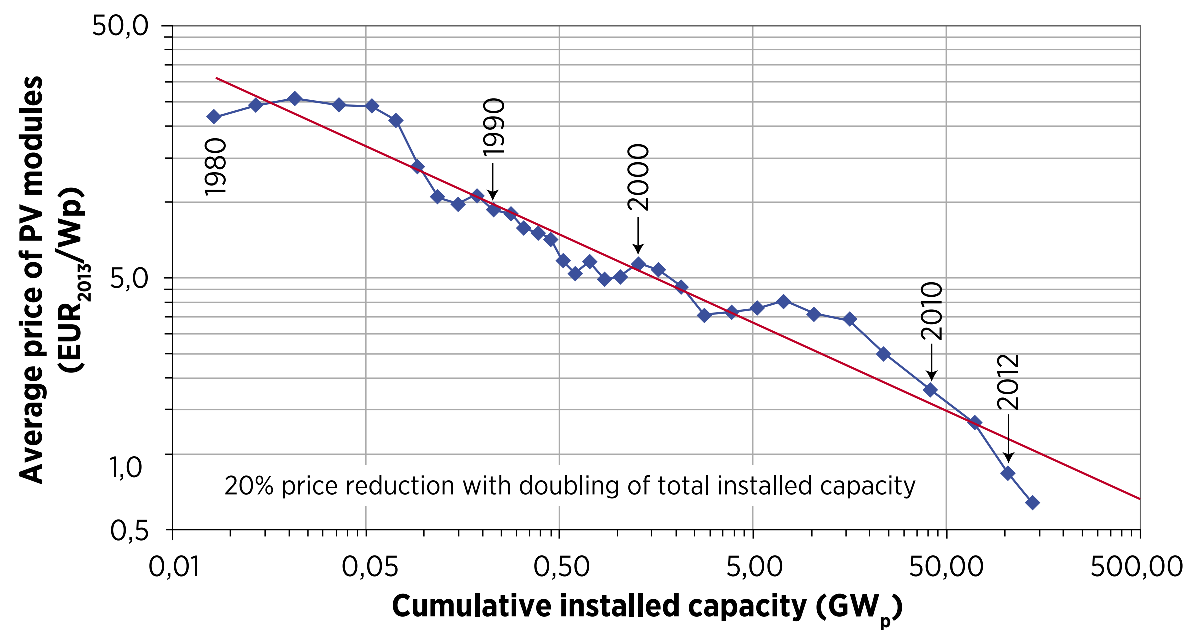
Other renewable energy technologies, aside from solar PV, have experienced cost reductions due to installation growth in Germany, although other countries played important roles as well. Spain, Denmark, China and the United States played a key role in achieving economies of scale for onshore and offshore wind power, and regional co-operation projects helped drive down the costs of CSP.

Germany´s role: reduction in solar PV costs

Germany's stable and ongoing support for solar PV, via the FiT, led to economies of scale that eventually drove down the costs of solar PV modules (see figure 49). The FiT that is paid for electricity from large-scale solar PV in the country fell from over EUR 40 cents per kWh for installations connected in 2005 to EUR 9 cents for those connected in 2014. This sudden reduction came as a major surprise to most industry experts and policy makers. Solar PV was long considered one of the most expensive renewable energy technologies, but today it is cost-competitive with both onshore wind and fossil fuel-generated power in Germany (Agora, 2015b).

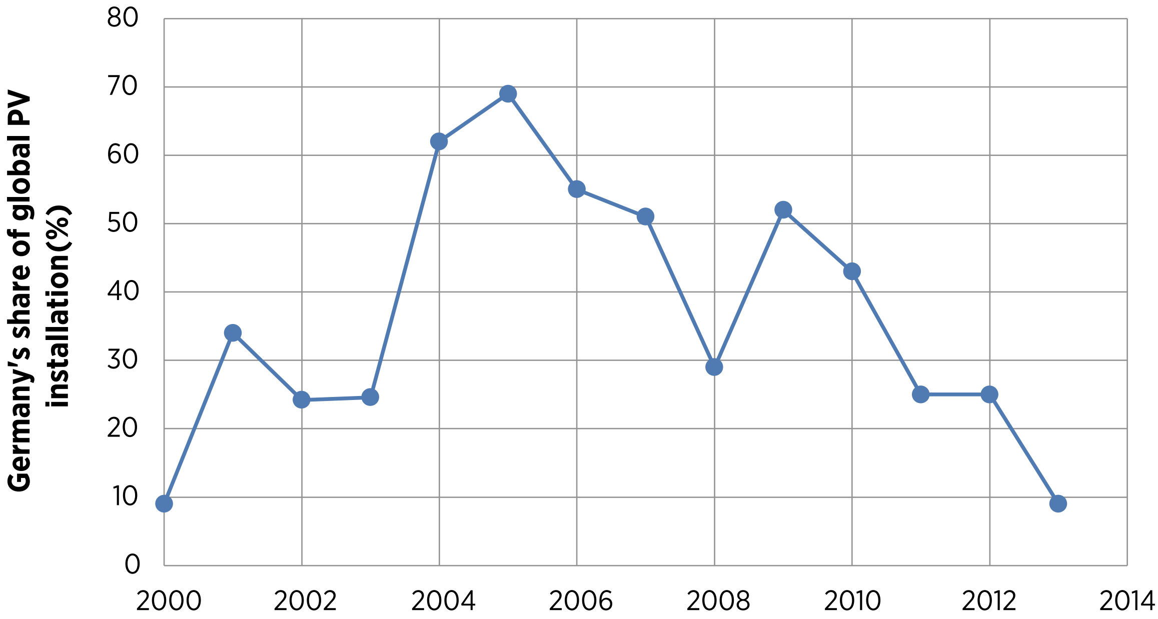
Germany´s average market share of global annual PV sales (installations in MW) between 2000 and the beginning of 2014 was 38.6% (see Figure 50). This period coincides with the largest cost reductions, from around

Figure 49: Solar PV module prices, 1980-2014



Source: Fraunhofer ISE, 2015b

Figure 50: Germany´s solar PV world market shares, 2000-2013



Source: IRENA analysis

EUR 6.0 per kW in 2000 to EUR 0.6 per kW in 2014 – a factor of 10. The German FiT shouldered around 40% of all investments during the commercialisation phase and thus has made an important contribution to cost reductions, leading to grid parity in numerous countries.

5.2 Role of Germany in the EU's renewable energy policy

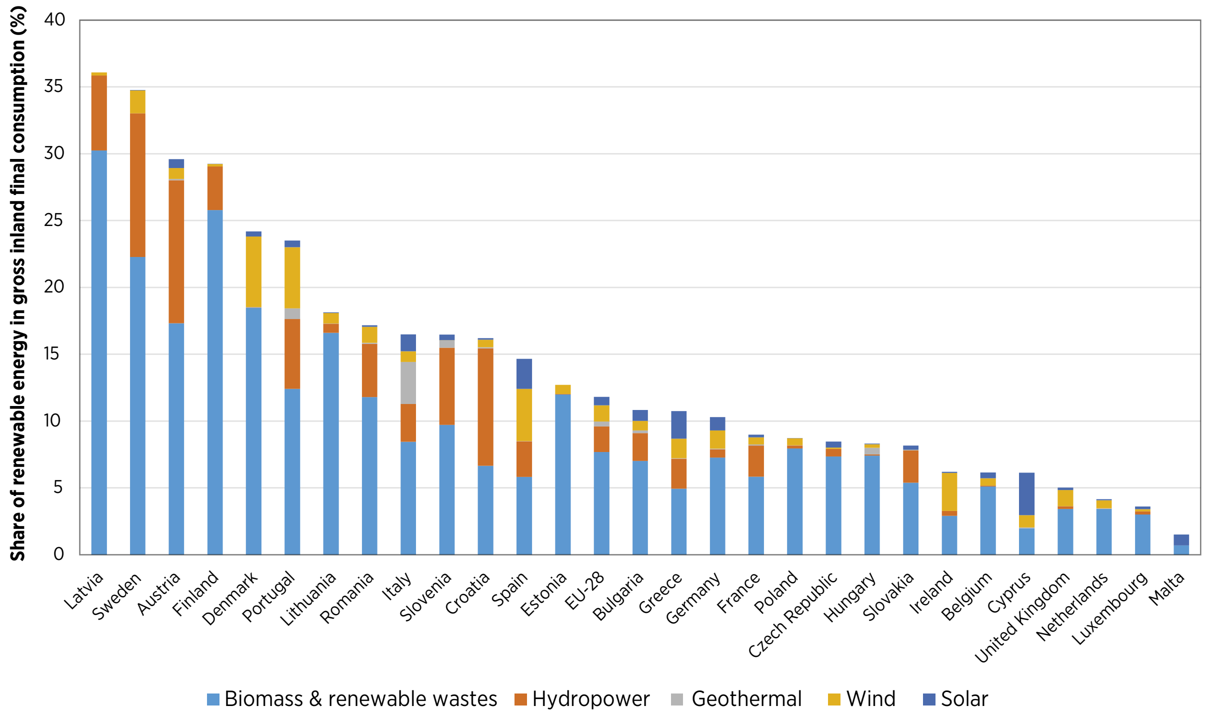
In order for the EU to reach its renewable energy targets for 2020 and beyond, Germany needs to continue to play a leading role in renewables expansion. This sub-section provides an overview of Germany´s role in the development and implementation of renewable energy targets.

Germany´s renewable energy policy development has been influenced greatly by EU energy policy, and *vice versa*. The interaction between German renewable energy policy and the EU (especially the Directorate-General for Competition) led to the initial shift from Germany's feed-in-law (*Einspeisegesetz*) in 1998 to the EEG in 2000, as a result of the liberalised European power sector. Since then, Germany has introduced several reforms to the EEG, under pressure from the EU, in order to comply with EU state-aid guidelines. These reforms include auctioning schemes (currently in the pilot phase for solar PV, but to be extended in 2017), mandatory direct selling of renewable power on spot markets and discontinuation of the FiT during periods of negative prices.

However, Germany is widely regarded in the EU as a role model for an energy transition pathway based on renewable energy and energy efficiency and had a large influence on the development of EU renewable energy and energy efficiency targets for 2020 and 2030. The high share of flexible solar and wind power generation in the German power grid has influenced the debate about future power market design not only in Germany, but across the entire European grid.

Germany increased its renewable energy share in gross domestic energy consumption from 9.31% in 2008 (BMU, 2010) to 10.3% in 2013 (see figure 51). However, overall renewable primary energy production in Germany increased by a factor of 2.7, from 527.5 PJ per year (12.6 Mtoe per year) to 1411 PJ per year (33.7 Mtoe per year) between 2003 and 2013 – the single largest increase in the EU.

Figure 51: Share of renewables in EU countries, by resource, 2013



Source: Eurostat, 2015

Germany is the single largest energy consumer in the EU, representing around 20% of the region's total energy demand. Under its national renewable energy action plan, Germany needs to increase its renewables share to 18% by 2020. To reach this target, the country needs, at a minimum, to maintain its renewable energy growth rate over the next five years. Germany's 2020 renewables target is not the highest in the EU – Nordic and Baltic states are targeting shares of 40% or higher – but Germany´s overall volume of renewable energy represents a significant share of the overall EU target and will play a key role in helping Europe meet its medium- and long-term energy and climate targets.

In October 2014, EU Heads of State and Government agreed on the targets and architecture for the EU climate and energy framework for 2030. The framework builds on the 2020 climate and energy package and

Table 14: Renewable power capacity additions in major producing countries and regions, 2004-2014

(in GW)	Small hydro	Wind	Biomass	Geothermal	Solar PV	Total
World total	0	322	54	3.9	175.2	555
Developing countries	5	2	2	0	0	9.2
China	4.5	114.2	7.7	0	28	115.9
EU-28	0	95	27.5	0.2	86.2	322.9
Germany	0	22.4	7.9	0	37.3	66.2
India	1.7	22	4.7	0	3.2	31
Japan	6.1	1.9	4.6	0	22.2	25.2
Spain	0.1	14.7	0.7	0	6	21.8
United States	0	59.3	8.9	1	17.9	87

Table 15: Renewable power installed capacity, by source, in Germany and the world, 2004-2014

	Small hydro	Wind	Biomass	Geothermal	Solar PV	Total
2004 (GW)	61	48	39	8.9	2	159
2014 (GW)	61	370	93	12.8	177	657
Change (2004 – 2014) (GW)	0	322	54	3.9	175	499
German market share of the global renewable energy (Market 2004 – 2014)	0.0%	7.0%	14.6%	0.0%	21.3%	13.3%

also is in line with the longer-term perspective set out in the Roadmap for moving to a competitive low-carbon economy in 2050, the *Energy Roadmap 2050* and the *Transport White Paper*. The agreed targets include a cut in greenhouse gas emissions of at least 40% by 2030 compared to 1990 levels, a binding EU target for renewable energy of at least 27% and an indicative energy efficiency target of at least 27%.

The decision underlines the EU's position as a world leader in combating climate change. The agreed greenhouse gas target is to be the EU's contribution to the global climate change agreement to be concluded in Paris in December 2015. The renewables and energy efficiency targets will improve the supply security of the EU and help reduce its dependency on imports. To achieve the greenhouse gas target, the EU ETS sectors would need to cut emissions by 43% compared to 2005. And the non-ETS sectors would need to cut emissions by 30% compared to 2005 – a measure that needs to be translated into individual binding targets for member states.

5.3 Germany's renewable energy in the global context

The German *Energiewende* has triggered renewable energy markets in other countries that also have contributed to the development of a global market for renewables. Germany played an especially important role in the initial phase of industry development, in particular for onshore wind and solar. Tables 15 and 16 show the renewable power capacity additions of major countries between 2004 and 2013. Germany added 14.5% of annual global installations during this period

Table 16: Top five renewable energy countries in the world by renewable energy investment, end-2014

	1	2	3	4	5
Investment in renewable power and fuels (not including hydro > 50 MW)	**China**	United States	Japan	United Kingdom	Germany
Investment in renewable power and fuels per unit GDP[1]	**Burundi**	Kenya	Honduras	Jordan	Uruguay
Geothermal power capacity	**Kenya**	Turkey	Indonesia	Philippines	Italy
Hydropower capacity	**China**	Brazil	Canada	Turkey	India
Solar PV capacity	**China**	Japan	United States	United Kingdom	Germany
CSP capacity	**United States**	India	–	–	–
Wind power capacity	**China**	Germany	United States	Brazil	India
Solar water heating capacity[2]	**China**	Turkey	Brazil	India	Germany
Biodiesel production	**United States**	Brazil	Germany	Indonesia	Argentina
Fuel ethanol production	**United States**	Brazil	China	Canada	Thailand

[1] Countries considered include only those covered by Bloomberg New Energy Finance (BNEF); GDP (at purchasers' prices) and population data for 2013 and all from World Bank. BNEF data include the following: all biomass, geothermal, and wind generation projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW estimated separately and referred to as small-scale projects or small distributed capacity; all ocean energy projects; and all biofuel projects with an annual production capacity of 1 million litres or more.

[2] Solar water collector (heating) rankings are for 2013 and are based on capacity of water (glazed and unglazed) collectors only; including air collectors would affect the order of capacity added, placing the United States slightly ahead of Germany rather than in sixth place, and would not affect the order of top countries for total capacity or per capita.

Source: Inserted from REN21, 2015

Table 17: Top five renewable energy countries, by capacity additions, end-2014

	1	2	3	4	5
POWER					
Renewable power (incl. hydro)	**China**	United States	Brazil	Germany	Canada
Renewable power (not incl. hydro)	**China**	United States	Germany	Spain / Italy	Japan / India
Renewable power capacity per capita (among top 20, not including hydro)[3]	**Denmark**	Germany	Sweden	Spain	Portugal
Biopower generation	**United States**	Germany	China	Brazil	Japan
Geothermal power capacity	**United States**	Philippines	Indonesia	Mexico	New Zealand
Hydropower capacity[4]	**China**	Brazil	United States	Canada	Russia
Hydropower generation[4]	**China**	Brazil	Canada	United States	Russia
Concentrating solar thermal power (CSP)	**Spain**	United States	India	United Arab Emirates	Algeria
Solar PV capacity	**Germany**	China	Japan	Italy	United States
Solar PV capacity per capita	**Germany**	Italy	Belgium	Greece	Czech Republic
Wind power capacity	**China**	United States	Germany	Spain	India
Wind power capacity per capita	**Denmark**	Sweden	Germany	Spain	Ireland
HEAT					
Solar water collector capacity[2]	**China**	United States	Germany	Turkey	Brazil
Solar water heating collector capacity per capita[2]	**Cyprus**	Austria	Israel	Barbados	Greece
Geothermal heat capacity[5]	**China**	Turkey	Japan	Iceland	India
Geothermal heat capacity per capita[5]	**Iceland**	New Zealand	Hungary	Turkey	Japan

[3] Per capita renewable power capacity ranking considers only those countries that place among the top 20 worldwide for total installed renewable power capacity, not including hydropower. Several other countries, including Austria, Finland, Ireland, and New Zealand, also have high per capita levels of non-hydro renewable power capacity, with Iceland likely the leader among all countries.

[4] Country rankings for hydropower capacity and generation differ because some countries rely on hydropower for baseload supply whereas others use it more to follow the electric load and to match peaks in demand.

[5] Not including heat pumps.

Source: Inserted from REN21, 2015

(or 18% when China is excluded, due to the significant differences in country size).

During the past decade, Germany installed a quarter of all grid-connected solar PV capacity worldwide and contributed greatly to cost reductions, standardisation and technology development via economies of scale, as a result of favourable market conditions. The global wind industry also has expanded greatly over the past 15 years, with the cumulative installed wind power capacity increasing from 17.4 GW in 2000 to 387 GW in June 2015 – spread across 89 countries and representing a growth factor of 22. By the end of 2014, 38 countries had an installed wind capacity of over 1 GW (GWEC, 2015).

Although Germany is still in the top five in renewable energy capacity additions, according to REN21´s *Renewables 2015 Global Status Report*, more and more countries from both the industrialised and developing worlds are investing in renewable energy. In 2014, China, the United States, Japan and the UK surpassed Germany in total renewable energy investments (see Table 16).

With regard to total installed renewable power capacity, Germany still ranks fourth worldwide (see Table 17). However, other players – including developing countries such as Mexico and South Africa – have entered the picture, putting the *Energiewende* in a more global perspective. Renewable energy is now becoming mainstream.

In terms of grid integration of large shares of renewable energy, especially variable renewables, Germany remains a clear front runner. The country's combined installed capacity of solar PV and wind power totals some 80 GW – higher than the actual average capacity demand of Germany.

China and the United States are the two countries besides Germany with the largest additions of renewables. China followed Germany's example by using a FiT to drive renewables policy. The United States, in contrast, developed a production tax credit (PTC) mechanism on a federal level (Renewable Portfolio Standards are an important driver on the state level). These fundamentally different approaches have led to different market development results. China's FiTs were implemented as early as 2003 to support the deployment of wind power. In the beginning, the tariff was determined on a case-by-case basis through bidding or negotiation. The U.S. federal renewable electricity PTC, meanwhile, is a per-kWh tax credit for electricity generated by qualified energy resources and sold by the taxpayer to an unrelated person during the taxable year.

Although Germany´s practical experience with and R&D for renewable energy integration are valuable for international comparison, other countries are advanced in renewables as well. Spain and Denmark have gained significant experience over the past decade and are now successfully integrating higher shares of wind and/or solar power than Germany.

Spain's dedicated "Control Centre of Renewable Energies" (Cecre) aims to optimise grid integration of wind and solar electricity, an initiative from which Germany can learn. Cecre's website provides a detailed overview of the situation in the power grid. The Electric Power Research Institute (EPRI) of California has documented the early experiences of Cecre (EPRI, 2010).

The Danish transmission system operator undertakes advanced grid integration research projects, such as the "cell project", which breaks down the power grid into clusters of demand and supply (Energienet). The project aims to integrate a share of 50% wind electricity into Denmark's power grid. Field test and power grid simulations were conducted between 2005 and 2011 in co-operation with scientists from different countries. An extensive description of the modelling and simulation efforts has been published, followed by a summary of the key field tests performed on the live distribution network (the pilot project region) in western Denmark. The documentation concludes with a summary of the major outcomes and lessons learned from the project and its relationship to Smart Grid development activities in Denmark, Europe and the United States.

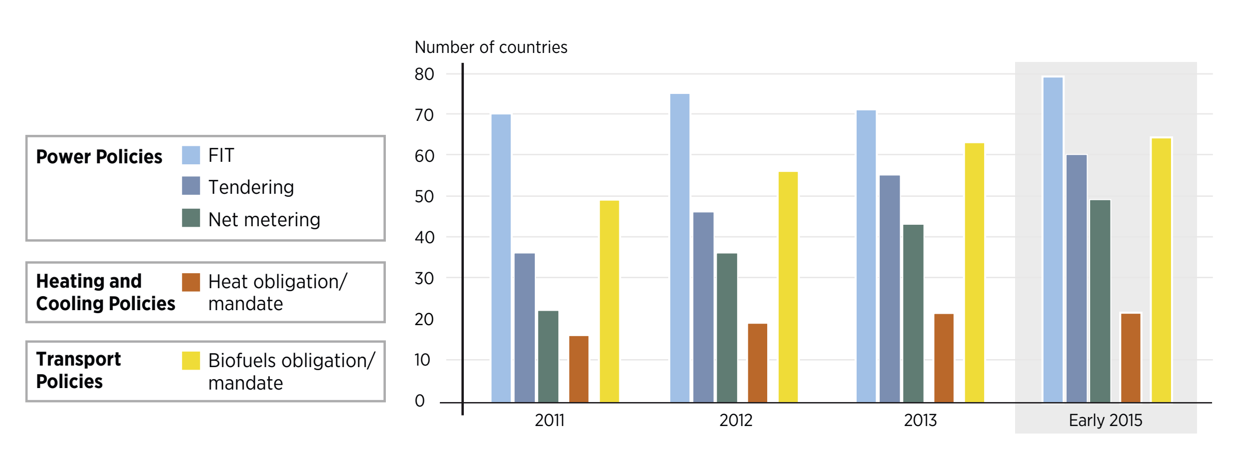
The Arab Future Energy Index (AFEX), inspired by the EU energy target, was established under the leadership of the Regional Centre for Renewable Energy and Energy Efficiency (RCREEE, 2015). The AFEX is a policy assessment and benchmark tool that aims to provide a comprehensive assessment of the investment climate for renewable energy development, as well as its progress to date in the Arab region (IRENA, 2014b). The assessment is based on the compilation and analysis of detailed, country-specific data according to a set of pre-defined indicators. AFEX Renewable Energy is designed with consideration of the private investor's perspective and consists of four evaluation categories: market structure, policy framework, institutional capacity, and finance and investment. These four categories are broken down into 10 factors, which subsequently are divided into sets of quantitative and qualitative indicators.

By early 2012, more than 100 countries had in place one or more policy instruments to support accelerated power generation from renewables (IRENA, 2015c). By far the leading support policy for renewables in the power sector is FiTs (see figure 52). Although their designs vary widely, all FiTs provide a stable tariff per kWh for several years to minimise investment risks. Germany was among the first countries to implement a FiT: the *Stromeinspeisungsgesetz* in 1991. Since then, close to 80 countries and/or regions have introduced such a scheme. The number of FiT systems is still increasing, but auction systems have grown as well, especially since 2011. Net metering – particularly for solar PV – has remained at a relatively low level in recent years.

With decreasing costs for renewable power – especially solar PV and wind – the financial support that comes with mechanisms like FiTs becomes less relevant. As the next step, the integration of large shares of renewables requires a focus on infrastructural policies – especially grid access and priority dispatch – and overall market design. Germany is currently developing a new power market design – "electricity market 2.0" – which reflects the "new reality" of a renewables-dominated electricity system.

In the heating and cooling sectors, heat mandates are used almost exclusively across all countries, including Germany (IRENA, 2015c). Although Germany started to

Figure 52: Number of countries with renewable energy policies, by type, 2011-early 2015



Source: REN21, 2015

"Note: Figure does not show all policy types in use. Countries are considered to have policies when at least one national or state/provincial-level policy is in place."

develop FiT-based heating, growth was below expectations due to the lack of grid infrastructure.

Germany introduced biofuels obligations in 2014, whereas the United States launched its renewable fuels standard in 2005 and Brazil introduced biofuel mandates much earlier, realising higher shares of renewables in its transport sector. As in the heating sector, Germany's transport sector has in place obligations/ mandates for a certain amount of renewable energy in the system. However, this is now changing to a target based on greenhouse gas emission reduction.

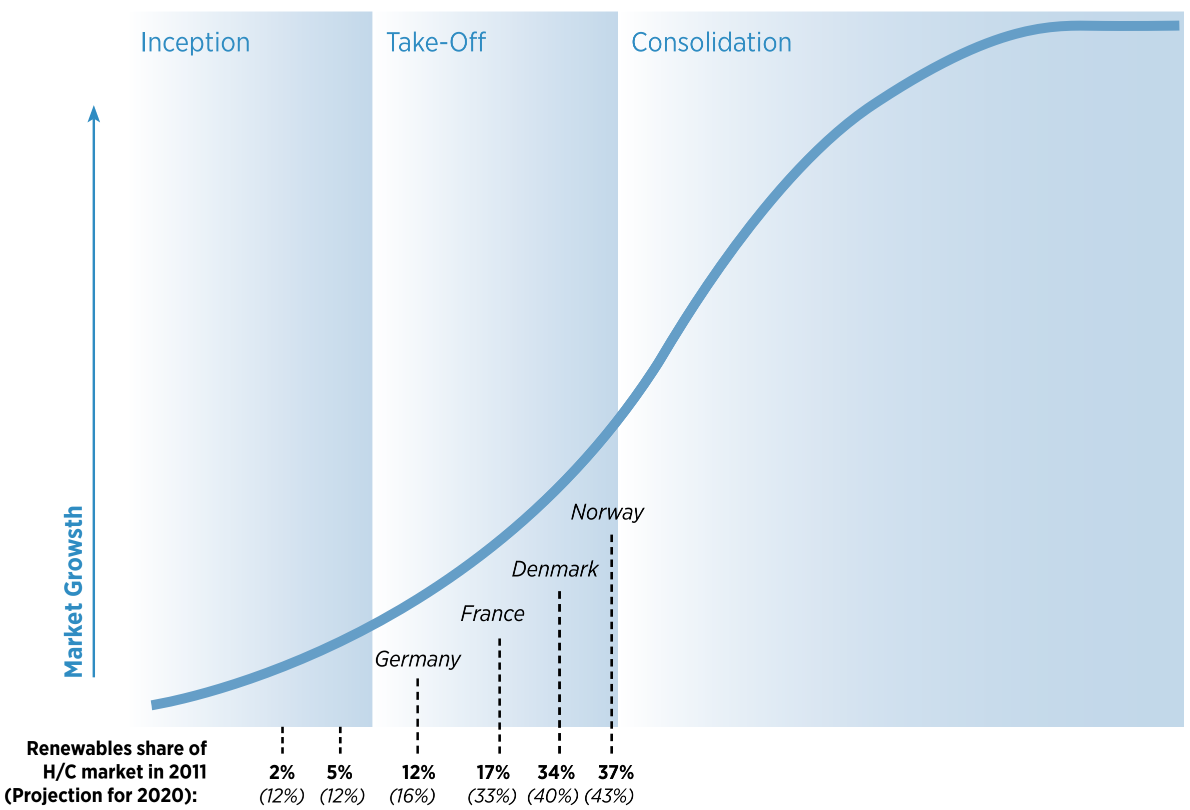
Except for a few global leaders such as Austria and Denmark, most countries have overlooked the need for renewable heating and cooling policies in buildings. This is now starting to change. In 2012, the UK launched the Renewable Heating Incentive (RHI) for commercial and industrial consumers, the first comprehensive, performance-based incentive for renewables-based heating; it was expanded in 2014 to cover residential applications (Prime, 2015; IRENA, 2015d). The RHI pays a set tariff to residential, commercial, public and industrial consumers for every unit of renewable heat generated on a pence-per-kWh basis.

Conventional district heating networks traditionally have supplied consumers using high- or medium-temperature heat (in high-pressure systems). These systems typically are served by only biomass, CHP or fossil fuel boilers and have hindered the widespread integration of low-temperature renewables such as solar hot water or heat pumps. To address this technical barrier, district heating companies and energy planners are preparing to pilot low-temperature district heating grids. Due to their lower operating temperatures, such networks are much more efficient and can enable end-users to deliver low-temperature surplus heat from buildings back to the thermal grid. Low-temperature networks are expected to "serve as a backbone of smart cities", increasing communities' flexibility to integrate renewable heating and cooling and energy efficiency technologies into buildings (REN21, 2015).

A 2014 IEA report analysed the status of renewable heating policies worldwide (IEA-RETD, 2015). Figure 53 indicates Germany's position in the international context: it is ahead of the UK and Ireland in terms of the renewables share, but behind France, Denmark and Norway.

On a global level, the trend in renewable heating policies is moving clearly towards the use of technology-neutral heating and cooling targets, often in connection with building codes and/or planning regulations (REN21, 2015). This reflects the trend towards "systems thinking", or combining different renewable energy technologies across sectors (power, heating, industry and transport) to improve the integration of flexible solar PV- and wind-based generation. Currently, 47 countries worldwide have renewable heating/cooling targets (IRENA, 2015d).

Figure 53: Deployment of renewable heating and cooling policies in IEA-RETD countries



Source: IEA-RETD, 2015

The growing international renewable energy industry is creating an increasing number of jobs around the world. According to IRENA's *Renewable Energy and Jobs Annual Review 2015* (IRENA, 2015e), in 2014 an estimated 7.7 million people worked directly or indirectly in the renewable energy sector in 2014. Solar PV is the largest employer, with 2.5 million jobs, most of which are concentrated in China because of its undisputed lead in manufacturing as well as its rapidly expanding domestic market. Japan, the United States and Bangladesh also have boosted their solar PV employment.

Liquid biofuels remains the second largest employer, with close to 1.8 million jobs. Global wind power employment crossed the 1 million jobs threshold in 2014. Growth has been especially strong in China and the United States, with Brazil and the EU experiencing moderate increases (REN21, 2015). The growing work force adds to the positive image of renewables and leads to greater acceptance. Both in Germany and internationally, the local value chain and the connected positive influence on regional economies is a strong driver for renewables.

5.4 Regional integration to realise higher shares of renewables

Germany is at the centre of European energy markets and is linked closely with the electricity markets of its neighbours. According to the German "Green Paper", Germany and Austria have a common bidding zone and Germany is directly coupled with the Nordic countries (Denmark, Finland, Norway and Sweden), the UK and the other countries of Central-Western Europe (Belgium, France, Luxembourg and the Netherlands) via a common market-clearing algorithm. Germany is indirectly coupled with the Baltic states and Poland, which themselves are coupled with the Nordic market via a common market-coupling algorithm.

Germany can realise its energy and climate targets via better integration with EU markets. Regional integration is regarded as a core component for strengthening power markets and the European electricity markets that already are coupled. Regional cross-border co-operation that supports renewable electricity integration requires new power market designs to make it a strong business case for all stakeholders. In July 2015, the European Commission adopted new market rules for the creation of the internal energy market. The rules, which entered into force in August 2015, provide a legal framework for electricity trading and make market coupling binding across the EU; they are estimated to save customers up to EUR 4 billion per year (EC, 2015a).

The European power system is going through additional changes. One of the five dimensions of the "Energy Union" strategy is to work together on security of supply (EC, 2015b). This will benefit all European countries, including Germany. The German "White Paper" specifically elaborates strengthening the European electricity market as a core action area (BMWi, 2015b). To accommodate higher shares of renewables and to ensure security of supply, market integration must be intensified. This requires flexible markets both on the supply and demand side within EU borders and beyond. Integrated markets offer greater availability of flexibility potential and also provide the advantage of using smoothing effects and efficiency gains. To achieve this, expanding cross-border trade, demand-side management and distributed generation, as well as strengthening grid infrastructure and employing high-voltage long distance connections, will be key.

As a basis for integrating electricity markets, the European Commission has proposed the European target model, with four components: the coupling of national electricity markets in the day-ahead markets, cross-border electricity trade (intraday market), framework for long-term transmission right and shared methods for the relevant underlying capacity calculations. Rules for participants are implemented in the network codes. The Agency for the Cooperation of Energy Regulators (ACER) prepares draft framework guidelines, which form the basis for drafting network codes (ACER, 2012).

Network codes become binding after the EU law is modified within the comitology committee chaired by the European Commission. There are 10 network codes, at different stages of deployment. As of late September 2015, ACER had published a recommendation for five of the network codes. For two of the codes, comitology has begun, and for another two, a cross-border committee has delivered an opinion. The network code for capacity allocation and congestion management has formally begun implementation (ENTSO-E, 2015a).

One of the key network codes focuses on electricity balancing, the final step in realising an integrated electricity balancing market. Balancing is important to ensure affordable supply security with low environmental impacts. It also can reduce the need for back-up generation. To date, the progress in integrating national balancing markets has been limited. This is due mainly to differences in existing national balancing markets and in balancing resources. However, there is a large potential for harmonisation to achieve a single European electricity balancing market by increasing cross-border competition in the balancing time frame and improving balancing efficiency.

The time frames within which the European balancing market should be achieved represent a balance between the expectations of different stakeholders and the current limited progress in the integration of balancing markets compared to other markets (*e.g.*, the day-ahead market).

According to the European Commission's Energy Union document, much progress has been made in market integration. However, fragmentation in the energy sector across European countries remains an issue, and the current market design results in only limited investments and competition.

The EU has a specific focus on infrastructure projects, including systems for both electricity and natural gas. In 2014, 33 essential projects were identified to improve security of supply and better integration of energy markets. The current interconnection targets are 10% by 2020 and 15% by 2030. According to the EU investment plan, infrastructure investment needs (for both electricity and natural gas) are EUR 200 billion within the next decade.

European 10-Year Network Development Plan and Germany's role

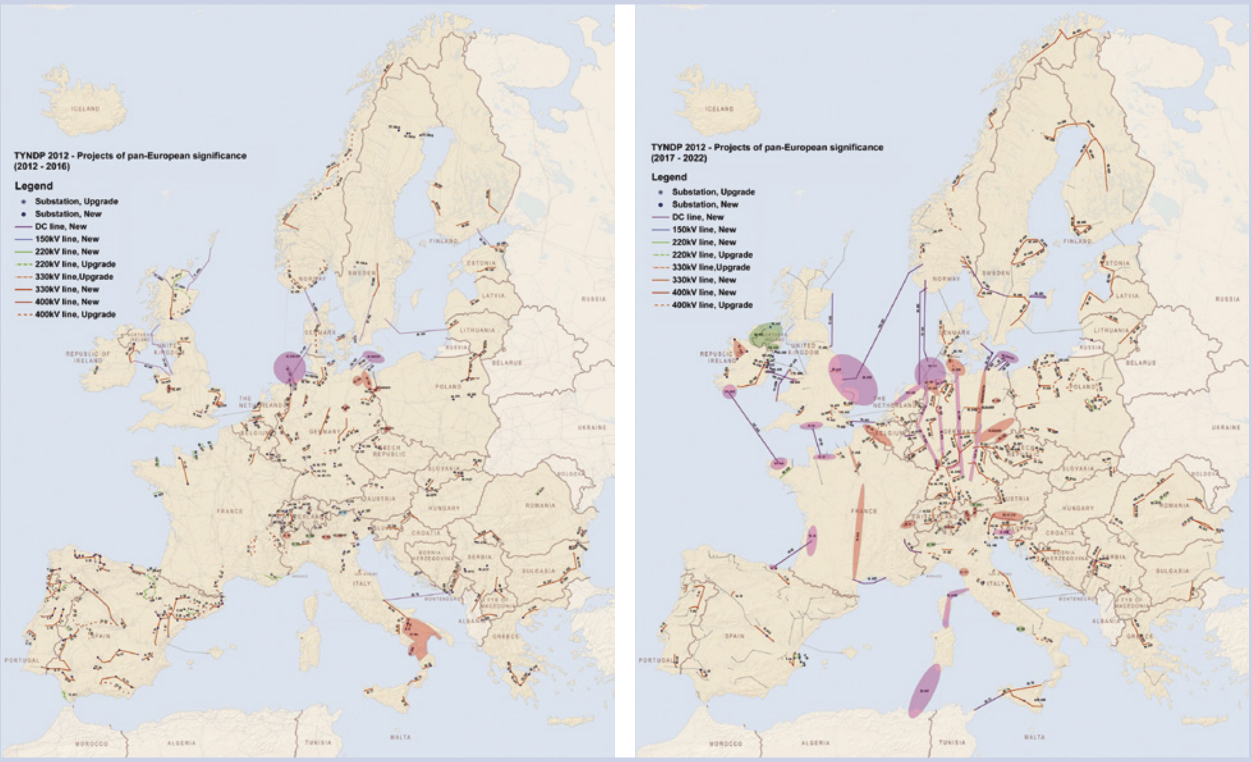
The European Network of Transmission System Operators for Electricity (ENTSO-E) and its members play a key role in developing and facilitating a new electricity market. Transmission system operators have made considerable progress towards creating an internal energy market and delivering the network codes. However, there is further room for ENTSO-E to improve its already integrated electricity market, particularly in six key areas: 1) implementation of all 10 electricity network codes, 2) facilitation of investments in indispensable transmission infrastructure, 3) facilitation of member states' energy mix and security of supply policy co-ordination at the regional and European levels, 4) progress towards co-ordinated mechanisms in energy security situations, 5) updating the market design to deliver a more secure energy supply and better prices to citizens, and 6) fostering RD&D in transmission networks (ENTSO-E, 2015b).

One important area that requires focus is the need to complete grid investments to reach the internal energy market. ENTSO-E's *10-Year Network Development Plan* (TYNDP), published in 2012, outlines all planned projects for the coming period on the basis of a grid modelling that includes future renewable targets for each member state. The TYNDP started as a collection of national transmission system operator plans, but it aims towards transnational planning. Figure 54 shows the geography of investments. The left-hand map shows all mid-term commissioned projects (*i.e.*, in the first five-year period, 2012-2016), and the right-hand map shows projects commissioned from 2017 onwards. The latest version of the TYNDP, released in 2014, highlights the need for a total of EUR 150 billion in investments between now and 2030 (ENTSO-E, 2014).

Germany is geographically located in the centre of the EU and plays a major role both in cross-border trade and the integration of (renewable) electricity. Projects of pan-European significance total about 52 300 km of new or refurbished extra-high voltage routes, compared to the existing grid length of about 305 000 km. The expected commissioning dates are split nearly equally between the two five-year periods.

Compared to TYNDP 2010, the TYNDP 2012 figures represent a 25% increase in grid expansion or enforcement projects. Several extensive new investments are under consideration, including more than 3 000 km of subsea routes (developing in total 10 000 km of offshore grid

Figure 54: Mid-term (left) and long-term (right) projects under the TYNDP



Source: ENTSO-E, 2012

key assets) and more than 7000 km of routes inland, mostly to bring to load centres the power generated on the outskirts of Europe.

Grid development requires long-term planning and consideration. ENTSO-E has developed four visions for 2030, characterised by different shares of renewable and conventional power generation, to examine the challenges and opportunities for transmission system operators. One scenario is developed "top down" by ENTSO-E, and a second is based on information about grid expansion plans from national grid operators. This so-called SAF-B scenario uses a bottom-up approach to extrapolate information using the current investment perspectives of market players (ENTSO-E, 2012).

The basis for these scenarios is the European 20-20-20 strategy, which includes the following objectives:

- Power demand evolution influenced by the past economic crisis, strong energy efficiency measures, and the switch from fossil fuel to electricity (heat pumps, electric vehicles) in end-use applications and development of electronic devices;
- Renewable energy continues to grow, mostly from wind and solar PV, providing 38% of regional electricity demand by 2020;
- Depending on the share of gas- and coal-fired units in the mix in the coming 10 years, CO_2 emissions of the power sector also decline.

ENTSO-E assumes 220 GW of extra wind and solar energy capacity by 2022 (10 years following the report's publication in 2012) and acknowledges that "80% of the identified 100 bottlenecks are related to the direct or indirect integration of renewable energy sources (RES)"; this is comparable to the assumption of Reference Scenario 2030 (TNYDP, 2012). Of the estimated capacity expansion of 220 GW, much is assumed to be installed in Germany, particularly offshore wind but also PV. As of November 2015, ENTSO-E had not yet published a renewable energy scenario reflecting the European targets for 2030 for the next updated TYNDP, scheduled to be published in 2016.

The TYNDP is closely linked to the grid expansion plans of Germany's four transmission system operators. Interconnection with neighbouring countries to exchange (renewable) electricity and/or dispatch capacities is vital and beneficial for better integration of large shares of flexible wind and solar power. Higher exchange capacities through grid interconnection with countries that share a border with Germany can greatly reduce integration costs for renewables. A study commissioned by Greenpeace (2014) calculated the negative effects of a lack of interconnection between Germany and the rest of Europe and potential financial damages in case of conflicting energy policies. It concluded that capacity factors, both for renewables and conventional power plants, are reduced significantly when grid interconnections are not available.

Germany's increased ambition for renewable energy in the power sector will affect grid integration as well as cross-border trade, due to higher solar and wind shares. However, storage technologies such as pumped hydro for seasonal storage or batteries for short-term storage are planned to a large extent. In 2015, storage capacities are much more expensive than transmission capacities (ENTSO-E, 2015b). However, new battery technologies could help to integrate far more renewables, especially low-voltage solar PV. By 2030, the largest uses of battery storage will be for solar PV systems. As the cost of storage declines and as FiT payments decline and eventually end, system owners increasingly will store electricity and offset purchases at hours when electricity is more expensive. These storage technologies can be managed better with demand-side measures and with smart meters, especially in distribution networks.

Pentalateral Energy Forum

In 2005, Energy Ministers from the Benelux countries (Belgium, the Netherlands and Luxembourg) as well as Germany and France created the Pentalateral Energy Forum (Penta), which Austria and Switzerland also later joined as observers in 2011. Penta is an inter-governmental initiative, co-ordinated by the Benelux secretariat, with a core objective of promoting collaboration on cross-border exchange of electricity. It provides a framework for regional co-operation on improved electricity market integration and security of supply (GoB, N.D.).

Penta comprises three support groups, dealing with issues around market coupling, security of supply and flexibility. It has a track record of implementing innovative measures such as the first (and so far the deepest)

Box 4: Required network expansion and changes in scenarios with high renewable energy shares

Under an accelerated renewable energy scenario developed by Greenpeace and the consultancy Energynautics (2014) – the "Energy [R]evolution 2030" scenario – Europe covers 53% of its load with wind and solar PV by 2030. If hydropower, biomass, geothermal and CSP – which are called "renewable controllable generation" sources – are included, the total load coverage by renewables would increase to 77% by 2030 across Europe.

A conflict scenario illustrates what happens if non-variable coal, lignite and nuclear power plants are kept in the system while variable resources are added across Europe (with the exception of France, Poland and the Czech Republic, which follow a baseline by keeping and extending less-flexible base-load power plants). All other EU countries would implement high levels of renewables combined with flexible controllable generation. Coal and nuclear would have priority in the merit order, dispatched inflexibly according to their residual load, with a 20% flexibility band. The flexibility band identifies to what extent the power plant can vary its power output. The network expansion would be determined to reduce curtailment of renewables, and batteries are assumed to be coupled with 10% of all solar PV systems, with no TYNDP projects assumed; expansion is determined based on today's power grid.

Renewable power supply in the EU increases, showing high growth rates, and countries like France and Poland – which currently rely on more than 70% coal and nuclear power – achieve shares of over 50% renewables by 2030. France, the Czech Republic, Poland and Spain remain electricity exporters. Spain achieves a full renewable electricity supply, with a minor need for natural gas power plant back-up, while some gas power plants in France and the Czech Republic operate with high capacity factors in 2030.

Curtailment of wind and solar plants is kept to minimum. Inflexible controllable power plants such as coal are pushed out, and "flexible" controllable renewables cover the entire residual load. Thus, in the accelerated renewable energy scenario, there is no longer space for any baseload power plants by 2030. Some key results include:

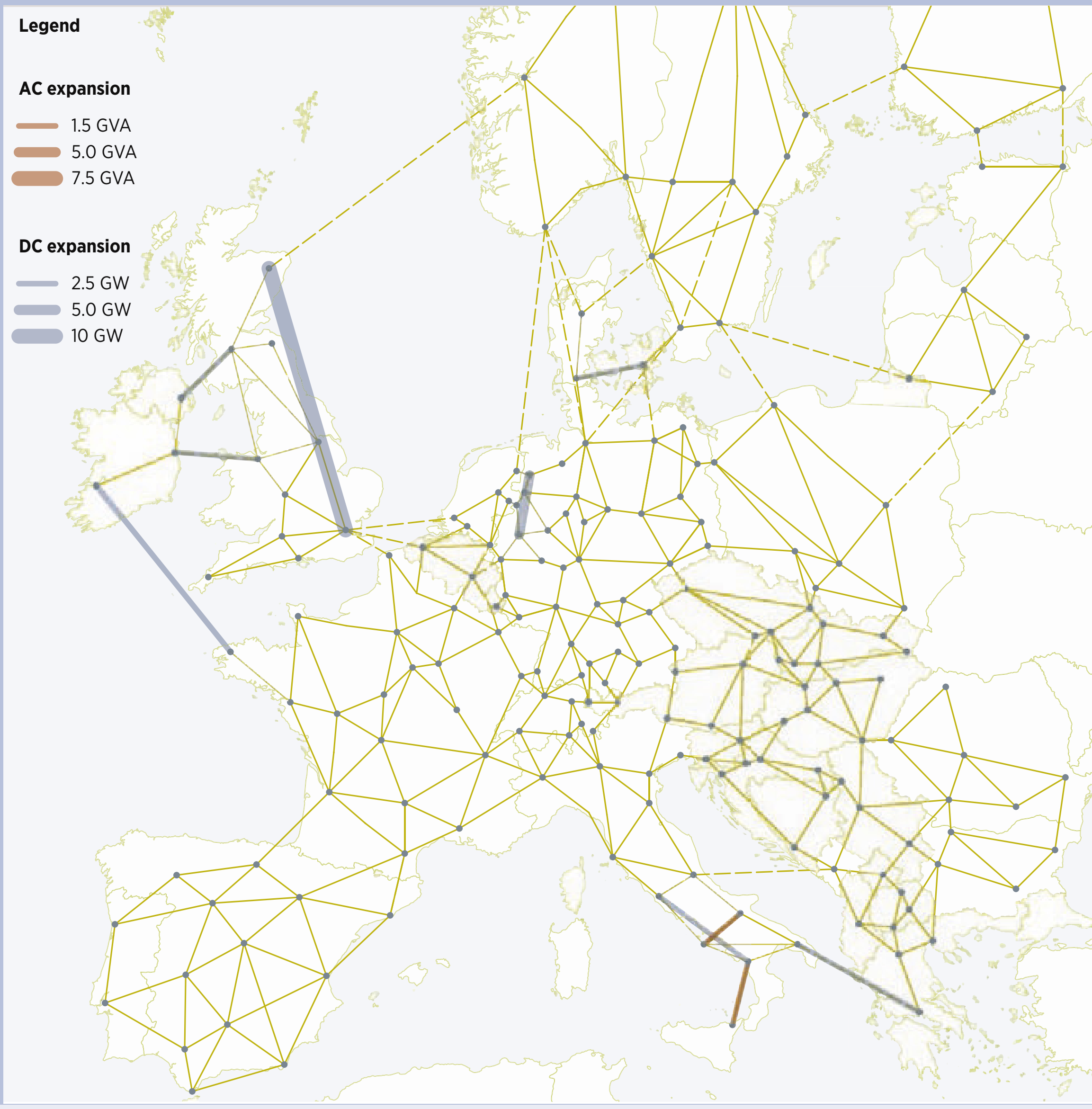
Batteries (with a nominal power of 10% of installed solar PV capacity) have reduced network extension needs by around 10%, through capping of solar PV peaks.

- By starting with today's network instead of the TYNDP, and by using an optimised overlay high-voltage direct current (HVDC) grid, total network extensions can be reduced by a further 40%.
- By encouraging expansions of HVDC over high-voltage alternating current (HVAC), total network extensions are reduced by a further 19%.
- The accelerated renewables scenario – with its focus on DC transmission corridors – needs fewer lines because the power is transferred directly from one region to another and stops electricity from spreading out in the neighbouring network ("loop flows"), which causes further stress on the AC network and requires more expansion.
- As a side effect of the HVAC overlay network, there is also lower curtailment, which has a big impact on the total system price. HVDC has lower thermal losses and has no need for reactive power compensation along the line.

Key new European power corridors include (see figure 55):

- Germany's North Sea offshore wind to the Ruhr and then to southern Germany
- Spain to France to export power from Spain and Portugal's large wind and solar PV plants
- Scotland to southern England for wind
- France's Atlantic coast to Paris for wind
- Through Italy

Figure 55: Network expansion in 2030 under a high renewable energy share scenario



Source: Greenpeace, 2014

Note: Red is AC extensions, blue is DC extensions, yellow is existing AC and dashed yellow is existing DC. The thickness of the lines is in proportion to the size of the extensions.

coupling of day-ahead markets and the first assessment of regional generation adequacy in Europe.

In recent years, Germany has given political momentum to the Penta regional initiative by pushing for enhanced market integration and regional assessment of security of supply. Since 2014, the German government has reinforced its co-operation with its neighbours, both bilaterally and regionally within initiatives like Penta and within the group of "12 electrical neighbours". A set of no-regrets measures has been highlighted in this context in order to move jointly towards greater system flexibility (Fraunhofer IWES, 2015).

The role of European carbon pricing for renewables

The price of EU allowances (EUA) in the EU Emissions Trading System fell from almost EUR 30 per tonne of CO_2 in mid-2008 to less than EUR 5 per tonne in mid-2013. As of mid-2015, it had increased to around EUR 8 per tonne. According to Koch *et al*. (2014), the EU ETS and the region's renewables deployment targets work at cross-purposes, and the growth of wind and solar PV has not contributed greatly to the drop in EUA prices. The sensitivity of carbon price changes to wind and solar growth is relatively minor. Hence, the effects of policy interaction between the ETS and renewables are moderate. The study also concluded that 90% of the carbon price variation remains unexplained, and further research is required to identify the actual drivers.

However, CO_2 emission reduction efforts during a time of economic crisis, as well as the use of international project certificates (Clean Development Mechanism / Joint Implementation) in the ETS, can be considered reasons for the current surplus of EUAs, which has led to the price drop. Thus, reform of the EU ETS is required, and the large renewable expansion is not an outcome of the European carbon price policy. Germany's electricity market "White Paper" also highlights the need for EU ETS reform to achieve a better steering towards low-carbon renewable and natural gas power generation developments. The EU ETS should address exports of lignite- and coal-based electricity as well, with the aim of reducing their volumes.

The reform may not deliver – in a sufficient time frame – the incentives that Germany requires to realise its targets for greenhouse gas emission reduction. This calls for the development of national mitigation actions. Energy efficiency alone will not be enough to achieve any target. As discussed in section 4, renewable energy needs to be core part of this action, and synergies with energy efficiency must be utilised to their full extent.

5.5 Perceptions of the *Energiewende*

Globally, German's (renewable) energy policy is followed with great interest, and there is broad agreement across the international community about the country's overall approach. However, certain aspects of German energy policy (such as the nuclear phase-out) have received criticism (Table 18), while others (such as the expansion of onshore wind) tend to be viewed positively. In recent years, several surveys about international perceptions of the *German Energiewende* have been published. This sub-section summarises the findings of three very diverse reports, by Greenpeace (Jungjohann, 2014), BP (2013) and Germany's Konrad-Adenauer-Stiftung (KAS, 2013).

The main conclusion of these surveys is that the *Energiewende* generally has a positive image. However, another common finding is that communication of the *Energiewende* (especially regarding its motivations and implementation) with neighbouring countries and trade partners can be further improved. The German government has taken this recommendation seriously and has begun to address it, including through an inter-ministerial working group and through a concerted effort to provide more information in English.

According to Jungjohann (2014), although international media outlets report frequently on the *Energiewende*, they often fall short of comprehensive coverage. Only a fraction of German media reports are available in English, and arguments often are translated out of context. In contrast, German media reports on the *Energiewende* tend to be comprehensive and balanced. Articles often address how the energy transition can succeed, what its opportunities and challenges are, and how policies should be designed.

The review of studies also suggests that there are specific factors affecting a country's perception of the *Energiewende*, such as fossil fuel resources, utility-state relations, geographic proximity to Germany and language. Sceptical views of the *Energiewende* seem to be more common in Europe and the United States, in comparison to emerging economies or developing countries. A negative perception is more likely in countries that – as a result of the *Energiewende* – fear a decrease in fossil fuel exports to Germany (such as Russia) or see business opportunities at risk (like the US shale gas industry). Perceptions also are more likely to be critical in countries that are affected directly by the *Energiewende*, such as Poland and the Czech Republic, where loop flows through their grids are increasing.

The *Energiewende* often is perceived as being unique and exceptional, but its goals are less exceptional than is generally assumed. Many countries are adopting policies aimed at significantly expanding renewables – such as Denmark, but also large energy consumers like China, France and the United States. One of the strongest drivers of the *Energiewende* – community and citizen energy – is probably its most overlooked feature. It also is important to highlight that the *Energiewende* is embedded in EU frameworks for 2020 and 2030 targets.

The BP survey (2014) finds that awareness of the *Energiewende* is relatively low among the general public in neighbouring countries, but its overall goals are supported. BP conducted a three-question survey in five countries bordering Germany to find out what its citizens think about the *Energiewende*. The main finding reveals that those who have heard of the *Energiewende* support the idea overwhelmingly. The majority of people responded that the *Energiewende* creates new jobs and reduces fossil fuel imports (Morris, 2014).

The expert survey from KAS (2013) analysed how the emerging countries of Brazil, China and South Africa perceive the *Energiewende*. All three countries clearly

Table 18: Common claims critical of the Energiewende

Category	Claim
Social	• The *Energiewende* burdens the poor with high energy prices to cross-finance the solar panels of wealthy homeowners.
Procedural	• Germany overreacted to Fukushima and acted too abruptly. • The sudden closure of nuclear power plants in 2011 was not communicated to neighbouring countries in advance and endangered their supply security. • By phasing out nuclear, Germany is internationally isolated.
Cultural	• Germany's opposition to nuclear energy is a result of "German angst". • Opposition to renewables and the *Energiewende* is rising in Germany. • The *Energiewende* is an unpopular measure orchestrated from above.
Economic	• The *Energiewende* is a burden on Germany's economy. It is economic suicide, because it drives up energy prices, kills job and will result in de-industrialisation. • Renewables receive massive subsidies, whereas nuclear power and fossil fuels have to play by market rules. • The troubles facing German utilities (RWE, E.ON) are an indicator that the *Energiewende* is missing its goals and is failing.
Technical	• The shutdown of nuclear power plants will threaten Germany's energy security and lead to more power imports from other countries. • Renewables undermine grid stability in Germany and neighbouring countries. • Germany is using the grid in other countries to dump its excess wind and solar power on to its neighbours, which cannot compete with those highly subsidised imports. • Wind and solar are laughably small contributors to German grid power.
Environmental	• Germany is building more coal plants and burning more coal because of its nuclear phase-out, and emissions are rising. • The *Energiewende* drives more lignite mining.

Source: Jungjohann, 2014

saw the potential in the switch, but there also was great interest, from a short-term perspective, on the potential impact of the transition on energy security and energy costs.

One of the most significant findings was the positive overall image that Germany enjoys in the three countries. The experts from Brazil, China and South Africa thought that, although the *Energiewende* was an ambitious project, Germany, of all countries, would succeed in making it a reality. The experts noted that Germany's future independence from raw material imports would be one of the positive long-term effects. Given that Germany lacks raw materials, the experts considered the decision to make the switch to be entirely logical. Another common opinion was that the *Energiewende* would strengthen Germany's economic power in the long term, and the experts saw it as a potential model for a new industrial revolution (KAS, 2013).

5.6 International co-operation

As explained earlier in this report, renewable energy policy and promotion has a long history in German policy making. Yet Germany's remarkable influence on international renewable energy policy and governance is frequently overlooked. With its *Energiewende*, the European and international dimensions of renewable energy promotion become very important, and Germany is playing an important role in this area (Roehrkasten and Westphal, 2013).

Germany has been active in raising awareness, spreading knowledge and sharing its experiences about renewables with stakeholders from other countries through various international-level meetings and conferences. The recent "Berlin Energy Transition Dialogue" in March 2015 aimed to initiate an international dialogue to tackle the global challenges of renewables on an industrial and system-wide scale. The meeting provided a platform to meet and share experiences of German and international stakeholders with the most important energy sector decision makers.

A recent comprehensive survey on *Global Governance of Renewable Energy* (Roehrkasten, 2015) documents Germany´s role in the context of renewable energy on the international level over the past 10 years. The survey notes that German initiatives on global renewable energy governance were fuelled largely by the limited outcomes of United Nations (UN) processes. Because limited action was achieved in defining time-bound, and defined targets, Germany opted for initiatives outside the formal UN context. The main focus of government action was institution building. Germany launched the multi-stakeholder network REN21, initiated the creation of IRENA, and instituted a series of global international renewable energy conferences, held initially in Bonn in 2004 with subsequent events in Beijing, Washington, Delhi, Abu Dhabi and Cape Town.

While these initiatives oscillated between "coalitions of the willing" and broad participation and representativeness, they all focused on one major goal: supporting governments around the globe to increase the deployment of renewable energy sources. The initiatives were grounded in domestic policy efforts to promote renewable energy, which focus primarily on the electricity sector. The main driving force behind the domestic policies has been a strong anti-nuclear movement. Concerns about climate change also played a role (Roehrkasten, 2015).

The Federal Environment Ministry (BMUB) has been the main driver behind German initiatives on global renewable energy governance (in 2013, energy affairs were moved to the BMWi). It has been joined by the Federal Ministry for Economic Cooperation and Development (BMZ). At a later stage, the Ministry of Foreign Affairs (Auswärtiges Amt) played a role when Germany pushed for IRENA's creation. During that time, neither industry associations nor non-governmental organisations (NGOs) showed major engagement, since NGOs in particular feared driving away attention from the ongoing international climate negotiation under the UNFCCC process.

According to the German government, transboundary policy making on renewable energy is intrinsically linked to global environmental protection. In Germany's deliberations on global renewable energy governance, references to climate protection are never missing. Sustainability, particularly in its ecological sense, is presented as the core criterion to guide the choice among different renewable energy options (Roehrkasten, 2015).

Market structures and policies that discriminate against renewable energy pose a major barrier to the worldwide spread of renewables. Transboundary policy making should aim primarily at improving domestic regulatory frameworks. To do so, it should commit governments to promoting renewables and support governments in realising their commitments.

The German government presents IRENA, the IEA and REN21 as the most relevant global governors. All of these organisations provide information and policy advice on renewable energy. The government emphasises that transboundary policy making should focus on the worldwide promotion of renewables, thus targeting both industrialised and developing countries. It underlines that industrialised countries should take the lead in the worldwide promotion of renewable energy, whereas it attributes developing countries with a rather re-active role (Roehrkasten, 2015). Additionally, Germany has engaged countries globally on renewables through the G7 and G20, including in 2015 through Germany's G7 presidency.

5.7 Learnings from this section

Role of Germany in the EU: past and present	• The *Energiewende* has influenced climate and energy policy throughout the EU and beyond. Germany also has played a leading role in the development of the renewable energy industry within the EU. • Germany had the highest number of installations for onshore and offshore wind as well as solar PV in the past decade.
Role of Germany in the EU renewable energy policy	• In order for EU to reach its renewable energy targets for 2020 and beyond, Germany needs to continue to play a leading role with regard to renewables expansion.
Renewables in Germany in the global energy context	• The *Energiewende* triggered renewable energy markets in other countries that also have contributed to the development of a global renewable energy market, both in terms of German renewables capacity and via implementation of the FiT. In addition to Germany, other countries have advanced in renewable energy, such as China, Japan and the United States. Countries such as Denmark and Spain have implemented similar or even higher shares of variable renewables in their power systems. • Worldwide, the focus on renewables for heating/cooling markets has been limited, including in Germany, but several countries, such as the UK, are introducing policies to accelerate renewables uptake.
Regional integration to realise higher shares of renewables	• Germany is at the centre of European energy markets and it is closely linked with the electricity markets of its neighbours. Regional integration is needed for security of supply and higher flexibility if Germany is to achieve higher shares of variable renewables in its power system. The main challenge lies in grid infrastructure. EU ETS reform is needed, but this may not provide sufficient incentives in the short term. Germany may need to develop national mitigation measures to reach its long-term greenhouse gas emission reduction targets, with renewables and energy efficiency playing the main role.
Perception of the *Energiewende*	• The *Energiewende* generally has a positive image. Communication of the *Energiewende* – its motivations and implementation – with neighbouring countries and trade partners can be further improved. • China, Brazil and South Africa find the impacts of the *Energiewende* on energy security and energy costs to be the most interesting.
International co-operation	• Germany has been playing a remarkable role in foreign renewable energy policy and international governance for promotion of renewables and sharing experiences from its *Energiewende*, with a specific focus on institution building such as IRENA and REN21.

6 LEARNINGS FROM THE REPORT FOR GERMANY, THE EU AND INTERNATIONALLY

Each section of this report has provided insights and learnings that are relevant to German, EU and international audiences. This section provides a high-level overview of these learnings fit into seven key areas and details some of the important topics that will need to be addressed when moving into higher levels of renewable energy deployment. This section is meant only to provide a guide, for different audiences, to the learnings from this report and to where more effort is needed. More in-depth insights are provided in the sections themselves. To assist the reader in finding this information, for each of these seven areas, links are provided to the relevant sections.

The three key sections of this report include:

- **Section 3: Germany's *Energiewende*: market frameworks and economic results** documents the past decade of the *Energiewende*: experiences, challenges and areas where more attention is required going forward.
- **Section 4: A view to 2030: Reference Case, REmap, challenges and solutions** takes a forward-looking view and discusses Germany's renewable energy potential, including planned deployment as well as additional technology options, many in the end-use sectors. It quantifies these technologies in terms of potential, costs and benefits and lays out some of the challenges, solutions and action items that can help in realising them.
- **Section 5: European and international-level prospects** puts all this into a wider context both on the European level as well as on a global scale. It addresses the role of Germany within the EU and the importance of the EU and regional integration, and outlines Germany's role at the global level for renewables deployment.
- Based on these sections, this report identifies the following seven key areas with important take-aways and learnings.

The future of the *Energiewende*

The *Energiewende* is an evolving effort that engages government, private sector and civil society. Its evolution will continue to 2030 and beyond. The *Energiewende* has inspired other countries to reinforce and grow their ambitions to increase renewable energy use. The German energy system already has been transformed by steadily increasing shares of renewables. The solutions that Germany and its neighbours pioneer in the coming years will enable the realisation of ambitious long-term energy and climate goals; however, these solutions also must result in a cost-effective energy system. To enable this, several key themes emerge:

German level:

- Continue with a stable and predictable policy framework to maintain a strong basis for the renewable energy industry and to enable R&D to remain competitive in the global market
- Support infrastructure projects and long-term integrated energy planning for transmission and distribution that allow for the integration of high shares of renewables
- Utilise sectoral linkages among power, heating and transport
- Develop national actions for climate change mitigation in co-ordination with EU ETS improvements

European and international levels:

- In view of Germany's leading role in the EU to achieve renewable energy targets, help other

- member states adopt ambitious renewables policy and targets
- Have the EU play a stronger role in enabling regional partnerships to support the grid integration of renewables
- Improve the EU ETS by considering increased cross-border trade of electricity and making renewables a core part of climate policy

Additional reading:

Long-term strategy for future energy supply (section 3.1)

Renewable electricity and infrastructural changes (section 3.1)

Future of the *Energiewende*: the German government's plan (section 3.11)

The essential role of end-use sectors in accelerating renewable energy uptake (section 4.7)

The role of European carbon pricing for renewables (section 5.4)

Regional integration to realise higher shares of renewables (section 5.4)

Power sector and market design

In REmap 2030, two-thirds of Germany's total power generation is from renewables, and, even more importantly, half is from the variable renewable energy sources of solar and wind. For many other countries, operating higher shares of variable renewables in the power system increasingly will be the case. How Germany and other forerunners integrate these rising shares will start to define the future of world power systems.

Generating 50% of electricity from variable renewable energy by 2030 will require changes in Germany's power system. The country's "electricity market 2.0" is a step in the right direction. It highlights the importance of flexibility measures, including cross-border exchange, demand-side management (including smart grids/metering that incentivises customers to save energy, and other measures) as well as sectoral linkages among the power, heating and transport sectors. In particular, sectoral linkages make it possible to achieve even higher shares of renewables and reduce the need for costly flexibility measures such as curtailment or battery storage. The use of CHP generation coupled with heat storage, heat pumps and electric vehicles all can be scheduled to accommodate the variability in solar and wind generation. As Germany continues down the path towards integrating higher shares of renewable power, important power system and market design themes will emerge:

German level:

- Support renewables via reliable policies and protect the distributed ownership structure that allows for broad public acceptance
- Expand the transmission grid, including through support for underground transmission infrastructure and higher capacity power lines or new lines along existing infrastructure (such as highways, tracks and/or inland waterway transport routes) that can accelerate expansion
- Build a resilient supply system by deploying a cascade of flexibility measures

European and international levels:

- Plan for higher shares of renewables by considering German experiences for systems thinking and sectoral integration
- Support RD&D for power sector technologies and for further innovation that includes market design and finance models
- Include specific policies for storage technologies as part of both centralised and decentralised levels of the new market model to build up a resilient supply system

Additional reading:

Tariffs and costs of the *Energiewende* (section 3.2)

Market design and electricity pricing (section 3.3)

Power sector challenges and solutions (section 4.6)

Regional integration to realise higher shares of renewables (section 5.4)

European 10-Year Network Development Plan and Germany's role (section 5.4)

Regional integration and infrastructure

Germany consumes approximately 20% of EU total energy demand, and the country will play a major role in helping the EU realise its regional energy and climate targets. Likewise, Germany will not achieve its REmap 2030 potential without further market integration with the EU. Germany is at the centre of European energy markets and is linked closely with the electricity markets of its neighbours. Regional integration already is regarded as a core component to strengthen the

EU's coupled power markets. Integrated markets offer greater flexibility and balancing potential as well as gains from using smoothing effects. The next steps and key themes include:

German level:

- Germany is at the centre of European energy markets and it is linked closely with the electricity markets of its neighbours. Regional integration is needed for security of supply and higher flexibility if Germany is to achieve higher shares of variable renewables in its power system.
- Maintain and expand regional partnerships to realise higher shares of renewables in the energy system
- Support measures and system thinking that enable the use of variable renewable power across sectors

European and international levels:

- Intensify European co-operation to support the integration of large shares of renewables into power grid
- Improve the already integrated electricity market by implementing the 10 network codes, facilitating investments in transmission infrastructure, facilitating co-ordination of EU member states' energy mix and security of supply policy at the regional and European levels, developing co-ordinated mechanisms in energy security situations, updating market design to deliver secure and affordable energy supply, and fostering RD&D in transmission networks

Additional reading:

Renewable electricity and infrastructural changes (section 3.1)

Power sector challenges and solutions (section 4.6)

Regional integration to realise higher shares of renewables (section 5.4)

Heating in buildings and industry

Heating accounts for the largest share of final energy demand in Germany. Policies have been effective for renewables uptake in new buildings, but they have been less effective for heating applications in the existing stock and, in particular, for the industry sector. In the building sector, the focus should remain on energy efficiency improvements, but renewables increasingly will be deployed when old buildings are renovated and when new buildings are built. The existing building stock therefore will need to be renovated at a higher rate, and this renovation should include the installation of renewable heating systems. The industry sector has specific heating supply requirements that are determined by the temperature level of processes. REmap shows the high potential of renewables for industrial applications. It suggests significant deployment of renewable heat technologies, including heat pumps (in buildings, industry and district heating sectors) as well as solar thermal and biomass. Some key areas of focus include:

Building sector:

- Support policies that result in higher renovation rates (for efficiency) that can include renewable heating deployment support. Many renewable technologies also result in energy efficiency gains, and policies should recognise and support this synergy.
- Because Germany's building stock is very diverse and consists mostly of old buildings, policies supporting renovation should differentiate clearly based on building type and be tailored for the varying expectation of return on investment for different building owners. In additional to aiming to improve energy efficiency standards, policies should take into account the latest available technologies for renewable heating.
- Monitor implementation of renovation targets to adopt policies in case targets are not met
- Plan for renewables-based district heating networks in newly built areas

Industry sector:

- Implement an analytical framework to estimate the renewable energy potential in Germany's manufacturing industry, by sector and plant type
- Establish benchmarks and targets for renewable energy-based process heat supply and develop a dedicated programme to increase renewables uptake for process heat generation, including during retrofits of existing plants
- Support technology deployment based on the heating temperature need. For high- and

medium-temperature needs, incentivise biomass CHP that employs state-of-the-art technology. For low-temperature heat, particularly for smaller-scale industrial plants, utilise solar heating and heat pump potential.

Additional reading:

Renewable heating and cooling in the building sector (section 3.4)

Renewable energy in the manufacturing sector (section 3.5)

The essential role of end-use sectors in accelerating renewable energy uptake (section 4.7)

Transport sector

Renewables deployment in the transport sector has been limited in recent years as liquid biofuels consumption has remained stable and as electric vehicle sales have been below forecasts. The sector is relatively complex, with different transportation segments displaying different levels of energy intensity and varying fuel type requirements and quality. The share of renewables in the transport sector is the lowest among all sectors in Germany, at around 5%. Realising the 20% share as suggested by REmap will therefore be a significant challenge, especially because the domestic focus on renewables deployment in transport is less than for other sectors. This is partly an outcome of European agreements that play the main role in determining policy for both energy efficiency and renewables, especially for transportation. Key themes that emerge are:

German level:

- Expand recharging infrastructure for electric mobility, particularly along highways and suburban regions
- Create business opportunities for electric vehicles in new market design that utilises the link between storage and variable renewables
- Develop and implement sustainable biofuels for the aviation sector, where no other low-carbon technology alternative exists

European and international levels:

- Consider setting electrification targets for all logistics companies and that address public and freight transportation
- Develop electric mobility targets harmonised with renewable power supply that also allow for better integration of solar and wind through electric vehicle business opportunities
- Further support research on advanced biofuel production technologies based on waste and residues, as well as RD&D of commercial-scale production plants.

Additional reading:

Renewable energy in the transport sector (section 3.6)

Transportation (section 4.7)

Bioenergy

Half of the total final renewable energy use in REmap 2030 is from biomass. Biomass has only a low contribution to total renewables use for power generation, given the availability of other renewable energy technologies, such as wind and solar. However, biomass is an essential technology for heating and particularly for use in the transport sector, where alternatives for some modes like heavy transport, shipping and aviation are limited. Efforts to secure a sustainable source of supply, while directing its use to important applications, will be crucial. Some key learnings from this report include:

- Prioritise biomass use for applications where few or no low-carbon alternatives exist
- Develop a biomass plan to utilise limited biomass resources in the most sustainable and cost-effective way across their competing uses in the power, heating and transport sectors

Additional reading:

Renewable heating and cooling in the building sector (section 3.4)

Renewable energy in the manufacturing sector (section 3.5)

Biomass challenges (section 4.7)

Sectoral linkages and electrification

Sectoral linkages among power, district heating and the end-use sectors will accelerate. The deployment of end-use heating and transport technologies reduces the need for costly measures such as curtailment or battery storage. It also can allow for demand-side flexibility, thereby reducing the transition cost associated with increasingly high shares of variable renewable power. So far, the *Energiewende* has focused largely on the power sector. However, REmap analysis suggests that more than half of Germany's total final renewable energy use in REmap 2030 could be related to heating and transportation. The challenge of accelerating renewable energy uptake in Germany by 2030, lies in these end-use applications. To create a more sustainable heating supply, a systemic perspective is necessary – specifically, an integrated energy concept for heating, cooling, electricity and mobility will be necessary. Key factors that will enable a linking of these sectors include:

German level:

- Connect the power, heating and transport sectors via a specific "system policy"
- Use the new market design process to create business opportunities for heating storage and demand-side management technologies to support grid integration of renewable power supply
- Support the connection of power, district heating and natural gas grids with electric mobility to enable new business opportunities for utilities

European and international levels:

- Establish cross-sectoral targets for interconnection of the power sector with end-use applications
- Support and accelerate cross-sectoral renewable energy integration technologies to decrease the pressure on power grids and expansion requirements
- Establish global technical standards for the coupling of power, heating, natural gas and transport infrastructure

Additional reading:

Market design and electricity pricing (section 3.3)

The essential role of end-use sectors in accelerating renewable energy uptake (section 4.7)

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ANNEX A

Energy prices

Commodity	National energy price in 2030
Crude oil (USD/GJ)	27
Steam coal (USD/GJ)	7
Electricity (buildings) (USD/kWh)	0.35
Electricity (industry) (USD/kWh)	0.19
Natural gas (buildings) (USD/GJ)	29
Natural gas (power generation) (USD/GJ)	18
Petroleum products (fuel oil) (USD/GJ)	27
Diesel (USD/GJ)	59
Gasoline (USD/GJ)	71
Kerosene (USD/GJ)	98
Biodiesel (USD/GJ)	57
Conventional ethanol (USD/GJ)	70
Advanced ethanol (USD/GJ)	69
Biokerosene (USD/GJ)	104
Primary biomass (forest surplus) (USD/GJ)	19
Biomass residues (harvesting residue) (USD/GJ)	9
Biomass residues (processing/biogas) (USD/GJ)	3
Biomass residues (wood waste) (USD/GJ)	11
Municipal waste (USD/GJ)	2
Nuclear fuel (USD/GJ)	0.2

ANNEX B

Substitution costs of REmap Options, in the business perspective

REmap Option	Potential (PJ /year)	Substitution cost (USD_{2010}/GJ TFEC)
Battery-electric two-wheeler (passenger road vehicles)	0.6	-22.0
Solar PV (utility-scale)	3.0	-19.3
Wind (onshore)	91.9	-16.9
Heat pumps (buildings to district heat)	37.6	-15.0
Solar thermal (buildings to district heat)	1.8	-13.1
Wind (offshore)	60.6	-12.5
Battery-electric (passenger road vehicles)	5.9	-12.2
Water heating (solar)	20.0	-11.0
Hydro (large-scale)	3.6	-9.8
Plug-in hybrid (passenger road vehicles)	11.1	-7.1
Biodiesel (freight road vehicles)	7.0	-5.5
Biodiesel (passenger road vehicles)	77.6	-5.0
Solar PV with storage (residential/commercial)	39.4	-4.9
Advanced ethanol (passenger road vehicles)	4.2	-4.8
Biomass waste-to-energy	16.4	-4.7
Geothermal power	9.5	-1.9
Heat pumps (district heating)	27.6	-1.1
Heat pumps (low-temperature industry)	22.0	1.9
Solar thermal (industry)	24.8	2.1
Plug-in hybrid (light-freight road vehicles)	3.8	2.2
Biofuels (passenger aviation)	51.0	3.2
Space heating (solar)	36.0	4.7
Battery-electric (light-freight road vehicles)	2.9	8.9
Space heating (pellet burners)	56.0	10.0
Space heating (air-to-air heat pumps)	9.3	10.8
Hydro (small-scale)	8.5	11.0
Heat pumps (geothermal)	8.2	13.9
Biomethane (public road vehicles)	5.2	21.7

ANNEX C

Substitution costs of REmap Options, in the government perspective

REmap Option	Potential (PJ /year)	Substitution cost (USD_{2010}/GJ TFEC)
Battery-electric two-wheeler (passenger road vehicles)	0.6	-10.0
Biodiesel (freight road vehicles)	7.0	-6.1
Biodiesel (passenger road vehicles)	77.6	-5.8
Solar PV (utility-scale)	3.0	-5.6
Wind (onshore)	91.9	-4.1
Advanced ethanol (passenger road vehicles)	4.2	-3.8
Heat pumps (building to district heat)	37.6	-1.9
Battery-electric (passenger road vehicles)	5.9	0.1
Wind (offshore)	60.6	0.9
Solar thermal (building to district heat)	1.8	1.4
Biomass waste-to-energy	16.4	1.8
Water heating (solar)	20.0	2.9
Biofuels (passenger aviation)	51.0	3.0
Biomethane (public road vehicles)	5.2	5.8
Plug-in hybrid (passenger road vehicles)	11.1	6.5
Plug-in hybrid (light-freight road vehicles)	3.8	7.3
Heat pumps (air-to-air)	9.3	7.5
Heat pumps (low-temperature Industry)	22.0	9.2
Hydro (large-scale)	3.6	9.6
Heat pumps (geothermal)	8.2	14.2
Space heating (pellet burners)	56.0	14.0
Solar PV with storage (residential/commercial)	39.4	14.7
Heat pumps (district heating)	27.6	15.9
Geothermal power	9.5	17.5
Battery-electric (light-freight road vehicles)	2.9	19.2
Solar thermal (industry)	24.8	20.4
Space heating (solar)	36.0	22.8
Hydro (small-scale)	8.5	28.0

ANNEX D

Capital and O&M costs

	Capacity factor	Overnight capital cost	O&M Cost	Conversion efficiency	Production cost	
POWER SECTOR						
Renewable technologies	**(% capacity)**	**(USD/kW)**	**(USD/ kW/yr)**	**(%)**	**(USD/GJ_e)**	
Hydropower (small-scale)	53	9000	180	100	47	
Hydropower (large-scale)	54	5400	108	100	26	
Wind (onshore)	25	1300	52	100	19	
Wind (offshore)	42	2400	132	100	23	
Solar PV with storage (residential/commercial)	12	1400	14	100	31	
Solar PV (utility-scale)	13	800	8	100	16	
Geothermal	80	8200	328	10	34	
Conventional technologies						
Coal	85	3000	120	43	36	
District heating sector	**(% capacity)**	**(USD/kW)**	**(USD/ kW/yr)**	**(%)**	**(USD/GJ_{th})**	
Renewable technologies						
Biomass waste-to-energy	29	600	15	60	10	
Geothermal	30	1800	90	100	25	
Conventional technologies						
Natural gas	25	100	2	85	26	
BUILDING SECTOR						
Renewable technologies	**(% capacity)**	**(USD/kW)**	**(USD/ kW/yr)**	**(%)**	**(USD/GJ_{th})**	
Geothermal district heating	30	1100	28	100	12	
Solar thermal district heating	10	500	5	100	14	
Heat pumps (geothermal)	15	1500	38	400	68	
Heat pumps (air-to-air)	15	780	20	340	49	
Solar water heating	6	410	10	100	27	
Solar space heating	6	680	17	100	43	
Biomass heating	15	1600	40	80	66	
Conventional technologies						
Heating boiler (natural gas)	15	162	5	95	28	
Water boiler (natural gas)	15	150	5	95	27	

INDUSTRY SECTOR						
Renewable technologies	**(% capacity)**	**(USD/kW)**	**(USD/kW/yr)**	**(%)**	**(USD/GJ$_{th}$)**	
Solar thermal heat (low-termperature)	6	500	8	100	25	
Heat pumps (low-temperature)	35	750	26	100	37	
Conventional technologies						
Boiler (natural gas)	40	2000	100	95	23	
Boiler (coal)	40	1500	100	90	13	
	Unit activity of renewable technology vehicle	**Overnight capital cost**	**O&M cost**	**Fuel demand**	**Power demand**	**Production cost**
TRANSPORT SECTOR						
Renewable technologies	**(passenger or tonne km/yr/vehicle)**	**(USD/vehicle)**	**(USD/vehicle/yr)**	**(MJ freight/passenger or tonne km)**	**(MJe/passenger or tonne km)**	**(USD/passenger or tonne km)**
Advanced ethanol (passenger road vehicles)	15000	28000	2800	0.9		0.52
Biodiesel (passenger road vehicles)	15000	30000	3000	0.98		0.49
Biomethane (public road vehicles)	40000	4000	3000	1.06		0.49
Plug-in hybrid (passenger road vehicles)	15000	30000	2800		0.98	0.46
Plug-in hybrid (light-freight road vehicles)	100000	80000	8000		1.36	0.24
Battery-electric (passenger road vehicles)	15000	31000	2700		0.47	0.44
Battery-electric (light-freight road vehicles)	100000	98000	9800		1.11	0.26
Battery-electric two-wheeler (passenger road vehicles)	5000	4000	400		0.07	0.21
Conventional technologies						
Gasoline (passenger road vehicles)	15000	28000	2800	0.8	0	0.49
Diesel (passenger road vehicles)	15000	30000	3000	1.54	0	0.5
Diesel (freight road vehicles)	110000	120000	12000	1.16	0	0.25

ANNEX E

Sources for 2010, the Reference Case and REmap 2030

Item	Source	Remarks
2010 base year		
End-use energy demand and power/heat generation	AGEB (2010)	
2030 Reference Case		
End-use sector energy demand; generation for district heat, power (excluding item listed below)	Prognos, EWI and GWS (2014), Reference Case	
Power – solar PV	BMUB (2015)	*Energy Reference Forecasts* is higher than *Projection Report*; this would result in a decline in solar PV in REmap; therefore, the lower value from the *Projection Report* was used
REmap Options – power sector		
Renewable energy options (excluding items listed below)	BMUB (2015)	
Solar PV options	Prognos, EWI and GWS (2014), Target Case	
Increase in demand from electrification in end-use		Met with additional onshore wind capacity
REmap Options – district heating sector		
Biomass/waste options	Prognos, EWI and GWS (2014), Target Case	
Heat pumps	DLR (2013)	Analysis performed for IRENA; heat pumps assumed 50% in existing networks, 50% in new networks
REmap Options – end-use sectors		
Renewable energy options (excluding items listed below)	Prognos, EWI and GWS (2014), Target Case	
Industry – solar thermal heat, heat-pumps	IRENA (2014d)	Each assumed to meet around 2% of heat demand in sector
Buildings – solar thermal	Wüstenrot (2014); BMWi (2014), Zeilszenario	
Buildings – structural change to district/community heating: heat pumps, solar thermal	DLR (2013)	Analysis performed for IRENA; heat pumps assumed 50% in existing networks, 50% in new networks
Transport – electric vehicle power demand	Anonymous (2015), IRENA analysis based on input from forthcoming scenario study	Vehicle numbers provided in report are based on average passenger or tonne kilometres and average electricity use per kilometre

ANNEX F

REmap summary table

	2010	Reference Case 2030	REmap 2030
Total primary energy supply (PJ/year)			
Coal	3 340	2 420	1 796
Oil	3 530	2 272	1 951
Gas	3 228	2 159	1 893
Nuclear	1 534	0	0
Hydro	76	68	73
Bioenergy (incl. biogas, biofuels)	948	1 619	1 840
Solar thermal	18	106	189
Solar PV	42	202	250
Wind	136	515	778
Geothermal	19	95	261
Ocean / Tide / Wave / Other	1	1	1
Total	**12 872**	**9 456**	**9 032**
Total final energy consumption (PJ/year)			
Coal	592	415	415
Oil	3 335	2 158	1 644
Gas	2 353	1 633	1 471
Modern biomass (solid)	502	702	776
Modern biomass (liquid)	121	228	373
Solar thermal	18	106	189
Geothermal	19	86	221
Other renewables	0	0	5
Electricity	1 898	1 763	1 839
District Heat	473	364	408
Total	**9 311**	**7 454**	**7 340**
Gross electricity generation (TWh/year)			
Coal	290	249	178
Natural gas	87	64	72
Oil	8	0	0
Nuclear	141	0	0
Hydro	21	19	20
Biomass (incl. biogas)	33	67	67
Solar PV	12	56	69
CSP	0	0	0
Wind (onshore)	38	107	160
Wind (offshore)	0	36	56
Geothermal	0	1	4
Ocean / Tide / Wave	0	0	0
Total	**629**	**599**	**626**

	2010	Reference Case 2030	REmap 2030
Electricity capacity (GW)			
Coal	48	44	34
Natural gas	25	30	30
Oil	6	2	2
Nuclear	20	0	0
Hydro (excl. pumped hydro)	5	5	5
Biomass (incl. biogas)	11	10	10
Solar PV (utility-scale)	5	16	16
Solar PV (rooftop)	15	47	59
CSP	0	0	0
Wind (onshore)	27	48	72
Wind (offshore)	0	11	16
Geothermal	0	0	1
Ocean / Tide / Wave	0	0	0
Total	**162**	**212**	**246**

Note: Totals provided in this table are for the sectors covered in the REmap analysis, see section 2 for additional details about REmap sector coverage

LIST OF ABBREVIATIONS

AC	alternating current
AFEX	Arab Future Energy Index
AusglMechV	Equalisation Scheme Ordinance
BAFA	Bundesamt für Wirtschaft und Ausfuhrkontrolle (Federal Office for Economic Affairs and Export Control)
BDEW	Bundesverband der Energie- und Wasserwirtschaft e.V. (German Association of Energy and Water Industries)
BF/CO	blast furnace and coke ovens
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
BMWi	Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development)
BNetzA	Bundesnetzagentur (Federal Network Agency)
BoE	barrel of oil equivalent
Cecre	Control Centre of Renewable Energies (Spain)
CER	Certified Emissions Reduction
CHP	combined heat and power
CO_2	carbon dioxide
CSP	concentrated solar power
CWE	Central-Western Europe
DC	direct current
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Act)
EEWärmeG	Erneuerbare-Energien-Wärmegesetz (Renewable Energy Heat Act)
EJ	exajoule
ENTSO-E	European Network of Transmission System Operators for Electricity
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ESCO	energy service company
EU	European Union
EUA	EU allowances
EU ETS	EU Emission Trading System
EUR	euro
EV	electric vehicle
EWEA	European Wind Energy Association
FiP	feed-in premium
FiT	feed-in tariff
Gcal	gigacalorie
GEA	Global Energy Assessment
GFEC	gross final energy consumption
GJ	gigajoule

GW	gigawatt
HVAC	high-voltage alternating current
HVDC	high-voltage direct current
GW_e	gigawatt-electric
GW_{th}	gigawatt-thermal
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IWU	Institut Wohnen und Umwelt
KAS	Konrad-Adenauer-Stiftung
kW	kilowatt
kWh	kilowatt-hour
LHV	lower heating value
LT	low-temperature
m^2	square metre
MAP	Market Incentive Program
MBtu	million British thermal units
MJ	megajoule
MW	megawatt
Mtoe	million tons of oil equivalent
NAPE	National Action Plan on Energy Efficiency
NGO	non-governmental organisation
NO_x	nitrogen oxide
NREAP	National Renewable Energy Action Plan
NWE	North-Western Europe
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
PCR	Price Coupling of Regions
Penta	Pentalateral Energy Forum
PJ	petajoule
PM	particulate matter
PTC	production tax credit
PV	photovoltaic
R&D	research and development
RD&D	research, development and deployment
REN21	Renewable Energy Policy Network for the 21st Century
SE4ALL	Sustainable Energy for All
SME	small and medium-sized enterprise
SO_2	sulphur dioxide
TFC	total final consumption
TFEC	total final energy consumption
toe	tonne of oil equivalent
TWh	terawatt-hour
TYNDP	10-Year Network Development Plan
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
VAT	value-added tax

IRENA

International Renewable Energy Agency

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