Fraunhofer IEE

FRAUNHOFER INSTITUTE FOR ENERGY ECONOMICS AND ENERGY SYSTEM TECHNOLOGY IEE

ENERGY TRANSITION BAROMETER

2018

Introduction to the Barometer of the Energy System Transformation

The transformation of the energy supply system, with the aim of prohibiting further CO_2-emissions into the atmosphere, requires coordinating all the targets of all the energy-relevant sectors along technical and along economic dimensions. The optimal management of the process will not only help to ensure that climate-political targets be reached, but will also lever substantial macro-economic advantages/benefits to the economy of each country deciding to undertake such efforts.

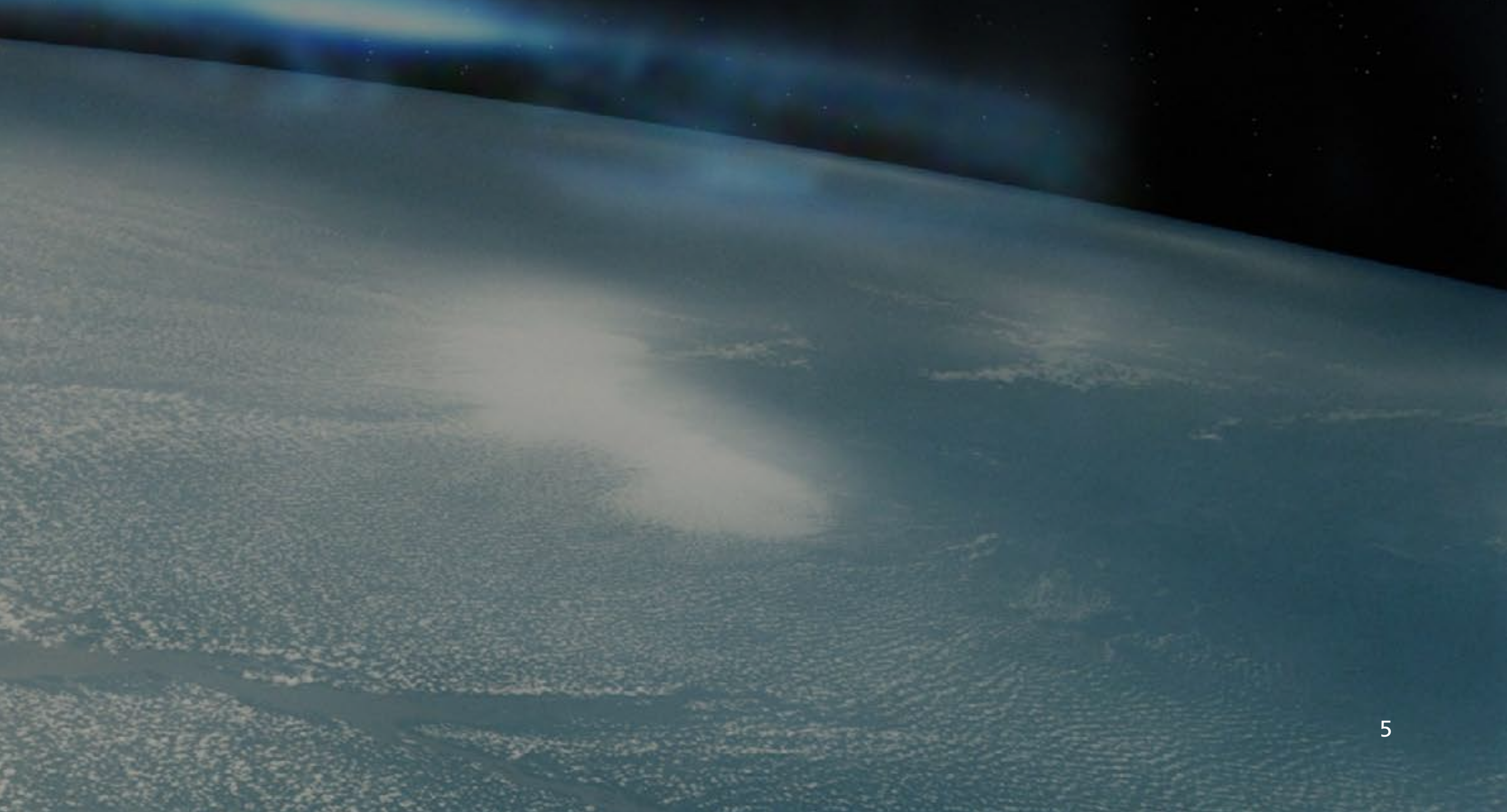
In order optimize this process we have developed our navigation instrument, the »Barometer of the Energy System Transformation«. This instrument is based on an algorithmic platform, on actual and historical data, as well as on the best available prognostic data for assessing future technology and price development (e.g. learning curves) plus further relevant influencing factors. Based on all this data, optimized transition paths are calculated, which then undergo cross-sectoral fine-tuning.

Target values referring to the different dimensions of the transformation are then derived which in turn are compared to the actual development status. Using these target values, the complex transformation process is presented in an easy-to-manage form, offering political, economic and industrial decision-makers a clearly structured basis for their decisions.

Since we were early in coining the concept of a »Barometer of energy system transformation« we allow ourselves to evaluate it critically: for all important target values of the energy system transformation, a monotonous rise or fall is desired. Thus, the CO_2-emission should fall continuously, the amount of renewable power generation should rise continuously, as should the extension of the electrical grids, and large technical storage should be spurred on. Yet a barometer sways to-and- fro. The metaphor of a barometer becomes more applicable if not only the absolute installed capacities, but also the rate of installation and even changes in this rate are used as evaluating criteria of the development. Fast changes in political steering instruments lead to a pendulum motion in the speed of development and the acceleration rate, similar to the atmospheric conditions measured by a barometer that indicate high or low pressure. The same alterations in a political course are very dangerous. They may lead to the loss of whole industries finding themselves in the early stages of development (build-up), to loss of trust on behalf of the investors and can, as such, hinder further development or even bring about a complete standstill. Superior management of the transformation process is an excellent way of keeping »pressure changes« as low as possible through foresighted navigation.

We wish that our barometer and the analytic instruments behind it can effectively support you in your role as a responsible decision maker. The barometer presented here applies to Germany, but it can be adapted to every other country by drawing upon the nationally relevant databases. We are happy to offer our support to you in all your endeavors in this field.

Prof. Dr. Clemens Hoffmann




2018

ENERGY TRANSITION BAROMETER

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ENERGY TRANSITION BAROMETER 2018

In the Energy Transition Barometer, we assess the state of the German energy transition every year. The selected indicators describe the energy system in its various technical dimensions. On the basis of current real values (December 2017), target values for 2050 are calculated with the help of our scenario modeling and target paths are shown which enable the energy system to be transformed into a 100 % renewable energy supply.
The barometer is divided into the following chapters:

- Final energy demand: Forecasts of future final energy demand provide information on the quantities of energy that have to be generated from renewable energy sources within Germany but in some cases also abroad.

- Wind energy: Wind energy is one of the two most important volatile, renewable generation technologies in our future supply system.

- Photovoltaics: This is the other most important volatile generation technology in our renewable future energy system.

- Balancing power plants: Balancing power plants ensure consistent output coverage and help to bridge periods of generation deficits.

- Bioenergy: Bioenergy allows a diverse and flexible supply due to its ease of storage.

- Power-to-gas: By converting electricity into an energy-rich gas (hydrogen, methane), excess electricity can be stored and, if necessary, converted back into electricity. This enables the compensation of power and energy fluctuations even over longer periods of time.

- Batteries: Short-term fluctuations in residual power can be compensated by batteries.

- Heat sector: The future development of the installed capacity of heat pumps is used as an indicator to evaluate the sector coupling of heat and electricity.

- Transport sector: Electric cars are added as new electrical consumers and form a link between the transport and electricity sectors.

- Investment activity and economic evaluation: Current and future investment volumes in the various technical components of the energy system and the economic evaluation of energy system transition are monitored.

The scenarios were calculated using the Fraunhofer IEE simulation model SCOPE. SCOPE takes into account imports and exports to neighbouring European countries and guarantees that electricity supply is provided at all times and in all countries. The framework condition for optimization is a 95 % reduction in CO_2 compared to 1990 by 2050. In addition, a balanced net import balance was chosen for electricity to ensure that Germany's electricity demand is generated on the balance sheet in Germany over a period of one year. This requirement amounts to 1,000 TWh. In addition, it is assumed that a further 1,100 TWh of electricity will be generated renewably at sunny and windy locations outside Germany to produce liquid fuels. The scenario is based on weather data from 2011.

FINAL ENERGY DEMAND 2050

In order to calculate the amount of energy required by a future energy system, consumption trends must be predicted. If the entire energy demand is to be made CO2 neutral in 2050, the entire final energy demand from electricity, heat, transport and material use must be balanced. The heat demand is divided into the following consumption groups: building heat, GHD (buildings, trade, services) process heat and industrial heat. The electricity sector is defined as conventional electricity consumption. The transport sector is divided into road, rail, air and sea transport. The material use of energy sources is accounted for in the category »non-energy consumption«. The corresponding expected future energy quantities can be seen in the graph. A total final energy demand of 1,850 TWh is expected [1–3].

The form of energy to be used depends on the respective end application - heat, electricity, gas, liquid fuels [4]. These energy forms in the heating and transport sectors will in future be increasingly directed into the electricity path. This sector coupling allows new flexible electrical loads to offset the volatile renewable generation peaks, thus flattening the residual signal (difference between consumption and generation output). The majority of our future energy requirements will then be generated in the form of electricity.

The electricity balance of our energy requirements in 2050 is also shown in the chart. Conventional electricity consumption is fully reflected in the electricity balance. To cover the heat demand of buildings, the required electricity demand can be significantly reduced due to the use of environmental heat. The use of heat pumps is the decisive coupling technology for the electrification of the heating sector. Four parts of heat can be generated from one part of electricity with the help of environmental heat.

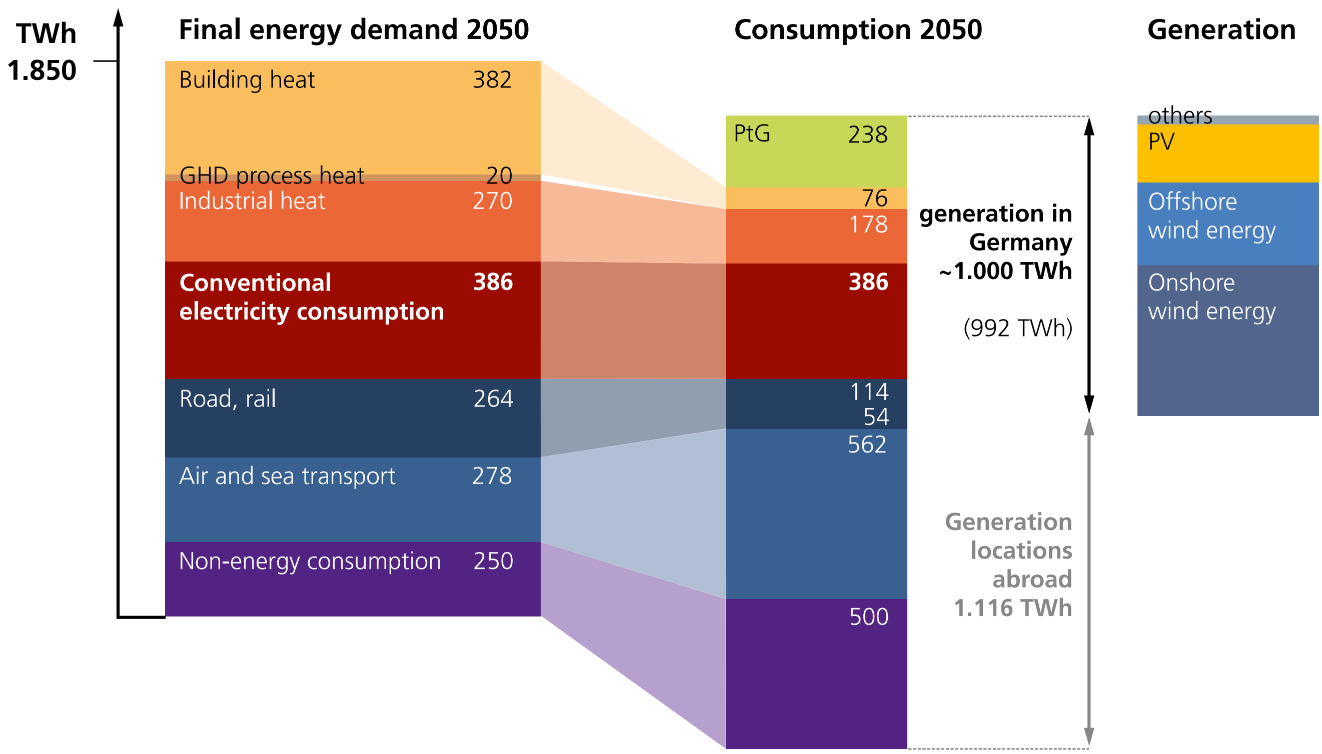
As far as transport is concerned, energy consumption can be transferred to the electricity sector through electromobility. In our scenarios we assume high degree of electrification of road traffic [5–7]. The remaining distances will be covered by hybrid vehicles powered by renewable fuels.

Excess power can be stored with the help of power-to-gas (PtG). The conversion losses and the proportion used as gas are shown separately in the diagram as PtG. The portion that is converted into electricity is in turn included in one of the consumer groups and is not shown separately.

The demand for all direct power applications and power-to-gas must be generated in Germany (about 1,000 TWh). Liquid fuels, which are mainly used in air and sea traffic or for materials, are easy to transport and store and can be produced at better locations abroad. Due to conversion losses in power-to-liquids, the electricity required to produce fuel is greater than the final liquid energy requirement [8]. Around 1,100 TWh of electricity must be produced abroad.

The corresponding generation for 2050 is shown in the right bar and shows the scenario results optimized by SCOPE. Almost 800 TWh are generated from wind energy, about two thirds onshore and one third offshore. 200 TWh are generated by photovoltaics.

» Germany needs 1,000 TWh of renewable electricity by 2050.



WIND ENERGY

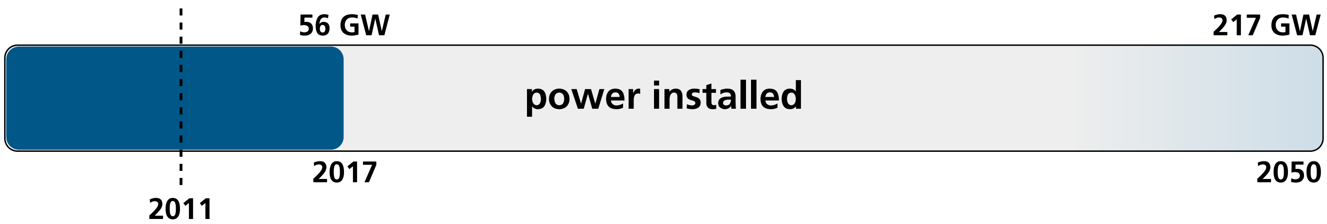
For each dimension of the Energy Transition Barometer, a representative indicator is chosen to show its development. For wind energy, these are the installed onshore and offshore capacities. The monitoring of the technical dimensions is visualized in two graphs. The barometer bar shows the current level of the development relative to its target value. The target value which, according to our scenario, must be reached by 2050, is shown at the very end on the right as an absolute value. The current status is demonstrated by the level indicator and the value in the reference year 2011 by the dashed line.

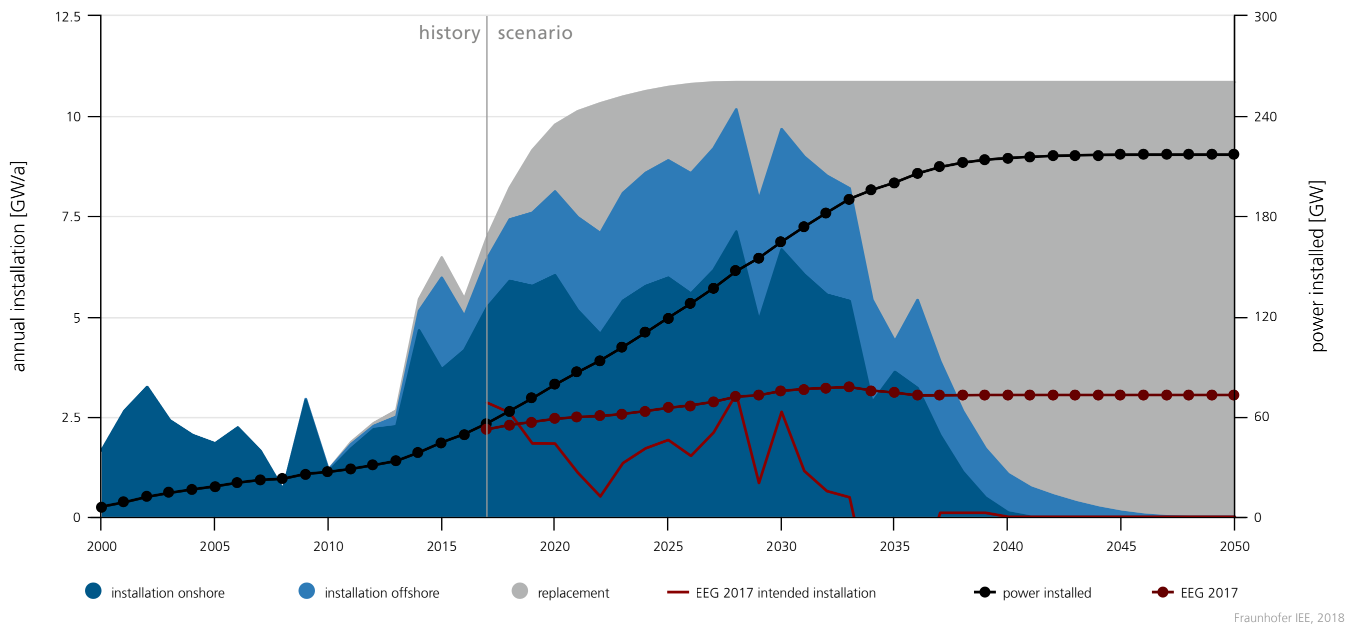
The chart below shows the development over time. The areas show the annual net installations, as well as the replacement, and are plotted on the left axis. The transition between the historical actual values [9] and our scenario values is marked by the grey vertical line. In the long term, a gross capacity expansion of almost 11 GW/a is to be achieved with a system lifetime of 20 years [10]. Measured against our scenario calculations, the current installation rates are much too low.

The dotted marking lines show the cumulative installed capacities. They are applied on the right axis. According to our scenario calculation, 217 GW must be installed by 2050. The expansion path was optimized according to the criterion of installation activities being as even as possible and consisting of (net) additions and the replacement of old systems. This means that fluctuations in the market are kept to a minimum. In addition, a decline in the installation rate is to be prevented in order to avoid economic burdens on manufacturers and installers caused by a market overshoot.

The annual net addition according to to the Renewable Energy Law (EEG 2017) is shown in red and the resulting cumulative performances as a dotted line. If we'd follow the EEG expansion, only 73 GW would be installed by 2050 [11]. Based on our scenarios, we consider this to be clearly too low [11]

» *The expansion which have been set by the German government are far too low.*





PHOTOVOLTAICS

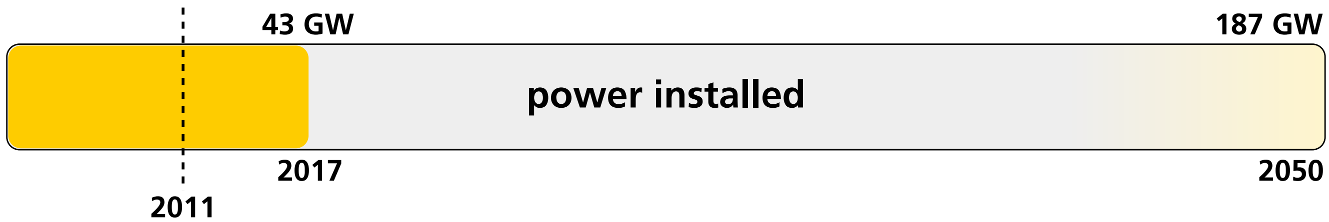
The chosen indicator for photovoltaics is the installed capacity. The barometer bar shows the current level of 43 GW relative to our scenario target of 187 GW in 2050. The dashed line shows the installation status in 2011 as a reference value.

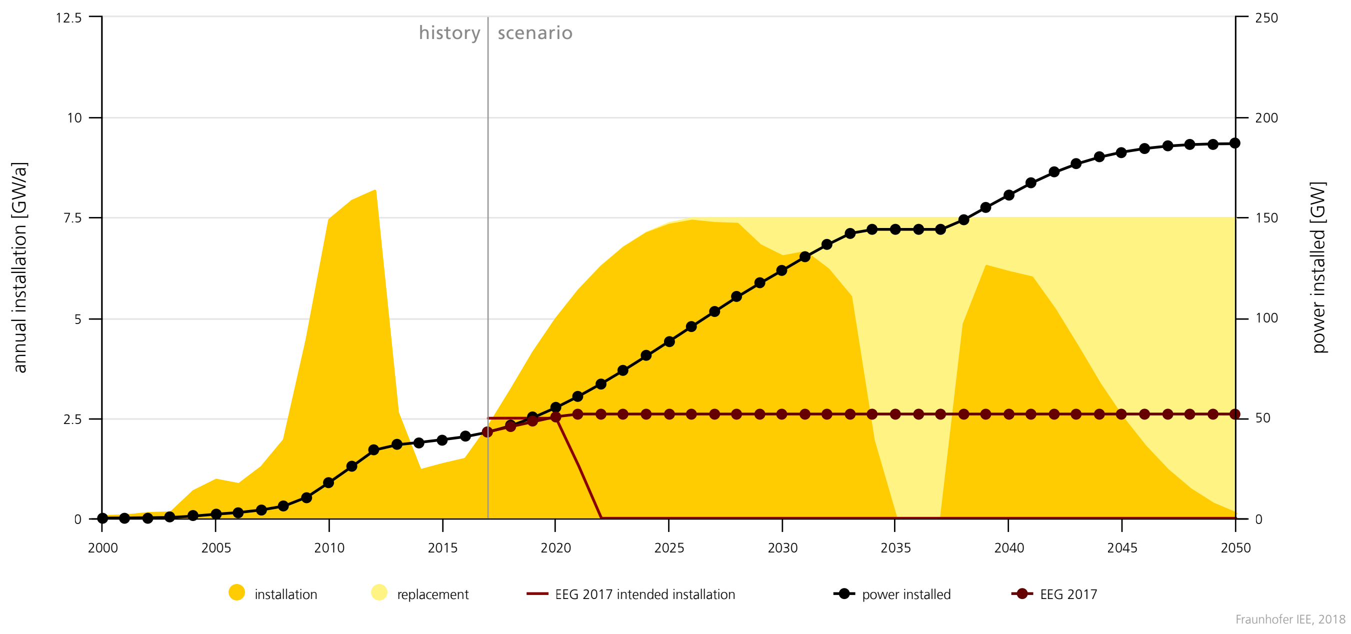
The graphic below shows the development over time. The historical values are taken from the time series published by the BMWi [9] and are separated from our future scenario values by the grey vertical line. The areas show the annual extension and are applied on the left axis. The net extension is marked in dark yellow, the replacement in light yellow. In the long term, a market volume of 7.5 GW per year would have to be achieved in order to meet the target installation of 187 GW required by our scenario with a system life of 25 years [12]. In the past, higher annual installation rates have already been achieved [9]. At the moment, however, the annual installations are clearly too small. The development path was optimised according to the same criteria as for wind energy (see wind energy chapter). Accordingly, we should achieve higher installation rates quite soon to avoid the market being overshot

The dotted lines refer to the right axis. They show the cumulative installations and thus represent the integral of the area. The target value corresponds to the target value of the barometer bar and is 187 GW, according to our scenario. With this installed base, around 200 TWh of energy could be generated.

The target extension according to EEG 2017 is shown in red [13]. The hard limit of 52 GW set in the EEG would already be reached in 2022 and thus prevent any further expansion. If we were to follow the expansion target in line with the EEG 2017, by 2050 we would only have installed 52 GW. Our scenario shows the demand for installed capacity to be about four times as high.

The rate of pv installation is insufficient.





BALANCING POWER PLANTS

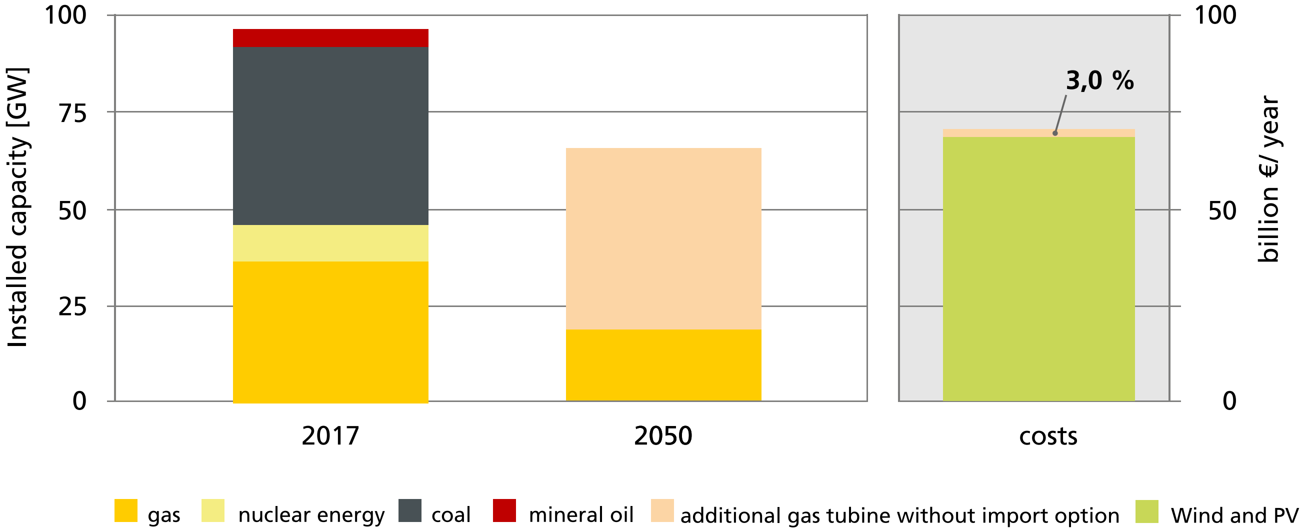
Balancing power plants must ensure that sufficient power can be provided to meet demand at all times, even in the event of generation shortfalls. Due to the increasing use of volatile renewable energies, generation fluctuations are also increasing. On the one hand, demand side management can be used to adapt flexible consumption to generation; on the other hand, balancing power plants must be available to satisfy inflexible consumption at all times. The thermal power plant park in Germany in 2017 is shown in the left bar. Nuclear and mineral oil power plants provide the smaller, coal and gas power plants the major share of installed capacity [14].

In 2050, only gas-fired power plants should be installed. The question of the necessary installation performance is not easy to answer. When dimensioning the balancing power plant, the key issue is to evaluate the probability of a significant drop (50 percent and more) in generation output over a longer period (days, weeks) and over a larger area (diameter 500 kilometers and more). Such a happening would be a very rare weather event in a renewable energy system. Due to the assumed large-scale nature of this event, it is not possible to compensate for the performance deficit across national borders.

The low probability of such an event must be put in relation to the performance quality of the German energy system, and there are only a few minutes of failure per person per year. When assessing the tolerable probability for such an extreme, system-relevant weather event, the observation period must be stretched over 10 to 100 years. Methodologically, the evaluation of such events cannot be derived from the available time series, which are only available for a few years in the recent past. It must result from fundamental considerations concerning the probability of occurrence of such extreme meteorological and geological events.

If the question of the necessary balancing capacity is answered - based on scenarios, taking into account only one weather year (here 2011), the scenario results for Germany in the European grid show the need for a balancing capacity of 18 GW. If imports of services are not possible during the deficit periods, this results in a demand of 66 GW [15]. In this case, an additional 46 GW of gas-fired power would have to be installed at gas-fired power plants in order to cover the power requirements in Germany independently of import possibilities. The cost of these additional 46 GW of gas-fired power plants would amount to approximately 2 billion euros per year including depreciation of investments and operating costs [15]. In relation to the annual costs for the replacement and operation of wind energy and photovoltaic plants in 2050, the proportion of costs for the necessary additional gas power plants is just three percent.

» In 2050, the annual costs for the necessary balancing power plants will only amount to 3 % of the electricity production costs of PV and wind.



BIOENERGY

Deriving a future perspective for bioenergy is much more difficult than for other types of renewable energy. There are several reasons for this:

- Bioenergy can be used multisectorally. However, it is not sufficiently available to supply one, let alone all energy consumption sectors (electricity, heat, transport) on its own. There is increasing discussion about using biomass as a substitute for fossil raw materials in the future.

- Unlike the virtually feedback-free use of wind or solar energy on their original systems, the use of biomass always has an impact on its systems of origin, namely agriculture, forestry and waste management. This has recently led to undesirable effects on the original systems.

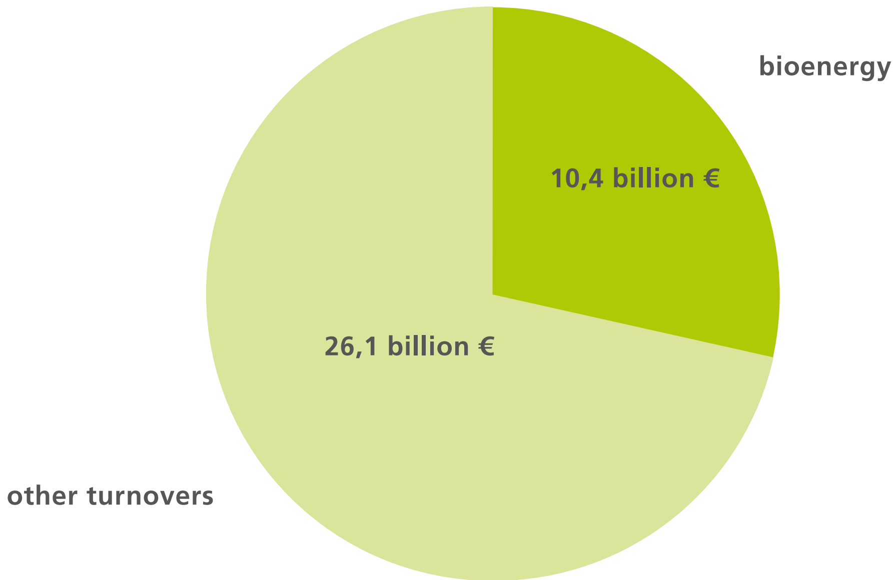
- Properly implemented, bioenergy offers numerous possibilities for achieving positive effects on the systems of origin. For example, cultivation systems that ensure greater biodiversity or protection of groundwater and soil can become more cost-effective through the subsequent energetic use of the resulting biomass. Bioenergy systems can continue to contribute to the economic stabilisation of the systems of origin on a macroeconomic and business management basis.

The last point in particular leads to the proposal that the energetic use of biomass should not to be defined by its use in the energy system, but to integrate it initially into its original systems in such a way that it provides maximum system benefit there. The biomass made available from this procedure can then be fed into the appropriate energy or material use.

The reference value of bioenergy will therefore be agricultural use. The biomass contribution making up 10.4 billion euros [16] of the total annual agriculture turnover 36.5 billion euros is shown [17]. Bearing in mind the yield volatility of agricultural products, this demonstrates that the energetic use of biomass is an important economic pillar for agriculture.

» *The energetic use of bioenergy has a considerable share in a farmer's turnover: 28 %.*

Turnover agriculture 2017: 36,5 Mrd €



POWER-TO-GAS

In order to monitor power-to-gas, the installed electrical power of electrolysers is our chosen unit of measurement. The barometer shows that we are still in the initial phase in relation to the scenario target of 66 GW. By the end of 2017, only 0.03 GW have been installed [18, own research].

The graph below shows the development of power-to-gas over time. The coloured areas represent the annual extension with reference to the left axis (own data bank, own extrapolation). In the long term, 3.2 GW gross should be added per year (replacement plus new installation). Our expansion path was optimized using the same criteria as for wind energy (see wind energy chapter). The dotted black line represents the cumulated installed power and refers to the right axis. It stops at 66 GW, corresponding to the demand for power-to-gas capacity in 2050, as calculated in our scenario.

To achieve the necessary installation capacity, we must overcome the initial phase of the market development curve and achieve higher annual installation rates. This can be achieved on the one hand by promoting technology and on the other hand by stimulating the market.

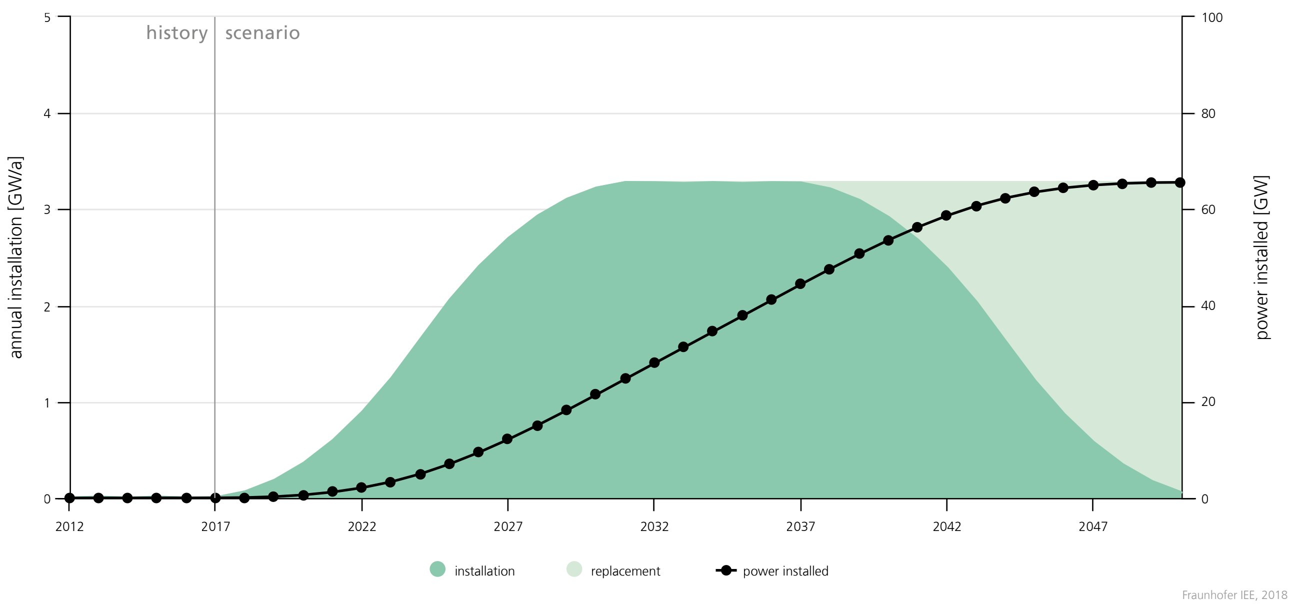
We still consider technology promotion to be necessary to enable the development of feasible business models for power-to-gas and thereby arouse the interest of the industry. Power-to-Gas is a typical application-oriented research field and requires close cooperation with the industry. Disadvantages must therefore be abolished in order to create a framework for power-to-gas plant-business models that are already economically viable today. The following measures could be implemented immediately to improve the marketability of power-to-gas plants:

1. recognize power-to-gas products as energy storage devices,
2. meet increasing demand for flexibility in the electricity market partly through power-to-gas and
3. make it possible to use it to relieve the grid,
4. use non-integrable power (feed-in management) for power-to-gas,
5. recognise power-to-gas products as biofuels,
6. recognise emission reduction possibilities of power-to-gas in the framework of the EU ETS (European Union Emissions Trading System),
7. promote technology development with the aim of reducing costs, increasing efficiency, etc. [19].

Furthermore, a market incentive can be used as a suitable instrument. Restricting it to niche markets could be helpful. Positive business models could thus be achieved earlier with the help of a market incentive, while at the same time avoiding technology overpromotion.

» *Power-to-Gas needs technology promotion and market stimulation in order to achieve positive results earlier.*

0,03 GW	power installed	66 GW
2017		2050



STATIONARY BATTERIES

The second storage technology we monitor is battery storage. The measured variable is the installed GWh capacity of all stationary and PV batteries. By the end of 2017, 0.8 GWh of storage capacity has already been installed in Germany, as can be seen in the barometer [20, 21, own assumptions]. According to our scenario calculation, 60 GWh would have to be installed by 2050 to satisfy our storage and balancing requirements.

The graph below shows the battery storage development over time. Historical values are separated from our scenario values by the grey vertical line. The areas show the annual net increase in capacity. The optimized expansion path is based on the same criteria as for wind energy (see wind energy chapter). The aim is to achieve the most market-friendly expansion possible in which changes in the annual installation rates are kept low. Moreover, overshooting of the market and a decline in the installation rates will be avoided. The dotted line shows the cumulative installed capacity. Thus the integral of the annual net installation is shown in purple.

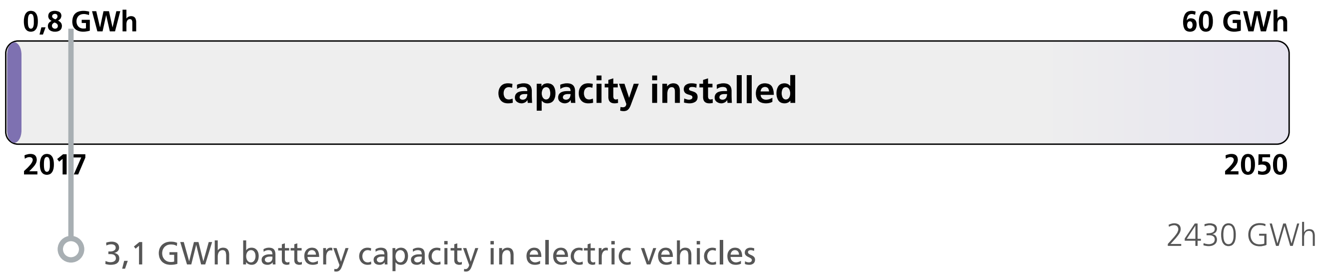
From an energy system technology perspective, we see a growing demand for batteries. However, the fluctuation margin in setting the target value is quite extensive. Battery capacity can easily be displaced by other shifting technologies such as electrolyzers, heat pumps, balancing power stations or electro mobility.

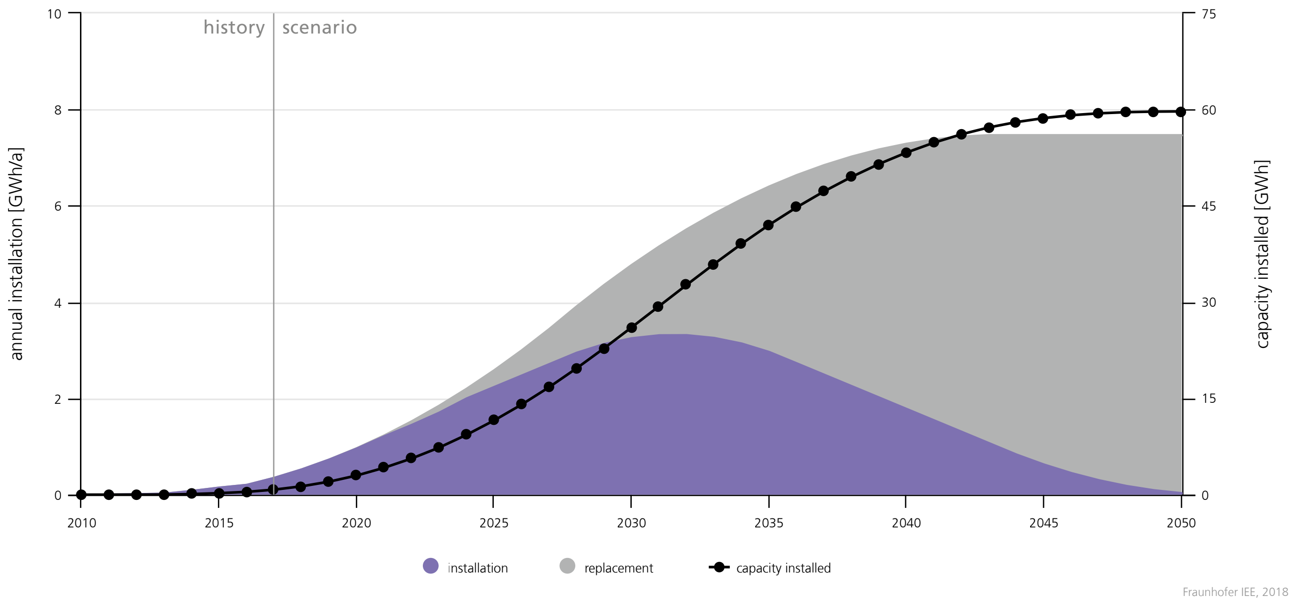
The required capacities in our scenarios tend to decline. The main field of application will concern grid-related system services.

From an investment perspective, the question arises as to how stationary and PV battery capacities relate to battery capacities in electro mobility.

At present, the electro mobility battery capacity exceeds the installation of stationary and PV batteries by a factor of four. At the end of 2017, there were 3.1 GWh of battery capacity installed in the stock of electric cars and plug-in hybrids in Germany [22, own market research]. For 2050 we expect the installed battery storage capacity in the mobility sector to be around 2,400 GWh (own assumptions, own extrapolation). This is forty times the calculated battery capacity requirement of 60 GWh as shown in our scenario. The market will therefore be determined by batteries for electric vehicles and not stationary batteries. Based on this the tremendous potential for batteries, it becomes obvious that industrial policy requirements are necessary to promote and enable the construction of battery production facilities in Germany and Europe.

» *E-mobility dominates the battery market. The battery capacity of electric vehicles exceeds the demand for stationary battery storage by a factor of 40.*





HEATING SECTOR

The heating sector is the largest CO_2 emitter of all sectors, thus having the greatest CO_2 reduction potential and therefore increasing efficiency is particularly important. Decarbonisation is necessary on both the consumer and the supplier sides. On the consumer side, this means implementing efficiency measures such as retrofitting buildings to save energy, and on the supplier side it means transferring the heating units into the electricity path, mainly through the installation of heat pumps. These two developments must not be seen in isolation from each other. Improved building insulation allows the flow temperatures of the heating system to be reduced, which in turn has a positive effect on the efficiency of the heat pump and thus on the required installation capacity.

The installed electrical capacity of heat pumps was chosen as representative for monitoring the heating sector. This indicator does not cover the whole sector, but it allows us to estimate our progress with sector coupling and the electrification of heat demand.

The barometer shows the target value from our installed electrical capacity scenario of 53 GW in 2050. 2.9 GW were installed in Germany by the end of 2017 [9].
The development of the installed capacity over time is shown in the graph below. The areas show the annual extension and replacement of the installation, the values refer to the left axis [9, 23]. Historical values are separated from the modeled future values by the grey vertical line. The optimized expansion path follows the same criteria as the other technologies (see Wind Energy). The values of the black dotted line refer to the right axis. It shows the cumulative electrical capacity and thus represents the integral of the red areas.

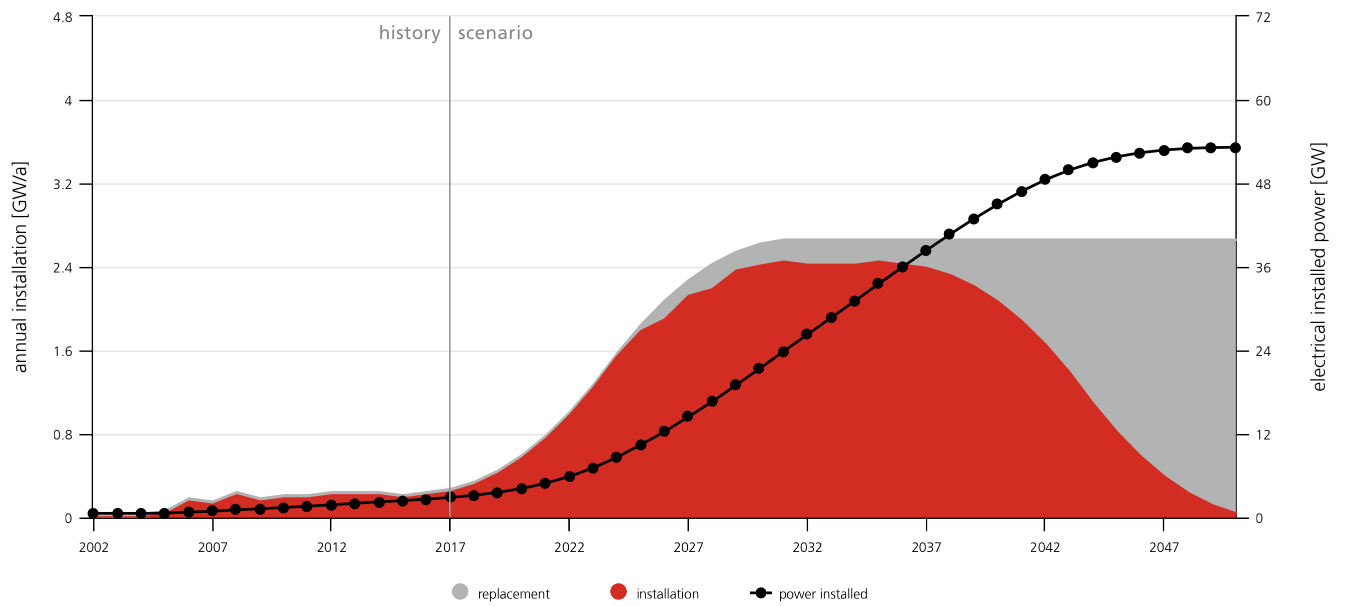
The installation rate for heat pumps is currently too low. Due to the inertia in the sector, installation rates in the building segment in particular should be increased. Heating systems installed today will remain in building stock for around 30 years and should therefore be directed into the electricity path as soon as possible.

The heating sector is the largest emitter of CO_2.

2,9 GW | 53 GW

electrical installed power

2017 | 2050



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TRANSPORT SECTOR

The transport sector is currently undergoing a tremendous change. Switching to sustainable drive systems is an important aspect in cutting emissions and reducing the pollution caused by particulate matter. Our indicator for assessing this development is the number of registered electric and hybrid cars, which are shown in the chart below. Electric cars are driven purely electrically. In addition to an electric motor that drives the vehicle directly, plug-in hybrids also have an internal combustion engine which can either drive the vehicle directly (parallel hybrid), or serve merely as an energy source for the battery (serial hybrid). Both plug-in hybrids and electric cars can be charged externally by means of a mains plug [24].

The annual net amount of new registrations is shown on the left axis and the current stock on the right axis. The light green bar shows the number of electric cars and the grey bar shows the number of plug-in hybrids, both representing the annual net amount of new registrations. The black line refers to the right axis and thus represents the total number of registered electric cars and plug-in hybrids. The graph is based on data from the Federal German Department of Motor Transport (Kraftfahrt-Bundesamt) [22]. Over the past ten years, the total amount has grown to almost 100,000 vehicles. We seem to have reached a phase of exponential growth with an annual doubling of the stock. The formation of public opinion has an important effect on growth rates, since in the transportation field mainly private investors are involved in the market. Even just discussions on restrictions for diesel vehicles can spur on electric mobility development.

The first barometer bar refers to these 100,000 e-vehicles and plug-in hybrids in 2017, and in our scenario we expect around 40 million vehicles by 2050, indicating that strong growth in this area is necessary to achieve the target. The German government has revised its target of one million electric cars by 2020 [25]. However, we regard the world market and not the German market as decisive for the development of electromobility, since a large part of the sales of German automobile manufacturers is also generated abroad.

Furthermore, the number of public charging points is displayed in the second barometer bar, since the transformation can only be carried out efficiently by providing the corresponding public charging point infrastructure. The barometer shows that there are currently only about 10,000 public charging points [26],in our scenario we expect about one charging point for every ten vehicles and thus 4 million charging points are required by 2050. A strong increase in the expansion of this infrastructure is therefore also necessary in order to achieve this goal.

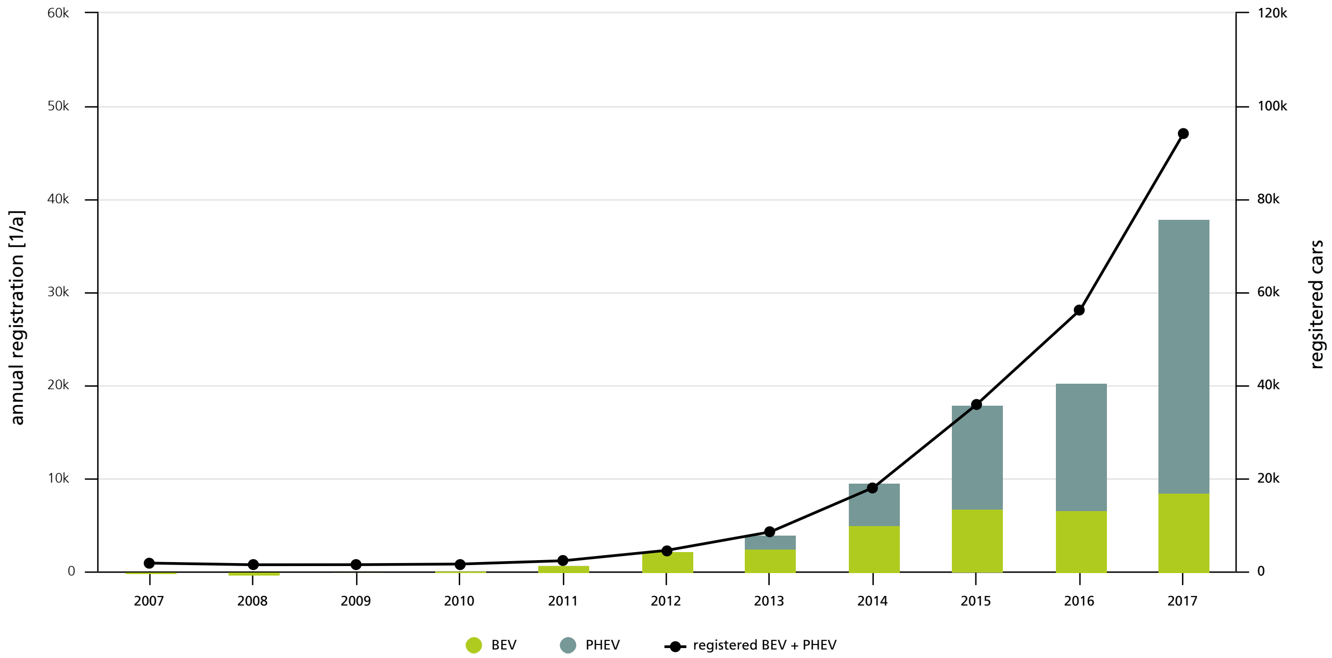
The lowest barometer bar represents the mineral oil consumption in the transport sector and, in comparison to the other bars, has an inverted scale. According to the Federal Office of Economics and Export Control (Bundesamt für Wirtschaft und Ausfuhrkontrolle), fuel consumption in 2017 was 645.06 TWh/a, compared with 600 TWh/a in 2011 [27]. By 2050 we must completely avoid traffic-related emissions in order to achieve a climate-neutral transport sector.

» The growth of German electromobility is currently determined by global developments in California and China.

0,1 Mio | 40 Mio

electric cars

2017 | 2050



Fraunhofer IEE, 2018

0,01 Mio | 4 Mio

public charging points

2017 | 2050

645 | 0 TWh/a

mineral oil consumption

2017 | 2011 | 2050

GREENHOUSE GAS EMISSIONS

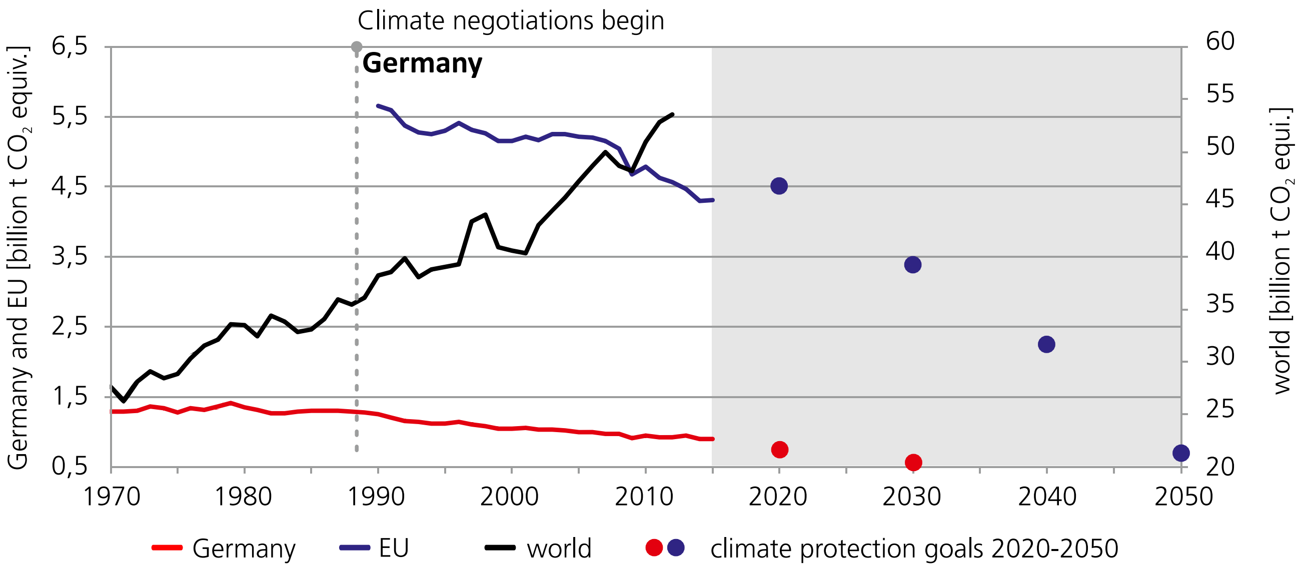
This year we have drawn the issue of greenhouse gas emissions into the focus of our attention, as these are mainly responsible for the man-made climate change. The graph on the left deals with their development and shows greenhouse gas emissions in billions of tons of CO_2 equivalents. The greenhouse gas emission indicator reflects the ecological dimension of energy production. It summarizes the various developments in technical dimensions and observes the actual target figure, namely the reduction of climate-damaging emissions. EU (purple) and German (red) data refer to the left axis, global emissions (black) to the right axis [32, 33].

Furthermore, the area on the right with the grey background shows the defined future climate targets of the EU and Germany [34]. The beginning of global climate conferences is marked by a grey dotted line on the left side of the graph. In 1988, the climate conference took place in Toronto, where scientists and government representatives participated together for the first time.

The graph shows that in 1990, Germany's greenhouse gas emissions were 1.3 billion tonnes of CO_2 equivalents, those of the EU 5.7 billion tonnes of CO_2 equivalents and global greenhouse gas emissions 38.2 billion tonnes of CO_2 equivalents. In comparison, Germany was able to reduce its emissions to around 930 million tonnes of CO_2 equivalents in 2012 and the EU to around 4.6 billion tonnes of CO_2 equivalents, which stands for a reduction of more than 28% for Germany and 19 % for the EU compared with 1990. In contrast, global values in 2012 developed to a level of 53.5 billion tonnes of CO_2equivalents, which corresponds to a growth of approximately 40 % compared to 1990 and almost 100 % compared to 1970.

Accordingly, German emissions in 2012 accounted for about 1.7 % of global greenhouse gas emissions and about 20 % of EU emissions. It becomes clear that although the EU as a whole and Germany alone have been able to slightly reduce their greenhouse gas emissions in recent years, global emissions have continued to rise sharply, despite climate negotiations and the efforts of the EU and Germany. One reason for this is the rapid growth of the emerging markets. This shows that international cooperation is essential in order to reduce emissions globally and thus to halt climate change.

» *Since 1990, greenhouse gas emissions in Germany have decreased by ~28 %, but increased worldwide by ~40 %.*



IMPACT OF POLITICAL INTERVENTIONS

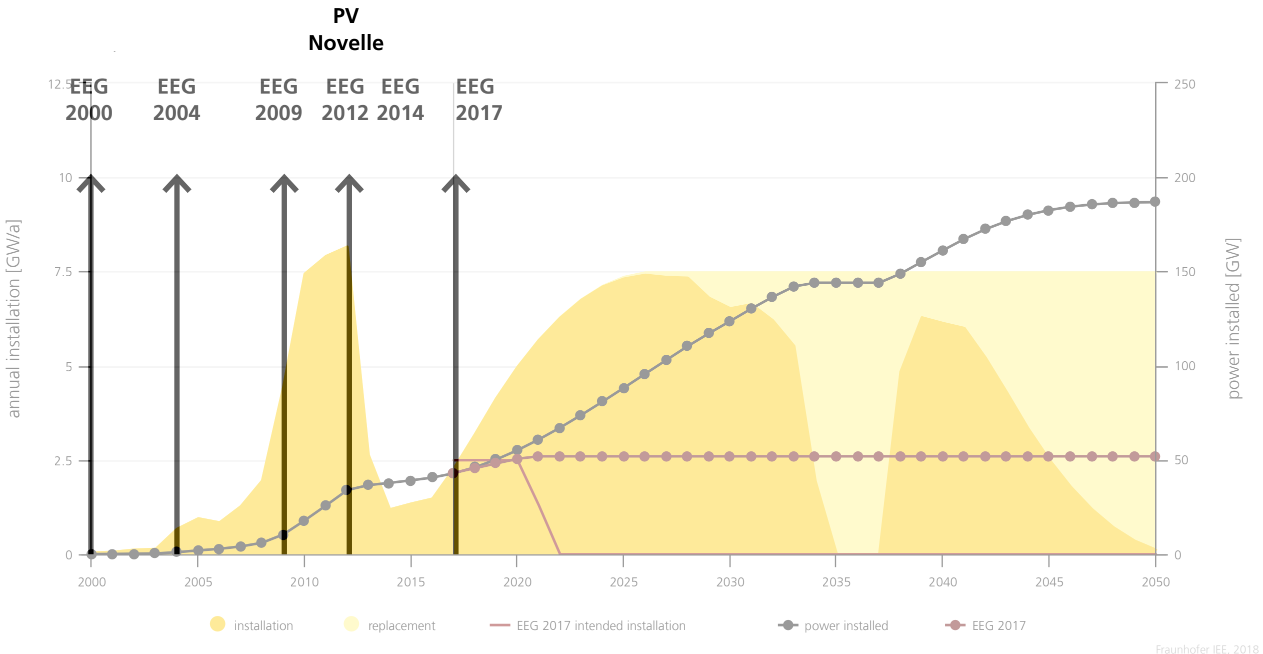
In this year's Barometer we include for the first time the effects of political action on the energy transition process. To date we have considered technical and economic indicators. With the development of greenhouse gas emissions over time, we have also included an ecological dimension for the first time. Considering the energy transition process as a social phenomenon as a whole, it is conceivable that indicators of social acceptance and governance for future versions of the barometer can be provided. Plotting the legally quantified expansion plans makes it possible to present political approach and (future) endeavours concerning the energy transition on a political level.

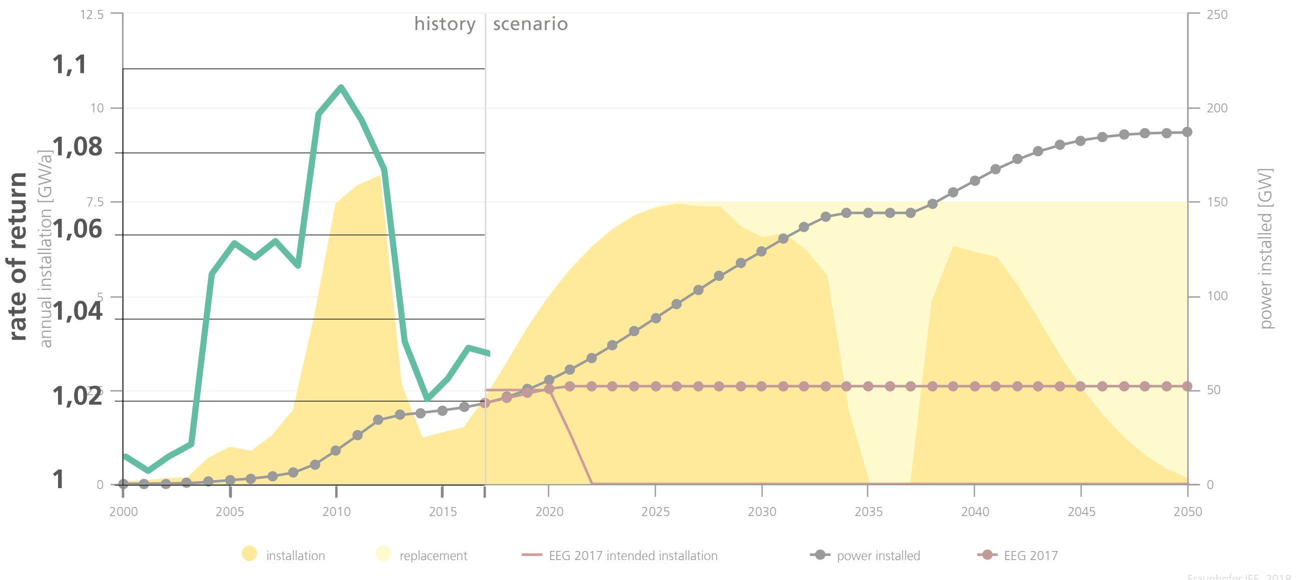
»Investor behaviour is influenced by the political framework.

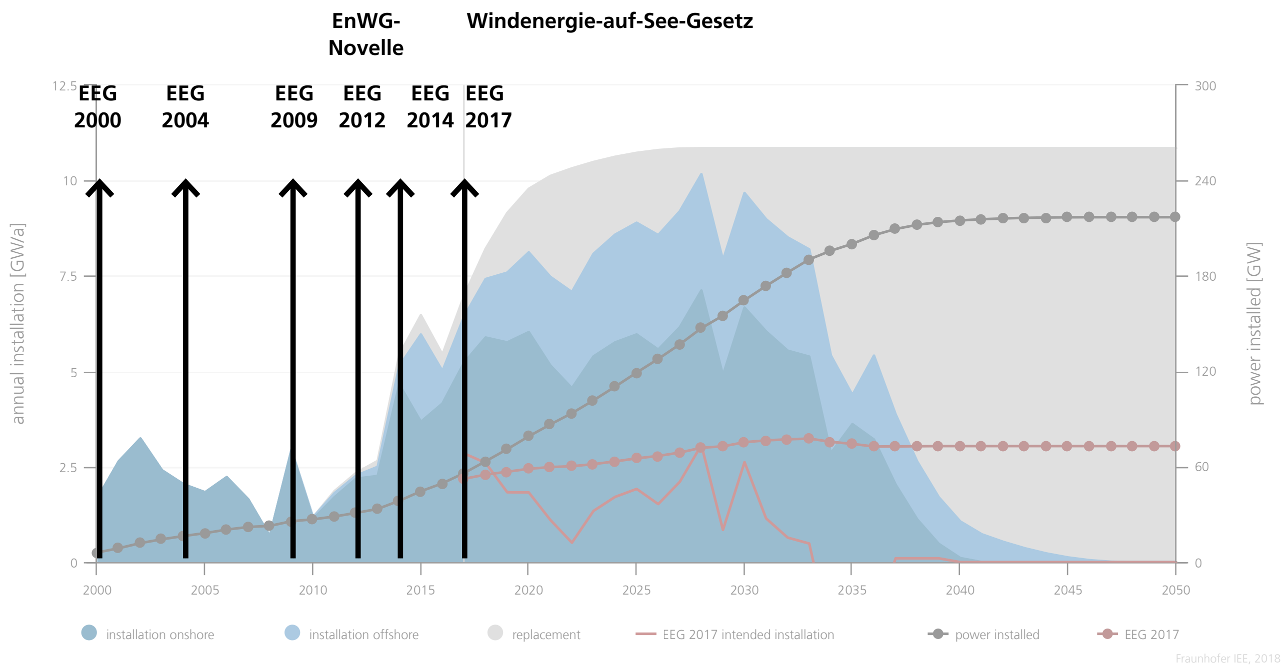
However, uncertainties are high and can vary from legislative period to legislative period. For example, the German expansion plan for various technologies defined in the Renewable Energy Sources Act (EEG) can be plotted as a curve in the monitoring chart (see chapter Wind energy and photovoltaics). In addition, we are interested in the extent – if any – of the influence of legal changes on the development of the installation and installation rates monitored by our barometer. To this end, we have included the respective legal changes as a time stamp in the historical development of photovoltaics, wind and heat pumps and we discuss how strongly correlations with investment behaviour become visible.

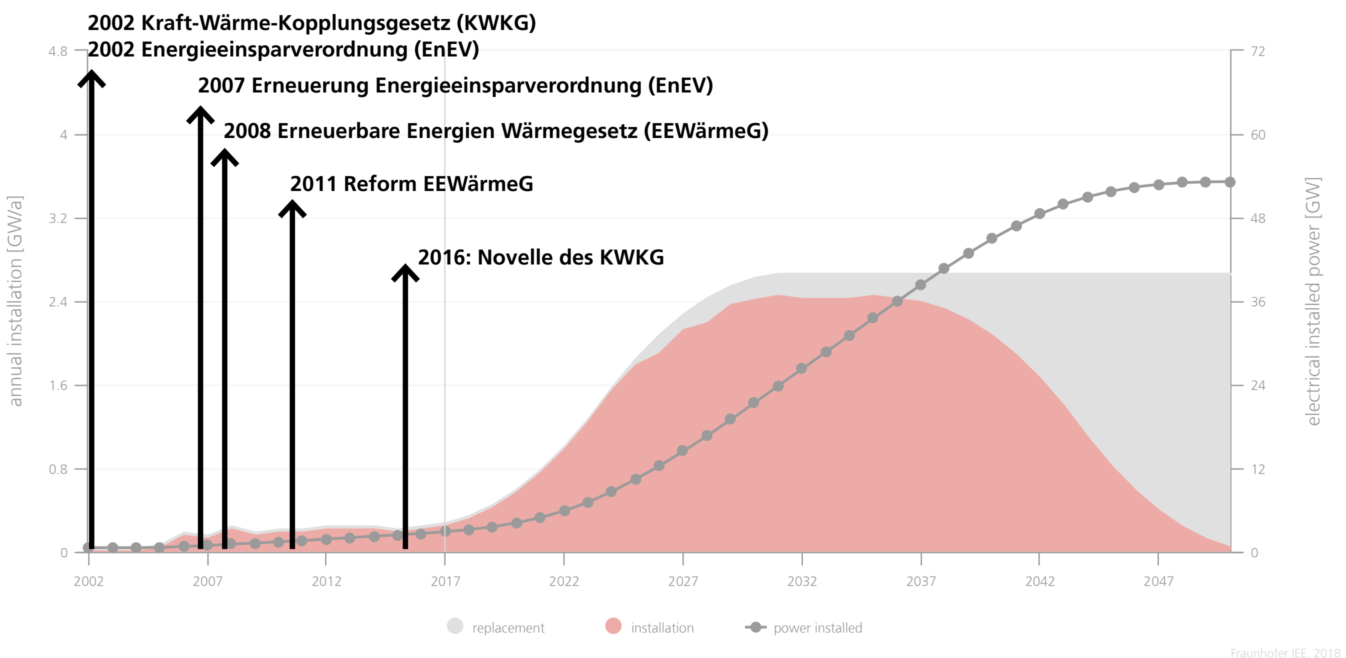
PHOTOVOLTAICS

The reaction of photovoltaics to changes in the law can be seen quite clearly. Since the project planning of PV systems can be implemented within a period of less than one year, the PV market reacts comparatively dynamically. The chart shows the influence of regulations on the development of the PV market in Germany. This is particularly clear in 2009 and 2012. As the Renewable Energy Sources Act 2009 came into force (Erneuerbare-Energien-Gesetz, EEG), the expansion of PV capacity leapt and reached annual expansion rates of more than 7.5 GW in the years between 2010 and 2012 [11]. Following the introduction of the Renewable Energy Sources Act in 2012 (EEG2012), the annual capacity increase fell significantly to only 2 GW per year. Such »scycle skip« interventions cause business-management damage and have a negative effect on the economy. Looking at the levels of subsidies set out in the EEG, it becomes obvious that not only the feed-in tariffs themselves are decisive, but also the plant costs. Accordingly, we expect investors' reaction to the market to follow the expected return. The graph below shows the internal yield of PV systems with an installed capacity of less than 30 kW [11, 35–37, own assumption, own extrapolation]. The curve confirms our expectations, the annual installation rate and the internal return correlate strongly positive with each other.


PV
Novelle
EEG 2000
EEG 2004
EEG 2009
EEG 2012
EEG 2014
EEG 2017
annual installation [GW/a]
power installed [GW]
installation
replacement
EEG 2017 intended installation
power installed
EEG 2017
Fraunhofer IEE, 2018


history
scenario
rate of return
1,1
1,08
1,06
1,04
1,02
1
annual installation [GW/a]
power installed [GW]
installation
replacement
EEG 2017 intended installation
power installed
EEG 2017
Fraunhofer IEE, 2018


EnWG-
Novelle
Windenergie-auf-See-Gesetz
EEG 2000
EEG 2004
EEG 2009
EEG 2012
EEG 2014
EEG 2017
annual installation [GW/a]
power installed [GW]
0
2.5
5
7.5
10
12.5
0
60
120
180
240
300
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
installation onshore
installation offshore
replacement
EEG 2017 intended installation
power installed
EEG 2017
Fraunhofer IEE, 2018


2002 Kraft-Wärme-Kopplungsgesetz (KWKG)
2002 Energieeinsparverordnung (EnEV)
2007 Erneuerung Energieeinsparverordnung (EnEV)
2008 Erneuerbare Energien Wärmegesetz (EEWärmeG)
2011 Reform EEWärmeG
2016: Novelle des KWKG
annual installation [GW/a]
electrical installed power [GW]
0
0.8
1.6
2.4
3.2
4
4.8
0
12
24
36
48
60
72
2002
2007
2012
2017
2022
2027
2032
2037
2042
2047
replacement
installation
power installed
Fraunhofer IEE, 2018

WIND ENERGY

The effect of legal intervention on wind energy is not immediately apparent. One reason for this being the inertia in the planning and installation of wind turbines. The project planning time for wind farms is significantly longer than than of photovoltaic systems. This means that the effect of a change in the law on the installation rate of wind turbines occurs with a time delay. Previously, the installation time for a wind farm sometimes exceeded the period between two EEG updates [11]. As a result, various effects overlap and the relation between changes in the law and market development cannot be directly captured visually. In addition, the internal return on wind energy would also have to be determined in order to take the costs into account and not just the revenues. When doing so, we expect the same effect as with PV, but more delayed.

HEAT PUMPS

In the field of heat, the multitude of laws that influence the installation of heat pumps is quite striking [38, 39]. It is necessary here to examine which law is decisive in influencing the reaction of investors.

TRANSPORT

Although there are legal incentive programmes for developing the electromobility market, these have only recently been brought into existence [40]. Therefore, a clear statement concerning the effect of legal interventions on investor behaviour behaviour about electromobility is concerned is not yet possible.

DEVELOPMENT OF INVESTMENT ACTIVITY

The evaluation of investment activity differs from the technical dimensions by being presented in a monetary unit of measurement in euros per year. The barometer bars show the investment volume we expectfor a steady market in 2050 for the various component technologies. Inflation was not taken into account but cost forecasts were made for the respective technology [28, own extrapolation]. Only the capital costs of the plants, which constitute the decisive volume from an investor's point of view, are taken into account. The costs for operation, maintenance and grid connection are not considered. In a steady market, only plant replacement will be necessary and additional capacity does not need to be installed. The barometer level indicates how much we are already investing in technology today (in 2017), in relation to the volume of the established market.

11 billion euros were invested in wind energy in 2017 [9]. According to our scenario, around 17 billion euros would have to be invested annually by 2050 to replace wind turbines. We assume the average lifetime of a plant to be 20 years [10].

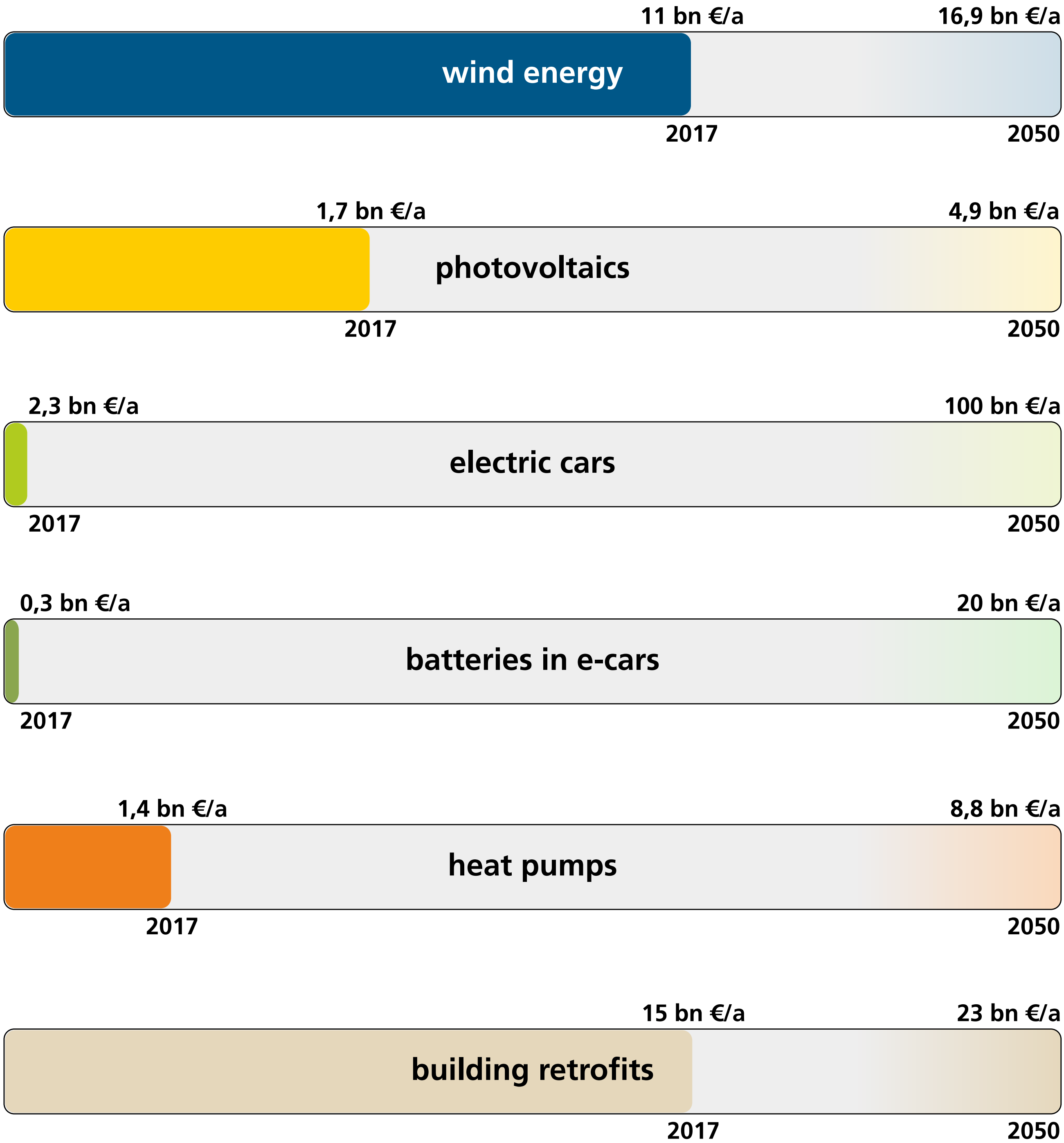
1.7 billion euros were spent on installing photovoltaic systems in 2017. According to our scenario, the target value for a steady market by 2050 is around 4.9 billion euros per year. We assume a plant service life of 25 years [12].

For electromobility, we estimate a target market of 100 billion euros. This corresponds to today's annual revenue on the passenger vehicle market in Germany. In our scenario there will only be a shift from conventional to electrically powered vehicles in future. In 2017, investments of 2.3 billion euros were made in electric cars and plug-in hybrids in Germany [22, own extrapolation]. In this year's Barometer, we considered batteries for electromobility separately, these being the key component of electromobility from an energy system perspective. The battery share of investments in electric vehicles amounted to 0.3 billion euros in 2017 [22, own market research]. We predict a long-term market volume of 20 billion euros per year here, which is solely investments in electric mobility batteries (own assumptions, own extrapolation). Around 1.4 billion euros were invested in the installation of heat pumps in 2017 [29]. We calculate the target market to be 8.8 billion euros per year.

The investment volume to be invested in a climate-neutral heating sector by 2050 [30] was taken into account in the retrofitting of buildings. In 2050 about 23 billion euros would have to be invested, last year it was about 15 billion euros. Only those costs were considered that would arise additionally for energy efficiency measures – e.g. no costs for scaffold construction are taken into account which would be necessary in order to renovate even if insulation measures are not carried out. When installing a heating system, only costs differential to a condensing boiler are taken into account.

Building retrofitting investments also include expenses for installing photovoltaic on-roof systems and heat pumps. In a strict sense these are double counts, as they have already been recorded in the corresponding barometer bars above (photovoltaic and heat pumps).

» The German automobile market has an annual turnover of 100 billion euros – this is the target market for electromobility.

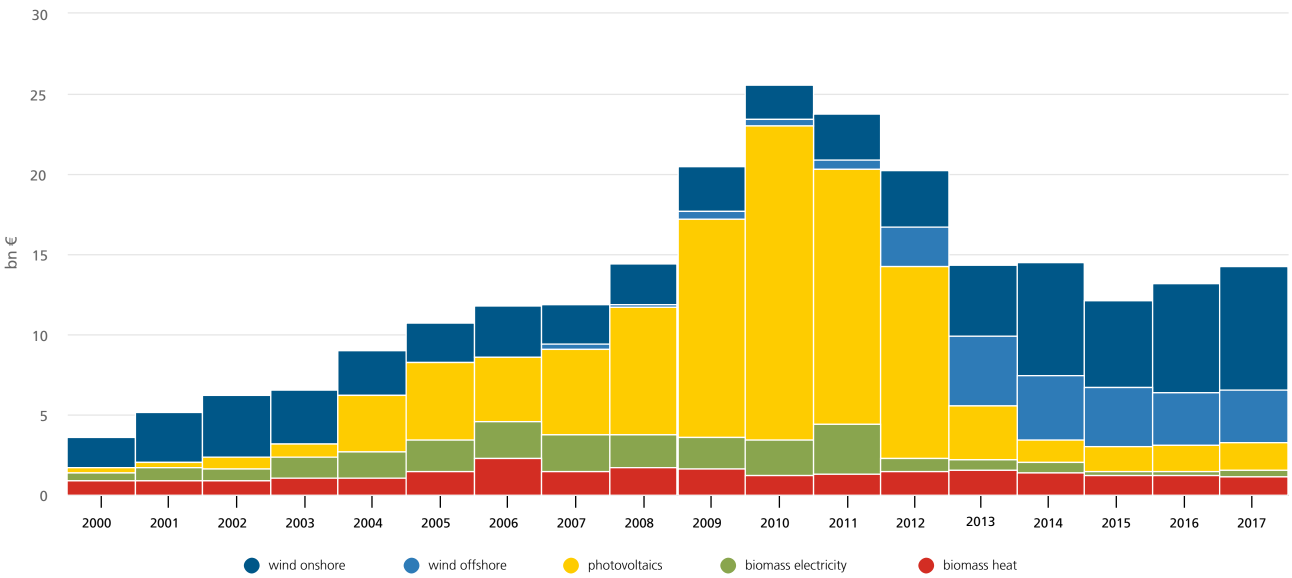


DEVELOPMENT OF INVESTMENT ACTIVITY

A long-term overview of the past developments in investment activity in setting up or replacing renewable energy plants is shown in the adjacent diagram. The amount of investments in onshore and offshore wind power, photovoltaic and biomass plants are shown, the latter divided into electricity and heat. The data are collected annually by the Federal Ministry of Economics and Energy (Bundesministerium für Wirtschaft und Energie, BMWi) [9]. The development shows significantly higher total investments of over 25 billion euros in the years 2009 to 2012 compared with only 14 billion euros in 2017, mainly due to the sharp decline in investments in photovoltaic systems. Since 2012, there have been significant investments in offshore wind power plants. Overall, investment in renewable energy plants seems to have stagnated since 2013.

According to our calculations, in a steady state market for a 100 % renewable energy system, around 22 billion euros per year will need to be invested in the construction of energy generation facilities (wind power and photovoltaics) (see Investment activity page 36).

» *Between 2009 and 2012, investments in renewable energy plants were significantly higher than today.*

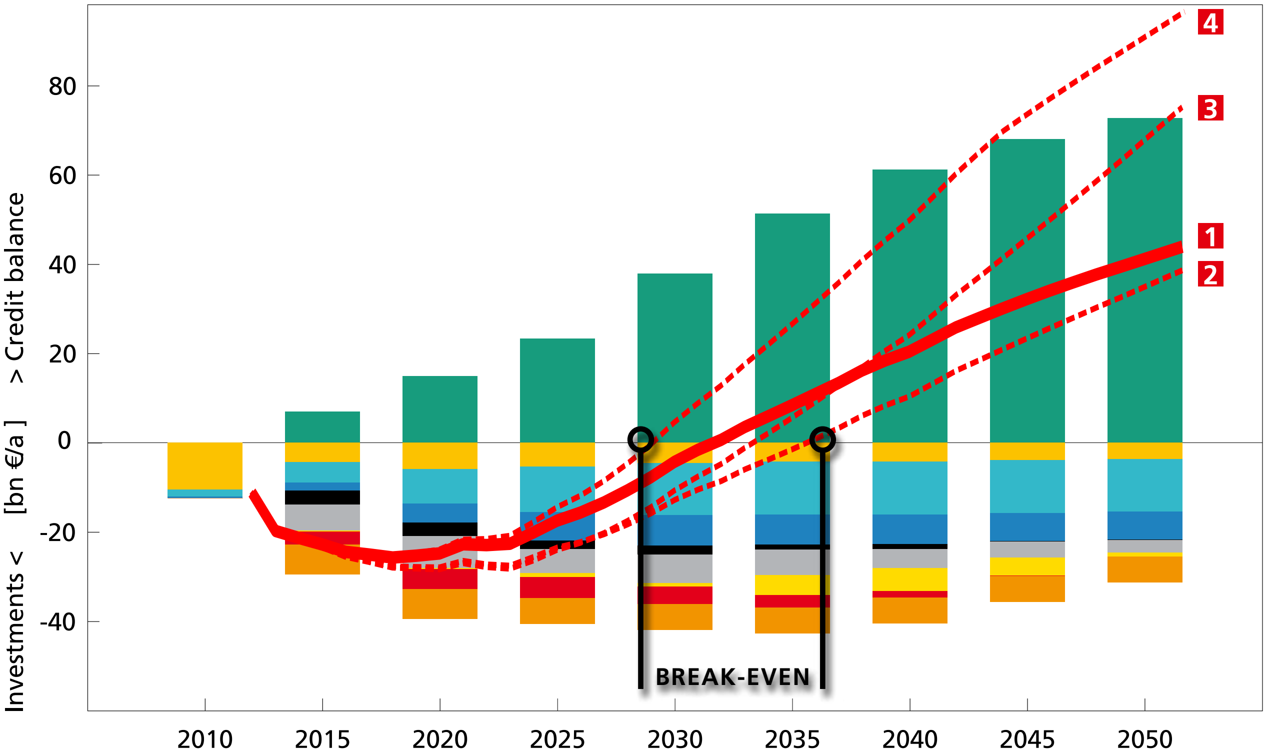


Fraunhofer IEE, 2018

BUSINESS MODEL FOR THE ENERGIEWENDE

We can codify past investment activity into the future by calculating the development costs of a cost-optimized transition scenario. We did this in the study »Business Model for the Energiewende« [31]. Investments in various generation and consumption technology (negative bars, see chart) are set against credits from obvioded primary energy use (positive green bars). The cumulative sum of expenditures and savings is represented by the dashed and solid lines. The lines distinguish between variations with different interest rates and primary energy costs (1-4). The breakthrough points of the cumulative contribution margins through the zero line are the break-even points of the transformation. Depending on various assumptions concerning interest rates and primary energy prices, positive gross margins will be achieved in the time frame between 2029 and 2035.

The energy turnaround is a business model with positive contribution margins: the break-even point depends on interest rates and primary energy costs.



Investments and credit for 1

- Fuel savings
- Photovoltaics
- Wind onshore
- Wind offshore
- Routine costs of infrastructure
- E-Mobility
- Power2Gas and other storage
- Heat pumps
- Building insulation
- Cost of capital

4 6,7% Return on investment, 2% interest on loans, primary energy price increase in accordance with climate protection scenario 2050

3 4% Return on investment, 2% interest on loans, primary energy price increase in accordance with NEP 2014 (Grid Development Plan 2014)

1 2,3% Return on investment, 0% interest on loans, primary energy price remains constant

2 2,3% Return on investment, 2% interest on loans, primary energy price remains constant

How emissions trading works

The Emissions Trading System (ETS) is based on a simple mechanism: participating companies are only allowed a defined amount of carbon dioxide emissions which decreases year by year. For these emissions, freely tradable certificates are issued to the participants - free of charge or at a charge. If the certificates received prove to be insufficient, companies must invest in climate protection measures. Alternatively, they can buy emission rights from participants who do not use up their own quota. This creates a market price for CO_2 emissions. The charm of emissions trading is its high economic efficiency. Thus, the system specifically gives an incentive to those companies having low costs for reducing their CO_2 emissions. Participants for whom a reduction in emissions would mean higher costs would also benefit from certificate trading. In this way, the CO_2 target is achieved in a comparatively cost-effective way. Investment expenditure is lower than is the case with a rigid regulatory emission target, which forces companies to reduce their emissions to a specific level which is applicable to all market participants – irrespective of their individual abatement costs. In addition, the principle of quantity control guarantees that the total CO_2 emissions of the companies are actually reduced to the set target value. The disadvantage of the ETS is that the price development of the emission certificates can only be predicted to a limited extent. This makes it more difficult for companies to calculate necessary investments in mitigation measures.

In recent years, emissions trading systems have been introduced all over the world - across national borders as well as at the level of individual states or, as in the USA and China, even

federal states and regions. The system was pioneered by the EU, which already implemented ETS in 2005. Today, metal, chemical, cement, glass and paper industries as well as refineries, the aviation industry and operators of thermal power plants participate. Together they account for around 45 percent of European CO_2 emissions. In Germany, around 1,900 industrial plants and power plants are subject to emissions trading.

In the ongoing trading period until 2020, the volume of emission certificates will fall by 1.74 percent annually. Power plant operators can purchase the required certificates solely at auction; industrial companies, on the other hand, receive a large proportion free of charge. This is intended to prevent companies from relocating their production to countries with lower climate protection standards. The quantity of certificates allocated free of charge is based on efficiency benchmarks, thus giving companies an incentive to invest in reducing their emissions.

However, the steering effect of the European ETS is low at present, as certificate prices are currently very low due to an oversupply of emission rights. The EU has therefore decided to increase the reduction rate to 2.2 percent in the trading period beginning in 2021. In addition, as from 2019, 24 percent of surplus certificates will be withdrawn from the market each year and transferred to the so-called market stability reserve. Beginning in 2023, only as many emission rights may remain in the reserve as were auctioned during the previous year. Other certificates will become invalid. In addition, member states are given the right to permanently withdraw allowances if demand falls as the result of their own national measures such as a coal phase-out.

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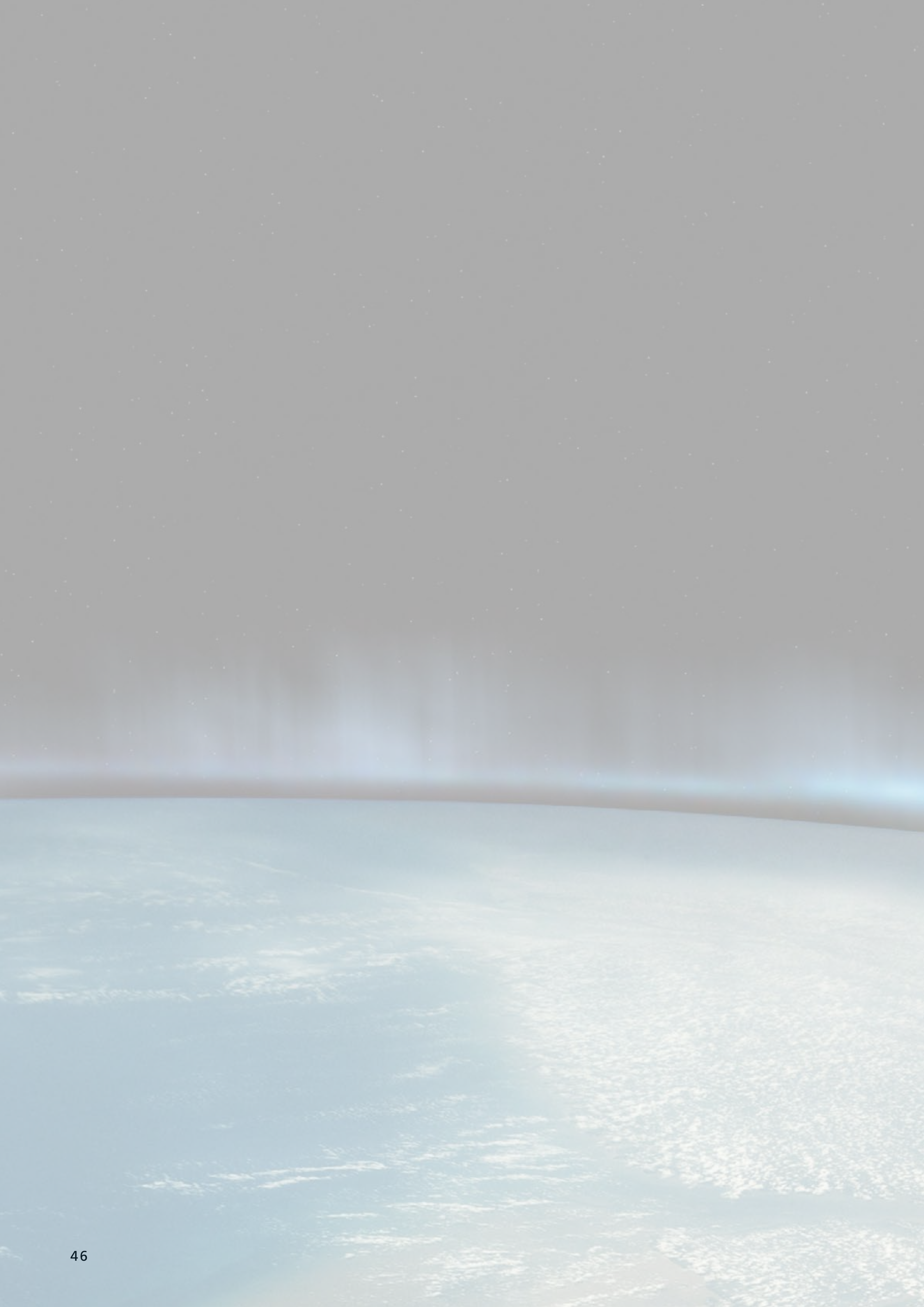

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