Sustainable social market economy

# Green Tech made in Germany: How fit for the future are we?

BertelsmannStiftung

## imprint


December 2023

Bertelsmann Foundation
Carl-Bertelsmann-Strasse 256
33311 Gütersloh

**Contact:**

Andreas Esche | Director
Sustainable business project
Telephone: +49 5241 81-81333
Email: andreas.esche@bertelsmann-stiftung.de

Dr. Daniel Schraad-Tischler | Director Project
Innovation and Startup Dynamics Telephone: +49 5241
81-81240 Email: daniel.schraad-
tischler@bertelsmann-stiftung.de

**Responsible:**

Dr. Jan C. Breitinger
Daniel Posch
Dr. Marcus Wortmann

**Cooperation:**

Viktoria Roeckl

**Authors:**

Kai Gramke
Klaus Jank
Daniel Posch
Jochen Spuck



DOI number: 10.11586/2024001

# Green Tech made in Germany: How fit for the future are we?

Kai Gramke1
Klaus Jank1
Daniel Posch2
Jochen Spuck1

A study commissioned by the Bertelsmann Foundation. Implemented by EconSight AG.

**A cooperation of projects:**

Sustainable business

Strengthen innovation and start-up dynamics

1: EconSight AG
2: Bertelsmann Foundation

About Us

## Sustainable social market economy

Combining economic performance and social participation productively – that is the core idea and recipe for success of the social market economy. However, climate change and the limitation of natural resources, a declining workforce, globalization processes and digital change are putting our current economic and social model under pressure.

In order for the social market economy to remain a reliable model for future generations, we must transform it into a sustainable social market economy.

The ecological transformation creates interactions and Conflicts between the different target dimensions of one Sustainable social market economy. The focus of work “Economics of Transformation” is dedicated to the macroeconomic interrelationships between various target parameters and creates empirical control knowledge for bundles of economic policy measures that can prevent the inherent conflicts of objectives, resolve them or release synergy potential. This focus paper is part of a series of publications on the economic policy trade-offs of a sustainable social market economy.

# Contents

# Illustrations

# Table



# Text box

# 1 Executive summary

Climate protection and sustainability are among the most important global challenges. The climate goals can only be achieved with joint efforts from politics, society and business. The transformation of the energy system towards renewable energies, the economy towards higher energy efficiency and the energy-efficient renovation of the building stock cause transformation costs. Technological breakthroughs can reduce the costs required for the energy transition. In order to achieve long-term climate goals, negative emissions will increasingly be necessary from 2030 onwards. This requires technologies that are currently still being developed and refined.

In this study, the most important global trends in green technologies and Germany's research position in this regard are examined based on a patent analysis. When selecting the technologies or general categories, various sources and expert know-how were used. For the analysis, 60 technologies designated as green, which either already had a large number of patents or at least a high growth in the number of patents, were selected from these sources and assigned to ten thematic main categories.

During the evaluation, all active patents, including older ones that were still valid, were taken into account for this study. The advantage of this method is that not only the dynamics of the development of the patent portfolio over time, but also the absolute sizes and strengths of the patent portfolios at the current point in time can be measured. Furthermore, the focus of this study was on the patent quality, which was derived from the combination of citations of the patent and its country coverage and depicted the so-called world-class patents: the existence and development of the top ten percent of patents per technology.

**Germany is responsible for half of the EU's world-class patents**

With almost 10,000 developed active world-class patents in green technologies, Germany is responsible for half of the world-class patents from the EU-27. It is the only European country that can compete with the world's most important research countries in terms of patent numbers.

Germany's technological strengths lie particularly in the categories "New Energy", "New Mobility" and "Efficient Production", in which German companies hold a large absolute number of world-class patents and an above-average share of global world-class patents. Germany is also an important research player in the international comparison in the areas of “adaptation technologies to climate change”, “efficient mobility” and “hydrogen economy”.

When it comes to sector classification, a large part of the research activities in green technologies are carried out in key German industries such as the electrical industry, the automotive industry, the chemical industry or mechanical engineering.

In Germany, on the other hand, the importance of the ICT (information and communications technology) industry is not particularly high in terms of the number of world-class patents in green technologies. In the USA, for example, companies from the ICT segment play a more important role in cutting-edge research in the green tech sector. Germany, on the other hand, does not perform particularly well in an international comparison when it comes to technologies with a high degree of digitalization.

Even though the number of world-class patents from Germany in most green technologies has increased significantly in recent years, the international development has been even more dynamic because Germany's global share has fallen overall in all ten main green categories. Germany must improve here in order to maintain its overall good international research position in green technologies.

**The USA is at the forefront of green tech patents, but China is rapidly catching up**

In a global comparison, the USA is the leading top research location in green technologies, with one in three world-class patents developed worldwide. The US global share is particularly high in the “Efficient Mobility” category, particularly in the individual technology of energy-efficient aircraft turbines. The USA is also the most important location for German companies for research activities in green technologies abroad.

China, which has seen its world-class patents rise from just over 1,000 to nearly 37,000 between 2010 and 2022, is expected to soon displace the US from the top spot. In the “Sustainable Consumables/Recycling” category, China’s global share is now around 40 percent.

With a portfolio of world-class patents of over 31,000 in 2022, Japan ranks third. It is a global technology leader in the energy storage and hydrogen economy categories.

The EU follows in fourth place with around 19,000 world-class patents. It plays an important role in global research competition, especially in the categories “New Energy” and “Efficient Mobility”.
In recent years, the EU has achieved a slightly higher rate of growth in world-class patents than the USA and Japan.

Another important country in the field of green tech is South Korea with almost 7,700 world-class patents in 2022. South Korea's technological strength lies primarily in the area of "energy storage", but the country also has a very high level of research momentum in other technology areas.

**At a global level, a lot of research activity in the categories of new mobility and efficient production**

At a global level, within the ten main green technology categories, there are the most world-class patents in the two areas of “Efficient Production” and “New Mobility”, which have developed at an above-average rate since 2010. The main growth drivers in the “Efficient Production” category are the increasing networking of production processes and in

“New mobility” means massive technological changes in the automotive sector with the change to electromobility and the increasing importance of digitalization.

The highest relative growth occurred in the “Energy-efficient systems” category, in which world-class patents have increased more than fivefold since 2010. In the next category, “New Energy,” development was less dynamic. A warning sign regarding the goals of the Paris Climate Agreement, as this category includes key areas for the decarbonization of the economy.

# 2 Introduction

Climate protection and sustainability are among the most important global challenges. The war in Ukraine has increased pressure, especially in Europe, to reduce dependence on oil and gas. It is undeniable that the climate goals can only be achieved as a joint effort between politics, society and business. The conversion of the energy system away from fossil fuels towards renewable energies, the energetic renovation of the building stock and the conversion of industrial processes towards higher energy efficiency cause high transformation costs.1 Technological innovations play a central role in this, as technological breakthroughs increase the costs required for the energy transition can lower.

The power of innovation plays a central role in the (further) development of green technologies that drive the energy transition. From 2030 onwards, negative emissions (e.g. through carbon dioxide filters, capture and

binding).2 This requires technologies that are currently still in the demonstration or prototype phase.3 Major innovation efforts must therefore be made in order to bring these new technologies onto the market in a timely manner. Technical progress and new developments in green technologies certainly cannot alone save the climate. But as technology advances, adaptation becomes easier, personal limitations become fewer, and success becomes more likely.

This study uses a patent-based technology analysis to show the global trends in the most important green technologies. The aim is to identify the countries that have the best technological foundations, e.g. B. to develop more efficient photovoltaic cells, better fuel cells, new battery recycling methods or market-ready carbon capture or storage systems. A particular focus is on Germany's positioning and

[1] The study “Sector coupling – options for the next phase of the energy transition” (2017) by acatech/Leopoldina/Akademienunion estimates the cumulative additional costs for the energy transition in Germany by 2045 to be between 500 billion euros and 3,000 billion euros. This estimate only takes into account the costs for investments in technical components and infrastructure as well as the maintenance of the energy system, but does not take into account other economic effects of the energy transition or external costs due to CO2 emissions (see: https://www.ifo.de/medienartikel/2019-07-12/what-the-energy-transition-will-really-cost-us).

[2] Erlach et al. 2022.

[3] IEA 2021.

Development in green technologies: How future-fit is the German technology profile with regard to green transformation?

**Why patent analysis?**

The basis of technology analysis is the evaluation of patent data. Patents are an important proof of the success of research and development and therefore one of the most important innovation output indicators. The patent portfolio of an economy or its companies and research institutions forms an important basis for its innovation and therefore future viability. Based on the development of patents per year, the strength of the patent portfolios of the selected countries or regions can be analyzed and compared and the technological development can be shown.

All active patents, including older patents that are still valid, are taken into account as of the respective reference date (end of year).4 This differs from other patent analyzes in which often only new patent applications are counted per year. The advantage of the approach used in this study is that both the dynamics of the development of the patent portfolio over time and the absolute size and strength of a patent portfolio at the current point in time can be measured. In the case of evaluations based on patent applications, however, only the latest developments are recorded, while existing technological know-how from older patents is not taken into account.

Another important element is the focus on patent quality. The basis for assessing quality is a combination of citations to the patent and its country coverage.5 Our evaluations focus on the existence and development of the top ten percent of patents per technology - the world-class patents. The focus on world-class patents makes sense in order to reduce distorting effects caused by country-specific differences in patent systems. In China, for example, researchers are encouraged to patent as much as possible through tax breaks in order to increase the relevance of China as a research location.

**Selection of green technologies**

This study analyzes the most important global trends in green technologies and Germany's research position within them based on a patent analysis. The first step is to determine what green technologies actually are. We are guided by the United Nations definition of green technologies:

[4] The term of a patent is normally 20 years from the date of application, provided that the annual patent fees are paid. However, many patents expire early due to non-payment of annual fees if there is no sufficiently lucrative exploitation opportunity for the patent owner. The successful challenge of a patent or the non-granting of a patent after patent examination also results in a patent becoming inactive.

[5] For more information see the Methodology chapter.

“Green technologies protect the environment, are less harmful to the environment, use all resources more sustainably, recycle more of their waste and products and deal with residual waste more acceptably than the technologies they have replaced.”6

For this study, 60 individual green technologies were selected and assigned to the following ten thematic categories:

- New energy
- Energy storage
- Hydrogen economy
- New mobility
- Efficient mobility
- Efficient production
- Energy efficient systems
- Energy efficient appliances
- Adaptation technologies to climate change
- Sustainable consumables/recycling

[6] United Nations Rio Program of Action, 1992 (https://www.un.org/Depts/german/conf/agenda21/agenda_21.pdf).

TABELLE 1 **Technologieüberblick**

| Nr. | Name |
|---|---|
| | **Neue Energie** |
| 1 | AC/DC Wandler, Photovoltaik |
| 2 | Biotreibstoffe, Biomasse |
| 3 | Geothermie |
| 4 | Kernfusionsreaktoren |
| 5 | Meeresenergie & Wasserkraft |
| 6 | Organ. Solarzellen, Tandem- und Perovskitzellen |
| 7 | Schwimmende Offshore Windkraftanlagen |
| 8 | Silizium Photovoltaik Zellen |
| 9 | Solarthermie |
| 10 | Wärmepumpen |
| 11 | Windenergie |
| | **Energiespeicherung** |
| 12 | Bipolarbatterien |
| 13 | Feststoffakkumulator |
| 14 | Lithium Akkumulatoren |
| 15 | Natrium Ionen Batterien |
| 16 | Redox-Flow, Alkalimembran-Brennstoffzellen |
| | **Technologien zur Anpassung an Klimawandel** |
| 17 | Effiziente Beregnung & Bewässerung |
| 18 | Emissionsreduzierendes Tierfutter |
| 19 | IR/Wärmemanagement, Wärmedämmfassaden |
| 20 | Moderne Dämmstoffe |
| 21 | N2O, Nox-Abscheidung |
| 22 | Reinraumlandwirtschaft |
| 23 | Torrefaction, Pyrolyse, Biokohlenstoff |
| 24 | Wald, Bäume, Anpflanzung, Kultivierung, Aufforstung, Feuerwar- |
| 25 | Wasserentsalzung |
| | **Nachhaltige Verbrauchsmaterial. / Recycling** |
| 26 | Abfallmanagement |
| 27 | Fleischalternativen |
| 28 | Kunststoff-, Glas-, Papier-, Elektronikrecycling |
| 29 | Nachhaltige Verpackungen |
| 30 | Recycling von Batterien und Brennstoffzellen |
| 31 | Trinkwasseraufbereitung |
| 32 | Zementrecycling und Abfallwiederverwendung |

| Nr. | Name |
|---|---|
| | **Wasserstoffwirtschaft** |
| 33 | Grüne/Blaue Ammoniakproduktion |
| 34 | Grüne/Blaue Methanolproduktion |
| 35 | Herstellung von Brennstoffzellen |
| 36 | Produktion von grünem/blauem Wasserstoff |
| 37 | Wasserstoffelektrolyseur, Elektrolyse |
| 38 | Wasserstofferzeugung und -speicherung |
| 39 | Wasserstoffleitungen, Rohre, H2/Gas-Trennung |
| | **Neue Mobilität** |
| 40 | Autonome Straßenfahrzeuge |
| 41 | Batterieladegerät für Fahrzeuge |
| 42 | Eisenbahntechnologien |
| 43 | Elektrofahrzeuge, kein Hybrid |
| 44 | Elektromotoren |
| 45 | Vernetzte Autos, Interaktion im Straßenverkehr |
| 46 | Wasserstoff-Tankstelle |
| 47 | Wasserstofftank |
| | **Effiziente Mobilität** |
| 48 | Effizientes Autodesign |
| 49 | Energieeffiziente Flugzeugturbinen |
| 50 | Synthetische Treibstoffe |
| | **Effiziente Produktion** |
| 51 | Additive Fertigung |
| 52 | Digitale Landwirtschaft, Präzisionslandwirtschaft |
| 53 | Effiziente Glas- und Keramikproduktion |
| 54 | Effiziente Chemieproduktion, Petrochemie, Textil |
| 55 | Effiziente Metallproduktion |
| 56 | Kohlendioxidfilter, Abscheidung und Bindung |
| 57 | Treibhausgasred. Aluminiummetallproduktion |
| 58 | Vernetzte Produktion (Smart Factory) |
| | **Energieeffiziente Geräte** |
| 59 | Energieeff. Gebäude-, Beleucht.-, Büroelektronik |
| 60 | Energieeffiziente Gebäudetechnik |
| | **Energieeffiziente Systeme** |
| 61 | HGÜ-Hochspannungs-Gleichstrom-Übertragung |
| 62 | Intelligente Stromnetze (Smart Grid/Meter) |
| 63 | Intelligentes, vernetztes Haus (Smart Home) |

| BertelsmannStiftung

Various sources were used to select the content of the technologies or general categories. Worth mentioning here is the EU taxonomy for sustainable economic activities[7] , the Climate protection technologies from the European Patent Office (EPO)[8] , in which relevant patent classes were defined with experts from the Intergovernmental Panel on Climate Change (IPCC), among others, and the Green Technologies from the World Intellectual Property Organization

[7] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_de
[8] https://www.epo.org/de/node/447280.

(WIPO)9 . This was supplemented with EconSight's experiences from previous analyzes in the area of Green Tech.10

All technologies identified as green by the sources mentioned were analyzed and those selected for the list of 60 technologies in which there is either already a large number of patents or at least a high growth in the number of patents. A high number of patents shows that there is already extensive research activity, which is an indication of the relevance of the technology. A high growth in the number of patents indicates a high level of research momentum in a technology area, meaning that the importance of the technology is likely to increase in the coming years.

All technologies examined contribute to more sustainable economic activity.
However, the effect of the different green technologies differs. The decisive criterion here is the influence that the technologies have on the emission of climate-damaging emissions. For example, there are numerous technologies that cause no or at least hardly any climate-damaging emissions (e.g. many technologies in the “new energy” category such as wind or solar energy, which are central to the success of the energy transition).

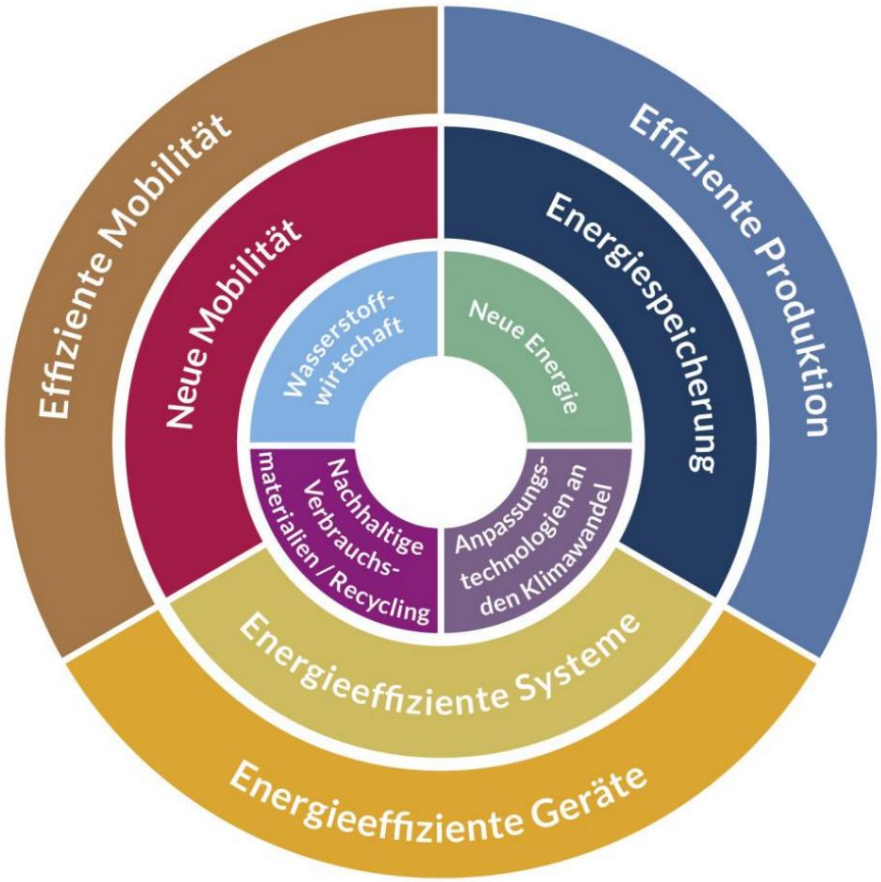
Other technologies, such as more energy-efficient aircraft turbines or efficient metal production, reduce emissions of climate-damaging emissions, but cannot completely avoid them. However, for the energy transition to succeed, both climate-neutral and efficiency-enhancing technologies are necessary. Even with a successful transformation of the economy towards green technologies, the demand for energy sources such as oil11 and gas will remain high in certain economic segments worldwide for a long time. Therefore, it is central to the success of the energy transition that emissions are reduced through the use of technologies (such as

Carbon dioxide filter, capture and binding)12 or green/blue hydrogen can be reduced.

Figure 1 shows the structure of the ten technology fields. The inner circle contains the central climate-neutral green technologies, while the outer circles contain the technologies that can at least significantly reduce emissions due to their efficiency-increasing effect. The efficiency decreases towards the outside.

[9] https://www3.wipo.int/wipogreen/en/.
[10] EconSight 2023.
[11] IEA 2022.
[12] acatech 2018.

ABBILDUNG 1 **Überblick der 10 Technologiefelder nach Wirkungsgrad**




Quelle: EconSight, 2023.

BertelsmannStiftung

## 3 Global trends in green technologies

Research activities in green technologies have increased significantly worldwide in recent years. This is shown by the development of global world-class patents: Between 2010 and 2022, the active inventory of global world-class patents more than tripled from almost 50,000 to over 150,000. In comparison, world-class patents in all technologies worldwide have only doubled in the same period (from around 750,000 to 1.5 million), meaning the research momentum in green technologies was clearly above average.

Within the ten main categories, “Efficient Production” is now the largest green tech main category in terms of patent numbers, with more than 40,000 world-class patents, just ahead of the “New Mobility” category with around 36,000 world-class patents. Growth in world-class patents in both categories was over 12 percent per year between 2010 and 2022.
Both categories have shown above-average dynamic development compared to the overall development of green world-class patents (+10 percent pa).

An important focus of the “Efficient Production” area is on technologies for more efficient production in the large energy-intensive metal and chemical industries as well as in agriculture. A key growth driver is the increasing networking of production processes. For example, predictive maintenance systems are intended to help production become more resource-efficient. These systems are data-driven maintenance methods that analyze the condition of production equipment and help predict malfunctions, disruptions and the timing of required maintenance. This allows problems to be resolved before they lead to downtime. In addition, components that are still intact are not replaced unnecessarily, thereby increasing efficiency and sustainability.

The patent growth in the overall category “New Mobility” is driven not only by the major car manufacturers and suppliers, but also by companies from other industries, such as electronics companies (e.g. Samsung), battery producers (e.g. CATL), chip manufacturers ( e.g. Intel) or software companies (e.g. Alphabet, Baidu). Massive technological changes are taking place in the automotive sector with the shift to electromobility and increasing digitalization (keyword autonomous driving).

13 The competitive pressure for the established players is therefore very high. Numerous new Asian automobile manufacturers are entering the market, and at the same time battery manufacturers, electronics companies and software companies are also trying to secure more and more of the value added. The established car companies must therefore invest heavily in new technologies in order to remain technology leaders in the future.

After a very dynamic development at the beginning of the 2010s, research momentum in the field of “new energy” has slowed somewhat since then. With regard to the goals of the Paris Climate Agreement, the slowdown in momentum represents a warning signal, as the category includes “green core technologies” such as solar and wind energy, which are central to the decarbonization of the economy. In order to achieve the Paris climate goals and thus limit the temperature increase to two degrees compared to pre-industrial levels, a significant further increase in energy production from renewable sources is a central prerequisite.14 The International Energy Agency (IEA) assumes in its “Net zero by 2050 ” scenario that almost 90 percent of global electricity generation in 2050 will come from renewable sources, with photovoltaic and wind turbines together accounting for almost 70 percent.15 Solar and wind energy are already comparatively mature technologies compared to other green technologies. However, the current problems faced by numerous companies when expanding offshore wind farms (e.g. high installation costs and high maintenance requirements) show that there is still a great need for innovation.

The Sustainable Consumables/Recycling category is the fourth largest category in terms of the number of global world-class patents. The recycling of raw materials, materials and products plays an important role in this category, but so does drinking water treatment

[13] Deloitte 2023.
[14] IEA 2022.
[15] IEA 2021.

an important single technology in this area. This category therefore includes technologies that play an important role in the functioning of the circular economy. The aim of the circular economy is to preserve the value of products, materials and resources for as long as possible by returning them to the product cycle at the end of their use, while minimizing waste generation. In the “Sustainable Consumables/Recycling” category, the number of world-class patents has increased significantly, especially since 2015.

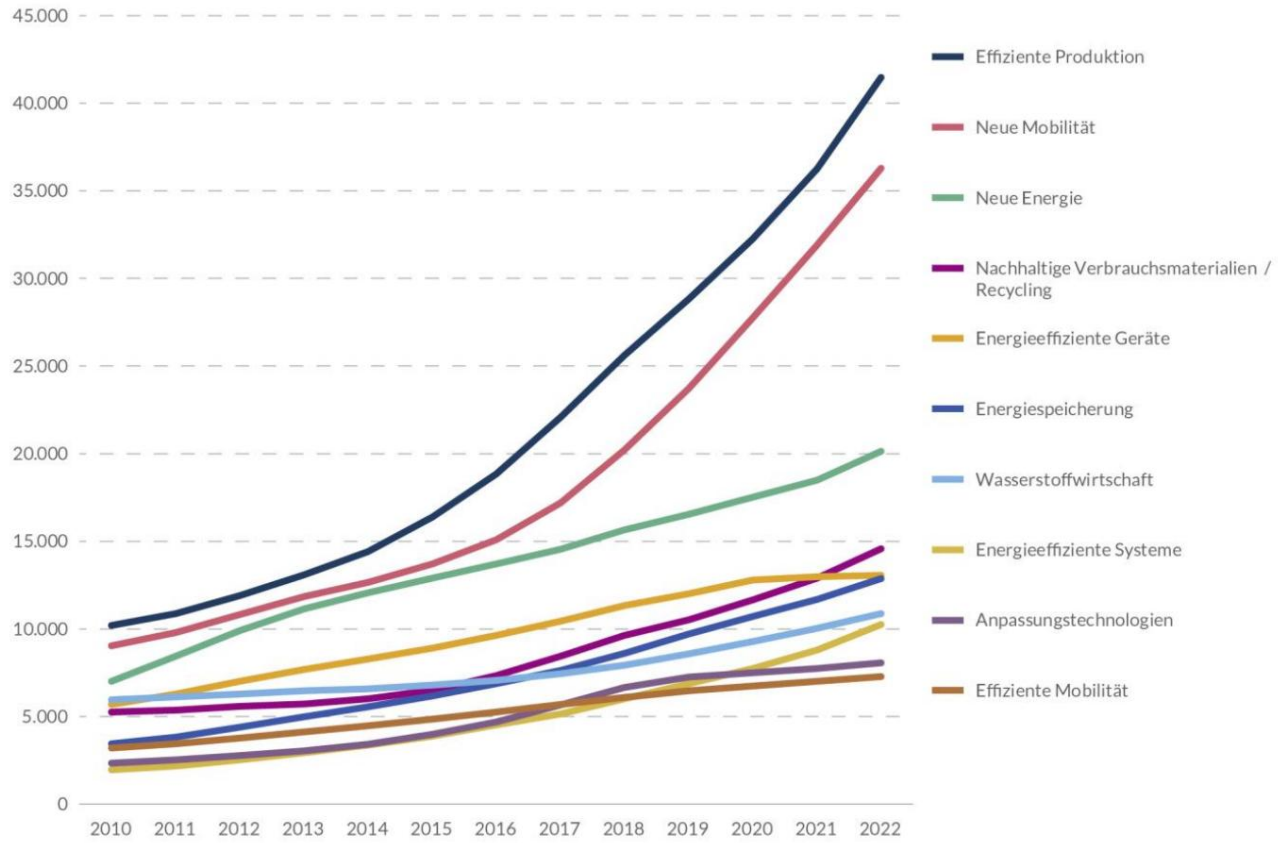
The highest relative growth occurred in the “Energy Efficient Systems” category, where world-class patents have increased more than fivefold since 2010, from just under 2,000 to over 10,000.
Efficiency technologies aim to minimize energy use. Intelligent power grids (smart grids), which aim to achieve the highest possible utilization of the existing infrastructure via grid control, are of great importance.

The development in the “hydrogen economy” category, which includes all technologies that represent the value chain surrounding green or blue hydrogen and fuel cells, is also interesting. After stagnating development in the first half of the 2010s, the number of world-class patents has increased again in recent years (Figure 2). Hydrogen is likely to play an important role in the decarbonization of the economy in the future due to its diverse possible uses. Hydrogen can use fuel cells to power electric motors, be used to produce climate-friendly fuels, store energy, heat houses or be used to produce green steel.

The main obstacles to the use of hydrogen in mobility applications are the high acquisition costs, the low availability of hydrogen infrastructure and the higher fuel costs compared to traditional drives and lower energy efficiency compared to electric cars.16 Therefore, the use of hydrogen or fuel cells in cars has not yet been possible push through. For example, only Toyota and Hyundai currently offer fuel cell vehicles on the German market. However, there is great potential for the use of hydrogen in trucks, trains or ships that cannot be electrified or can only be electrified at high cost.17

[16] e-mobile BW 2023.
[17] IEA 2023.

ABBILDUNG 2 **Entwicklung Weltklassepatente in den zehn grünen Oberkategorien, 2010 - 2022**




Quelle: EconSight, 2023.

| BertelsmannStiftung

If you look at the development of world-class patents at the level of individual technologies, there are considerable differences in the number of patents. In some established technologies, such as electric vehicles or lithium batteries, the number of world-class patents exceeds the 10,000 threshold. Other technologies, such as B. Bipolar batteries, however, are still at an early stage of development and the number of global world-class patents is still comparatively small.

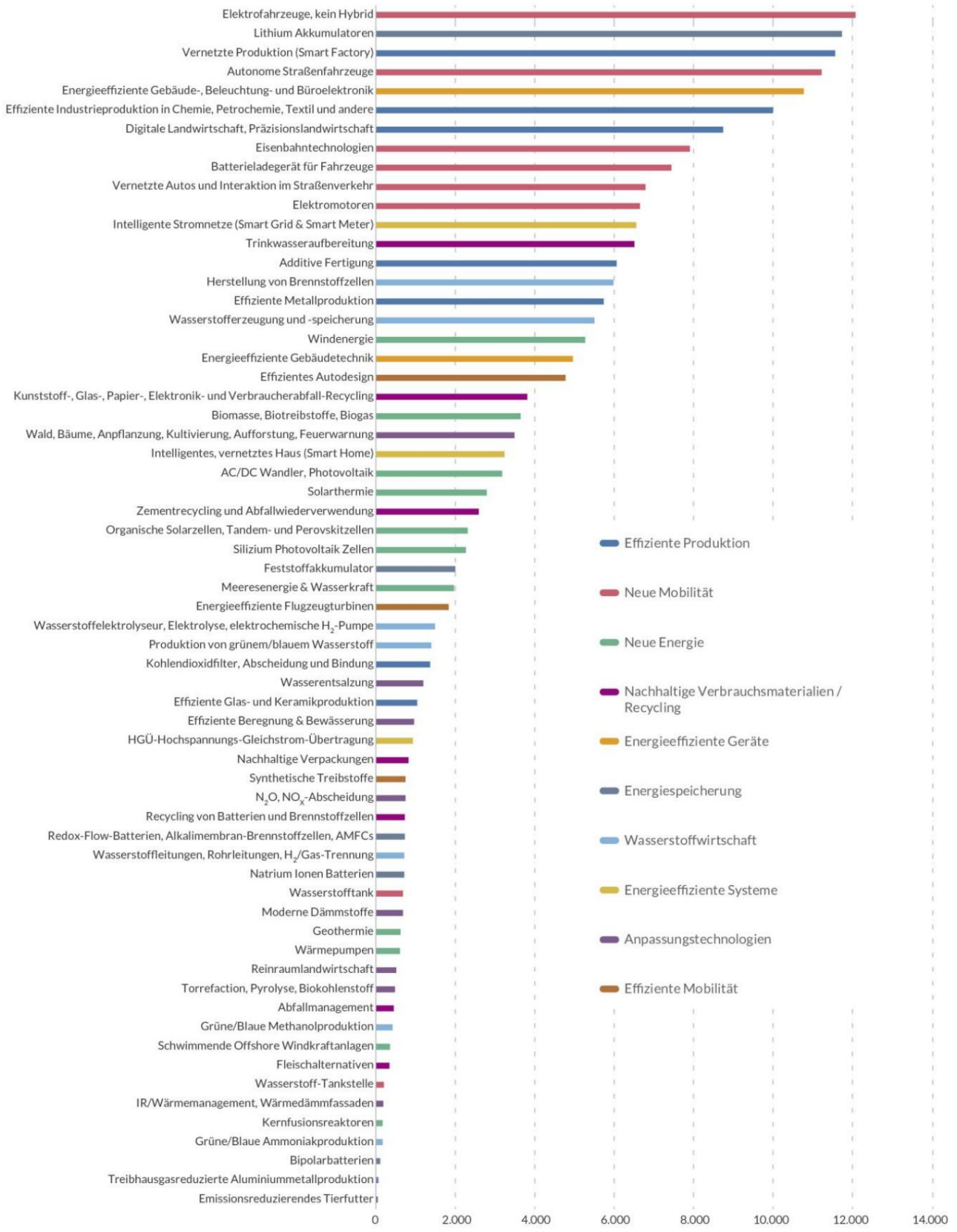
The single technology with the highest research momentum in terms of the development of world-class patents is autonomous road vehicles. The number of world-class patents in this technology tripled from almost 3,700 to over 11,000 between 2017 and 2022. The technology of autonomous road vehicles includes various elements: In order for vehicles to drive autonomously, they must first record their surroundings in real time. Sensors and perception systems are central to this, including lidar, radar, cameras and ultrasonic sensors. (AI) software is central to processing the collected data, enabling vehicles to recognize patterns, make decisions and adapt to different traffic situations. To date, there are only very few vehicles on the roads that have the capability of highly automated driving (so-called Level 3).

stage of development). With Level 3 vehicles, drivers can take their eyes off the road, but must be able to take over the vehicle at short notice in dangerous situations. The breakthrough of fully self-driving cars (Level 4 and Level 5 vehicles)

On the other hand, it is a long time coming due to technological and regulatory hurdles that have not yet been resolved.

In principle, research momentum was high in the vast majority of individual technologies. Only for silicon photovoltaic cells has the number of world-class patents fallen slightly in the last five years (Figure 3).

ABBILDUNG 3 **Zahl der Weltklassepatente in den grünen Einzeltechnologien, 2022**




Quelle: EconSight, 2023.

## 3.1 Development by region

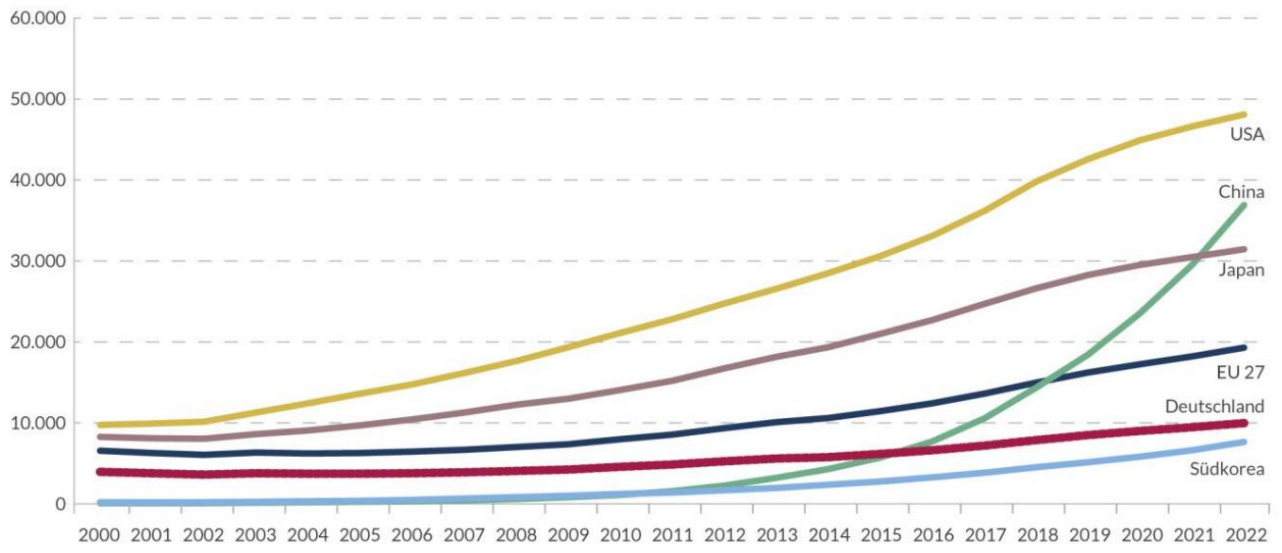
The USA is at the forefront of the world when it comes to the development of world-class green tech patents by place of invention. In 2022, the number of green tech world-class patents developed in the USA was around 48,000, meaning that every third world-class patent developed worldwide comes from the USA (Figure 4).

However, if the trend of recent years continues, China will soon displace the USA from the top spot. In China, the number of world-class patents has multiplied between 2010 and 2022, from just over 1,000 world-class patents to almost 37,000.

Japan follows in third place with a stock of world-class patents of over 31,000 in 2022. The EU follows in fourth place with around 19,000 world-class patents. In addition, the EU has achieved a slightly higher growth rate than the USA and Japan since 2010, with an average annual growth of 7.6 percent (compared to around 7 percent each in Japan and the USA). Another important country in the field of green tech is South Korea with almost 7,700 world-class patents.

South Korea achieved the second highest growth in world-class patents since 2010 after China.

ABBILDUNG 4 **Entwicklung Weltklassepatente in den wichtigsten Ländern/Regionen, 2010 - 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

## 3.2 Technology priorities of the regions

If you look at the technology focus of the largest regions, you can see that the two categories “Efficient Production” and “New Mobility” are very important in all regions (Figure 5).

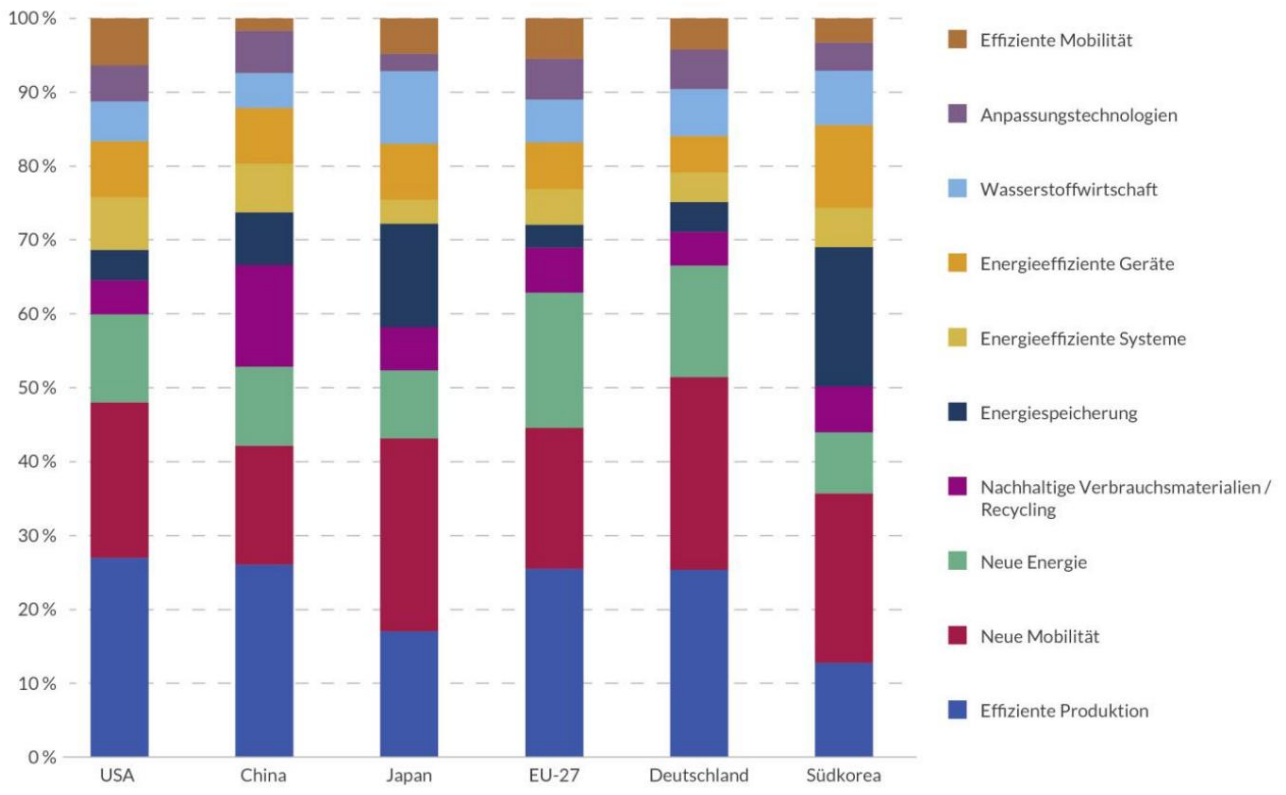
When it comes to “energy storage” technologies, however, South Korea and Japan in particular have an above-average representation. The presence of world leaders is responsible for this

Battery research companies in these two countries (e.g. LG Energy Solution and

Samsung SDI in South Korea, Panasonic and Toshiba in Japan). Japan is also the global technology leader in the hydrogen economy category. The EU and Germany play an important role in global research competition, especially in the “New Energy” category, while China has a clear research focus in the “Sustainable Consumables/Recycling” category. In China, the focus on the introduction and further development of the circular economy has been an important element of state economic policy as part of the five-year plans since 2006.18 Since then, government guidelines and investments have promoted the implementation of the circular economy, with the focus on the so-called 3R strategies (i.e. reduce, reuse, recycle; in German: reduce, reuse, recycle).

This has led to higher resource productivity in China, that is, the relative decoupling of resource consumption from gross domestic product (GDP) growth. The development of global world-class patents shows that extensive cutting-edge research activities in the area of “sustainable consumables/recycling” can now also be found in China.

ABBILDUNG 5 **Weltklassepatente der wichtigsten Ländern/Regionen nach Oberkategorien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

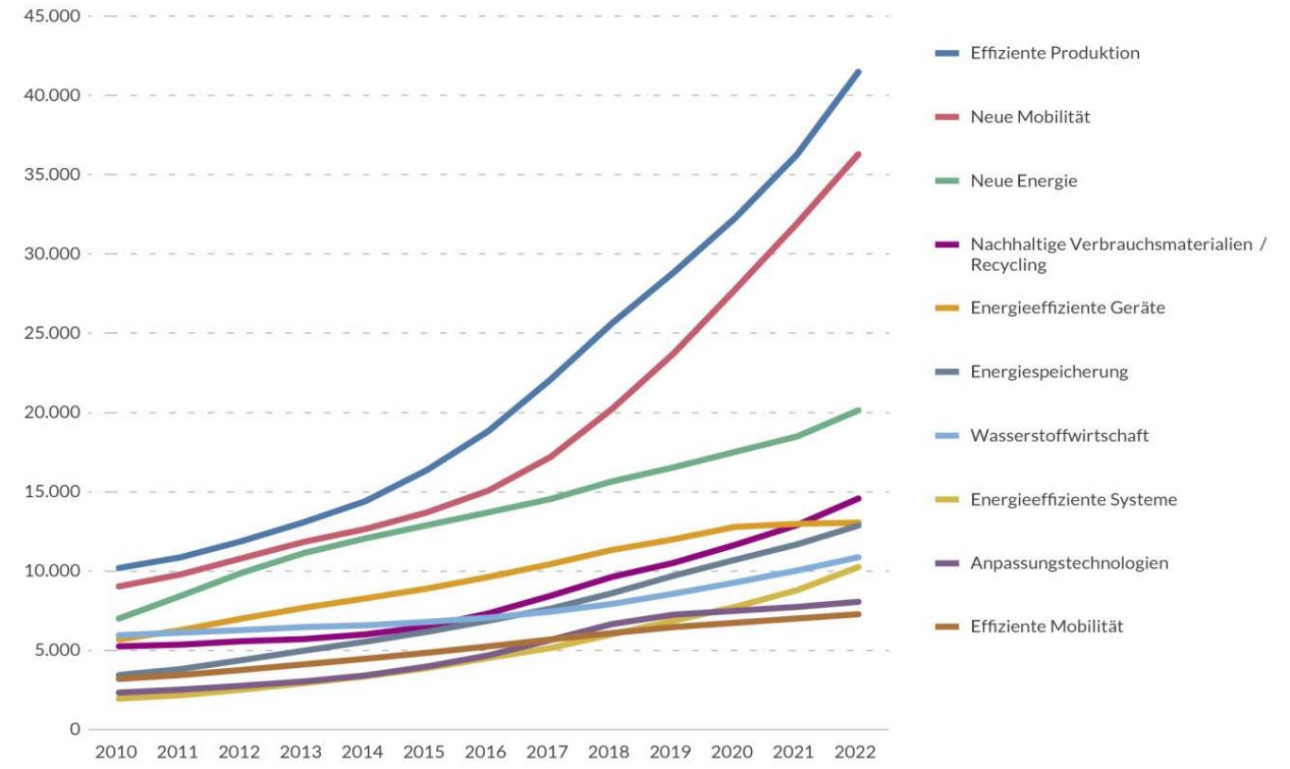
Of the approximately 150,000 active world-class patents in green technologies worldwide, more than 40,000 are in the “Efficient Production” category and around 36,000 are in “New Mobility” (Figure 6). Both categories have also experienced above-average growth since 2010

[18] Bleischwitz et al. 2022.

developed. While the total number of world-class green patents increased by around 10 percent per year between 2010 and 2022, the growth rates in the “Efficient Production” and “New Mobility” categories were over 12 percent per year in the same period. A key growth driver in the “Efficient Production” category is the increasing networking of production processes. In the area of “new mobility”, massive technological changes are taking place in the automotive sector with the change to electromobility and the increasing importance of digitalization (keyword autonomous driving). The global research priorities in green technologies therefore correspond well with the research priorities in Germany.

However, the highest relative growth occurred in the “Energy Efficient Systems” category, in which the number of world-class patents has more than quintupled since 2010 from just under 2,000 to over 10,000 (+15 percent pa). However, development was somewhat less dynamic in the “new energy” area (+9 percent pa). With regard to the goals of the Paris Climate Agreement, the slowdown in research momentum represents a warning signal, as the “new energy” category includes core green technologies such as solar and wind energy, which are central to the decarbonization of the economy. The development in the area of hydrogen is also interesting.
After a dry spell in the first half of the 2010s with a stagnating inventory of world-class patents, research momentum has picked up here in recent years. Overall, world-class hydrogen patents only increased by around 5 percent per year between 2010 and 2022.

ABBILDUNG 6 **Entwicklung Weltklassepatente in den zehn grünen Kategorien, 2010 - 2022**




Quelle: EconSight, 2023.

## 3.3 Technology profile USA

**Textbox 1: Technology profiles**

Technology profiles represent, on the one hand, the research activities of the selected companies in green technologies in detail, and on the other hand, they can also be used to demonstrate competitiveness in these technologies.

A standard comparison of technologies within a country would be done by comparing absolute patent numbers. However, some technologies are more patent-intensive than others.
For example, technological innovations in the field of telecommunications are patented more frequently than in other research areas. Reasons for the high patent intensity in telecommunications include the very high level of competition in the industry as well as the
important role of Asian telecommunications companies, which typically patent a lot. For example, the Chinese telecom equipment manufacturer Huawei was the leading patent applicant for European patents at the European Patent Office (EPO) in 2022.19

Therefore, a comparison of a patent-intensive technology with a less patent-intensive technology merely describes patent activity and says little about the relative competitiveness in these technologies. However, if you put patent activity in relation to global patent activity, you get the country's global share of this technology. This shows the country's importance in this technology and at the same time the relative competitiveness compared to other countries. The evolution of global share over two points in time shows the increase or decrease in competitiveness
over time.

Specifically, the following technology profiles (Figures 7 and 8) show the scope of top research activities in the green main categories or the individual technologies (size of the spheres corresponds to the number of world-class patents). If you put the number of world-class patents in relation to global patent activity, you get the country's global share of this technology or technology category (y-axis). The evolution of global share between 2017 and 2022 shows the increase or decrease in competitiveness over time (x-axis).

Since the number of world-class patents and patent growth sometimes differ significantly between different countries, the axis scales vary from profile to profile in order to achieve good readability. For reasons of readability, not all balls are labeled (Figure 8).

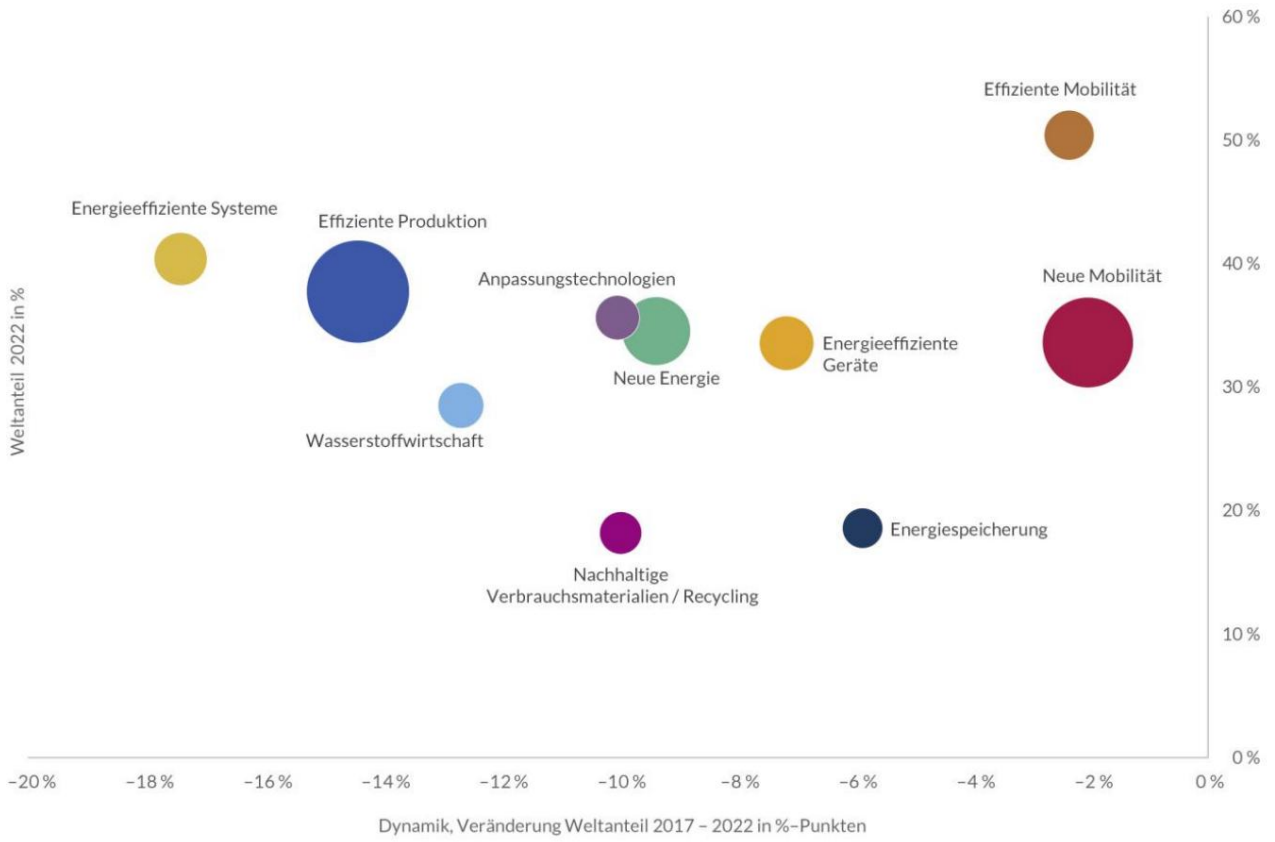
[19] EPO 2023.

The USA is a pioneer in many green technologies. With over 48,000 world-class patents in 2022, the US leads the world. This corresponds to a share of around 32 percent of all global world-class patents in green technologies.

Numerous companies with very extensive research activities in green technologies come from the USA.20 These include the US car manufacturer Ford, the industrial group General Electric, the mail order company Amazon and the software manufacturer Alphabet. In addition, leading US universities such as the Massachusetts Institute of Technology (MIT) and Harvard also have extensive research activities in green technologies.

The USA has a particularly high share of the world's world-class patents in the “Efficient Mobility” category, in which it owns more than every second world-class patent. This is primarily thanks to the research strength of US aircraft suppliers General Electric and Raytheon, which dominate the global market for energy-efficient aircraft turbines.

ABBILDUNG 7 **USA: Technologieprofil in grünen Oberkategorien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

[20] EconSight 2023.

However, most US world-class patents fall into the two categories “Efficient Production” and “New Mobility”.

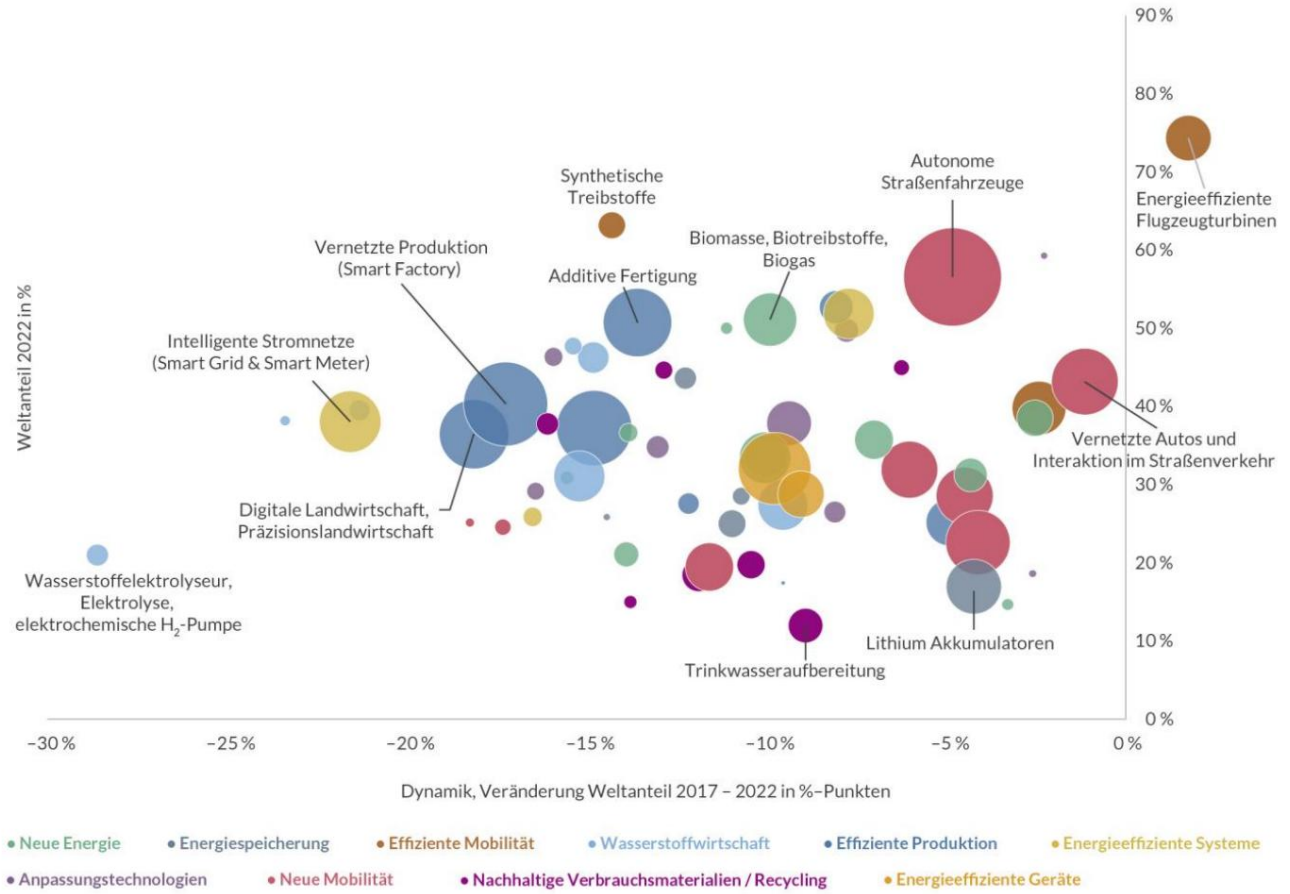
In the “Efficient Production” area, General Electric and Raytheon are again important players due to their activities in the area of 3D printing. The software company Alphabet also plays a notable role with strengths in smart factory and digital agriculture technologies.

Alphabet (mainly thanks to its subsidiary Waymo) and the two chip manufacturers Qualcomm and Intel are also becoming increasingly important in the “New Mobility” category.
This is primarily due to their expertise in the technologies of autonomous road vehicles as well as connected cars and interaction in road traffic. In the future, the use of these technologies should help to optimize traffic flows and reduce the number of accidents and thus also reduce energy consumption. Autonomous road vehicle technology is overall the technology with the most world-class patents developed in the United States (6,350 world-class patents in 2022). In addition to the companies mentioned, the large US car manufacturers Ford, General Motors and Tesla are of course strongly positioned in these technologies as well as in electric motors and electric vehicles.

In a comparison of the main green categories, the USA is positioned below average in the global research competition in the categories “Sustainable Consumables/Recycling” and “Energy Storage”. In these two categories, the U.S. share of world-class global patents is less than 20 percent (versus the average of 32 percent across all categories). When it comes to recycling and battery technologies, US research cannot currently keep up with the dynamism and quality of Asian competition from China, Japan and South Korea.

Overall, it must also be noted that the USA's global share in all major green categories has shrunk over the last five years. However, this picture is not only evident in the USA, but also in the EU and Japan. The main reason for this is the brilliant patent growth in China in recent years (see Chapter 3.4 China technology profile). China has more than tripled the number of world-class patents in green technologies since 2017 (from almost 11,000 to almost 37,000). No other large country has been able to achieve comparable growth. As a result, China's global share in all major green categories has increased since 2017, while the US share (as well as the EU and Japan's shares) has correspondingly decreased.

ABBILDUNG 8 **USA: Technologieprofil in grünen Einzeltechnologien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

## 3.4 Technology profile China

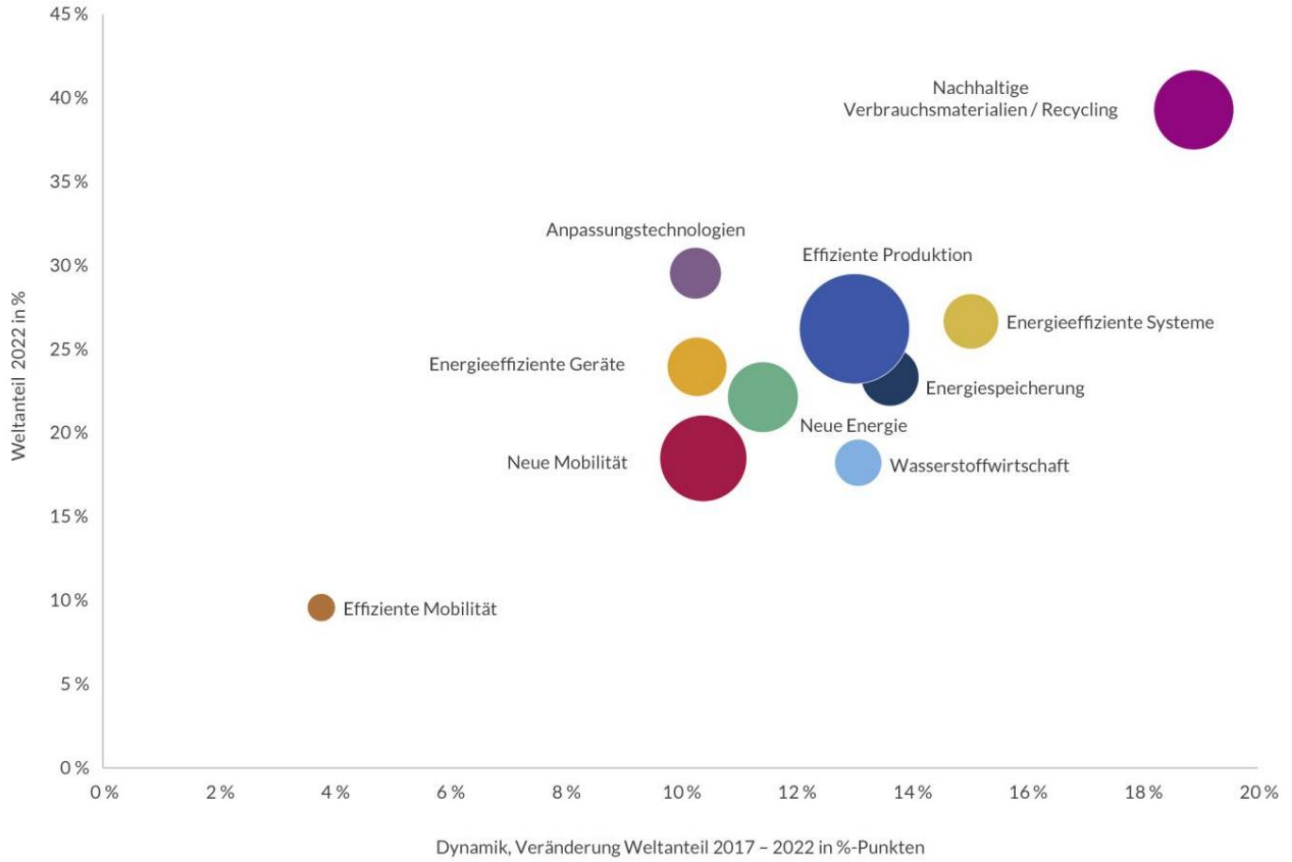
In the last 20 years or so, China has rapidly risen to become one of the leading research nations in green technologies. While China was barely present in these technologies at the beginning of this century, today the country is in second place behind the USA in a global comparison of world-class patents.

In terms of research dynamism, no other country can compete with China. This is shown by the Chinese technology profile, in which all ten green main categories are located to the right of the y-axis (Figure 9). This means that China has been able to increase its global share in all ten major categories since 2017.

The best example of China's technological rise is the Sustainable Consumables/Recycling category. The country has been able to almost double its global share in the last five years to almost 40 percent. This puts China at the top worldwide in this category. As mentioned in Chapter 3.2, the focus on the introduction and further development of the circular economy has been an important element of state economic policy since 2006. At the level of individual technologies, drinking water treatment and the

Highlighting battery and fuel cell recycling, cement recycling and plastic, glass, paper, electronics and consumer waste recycling as Chinese strengths.

ABBILDUNG 9 **China: Technologieprofil in grünen Oberkategorien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

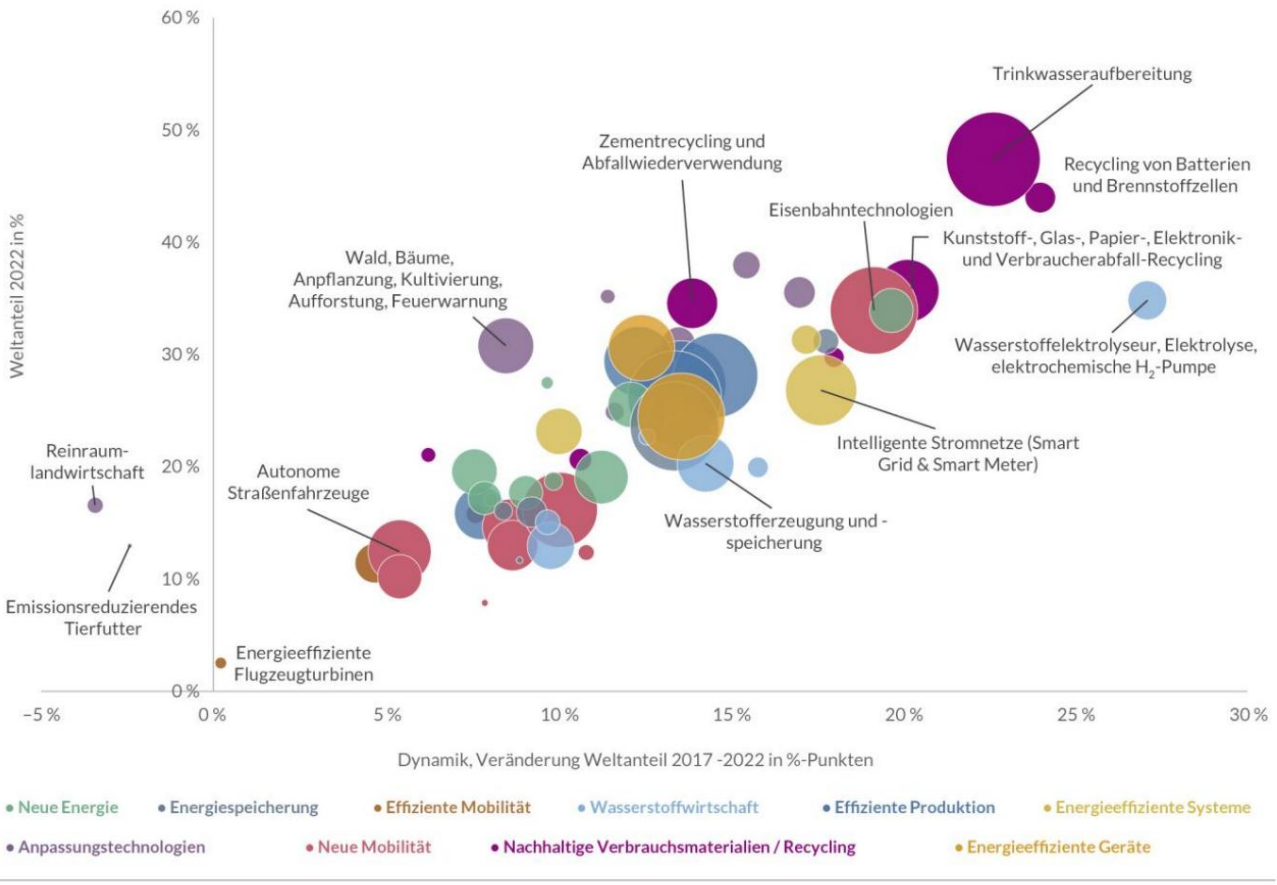
The largest technology field in China is also the area of “efficient production”. In terms of world-class patents, the technologies of networked production (smart factory), efficient industrial production in the (petro)chemical and textile industries as well as digital agriculture and precision agriculture are particularly important in China. The world's largest state-owned oil refining, gas and petrochemical conglomerate, China Petrochemical (also called Sinopec Group), has the most world-class patents from China in the area of "efficient production" (especially in technology-efficient industrial production in (petro)chemicals and textile industry).

In the area of “new mobility”, China has many world-class patents, especially in railway technologies (Figure 10). These technologies include railways including trams and other rail vehicles, recording everything that can be counted as rail transport, including individual parts, infrastructure, track and train management. Many Chinese world-class railway patents belong to state-owned railway manufacturer CRRC, the world's largest rolling stock manufacturer.

The only major category in which China's share of global world-class patents is less than 10 percent is “Efficient Mobility.” When it comes to energy efficient aircraft turbines, efficient

When it comes to car design and synthetic fuels, China is (still) technologically behind the world's leading countries. One explanation for this is that many Chinese car manufacturers (such as BYD) placed their research focus on electromobility or autonomous driving/networking early on and are therefore doing better in the area of “new mobility” (such as electric vehicles or autonomous road vehicles).

ABBILDUNG 10 **China: Technologieprofil in grünen Einzeltechnologien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

## 3.5 Technology profile Japan

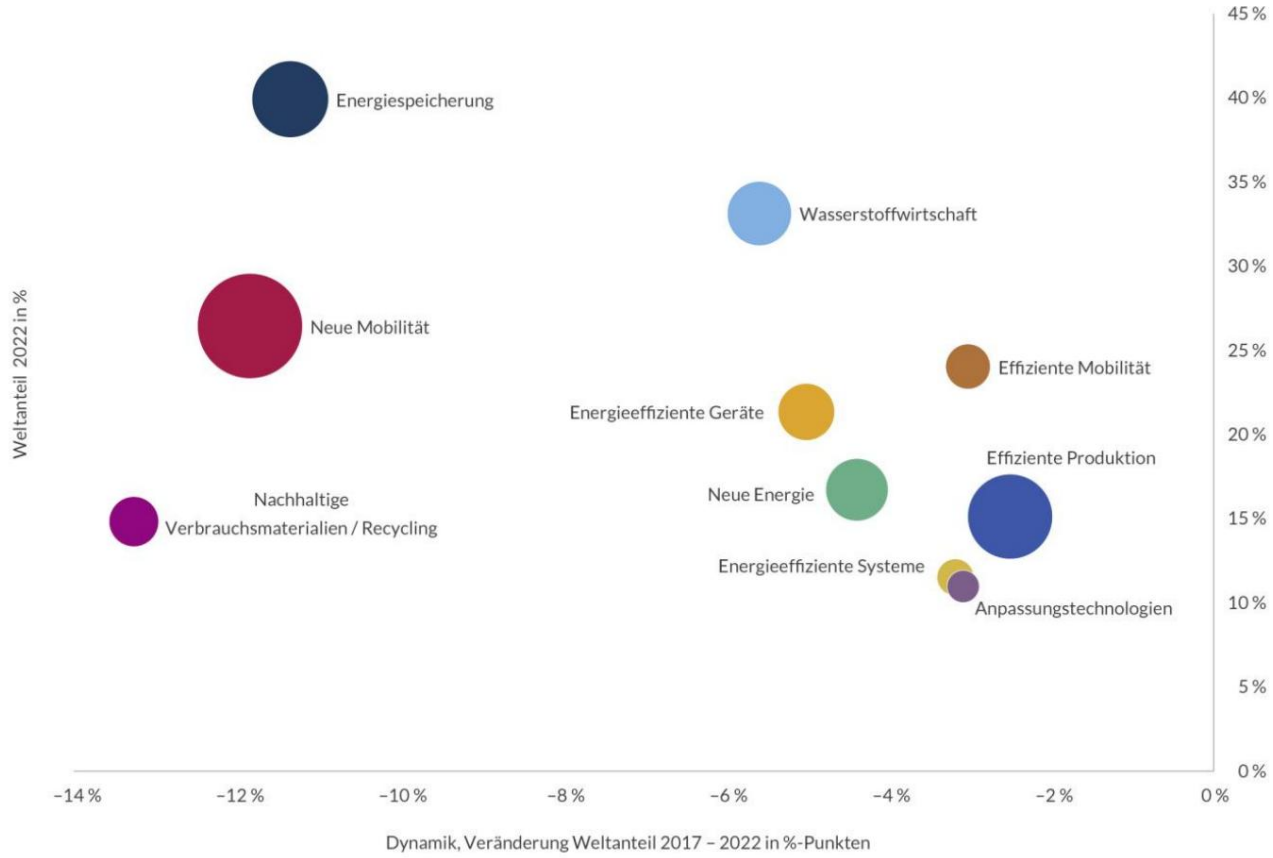
Japan is traditionally one of the leading locations in the field of green tech. In 2022, there were a total of over 31,000 world-class patents in green technologies from Japan. This corresponds to a share of 21 percent of all global world-class patents, putting the country in third place globally. Just like in the USA, Japan's global share in all green major categories has also shrunk in the last five years.

Japan has the highest global share in the two main categories of “energy storage” (world share of 40 percent in 2022) and “hydrogen economy” (33 percent). In both categories, Japan is the world's most important research location (Figure 11).

In the area of energy storage, Japan's strengths lie particularly in its technologies Lithium batteries (world share of 41 percent in 2022) and the next generation of batteries

such as solid-state batteries (46 percent) and bipolar batteries (55 percent) (Figure 12). Japan benefits from the presence of numerous technologically leading automobile companies and electronics companies in the country. Worth mentioning here are Toyota, Panasonic and Toshiba, which have many world-class patents for lithium batteries.

ABBILDUNG 11 **Japan: Technologieprofil in grünen Oberkategorien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

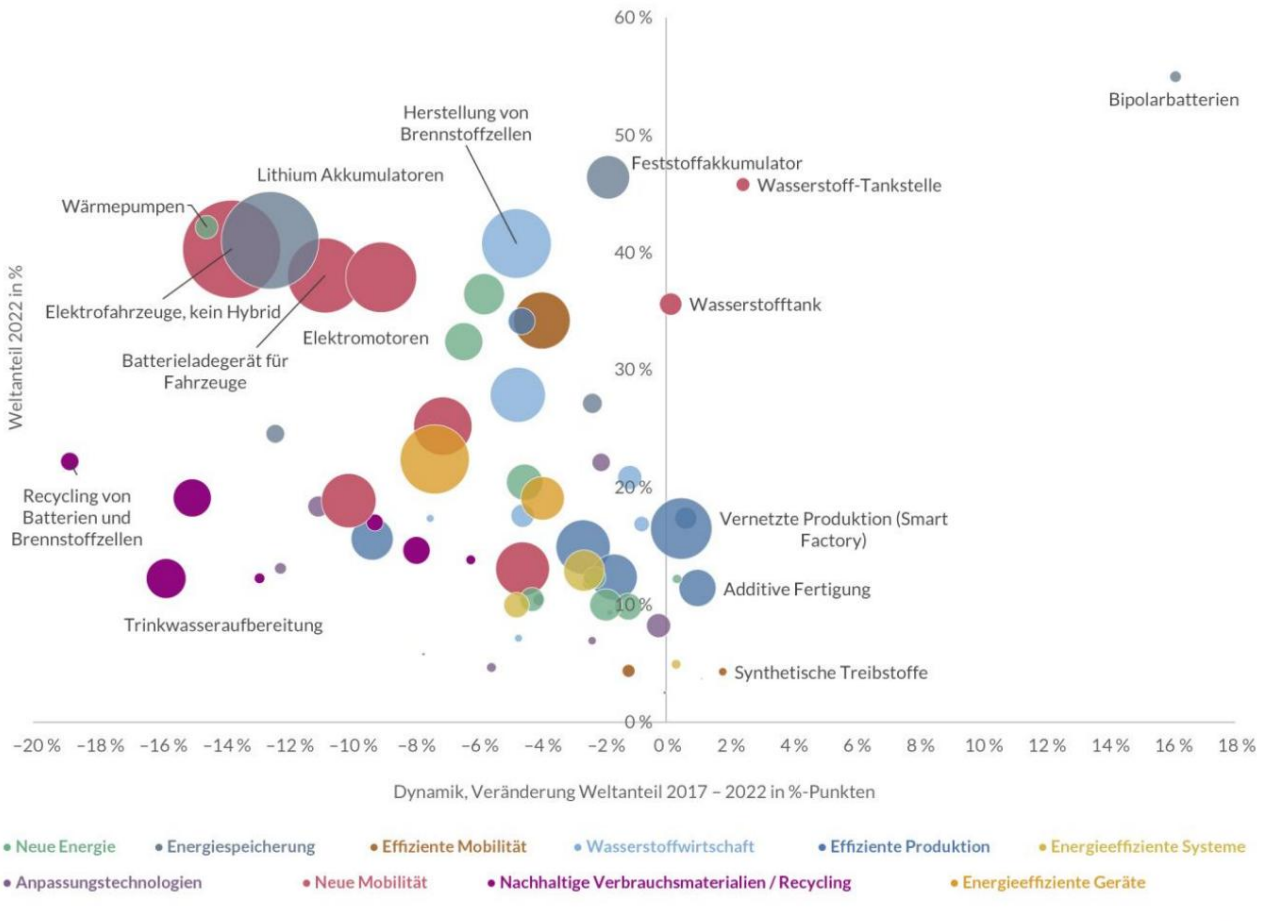
In the “hydrogen economy” category, Japan's technological know-how in the production of fuel cells is particularly noticeable (world share in 2022 of 41 percent). In terms of world-class patents, Toyota is the most important company in fuel cell research not only in Japan, but also worldwide. The Japanese car company has been researching fuel cells for many years and is pursuing a dual strategy in which it develops and produces both battery-powered electric vehicles and fuel cell/hydrogen cars. But other Japanese entrepreneurs such as Honda and Panasonic also have numerous world-class patents in the “hydrogen economy” category, especially in the technology for producing fuel cells.

Given the presence of numerous large car companies, Japan is of course also an important research location in the field of “new mobility” (world share of 26 percent in 2022). Japanese companies have a strong position here, especially in the area of “electromobility”. The Japanese global share in the individual technologies of battery chargers for vehicles, electric motors and electric vehicles is almost 40 percent. The global share of hydrogen filling stations (46 percent) and hydrogen tanks (36 percent) is also very high

Vehicles. On the other hand, the Japanese global shares in the technologies of connected cars (25 percent) and autonomous road vehicles (13 percent) are significantly lower.

In the two categories “Energy Efficient Systems” and “Climate Change Adaptation Technologies” Japan is not as strong as in the other green categories. In both categories, Japan's world share is just over 10 percent (compared to an average Japanese share of 21 percent of all global world-class patents in green technologies).

ABBILDUNG 12 **Japan: Technologieprofil in grünen Einzeltechnologien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

It is also noticeable that Japan has lost ground in international technology competition in the “Sustainable Consumables/Recycling” category in recent years.

For example, Japan's global share of world-class patents in battery and fuel cell recycling increased from over 40 percent to 22 percent between 2017 and 2022

sunk.

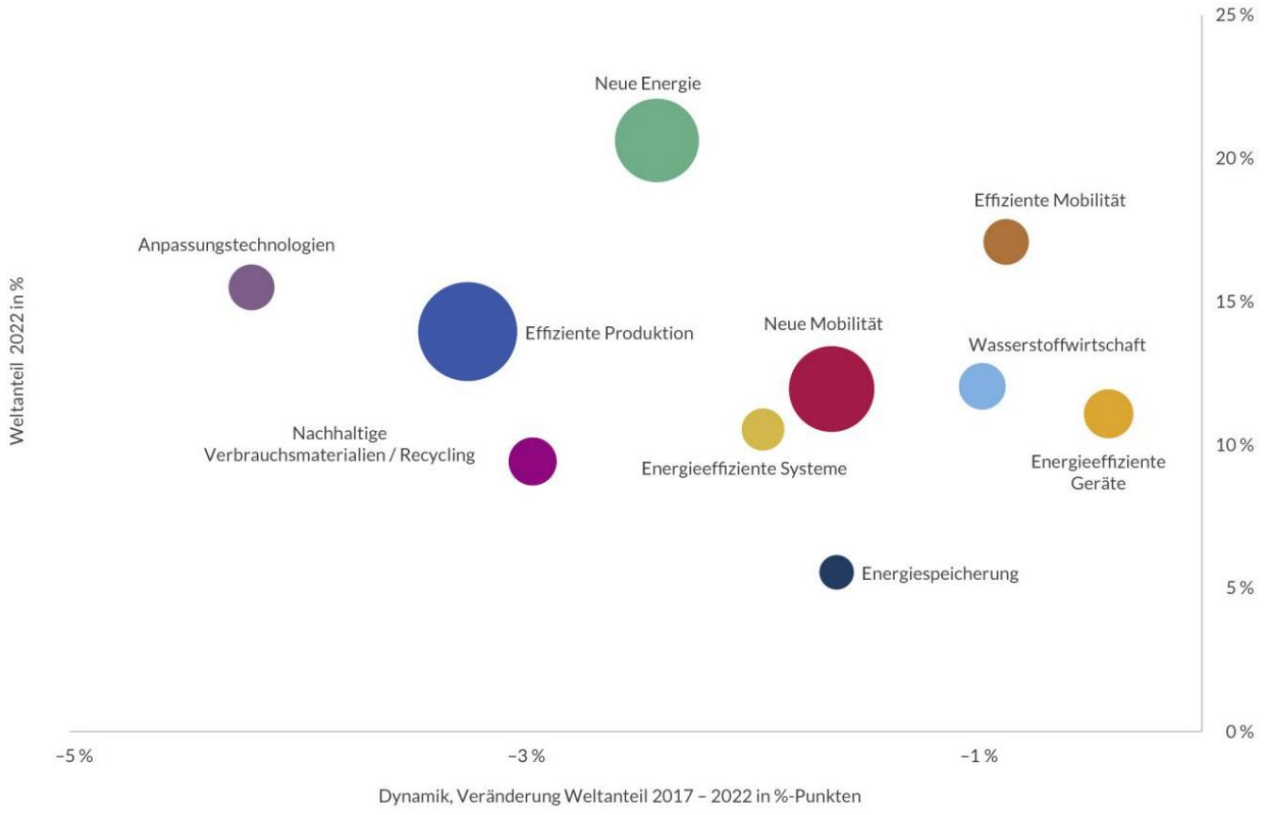
At the company level, what is striking about Japan is that the country has numerous technologically broad-based companies such as Panasonic, Toshiba and Hitachi, which are active in many different green technologies. This allows these companies to benefit from synergy effects through the increasing content linking of many green technologies in the sense of systems - e.g. B. are the intelligent link and the common

Management of renewable energies with electricity storage systems and the smart grid are necessary elements for the future stabilization of the transmission network.

## 3.6 EU technology profile

The EU is the fourth largest research player in green technologies with more than 19,000 world-class patents in 2022. This corresponds to a world share of almost 13 percent of the global green world-class patents. However, just like in the USA and Japan, the EU's global share in all green technology categories has also decreased. However, a positive signal for the European research location is that the EU's world-class patents have grown more strongly than in the USA and Japan since 2017. Research dynamics in the EU in the field of Green Tech have recently been higher than in Japan and the USA.

ABBILDUNG 13 **EU: Technologieprofil in grünen Oberkategorien, 2022**



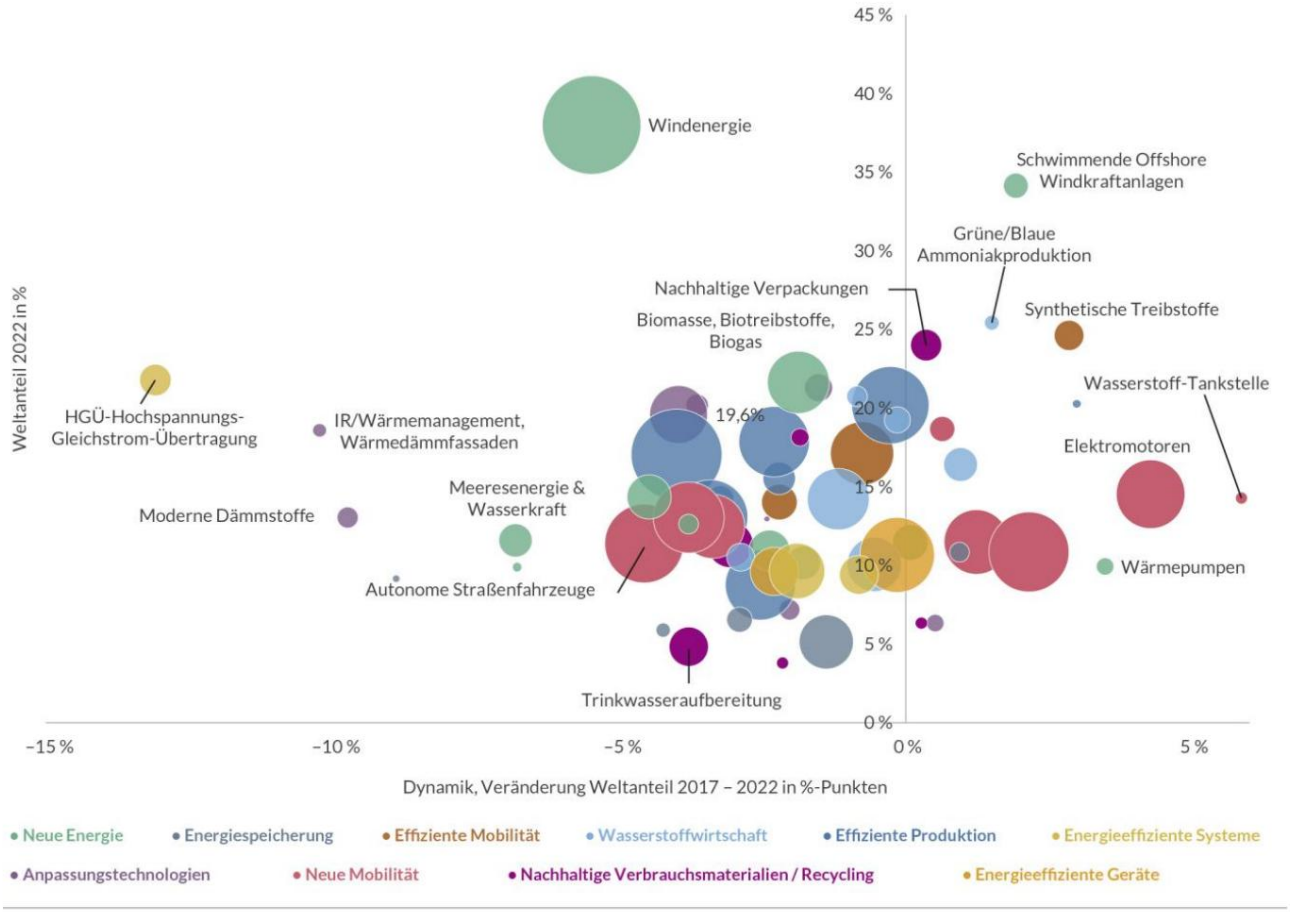

Quelle: EconSight, 2023.

| BertelsmannStiftung

The technology profile shows the EU's leading role in the area of “new energy” (Figure 13). Although the global share has fallen by more than two percentage points since 2017, the EU remains one of the most important research locations in the world with a global share of over 20 percent. Particularly noteworthy is the excellent research position in wind energy and offshore wind turbines (Figure 14). The EU has the most world-class patents in both technologies. Vestas and Siemens Energy (Siemens Gamesa) are the top wind energy research companies in Europe. Even though some wind turbine operators have recently had problems with escalating costs for offshore systems,

Offshore systems in particular are an area with a lot of future potential and are likely to play an important role in the further decarbonization of energy production.21

ABBILDUNG 14 **EU: Technologieprofil in grünen Einzeltechnologien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

The EU is also well positioned in the “Efficient Mobility” category, thanks to the research strength of European car companies in the two technologies of efficient car design and synthetic fuels. The conclusion is less positive for the “New Mobility” category, where the EU global share is 12 percent and therefore slightly below the global global share of green technologies overall (13 percent). When it comes to electromobility, European car manufacturers face strong competition from companies like Tesla and Chinese players like BYD, and companies from outside the industry like Alphabet, Intel, Qualcomm and Baidu want to secure a piece of the added value in the technologies of networked cars/interaction in road traffic and autonomous driving. The technology profile in individual technologies shows two opposing developments: In electromobility, European car companies have been able to expand their global share of electric motor and electric vehicle technologies in recent years. Both

[21] IRENA 2019.

However, with technologies such as networked cars/interaction in road traffic and autonomous driving, Europeans are losing ground to international competition.

In the area of energy storage, the EU only plays a minor role in international research competition. Here the world share of global world-class patents is just over 5 percent. When it comes to lithium batteries, a central component of electromobility, European companies are far behind the Asian market leaders. Even when it comes to potential next-generation batteries (solid-state batteries, bipolar batteries, sodium-ion batteries), European research players only have a few world-class patents.

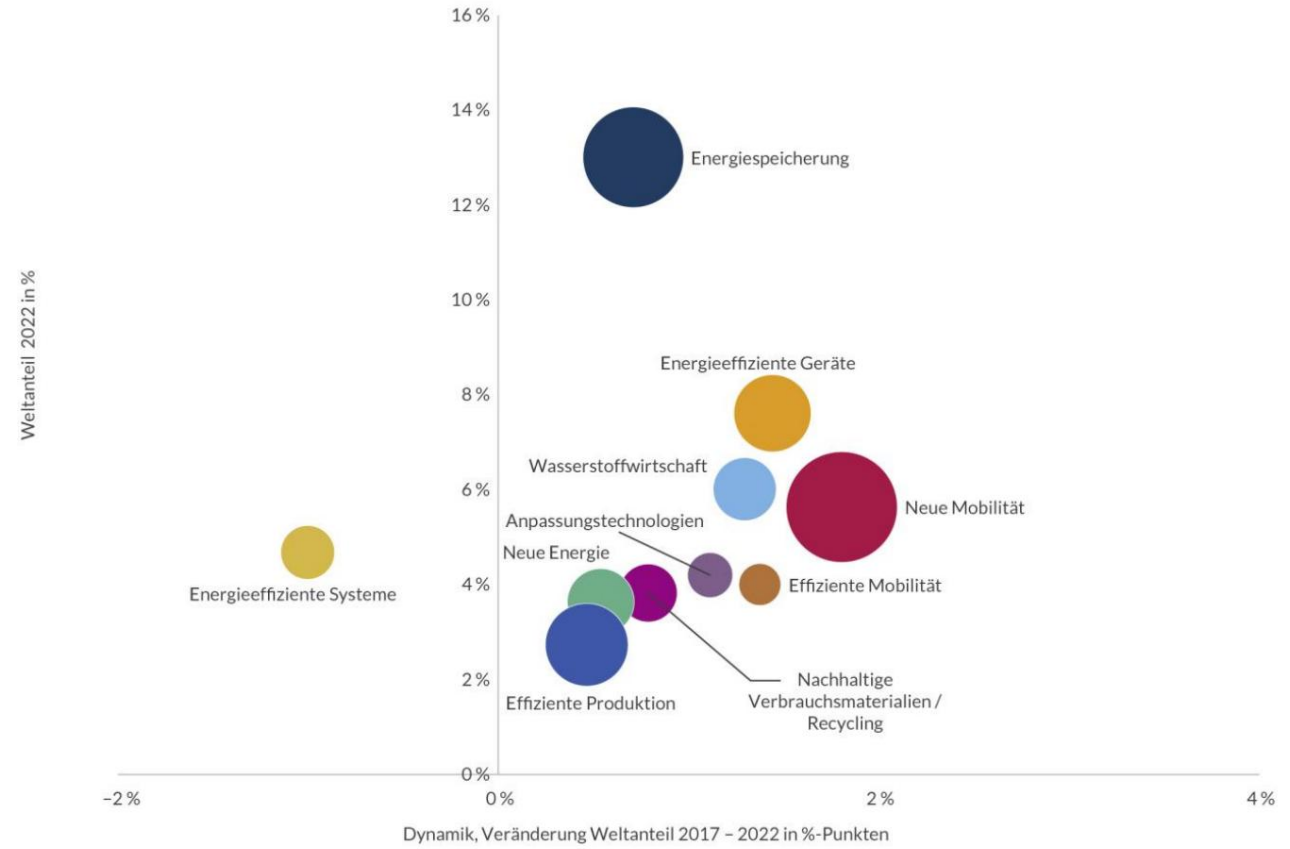
The EU is trying 1 within the framework of the European Battery Alliance (EBA) to improve the EU's position as a location for battery research and production and to ensure a secure supply of batteries in the future.22 Lithium battery production in the EU has also increased significantly in recent years , although a large part of battery production in the EU is still carried out by foreign battery producers, especially from Asia. A competitive disadvantage that the EU has in the production of batteries is the lack of domestic raw materials or capacity for raw material processing. For example, China controls over 80 percent of the world's refining capacity for Li-ion battery raw materials.23

## 3.7 Technology profile South Korea

In recent years, South Korea has become increasingly important as a research location for green technologies. The country was able to expand its global share in almost all of the main green categories; only “energy efficient systems” saw a decline.

[22] European Commission 2023.
[23] European Commission 2022.

ABBILDUNG 15 **Südkorea: Technologieprofil in grünen Oberkategorien, 2022**




Quelle: EconSight, 2023.

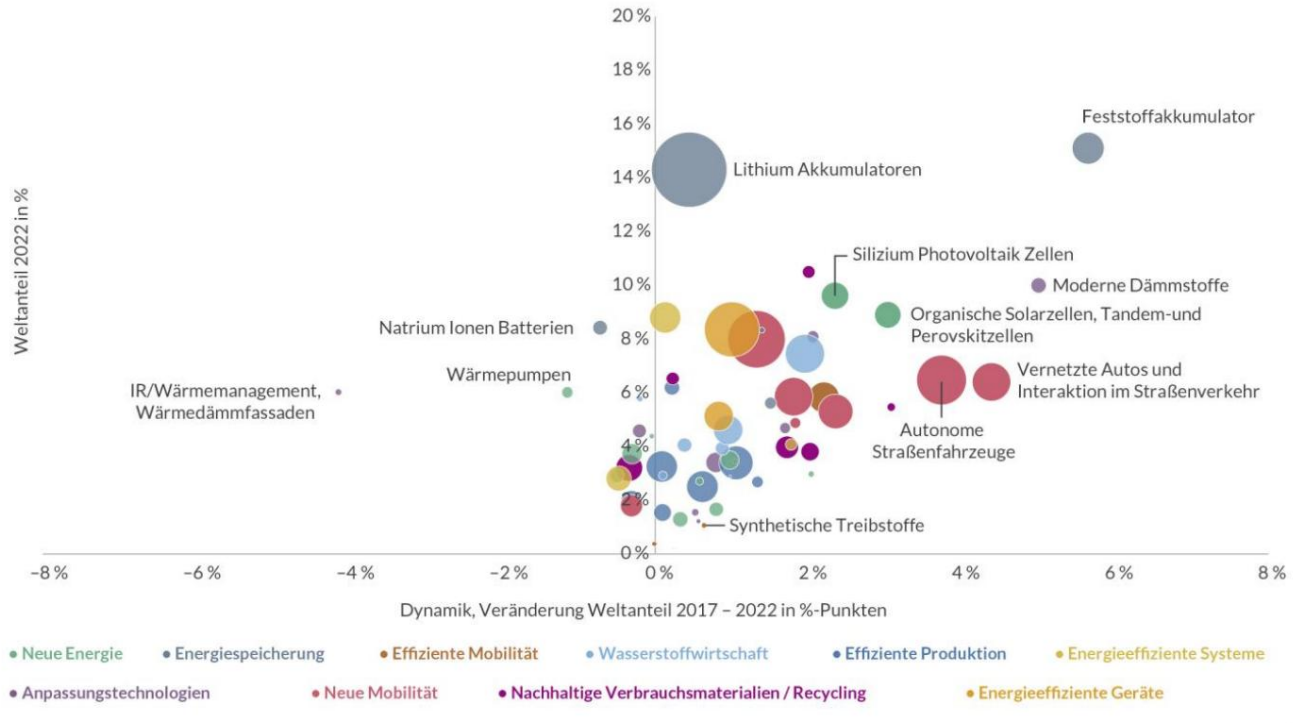
| BertelsmannStiftung

A look at the technology profile shows that South Korea is a top research location, especially in the “energy storage” category. In this category, the country had almost 1,700 world-class patents in 2022, which corresponds to a global share of 13 percent (Figure 15). South Korea has a strong position in both lithium batteries and solid-state batteries. Two of the most important companies in the field of battery technology, LG Chem/LG Energy and Samsung SDI, are located in South Korea (Figure 16).

There is also extensive research activity in the “energy efficient devices” category in South Korea. This is reflected in the comparatively high global share of 7.6 percent. The large electronics companies Samsung and LG Electronics are the most important here Research actors in the country.

In the other green main categories, South Korea's global share is even lower, but due to the high level of research dynamism, the country has been able to significantly expand its global share in certain technologies since 2017. Particularly noteworthy here are the technologies of connected cars and autonomous vehicles in the “New Mobility” category. modern insulation materials in the “adaptation technologies to climate change” category and novel organic solar cells, tandem and perovskite cells in the “new energy” category.

ABBILDUNG 16 **Südkorea: Technologieprofil in grünen Einzeltechnologien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

# 4 Development in Germany

Germany is by far the most important research country in green technologies in the EU. In 2022, there were almost 10,000 world-class patents in Germany, meaning Germany's share of all world-class patents from the EU was over 50 percent. Germany's share of all global green world-class patents was almost 7 percent in 2022.

## 4.1 Technology profile Germany

The technology profile shows that Germany has many world-class patents in the main categories of “new mobility”, “efficient production” and “new energy”. In the areas of “new energy” and “new mobility”, the German global share was also above average in 2022 (“new energy”: 8.7 percent, “new mobility”: 8.3 percent compared to an average of 6.6 percent in the green technologies overall). In the main categories of “sustainable consumables/recycling” and “energy storage”, however, Germany only plays a subordinate role in terms of cutting-edge research (world share under 5 percent in each case).

Overall, the technology profile shows a balanced positioning with strengths in many different green technology areas.

As in most industrialized countries, Germany's global share has fallen in all ten main categories over the last five years. This is mainly due to the rapid growth of world-class patents in China and, to a lesser extent, in South Korea.

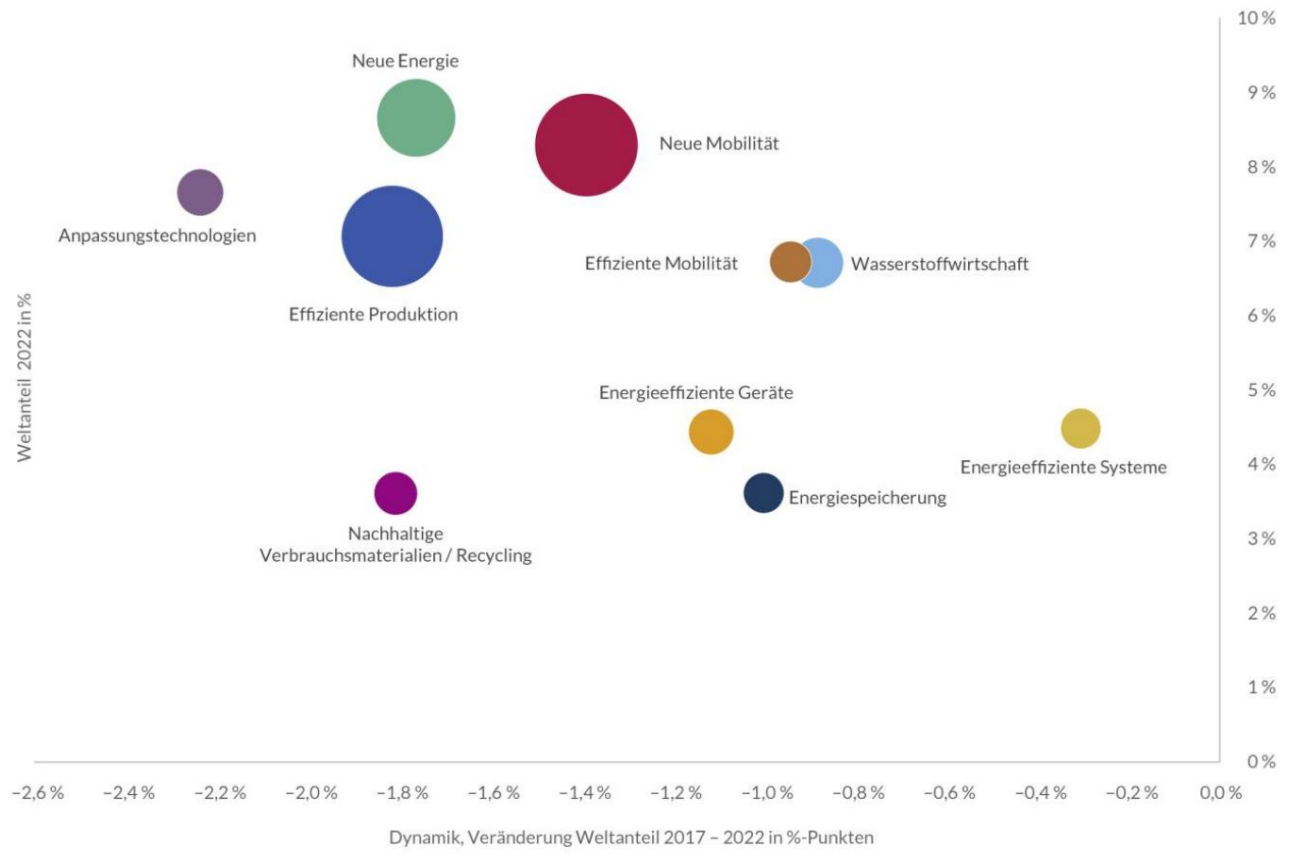
If you look at the industry classification of the companies responsible for the world-class patents, it becomes clear that a large part of the research activities in green technologies are carried out in key German industries such as the electrical industry, the automotive industry, the chemical industry or mechanical engineering. At the corporate level, Bosch (704 world-class patents), VW (630), Siemens (535) and BASF (525) are the most important research companies in green technologies in Germany.

A negative result is that the importance of the ICT (information and communications technology) industry in terms of the number of world-class patents in green technologies in Germany is not that high. However, digitalization is an important driver of innovation in green technologies. In other countries, such as the US, ICT companies (e.g. Alphabet) play a more important role in cutting-edge green tech research. The lack of impetus from ICT companies in Germany is therefore an explanation why Germany is particularly active in technologies with a high degree of digitalization, such as. B. autonomous vehicles or networked production/smart factories, do not perform particularly well in international comparison.

Germany also performs less positively when it comes to research dynamics. The analysis of research dynamics within the technology profiles is not based on the absolute increase in world-class patents, but on comparing the growth of world-class patents against the global average. If the growth rate is lower than the global average, the share of global world-class patents in a technology or an upper technology category decreases.

Although the number of world-class patents from Germany has increased significantly in most green technologies in recent years, international developments have been even more dynamic. In the technology profile, this is reflected in the fact that Germany's global share has fallen in all ten green main categories (balls are to the left of the y-axis; Figure 17). Although the world shares in most green technologies have fallen in almost all industrialized countries due to the rapid growth of world-class patents from China, the growth of world-class patents from Germany has also been slightly lower in the past than in the USA, Japan and most EU countries. Germany must therefore gain momentum in order to be able to maintain its good international research position in green technologies in the medium and long term.

ABBILDUNG 17 **Deutschland: Technologieprofil in grünen Oberkategorien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

In the “New Energy” category, almost every tenth world-class patent comes from Germany. The most important single technology is wind energy, in which Germany has a global share of around 16 percent. The companies General Electric, Siemens Energy (Siemens Gamesa), Enercon and Nordex in particular have many world-class patents developed in Germany.

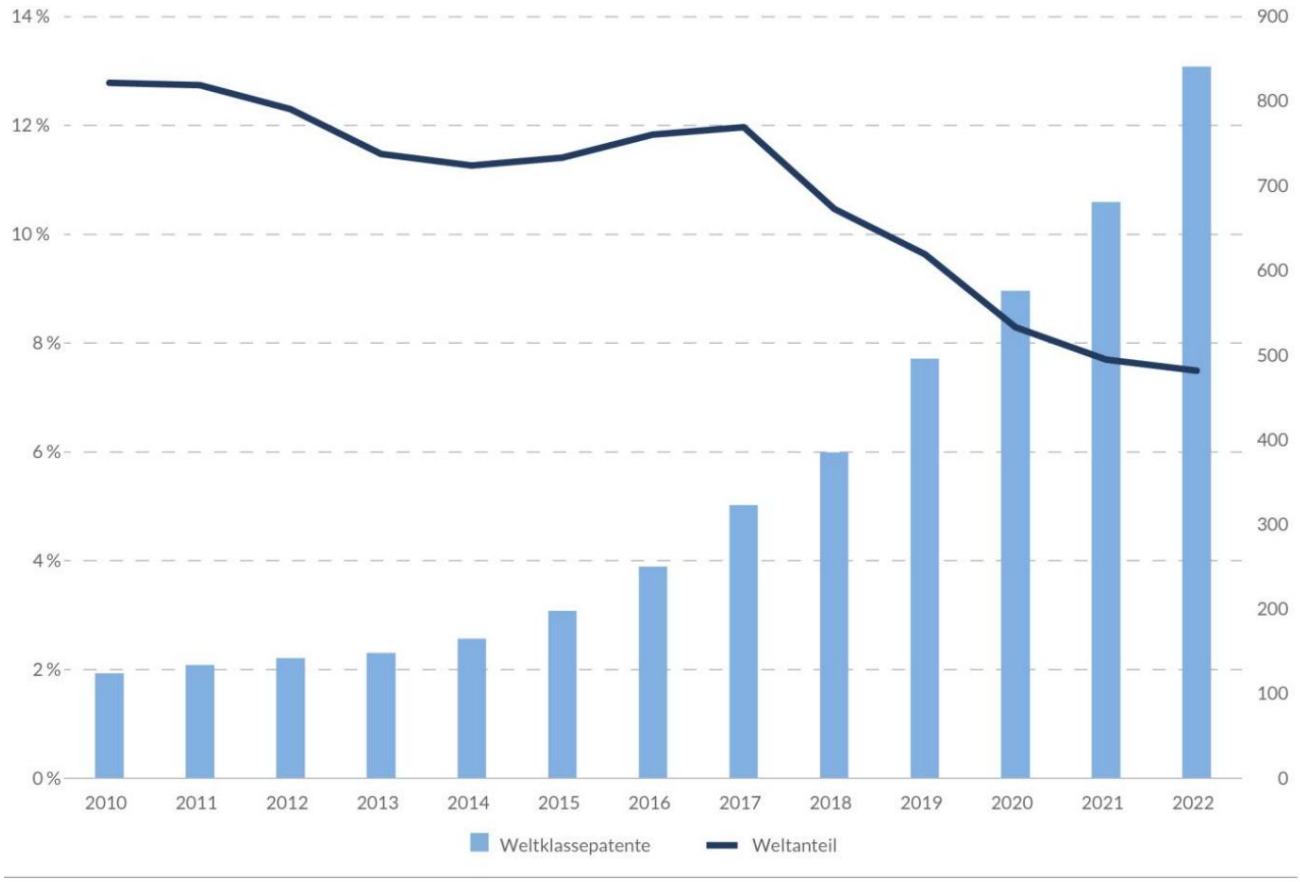
However, since 2017, Germany's global share has fallen significantly. Although the number of wind energy patents from Germany has continued to rise in recent years, the momentum has not been able to keep up with the strong patent growth in China. China will therefore have Germany in 2022

displaced from second place among the leading wind energy research countries, the USA remains at the forefront. In the other individual technologies in the “New Energy” category, Germany’s global share is lower than in wind energy. For example, the global share of the various solar technologies (silicon photovoltaic cells, solar thermal energy, organic cells/ perovskite cells) is only between 5 and 7 percent and for heat pumps the share is only 2.6 percent.

The largest technology category in Germany in terms of patent numbers is “New Mobility” with a total of just over 3,000 world-class patents in 2022. Germany is clearly the dominant research player in the EU in this area, so the picture is the same as in the EU. When it comes to the individual technologies of autonomous road vehicles and connected cars/interaction in road traffic, Germany has not been able to keep up with global dynamics over the last five years. The number of world-class patents from Germany has risen sharply in these technologies, but the world-class patents are still significantly stronger, especially in China

grown. Figure 18 shows this as an example of the technology of autonomous road vehicles.

ABBILDUNG 18 **Deutschland: Weltklassepatente und Weltanteil in autonomen Straßenfahrzeugen**



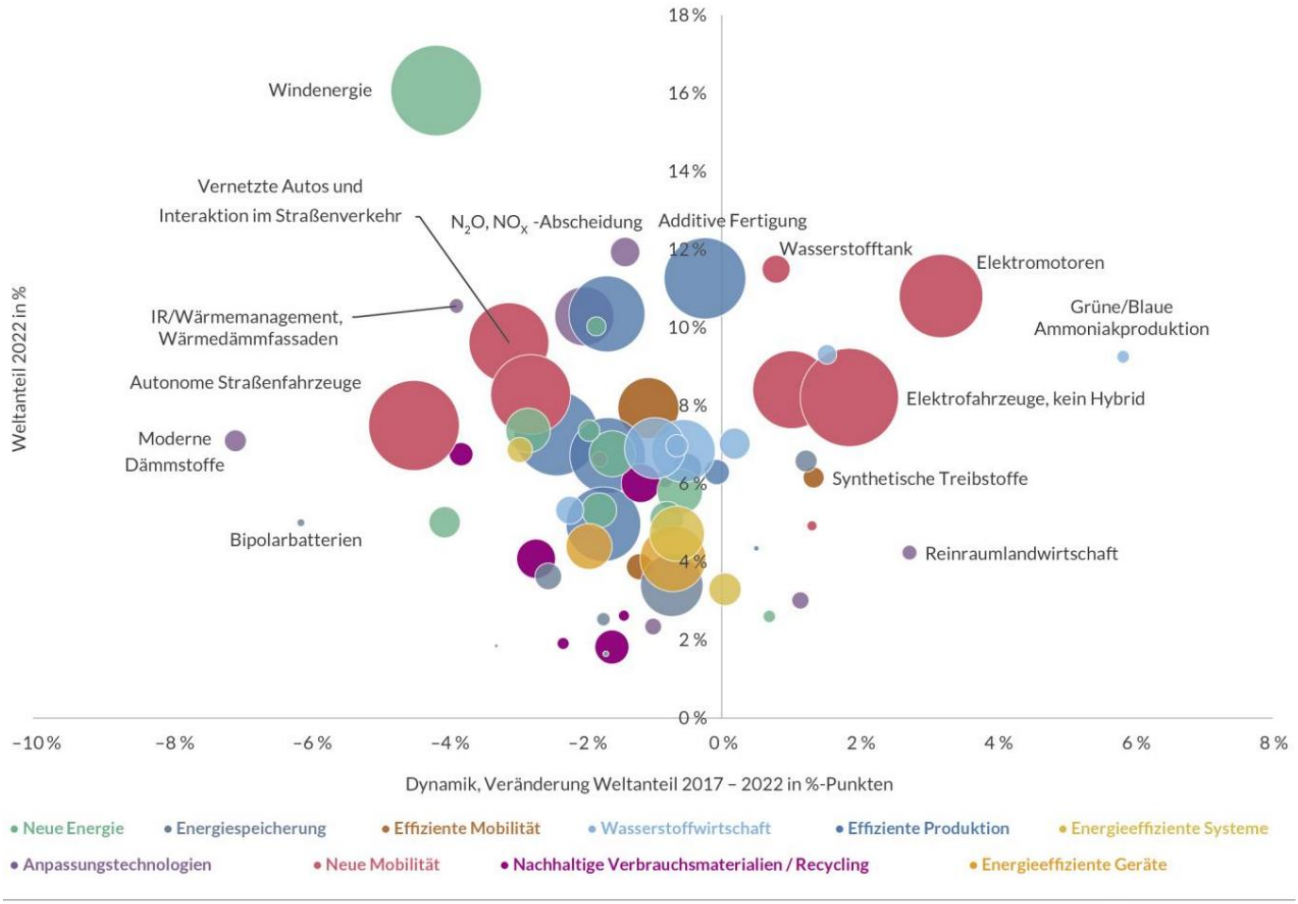

Weltanteil in % (linke Achse), Bestand an aktiven Weltklassepatenten (rechte Achse)
Quelle: EconSight, 2023.

| BertelsmannStiftung

While Germany has lost ground in the technologies of connected cars/interaction in road traffic and autonomous road vehicles, the position of the German research location in electromobility and the associated technologies of electric motors, electric vehicles and battery chargers has improved in recent years (Figure 19). When it comes to electric motors in particular, Germany now has a high global share of almost 11 percent and has increased this global share by more than three since 2017

Increase percentage points. Volkswagen, Bosch and BMW have the most world-class patents in Germany when it comes to electromobility technologies. Even if developments are moving in the right direction, it must be noted that the position in international research competition is not yet as strong as with traditional car drive technologies. For example, the German share of world-class patents for internal combustion engines was almost 24 percent in 2022.

ABBILDUNG 19 **Deutschland: Technologieprofil in grünen Einzeltechnologien, 2022**




Quelle: EconSight, 2023.

BertelsmannStiftung

A very important technology field for Germany as an industrial location is “efficient production”. With around 3,000 world-class patents, this is the second largest category in green technologies. At the level of individual technologies, additive manufacturing and efficient metal production stand out here. In both technologies, more than one in ten world-class patents come from Germany, and in additive manufacturing, Germany was able to keep its global share stable between 2017 and 2022. EOS and General Electric have the most world-class patents developed in Germany in these two technologies. On the other hand, the German research position in the important technology of networked production/smart factories can be expanded (world share of only 5 percent).

“Adaptation technologies to climate change” are also an exciting technology category. Although Germany has a fairly high share of 7.7 percent of world-class patents, at the same time this share has decreased significantly in recent years.
At the level of individual technologies, Germany, for example, was still the most important research location worldwide in IR technology/heat management/ thermal insulation facades in 2010. Since then, however, the global share of this technology has fallen from over 60 percent to just 10.6 percent. However, the overall number of patents in this technology is small worldwide. The largest single technology in the climate change adaptation technologies category is forestry, with 359 world-class patents

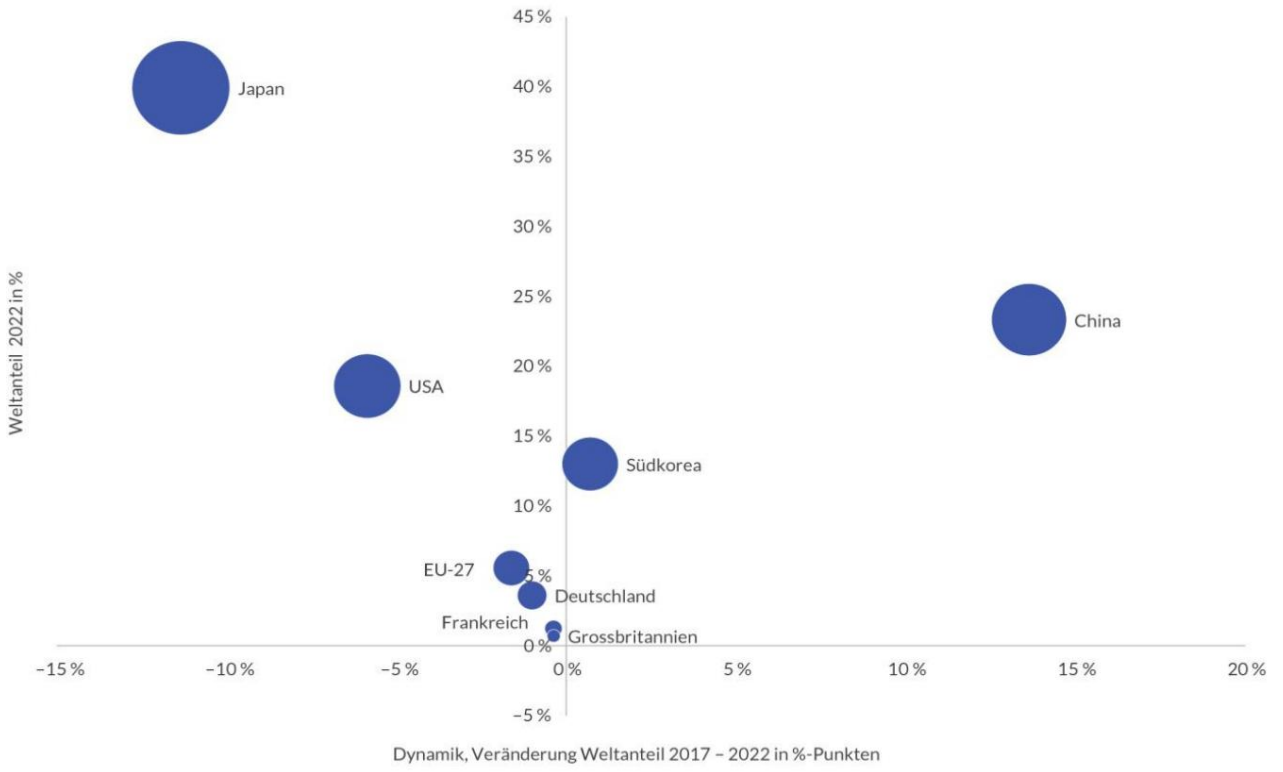
from Germany in 2022. Claas KGaA and the US agricultural technology group Deere are the top research players in forestry in Germany.

In addition, the German auto industry is comparatively weak when it comes to an important part of the value chain for electric cars, “energy storage”. The global share in this category is only 3.6 percent (Figure 20). Japan (e.g. Toyota, Panasonic) and China (e.g. CATL) are the world's leading countries in cutting-edge research in energy storage technologies. Germany's and the EU's small share of world-class patents in energy storage technologies is problematic, as the battery system within the drive train of an electric car is responsible for 57 percent of the value added.24

Germany only has a small global share of both the currently dominant lithium batteries and most of the potential next-generation battery types (less than 5 percent in each case). A positive exception are the redox flow batteries, which e.g. B. can be used as stationary energy storage. For these batteries, Germany achieved a significantly higher global share of 6.6 percent in 2022 and has even been able to expand this share since 2017.

However, redox flow batteries are still only a niche technology.

ABBILDUNG 20 **Forschungsposition der wichtigsten Länder in Energiespeichertechnologien**




Quelle: EconSight, 2023.

| BertelsmannStiftung

[24] e-mobile BW 2023.

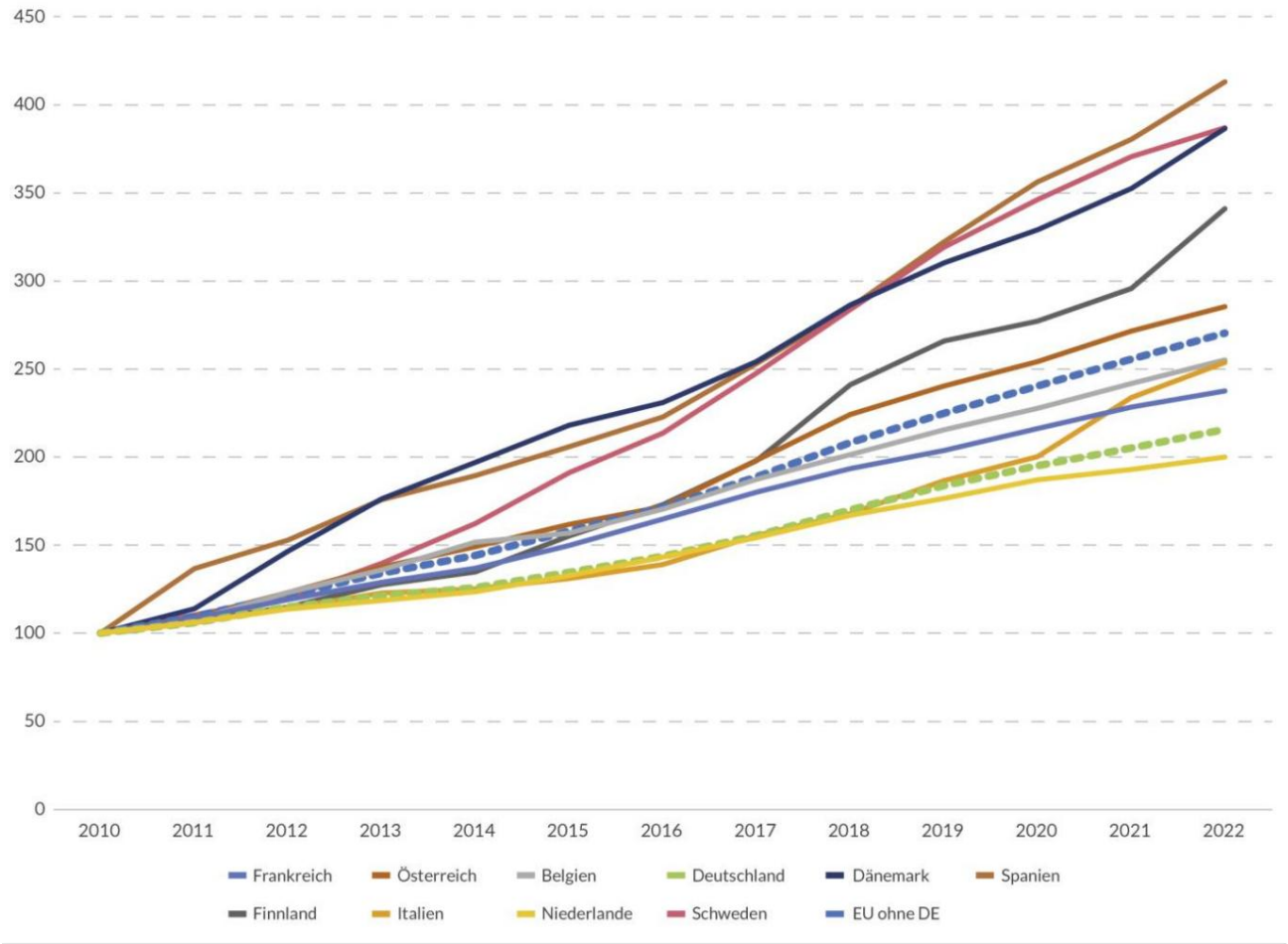
At the company level, it is noticeable that, similar to Japan, there are some technologically broad-based companies such as Siemens, Bosch or Volkswagen, which conduct cutting-edge research in many green technologies. This is an advantage given the high complexity of switching from centralized to decentralized energy systems.

## 4.2 Comparison with other EU countries

Overall, the number of world-class patents in green technologies in the EU-27 increased from around 8,000 to around 19,000 between 2010 and 2022. In Germany, the number of world-class patents grew from almost 4,600 to almost 10,000 over the same period. This means that the German share of the total world-class patents from the EU has fallen from 57 to 52 percent. In 2022, France was in second place among EU countries with around 3,000 world-class patents, followed by the Netherlands in third place with around 1,600 world-class patents.

If we look at the development of world-class patents in the most important EU countries, it can be seen that Spain and the Scandinavian countries in particular have been able to achieve very high research dynamics since 2010 (Figure 21). In Spain, world-class patents have quadrupled since 2010 (from around 150 to over 630) and Sweden and Denmark have also achieved similarly high growth rates. In terms of dynamism, however, Germany is one of the bottom performers in the EU comparison (growth of 116 percent since 2010 compared to an average growth of 170 percent in the remaining EU countries). Among the larger EU countries, only the Netherlands has seen less dynamism than Germany since 2010 (growth of 100 percent).

ABBILDUNG 21 **Entwicklung Weltklassepatente in ausgewählten EU-Ländern, indexiert (2010 = 100)**




Weltklassepatente in grünen Technologien, indexiert (2010 = 100)
Quelle: EconSight, 2023.

BertelsmannStiftung

## 4.3 Comparison of research activities in Germany versus worldwide

### Research activities of German companies

The patent analyzes presented so far are based on the regional allocation of patents according to the inventor's residence criterion (see Chapter 6 Methodology), i.e. a patent is assigned to a country if at least one researcher involved in the patent is resident in the corresponding country. This shows where the research performance actually took place. However, this perspective says nothing about who economically owns the technological property rights.

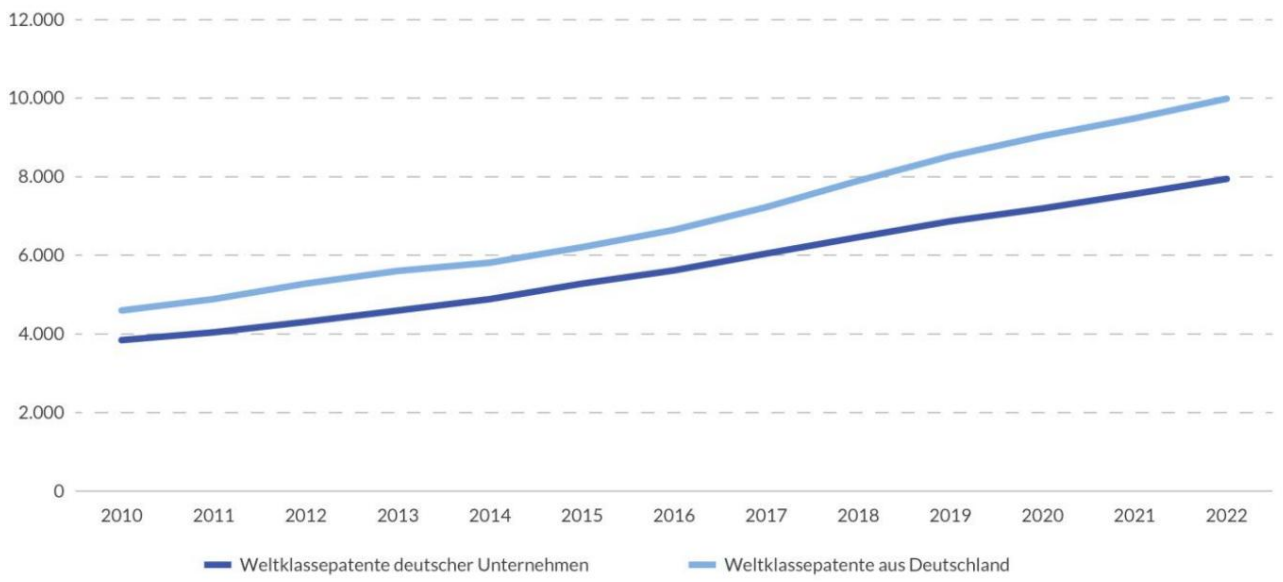
In this sub-chapter, the research activities of German companies at various international research locations are consolidated and assigned to the company headquarters (Ultimate Owner or Ultimate Country principle).
In addition to the question of where the research work was carried out, this also shows who “owns” the research work.

In total, in 2022 there were almost 8,000 world-class patents in green technologies that were attributed to companies or research institutions/universities in Germany. It should be mentioned here that not all world-class patents worldwide can be assigned to an “ultimate owner” or “ultimate country”. Although there is information about the inventor and applicant address for every patent application, the applicant is not always the owner of the patent.

Particularly when it comes to patent applications from smaller companies, ownership information is not always available. In total, there were around 100,000 world-class patents worldwide in 2022 that are assigned to an “Ultimate Owner” and “Ultimate Country,” meaning that around two thirds of all global world-class patents can be assigned to a country using the “Ultimate Owner” method.

Figure 22 shows the development of world-class patents from German companies in green technologies compared to all world-class patents developed in Germany since 2010. It shows that the number of world-class patents from Germany has increased somewhat more, but overall the trend is similar. This is an indication that Germany remains an attractive research location for companies.

ABBILDUNG 22 **Weltklassepatente deutscher Unternehmen vs. Weltklassepatente aus Deutschland**




Bestand an aktiven Weltklassepatenten in grünen Technologien pro Jahr
Quelle: EconSight, 2023.

| BertelsmannStiftung

In fact, the proportion of world-class patents from German companies involving researchers with a German address has increased slightly from 65 to 68 percent since 2010. Looking across all companies, there appears to have been no trend towards relocating research activities abroad or relocations were more than compensated for by new activities at home.

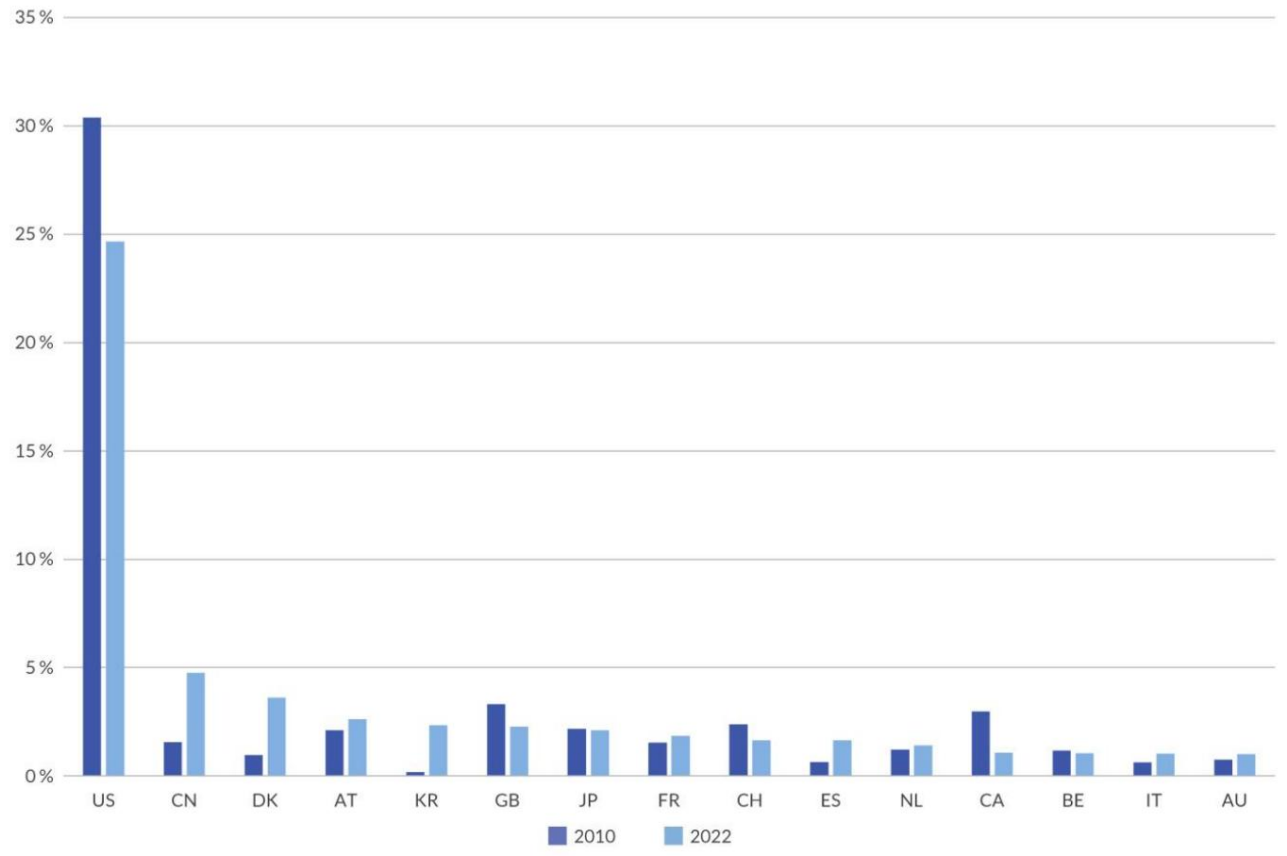
**Most important foreign research locations for German companies**

However, there have been certain shifts in the regional focus of German companies' research activities abroad. Like Figure 23

shows, the USA is still by far the most important location for research activities in green technologies by German companies abroad. Almost every fourth world-class patent from German companies involves researchers based in the USA.25 This proportion is higher than the sum of all such research collaborations with other EU countries. There is still potential for improvement for more intensive research cooperation in green technologies within the EU.

Siemens and BASF are the two German companies with the most in the USA (co-)developed world-class patents in green technologies (more than 300 each). However, the US share has fallen by around five percentage points since 2010. China, Denmark, South Korea and Spain, in particular, have become more important as research locations for German companies.

ABBILDUNG 23 **Top 15 der Forschungsstandorte deutscher Unternehmen im Ausland**




Anteil Länder an Weltklassepatenten deutscher Unternehmen in grünen Technologien in %
Quelle: EconSight, 2023.

| BertelsmannStiftung

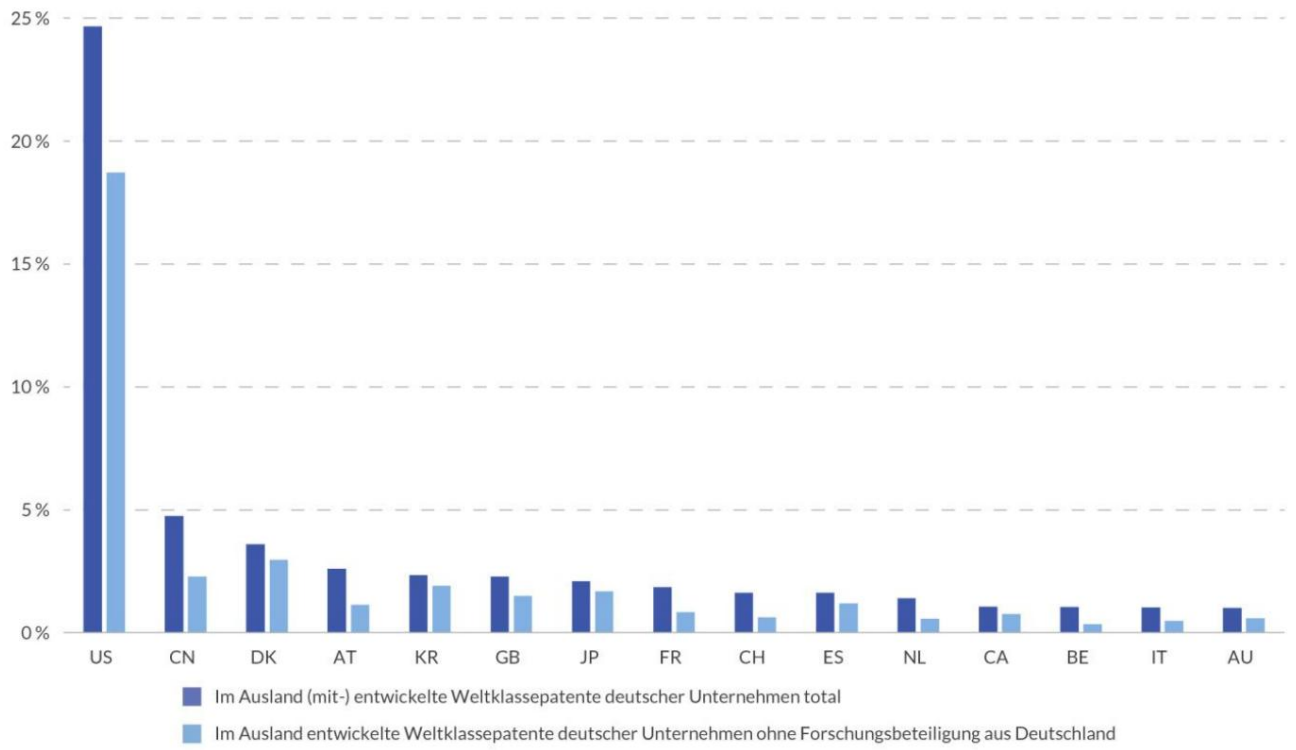
It is also noteworthy that the USA is very important for German companies as a research location, especially in cutting-edge research. If you don't look at them

[25] This includes world-class patents involving only researchers at a German company's US research site, as well as patents involving both US researchers and researchers at German sites.

World-class patents, but all patents, the US share of all patents from German companies is not 25 percent, but only around 10 percent.

If the analysis is limited to world-class patents that were developed by German companies abroad without the involvement of researchers with a German address, the USA is also far at the top of all foreign locations with a share of almost 19 percent (Figure 24). What is striking in this analysis is that China's importance, with a share of 2.3 percent, is less than half as high as in the analysis of all world-class patents held by German companies abroad. The importance of joint ventures between German and Chinese companies in research activities in China plays a possible role here.26 As a result, both researchers from Germany and researchers in China are often involved in the development of world-class patents.

ABBILDUNG 24 **Top 15 der Forschungsstandorte deutscher Unternehmen im Ausland 2022 (Vergleich alle Weltklassepatente vs. Weltklassepatente ohne deutsche Beteiligung)**




Anteil Länder an Weltklassepatenten deutscher Unternehmen in grünen Technologien in %
Quelle: EconSight, 2023.

BertelsmannStiftung

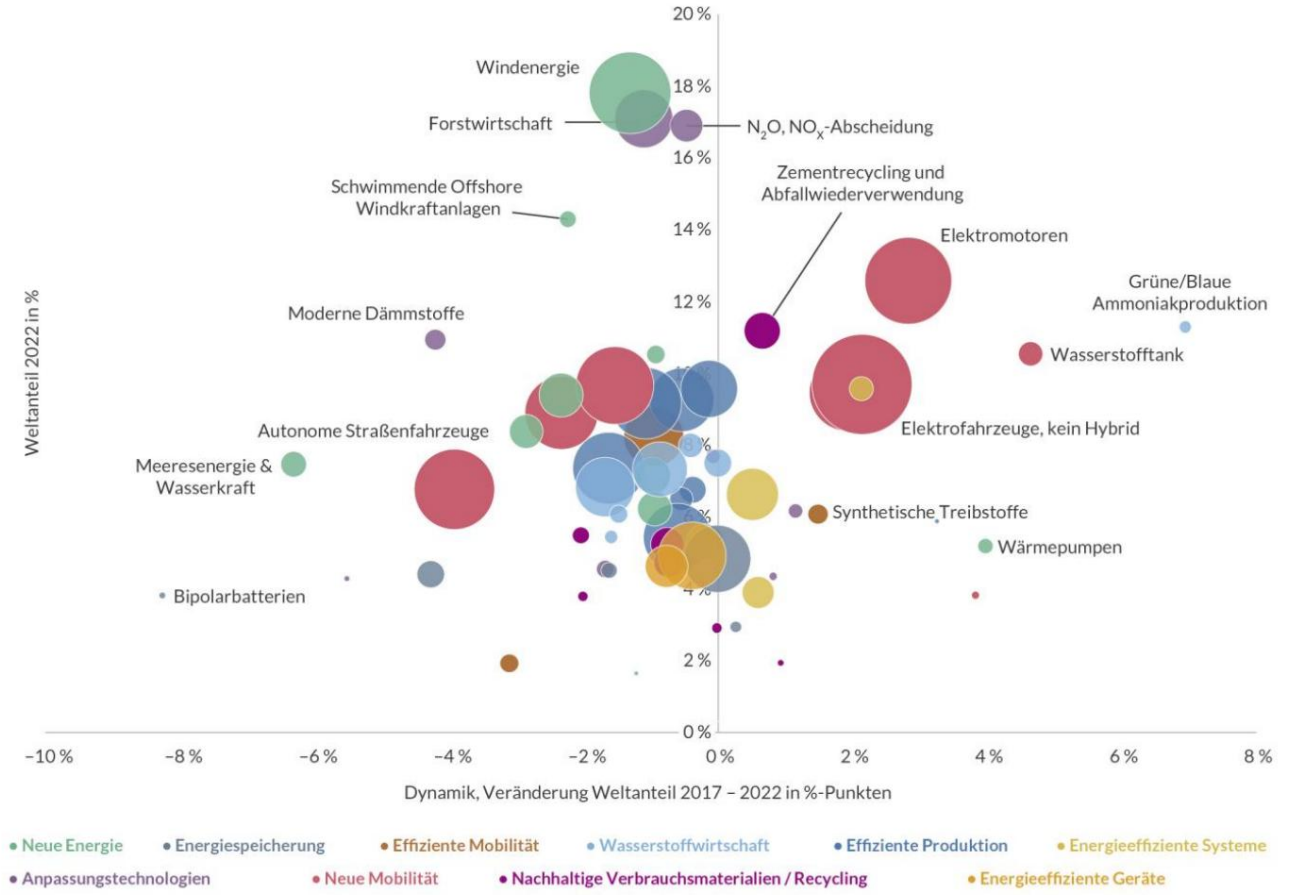
**Green technology profile of German companies (Ultimate Country Perspective)**

Analogous to the previous chapters, the international research activities of the Companies from Germany can also be presented in the form of technology profiles

[26] Clingendael 2022.

To be able to identify differences between the inventor's residence and the “Ultimate Country” perspective in the individual technologies (Figure 25).

ABBILDUNG 25 **Technologieprofil in grünen Einzeltechnologien (Ultimate Country Perspektive)**




Quelle: EconSight, 2023.

BertelsmannStiftung

Basically, the technology profile of German companies looks very similar to the technology profile of all world-class patents from Germany. However, there are also notable differences in some technologies. It is striking that the global share of German companies and universities in global world-class patents is significantly higher, especially in the category of “adaptation technologies to climate change”, such as forestry, N2O, NOx capture and modern insulation materials. This means that German research actors carry out an important part of their research activities in these technologies abroad. The same result also applies to the technologies of cement recycling/waste reuse, water treatment and offshore wind turbines.

In principle, a larger share of the world share of German companies/universities in a technology compared to the world share of all world-class patents from Germany can be an indication that the research conditions in this technology are more attractive abroad.

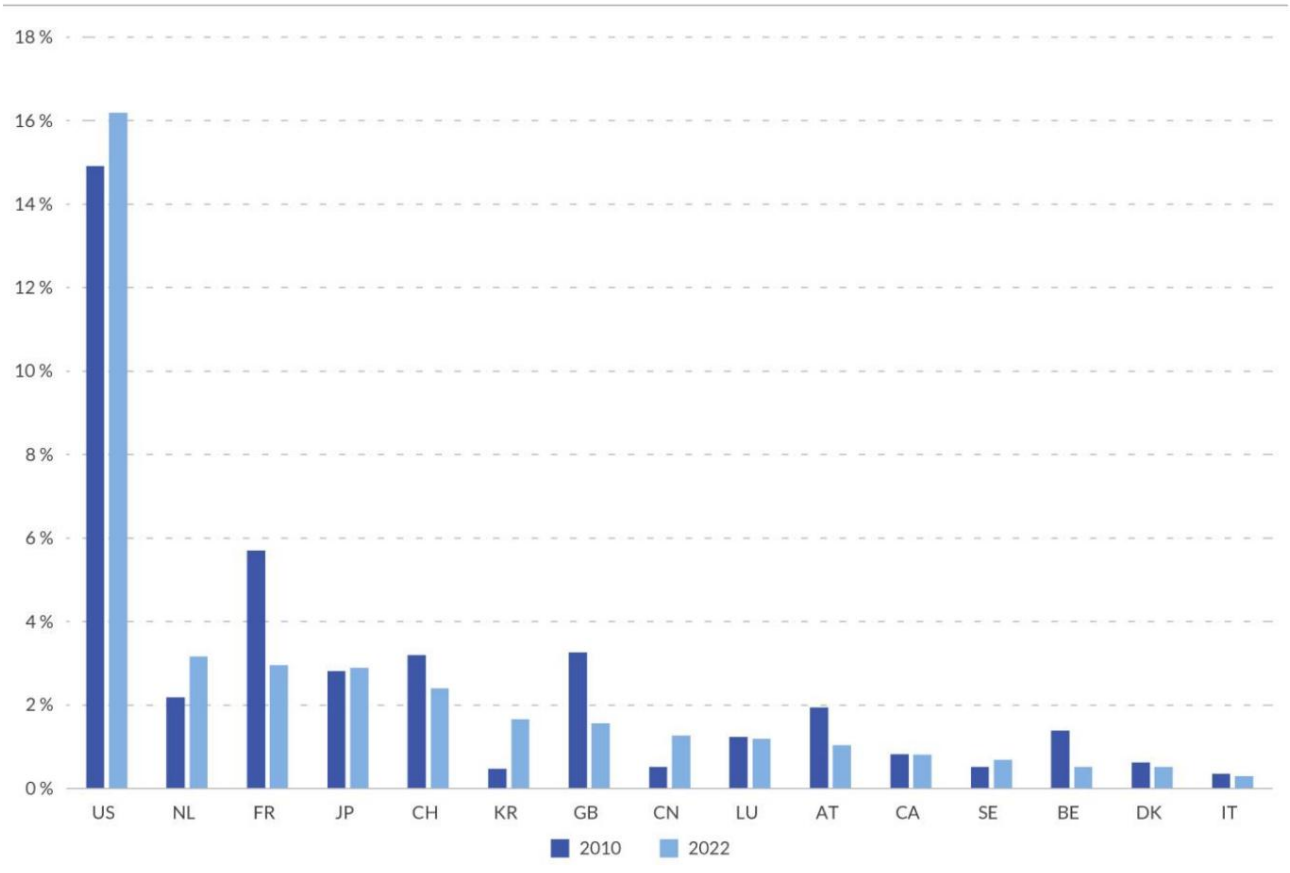
In contrast, the global share of German companies in the technologies of meat alternatives and green/blue methanol production is several percentage points lower than if all world-class patents from Germany were counted. This means that foreign research activities in Germany play an important role in these technologies. The

German research location appears to be very attractive in these technologies. However, the total number of world-class patents in both technologies is still relatively small (green/blue methanol production: 16 world-class patents from German companies/universities compared to 39 world-class patents from Germany in 2022, meat alternatives: four world-class patents from German companies/universities compared to 23 world-class patents from Germany in 2022) .

**Foreign research activities in Germany by country of origin**

The analysis of the world-class patents developed in Germany based on the companies' countries of origin shows that US companies in particular are conducting cutting-edge research activities in green technologies in Germany (Figure 26). The share of US companies in all world-class patents developed in Germany was over 16 percent in 2022, around one percentage point higher than in 2010. General Electric (GE) and John Deere are two US companies that have large patent portfolios in Germany . The Netherlands, France and Japan follow in the next places in the country of origin ranking with a share of around 3 percent each.

ABBILDUNG 26 **Herkunftsländer ausländischer Unternehmen mit in Deutschland entwickelten Weltklassepatenten**




Anteil Länder an Weltklassepatenten deutscher Unternehmen in grünen Technologien in %
Quelle: EconSight, 2023.

| BertelsmannStiftung

## 4.4 Distribution of green tech world-class patents by industry

The previous analysis evaluated the companies' research activities at the technology level. An alternative analysis perspective is to evaluate green tech research activities based on the industry structure. For this purpose, the 250 best green tech companies in Germany based on world-class patents were assigned to economic sectors. This meant that around 8,000 world-class patents could be allocated to the industries for 2022, which corresponds to around 80 percent of all green tech world-class patents from Germany (Figure 27).

This perspective shows that many world-class green tech patents are developed by companies in the electrical industry. Siemens is at the forefront here with over 500 world-class patents. Siemens has numerous world-class patents, especially in the two areas of “new mobility” (railway technologies) and “efficient production” (smart factory).

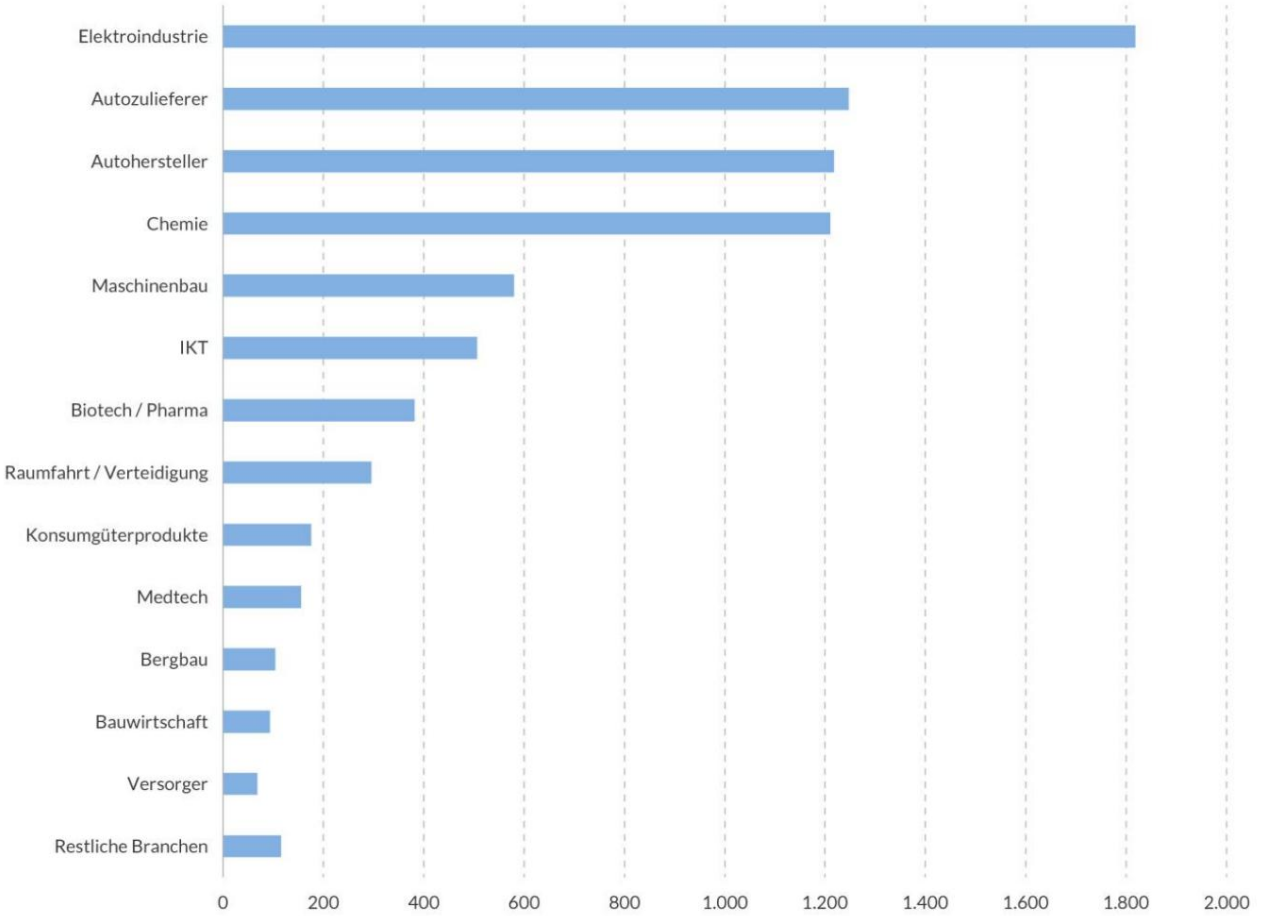
In addition, automobile manufacturers and suppliers are also taking on their role as technology leaders in Germany when it comes to green technologies. There are more than 1,200 world-class green tech patents in both industries. The leading research company is Bosch with over 700 world-class green tech patents. No other company has more green tech world-class patents in Germany. Bosch is researching electric motors and batteries in particular in the area of “new mobility”, but also has numerous world-class patents in the area of “hydrogen economy”.27

The chemical industry is also very important for green tech research in Germany with also over 1200 world-class patents in 2022. BASF (525 world-class patents) and Evonik (215 world-class patents) are both among the top 10 research companies in Germany in green technologies.

The mechanical engineering (580 world-class patents) and ICT (507 world-class patents) sectors follow in the other places in the industry ranking. At first glance, the high number of green tech world-class patents in the biotech/pharma sector (382 world-class patents) is surprising. The company Merck KGaA is primarily responsible for this, with over 250 world-class patents. In addition to its focus on life sciences, the company also has research activities in various green tech areas such as: B. environmentally friendly solvents, efficient OLEDs, meat substitutes or materials for solar modules.28

[27] Roland Berger 2021.
[28] https://www.merckgroup.com/de/sustainability/products-and-innovation/products.html.

ABBILDUNG 27 **Green Tech-Weltklassepatente nach Branchen in Deutschland im Jahr 2022**




Branchenzuteilung basierend auf eigenen Berechnungen, gemäß primärem Geschäftszweck
Quelle: EconSight, 2023.

| BertelsmannStiftung

Overall, the evaluation of the green tech world-class patents by sector shows that the companies in the classic German key industries such as the automotive industry, electrical industry and chemicals are also the most important technology leaders in Germany when it comes to green technologies. At the same time, it is noticeable that the importance of the ICT industry in terms of the number of world-class patents is not that high. In other countries, such as the USA, ICT companies play a more important role in cutting-edge green tech research. The lack of impetus from ICT companies in Germany is therefore an explanation why Germany is particularly active in technologies with a high degree of digitalization, such as. B. autonomous vehicles or networked production/smart factories, do not perform particularly well in international comparison.

**Distribution of the green main categories by sector**

In addition to the breakdown of world-class patents by industry, Figure 28 also shows the associated green tech upper category. The most important research companies in the electrical industry such as Siemens and GE are primarily active in the areas of “new energy” and “efficient production”.
As expected, automobile manufacturers and suppliers have many world-class patents, especially in the area of “new mobility”. The research activities of chemical companies in

Germany are relevant for a variety of green tech upper categories. In addition to the area of “efficient production,” chemical companies like BASF also have numerous world-class patents in the areas of “new energy,” “hydrogen economy,” “adaptation technologies to climate change,” and “sustainable consumables/recycling.”

ABBILDUNG 28 **Green Tech-Weltklassepatente aufgeteilt nach Branchen und Oberkategorien in Deutschland im Jahr 2022**


Branchenzuteilung basierend auf eigenen Berechnungen, gemäß primärem Geschäftszweck
Quelle: EconSight, 2023.

| BertelsmannStiftung

## 5 Conclusion

### Technological progress is central to achieving climate goals

Innovations play a central role in achieving long-term climate goals. Technical progress and new developments in green technologies cannot be used alone

Save the climate. But as technology advances, adaptation becomes easier and success becomes more likely.

**High research momentum worldwide**

A positive result of the present study is that research momentum in green technologies is very high worldwide. The number of global green tech world-class patents tripled between 2010 and 2022, making development significantly more dynamic than the average for the remaining technology areas. This high level of dynamism is also urgently needed because the success of the climate change requires numerous technologies in the medium and long term that are currently still in the prototype phase.

**High research activity in the categories “New Energy” and “New Mobility”**

Within the ten green main categories examined, “Efficient Production” and “New Mobility” are the largest main categories in terms of world-class patents. A key research focus in “Efficient Production” is the increasing networking of production processes, while in “New Mobility” it is primarily the change to electromobility and increasing digitalization (keyword autonomous driving) that are boosting research activities.

**Greater research momentum in the “new energy” category is necessary**

However, the most important category for achieving the climate goals is the area of “new energy”. A further expansion of renewable energies, especially wind and solar energy, is the prerequisite for ensuring that global climate-damaging emissions can be reduced sufficiently in the coming years. However, the expansion of wind energy in particular is currently taking place too slowly. The current problems faced by numerous companies when expanding offshore wind farms (e.g. high installation costs and high maintenance requirements) show that there is still a great need for innovation. It is therefore a warning signal that research momentum in the field of “new energy” has since slowed down, after a very dynamic development at the beginning of the 2010s.

**The USA is at the forefront of world-class patents, but China is rapidly catching up**

In a global comparison, the USA is the world's leading top research location in green technologies. Every third world-class patent developed worldwide comes from the USA. USA is at the top in the categories “New Energy”, “New Mobility”, “Efficient Mobility”, “Energy Efficient Systems”, “Energy Efficient Devices”, “Climate Change Adaptation Technologies” and “Efficient Production”.

But the most important growth engine worldwide is China. The country has more than tripled its world-class patents in green technologies in the last five years alone (from 11,000 to 37,000), placing it in second place overall in the world. China is now one of the top three research locations worldwide in almost all green major categories. In the “Sustainable Consumables/Recycling” category, China is already in first place.

Japan ranks third in world-class green tech patents and is the world's leading research location in the energy storage and hydrogen economy categories.

The EU follows in fourth place. It plays an important role in global research competition, especially in the categories “New Energy” and “Efficient Mobility”.

**Germany is the top research location for green technologies in the EU**

Germany is by far the most important research country in green technologies in the EU. In 2022, there were almost 10,000 world-class patents in Germany, meaning Germany's share of all world-class patents from the EU was over 50 percent. Germany's share of all global green world-class patents was almost 7 percent in 2022.

The German technology profile shows that Germany has many world-class patents and a high global share, especially in the areas of “new mobility”, “efficient production” and “new energy”.

In the “New Energy” category, almost every tenth world-class patent comes from Germany. The most important single technology is wind energy, in which Germany has a global share of around 16 percent.

A very important technology field for Germany as an industrial location is “efficient production”. When it comes to individual technologies, material-saving additive manufacturing (3D printing) and energy-efficient metal production stand out. In both technologies, more than one in ten world-class patents comes from Germany. On the other hand, the German research position in the important technology of networked production/smart factories can be expanded (world share of only 5 percent).

**Germany is catching up when it comes to electromobility, but has room for improvement when it comes to autonomous mobility Driving and energy storage technologies**

The largest technology category in Germany is “New Mobility” with a total of just over 3,000 world-class patents in 2022. When it comes to the individual technologies of autonomous road vehicles and connected cars/interaction in road traffic, Germany has not been able to keep up with global dynamics in the last five years. However, the position of the German research location in electromobility has improved in recent years. When it comes to electric motors in particular, Germany now has a high global share of almost 11 percent and has been able to increase this global share by more than three percentage points since 2017.

The research position of Germany and the EU as a whole is less good in the “energy storage” category, an important part of the value chain for electric cars. The German world share of global energy storage technologies is only 3.6 percent and the EU share is only slightly higher at just over 5 percent. Japan, China, the USA and South Korea are all clearly ahead of the EU and Germany.

**The companies in Germany's key industries are the technology leaders in green technologies, but there is a lack of positive impulses from ICT companies**

The evaluation of the green tech world-class patents by sector shows that the companies in the classic German key industries such as the automotive industry, electrical industry and chemicals are also the most important technology leaders in green technologies. It is also noticeable that Germany has some technologically very broad companies such as Siemens and Bosch, which conduct cutting-edge research in many green technologies. This allows these companies to benefit from synergy effects through the increasing content linking of many green technologies in the sense of systems - e.g. For example, the intelligent connection and joint management of renewable energies with electricity storage systems and the smart grid are necessary elements for the future stabilization of the transmission network.

A negative result is that the importance of the ICT industry in terms of the number of world-class patents in green technologies in Germany is not that high. However, digitalization is an important driver of innovation in green technologies. In other countries, such as the USA, companies in the ICT segment (e.g. Alphabet) play a more important role in cutting-edge green tech research. The lack of impetus from ICT companies in Germany is therefore an explanation why Germany is particularly active in technologies with a high degree of digitalization, such as. B. autonomous vehicles or networked production/smart factories, do not perform particularly well in international comparison.

**The USA is the most important international research location for German companies**

The USA is by far the most important foreign location for research activities in green technologies by German companies. Almost every fourth world-class patent from German companies involves researchers based in the US. This proportion is higher than that
Sum of all such research collaborations with other EU countries. This means that there is still room for improvement for more intensive research cooperation in green technologies in the EU.

## 6 Methodology

**Analysis approach: Evaluation of technology portfolios based on patent data**

The basis of technology analysis is the evaluation of patent data. Patents are an important proof of the success of research and development and therefore one of the most important innovation output indicators. The patent portfolio of a (regional) economy or its companies and research institutions forms an important basis for its innovation and therefore future viability. Above all, innovations in the high-tech area are fundamental to remaining competitive and solving pressing social challenges. Patent analyzes help to uncover the strengths and weaknesses of a region or country. The focus of patent analyzes is naturally exclusively on the innovation activities of companies and research institutions. Strengths or weaknesses in areas of the value chain that are not or less influenced by companies' innovation activities (such as sales, marketing, etc.) cannot be identified through patent analysis

be recorded. The same applies to strengths or weaknesses with regard to location factors (e.g. Energy costs, availability of skilled workers, tax burden, etc.).

**How are patents defined in the study?**

In this study, the terms patents and patent families are used interchangeably. Technically speaking, the term “simple patent family” or “simple family” is correct. Companies often apply for a patent for an invention in several countries. This results in multiple patent applications (or, if successfully granted, multiple patents) for the same invention. Patents and applications linked in this way are collectively called a “patent family” or “simple family”. The patents of a “simple family” all have exactly the same priority. The priority period begins with the first application of an invention in any country. Within the following twelve months, the applicant is entitled to patent the same invention in other countries. For these subsequent applications, the applicant can claim the priority date of the first application. This means that for these further applications this priority date will be taken into account when assessing the novelty of the invention.

**Active patent portfolio instead of new applications**

Based on the development of patents per year, the strength of the patent portfolios of the selected countries or regions can be analyzed and compared and technological development can be shown. All active patents, including older patents that are still valid, are taken into account as of the respective deadline (end of year). The term of a patent is normally 20 years from the date of application, provided that the annual patent fees are paid. However, many patents expire early due to non-payment of annual fees if there is no sufficiently lucrative exploitation opportunity for the patent owner. The successful challenge of a patent or the non-granting of a patent after patent examination also results in a patent becoming inactive. The analysis based on active patents differs from other patent analyzes that often only count new patent applications per year. The advantage of the approach used in this study is that both the dynamics of the development of the patent portfolio over time and the absolute size and strength of a patent portfolio at the current point in time can be measured. In the case of evaluations based on patent applications, however, only the latest developments are recorded, while existing technological know-how from older patents is not taken into account.

**Which patent is the best in a green technology?**

A single patent rarely describes a significant development.29 As a rule, patents are detailed and very technical. The layperson cannot immediately tell whether a patent is significant in the sense of a major technological advance or whether it is a small one

[29] An exception is patenting in pharmaceutical technologies. In many cases you will find a direct so-called “patent to product mapping”, i.e. an assignment of a patent to a specific product.

incremental innovation. An example might explain this: The iPhone is one of the most important inventions of the last 15 years, but there is no iPhone patent. However, there are hundreds of Apple patents that deal with different aspects of the device. Altogether, these patents form the basis for the development of the iPhone. What the individual patents have in common is that they are all rated very high in quality. This high rating is the central selection feature for us in this study.

The more high-quality patents are developed in green technologies in a country, the higher the likelihood that something significant will develop from this patent portfolio. EconSight30 evaluates all patents and separates the relevant patents from the less relevant ones. For this study, only the 10 percent most important patents per technology were identified - the world-class patents.

**What are world class patents?**

The number of high-quality patents developed in green technologies per country is measured. In order to determine the quality of the individual patents, the country coverage and the citation frequency are determined. Country coverage calculates the worldwide legal coverage of patent protection. It shows how companies evaluate the importance of their own invention. The larger the number of countries in which the patent is filed, the more expensive the patent protection becomes. Broader international country coverage signals that the patent applicant considers his patent to be promising (self-assessment). EconSight attaches particular importance to a realistic country classification because although a patent can be registered in many countries, only a few countries are strategically relevant. What is measured is whether a patent has reached the “critical mass” (several large countries such as the USA, China, Japan, Europe, but also central medium-sized countries such as Great Britain, Germany, South Korea). Whether a patent is also active in many small countries is irrelevant to the basic quality.

The citation frequency of the patent depends on how often the examiners of the various patent offices refer to it and cite it. The patent offices use very similar methods to check whether a patent application is new and inventive and use other published patents to do this. This shows how important an invention is compared to other patents in the same technology (external assessment). Here too, EconSight places particular emphasis on the relevance of the measured values. While other rating systems simply count citations or, at best, give more weight to recent citations than older ones, EconSight focuses on business-relevant citations. For example, a citation of a patent by a single inventor is worth less than a citation by a large company like Alphabet.

The individual patent strength as a combination of relevant country coverage (achieving a “critical mass”) and relevant citation frequency (“business relevant” citations) suggests this

[30] EconSight 2023.

determine what impact a patent family has on competition and allows a quantifiable division into important and less important patents. EconSight focuses the analysis on the so-called world-class patents: the best 10 percent of all patents within a defined technology, measured by individual patent strength.

The focus on world-class patents makes sense in order to reduce distorting effects caused by country-specific differences in patenting systems. In China, for example, researchers are encouraged to patent as much as possible through tax breaks in order to increase the relevance of China as a research location.

**How is a company defined – the ultimate owner principle**

The companies' patents are reported according to the ultimate owner principle. Each patent is assigned to the highest controlling economic entity (ultimate owner). Accordingly, all patents from Audi, Volkswagen and Porsche are assigned to the VW Group. The companies LG Electronics, LG Chem and LG Display, on the other hand, are independent listed companies and are therefore reported separately.

A minority shareholding does not lead to economic control. For example, Daimler Truck Holding AG is listed on the stock exchange as an independent company and Mercedes-Benz Group AG holds less than half of the shares (30 percent, as of May 2023).

The ultimate owner principle also consolidates all company purchases at the level of the controlling economic entity. These are the activities of the robotics company KUKA
assigned to the Chinese Midea Group.

**Regional allocation of patents**

A patent is the result of research work that is usually carried out by several researchers, sometimes from more than one institution and sometimes from more than one country. The question arises as to how these patents should be counted and to which region or country they should be attributed. In patent analysis there are usually two options for geographically assigning patents. The first option is to assign the patents according to the address of the patent applicant (usually a company). A disadvantage of this approach is that in some cases the address of the registering company does not match the location of the invention. For example, a large company may register the patent at the address of its headquarters, even if the research actually took place at another location of the company. In order to avoid this problem, patents are often assigned geographically based on the place of residence of the inventors involved. This approach was also used in the present study. If researchers from several countries are involved in a patent, the patent is counted for each individual country.

# 7 short descriptions of green technologies

## New energy

**AC/DC converters, photovoltaics**

Conversion technology from direct to alternating voltage for photovoltaic systems.

**Biofuels, biomass**

The conversion of carbon compounds from biogenic sources (e.g. biowaste, manure, wood from short rotation plantations, etc.) through various technical steps and processes into electrical power or energy sources such as biogas or biofuels.

**Geothermal energy**

Geothermal energy uses the earth's heat to generate energy directly or indirectly. This can be used directly to heat buildings, for hot water or to generate electricity.
The advantage lies in the weather-independent and therefore controllable production.

**Nuclear fusion reactors**

This field describes technologies related to energy production through nuclear fusion, and includes stellarators, tokamaks and similar technologies.

**Ocean energy & hydropower**

Tidal power plants, current and wave power plants for generating electricity. The focus is on converting wave or tidal energy rather than storing electric water in water pump storage (as included in the energy storage category). However, some overlap with this area can be seen, as some plants combine more than one energy production technology.

**Organic solar cells, tandem and perovskite cells**

Collection group of non-silicon solar cells, based on organic dyes (polymer cells), usually with lower efficiency and (inorganic) tandem and perovskite cells with higher efficiency. Since the same organic molecules are used in organic PVs and in OLEDs, there is overlap with the OLED space.

**Floating offshore wind turbines**

Floating offshore wind turbines can be located further from the coast than traditional ground-based wind turbines.
The technical challenge lies in the stability of the floating platform.

#### Silicon photovoltaic cells

Classic silicon solar cells that convert sunlight directly into electrical energy based on doped silicon semiconductors. Silicon solar cells usually consist of polycrystalline or monocrystalline silicon wafers for energy conversion.

##### Solar thermal energy

Solar thermal systems, which, in contrast to photovoltaic systems, do not generate electricity, but rather heat, e.g. B. can be stored in hot water tanks. Depending on the technologies, different temperatures can be generated, up to process heat temperatures in concentrating systems.

#### Heat pumps

Heat pumps work in the opposite sense of a refrigerator. They extract energy from the environment (air, earth, water) and convert it into heat. Research is moving towards industrial use, which requires higher temperatures and adaptation to different environmental conditions.

#### Wind energy

Electricity generation through rotors, kites or other wind-moving installations.
Wind power-specific components such as rotor blades are also included.

### Energy storage

#### Bipolar batteries

In contrast to classic lithium-ion batteries, in bipolar batteries the cathode and anode are attached to a common electrode carrier. The advantage over lithium-ion batteries is that they require less space due to fewer components and connecting elements. The current flows over the entire surface of the battery. The battery in electric vehicles is expected to lead to significantly longer ranges.

#### Solid state accumulator

Accumulator or battery comprising a solid electrolyte made of polymers or oxides, e.g. B. grenades, and is less sensitive to electrolyte loss and ignition than technologies with liquid electrolytes.

#### Lithium batteries

Lithium accumulators, i.e. rechargeable power storage devices based on Li-ions as an electrolyte (and not lithium batteries in the true sense).

**Sodium ion battery**

Sodium batteries have similar properties to Li-ion batteries, but are larger in structure and therefore heavier. The benefits are expected to include charging time, better performance in colder temperatures, and lower price due to better material availability.

**Redox flow batteries, alkaline membrane fuel cells, AMFCs**

Flow batteries are technologically between fuel cells and rechargeable batteries. Flow or redox flow batteries consist of two typically large liquid chambers separated by a membrane. In the two chambers, liquid electrolytes, catholyte and anolyte, are pumped against each other and convert chemical energy into electrical energy. They typically suffer from lower energy density, require higher current density compared to lithium batteries, have lower charge and discharge rates, and need to be larger to compensate. However, material requirements are less critical and the design can be very flexible. They are long-lasting and use less harmful and cheaper chemicals, making them attractive for large stationary energy storage alternatives. Due to the use of alkaline electrolytes, redox flow batteries are related, but not identical, to alkaline fuel cells (AFCs), alkaline membrane fuel cells (AMFC), or alkaline anion exchange membrane fuel cells (AAEMFC). They are based on the transport of alkaline ions, usually hydroxide OHÿ, between the electrodes.

Original AFCs used aqueous potassium hydroxide (KOH) as an electrolyte. NASA used alkaline fuel cells for Apollo and Space Shuttle projects in the 1960s.
Both technologies, Redox Flow or AMFCs, are included in this technology definition due to their close relationship.

## Hydrogen economy

**Green/blue ammonia production**

Ammonia is traditionally produced for fertilizer production, but is increasingly developing into a hydrogen storage material or for direct use in combustion engines, e.g. B. for ships (then mostly liquid ammonia). It is made green if the hydrogen used is also green and the production is sustainable. Blue ammonia is created from hydrogen, during the production of which the resulting CO2 is captured, solidified or converted (e.g. into methanol).

**Green/blue methanol production**

Methanol, as one of the important energy sources and also as a hydrogen storage material, is increasingly being produced differently than petrochemical raw materials. Green methanol is methanol produced from renewable sources or using sustainably generated energy. Blue methanol is produced and converted in particular from CO2 exhaust gases. This means that it is not made from sustainable sources, but rather from waste that would otherwise end up in the environment.

**Production of fuel cells**

Fuel cells are complex to produce. In particular, the high number of thin layers that have to be stacked in a gas-tight environment leads to slow production with a lot of waste. Modern production methods and in particular the automation of fuel cell production are key to greater availability and competitive prices.

**Green/blue hydrogen production**

The technology focuses on hydrogen production using renewable energies, particularly electrolysis and fuel cells using electricity from photovoltaic and wind turbines.
The production of blue hydrogen from natural gas is also an option for quick, short-term use.

**Hydrogen electrolyzer, electrolysis, electrochemical H2 pump**

The electrolyzer is the heart of the process for splitting water into hydrogen and oxygen. Electrolysers come in various sizes, from large production facilities to small products. Current research focuses on reducing the cost of the electrolyzer unit and better understanding the degradation processes to extend the life of the device. Also included in the field are electrochemical hydrogen pumps, which are comparable in design but are intended primarily for purifying hydrogen from gas mixtures.

**Hydrogen production and storage**

This field includes the production of hydrogen, without distinguishing the process or treatment of the by-products (in particular the CO2 from steam reforming), as well as the storage and transport devices for hydrogen. It is a collection of the various production processes for hydrogen, with the classic process of steam reforming and the conversion of synthesis gas (from natural gas or methane) currently clearly dominating the modern methods of electrolysis and the use of fuel cells.

**Hydrogen lines, pipelines, H2/gas separation**

Hydrogen can be transported in gaseous or liquid form through pipelines and other pipe infrastructure typically designed for natural gas. It is often added to natural gas anyway and can be separated directly from the gas mixture, for example for fuel cells to generate electricity or at H2 filling stations. This area includes technologies for the separation and purification of hydrogen from gas streams as well as pipeline technology or specific pipes and equipment for the transport and handling of H2. It is a sub-area of hydrogen production and storage.

## New mobility

### Autonomous road vehicles

Autonomous road vehicle technology includes various elements: In order for vehicles to drive autonomously, they must first sense their surroundings in real time. Sensors and perception systems are central to this, including lidar, radar, cameras and ultrasonic sensors. (AI) software is central to processing the collected data, enabling vehicles to recognize patterns, make decisions and adapt to different traffic situations.

### Battery charger for vehicles

Charging systems for vehicle batteries in electric vehicles or hybrid vehicles include on-site and infrastructure installations, but also on-board charging technologies such as recuperation.

### Electric vehicles, not hybrids

Hybrid vehicles and electric vehicles share an electric motor. However, in hybrids it is significantly smaller than in electric vehicles and is only suitable for low speeds and short ranges. Hybrid vehicles have at least two drive motors, and of these, the gasoline-powered engine is generally the main power unit. Therefore, the general field of electric vehicles has been separated from hybrid-related patents. The field includes all types of vehicles and is not limited to road vehicles.

### Electric motors

Electric motors are very commonly used in all kinds of devices, from micro sizes to car drive motors. This area includes the area of automotive-related electric motors and includes the two sub-areas of winding and hairpin technologies for electric motors.

### Railway technologies

Railway technologies, including trams and other rail vehicle technologies. This field records everything that can be counted as rail transport, including individual parts, infrastructure, track and train management, etc.

### Connected cars and interaction in road traffic

The technology field includes patents that are primarily aimed at communication between road users. This includes communication between vehicles (V2V), but also communication between vehicles and infrastructure. A very large increase in efficiency is expected through improved communication between road users, especially due to the high traffic concentration in metropolitan areas.

### Hydrogen tank

Hydrogen can be stored in many ways, such as: B. metal hydrides or liquid **organic hydrogen carriers** (LOHC). But in most cases, especially for mobility, hydrogen is stored under pressure, at 700 bar. Pressure vessels are not new and have been made primarily from metal for years. The demand for light and safe

However, hydrogen tanks are the key to the successful application of hydrogen in transport. Hydrogen is not only the lightest gas available and places high demands on sealing technology, it is also explosive in air-oxygen mixtures. New technologies such as composite tanks have been successfully developed for automotive applications, while process-integrated tanks for gas stations, ships or heavy-duty vehicles are also being developed. This area is a sub-sector of hydrogen production and storage, but meets the specific demand for high pressure safe H2 gas tanks, which are one of the many key factors for successful H2 upscaling.

#### Hydrogen filling station

Hydrogen filling stations are crucial for the future hydrogen mobility market. This area includes the technologies behind this hydrogen supply to vehicles. Hydrogen can even be transported to these hydrogen filling stations through pipelines together with natural gas and then separated again or produced on site, for example by electrolysers.

### Efficient mobility

#### Efficient car design

This field specifically covers the optimization of vehicles, be it aerodynamics, tires or weight reduction.

#### Energy efficient aircraft turbines

Similar to cars and efficient combustion engines, aircraft turbines also have a large number of patents that focus on fuel savings. Turbines are huge energy producers and aircraft fuel consumption is a major cost factor in commercial aviation. Therefore, intensive research and innovation continues in the field of consumption and energy efficiency of aircraft turbines. This area is somewhat related to electric aviation (hybrid energy generation, on-board energy generation) as well as stationary turbines and wind energy, as many aspects of efficient turbines are also suitable and used for applications other than aircraft.

#### Synthetic fuels

Fuels, especially for mobility, made from non-petrochemical raw materials, in particular Fischer-Tropsch and similar processes. Synthetic fuels are usually made from synthesis gas, a mixture of CO and H2 (carbon monoxide and hydrogen). These can be converted into any petrochemical product. So far, natural gas has mostly been used as a source for CO. In the future, however, renewable sources will become increasingly important in order to be able to produce climate-neutral fuels.

## Efficient production

**3D printing (additive manufacturing)**

Manufacture of a wide range of products and spare parts for needs-based mass tailoring instead of mass production. While in conventional production objects are usually created from a block of material, in 3D printing the object is built up layer by layer.

**Digital farming, precision farming**

Support and optimization technologies in agriculture for the use of drones or satellites to optimize yields in a resource-saving manner.

**Efficient glass and ceramic production**

Technologies to avoid waste and to produce glass and ceramics more resource-efficiently.

**Efficient industrial production in chemicals, petrochemicals, textiles and others**

Technologies for energy-saving and resource-optimized production in chemistry and related areas.

**Efficient metal production**

Technologies for energy-optimized production of metals. The focus of the research activities is increasing the efficiency of the melting and holding furnaces. Optimized waste heat utilization also plays a role. Pig iron production also involves a profound change in the reduction process in order to avoid process emissions.

**Carbon dioxide filter, capture and binding**

Gas filter systems, separation devices and carbon binding processes enable the resulting CO2 to be bound directly. Ideally, the CO2 obtained is used again as a raw material and taken out of the cycle in bound form. In most cases these are industrial gas scrubbing systems and filters, but direct capture systems, i.e. those that filter CO2 from the air, are also recorded.

**Greenhouse gas-reduced aluminum metal production**

The production of aluminum requires a lot of energy, especially for cryolite electrolysis.
This current can e.g. B. come from sustainable sources and be integrated into metal production. In addition, the carbon electrodes in smelting electrolysis produce additional CO2 during the process, which is why alternative electrode materials are increasingly being used. There is some overlap with the technology of efficient metal production.

**Networked production (Smart Factory)**

Networking in industrial production through to a completely integrated factory. A key part of this technology are predictive maintenance systems, which include elements such as monitoring, data collection and image analysis, fault diagnosis and networked control of production. These systems are data-driven maintenance methods that analyze the condition of production equipment and help predict malfunctions, disruptions and the timing of required maintenance. This allows problems to be resolved before they lead to downtime. A small area also consists of adaptive control systems such as those used in automated factories (automated container terminals and goods transport, autonomous “assembly lines”).

## Energy efficient systems

**High-voltage direct current (HVDC) transmission**

HVDC is a direct current energy transmission technology that was specifically developed for power transmission over long distances and promises lower transmission losses than alternating current transmission technology. A transformation from or to alternating current usually takes place at the entry and exit points.

**Intelligent power grids (smart grid & smart meters)**

Power grids and power distribution with communicative distribution and control. These can be found in decentralized energy producers (e.g. wind turbines), but also in modern vehicles.
In the future, the aim is to set up such systems in larger regions in order to efficiently link many decentralized producers and consumers. This area also includes smart meters, which are typically used in homes as a central station to manage internal power distribution and are usually connected directly to the main grid.

**Intelligent, connected house (Smart Home)**

Devices in and around buildings consisting of sensors and network components. The focus is on the intelligent, energy-efficient interaction of the devices. The field overlaps with the technology of smart grids (smart grids & smart meters), as these smart meters are often smart houses' main contact with the power grid and manage the main power distribution in homes. Since car chargers are increasingly being integrated into smart houses, there is also an overlap with the technology field of battery chargers for vehicles.

## Energy efficient devices

**Energy efficient building technology**

This area includes technologies for thermal insulation, passive cooling, ventilation systems, heat pumps, thermochromic glasses and other energy-efficient building technologies.

**Energy efficient building, lighting and office electronics**

This field includes energy-efficient building electronics and end devices in home and office environments. This includes energy-saving measures for office equipment as well as efficient lighting technologies in buildings and the control of ventilation systems.

## Adaptation technologies to mitigate the consequences of global warming

**Efficient sprinkling & irrigation**

Sprinkling and irrigation of agricultural land is, along with crop protection and fertilizer handling, one of the main mechanisms for increasing the efficiency of crop production. With increasing demands due to climatic changes, irrigation is becoming more and more relevant. In addition, irrigation is an important aspect in modern precision agriculture and can be easily integrated into precision machines such as automated tractors or drones.

**Emission-reducing animal feed**

Feed additives to optimize the digestion of farm animals. The aim is to reduce the animals' methane emissions.

**IR/heat management, thermal insulation facades**

A major challenge is the increasing demand for better insulation and temperature management of buildings. Perhaps the largest energy-consuming aspect of buildings is the generation or stabilization of heat and the passive control of temperature peaks. The area covers materials and processes for the thermal management of buildings, mainly via the facade and windows. It therefore overlaps with modern insulation materials. It does not include active heating, ventilation and air conditioning (HVAC), but can overlap slightly when it comes to heat preservation and passive cooling.

**Modern insulation materials**

Various insulation materials are covered in this technology field, e.g. B. Aerogels or xerogels, as well as construction technologies that, on the one hand, have a better energy balance, but also protect against stronger temperature influences.

**N2O, NOx separation**

Various technologies to reduce or filter NOx, N2O and other higher gases. While N2O is a climate-affecting gas and filters for reducing or removing exhaust gases fall into this range, it also includes the filtration or conversion of NO or NO2 in automotive exhaust filters. Therefore, an overlap with exhaust gas catalyst technologies can be seen.

**Clean room agriculture**

Agriculture in clean rooms and artificial atmospheres, including in cities.

**Torrefaction, pyrolysis, biocarbon**

Conversion of biocarbon, especially carbon-containing waste, into carbon or methane using various processes. Included are processes for converting CO2 into solid, burable materials to reduce the CO2 concentration in the air. Also included are processes that use carbon-containing materials to reuse the CO2 for up-

/pyrolyze for recycling purposes. There is some overlap in biomass and biopolymers.

**forestry**

Forestry includes technologies related to tree plants, especially but not exclusively for forests, from planting, sowing, caring for, growing and harvesting trees, but also the monitoring of forests or forest fires and various other technologies related to tree and forest measurements or data processing.

**Water desalination**

Water desalination plants and technologies for converting salt water into drinking water.

## Sustainable consumables and recycling

**Waste management**

Technologies for the planning and implementation of waste treatment, in particular business methods and processes for waste categorization, optimization of payment and export, and waste labeling and sorting methods.

**Meat alternatives**

Products mostly plant-based (pea proteins, etc.) that serve as meat substitutes. The focus is particularly on texture adjustments and fermentation technologies.

**Plastic, glass, paper, electronics and consumer waste recycling**

Recycling consumer items such as plastics, paper, electronics, etc.

**Sustainable packaging**

Packaging based on renewable raw materials, e.g. B. cellulose, especially for the circular economy.

**Recycling batteries and fuel cells**

Recycling of various types of batteries, especially for the extraction of various, sometimes rare, elements and metals. Two sub-areas, pyrometallurgy and hydrometallurgy, are included in this

area included because they represent the most important production routes. Also included are technologies for recycling fuel cells.

**Drinking water treatment**

Water purification technologies, especially for drinking water, as well as biological water purification methods.

**Cement recycling and waste reuse**

When recycling cement, so-called recycled aggregates are used instead of gravel or chippings from natural sources. After a building is demolished, the concrete parts are crushed and then processed into high-quality aggregates.

## 8 Bibliography


acatech – German Academy of Engineering Sciences (ed.) (2018). *CCU and CCS – building blocks for climate protection in industry. Analysis, options for action and recommendations.* Munich. https://www.acatech.de/publikation/ccu-und-ccs-bausteine-fuer-den-klimaschutz-in-der-industrie-analyse-handlungsoptions-und-recommendations/ (Download dd.mm.2023).

acatech – German Academy of Engineering Sciences (ed.) (2017). *Sector coupling – options for the next phase of the energy transition.* Berlin. https://www.acatech.de/publikation/sectorkopplung-options-fuer-die-naechste-phase-der-energiewende/ (Download December 5, 2023).

Bleischwitz, Raimund, Miying Yang, BeijiaHuang and Xiaozhen Xu (2022). "The circular economy in China: Achievements, challenges and potential implications for decarbonization". https://www.researchgate.net/publication/360079126_The_circular_economy_in_China_Achievements_challenges_and_potential_implications_for_decarbonization (Download dd.mm.2023).

Clingendael (2022). "Sino-European joint ventures and the risk of technology transfers". https://www.clingendael.org/sites/default/files/2022-08/CA_Datenna_0.pdf (Download dd.mm.2023).

Deloitte (ed.) (2023). *Future of Automotive Mobility.* London. https://www2.deloitte.com/de/de/pages/consumer-industrial-products/articles/future-of-automotive-mobility.html (Download dd.mm.2023).

EconSight (ed.) (2023). *The 1000 best companies in 100 green technologies.* Basel. https://www.econsight.com/wp-content/uploads/2023/06/EconSight-Greentech-Studie- 2023-EN.pdf (Download dd.mm.2023).

e-mobile BW (2023). "Structural study BW: Transformation of the automobile/commercial vehicle industry in Baden-Württemberg through electrification, digitalization and automation". https://www.e-mobilbw.de/service/mediathek-detail/strukturstudie-bw-2023-der-automobilstandort-baden-wuerttemberg-am-wendepunkt (Download dd.mm.2023).

Envoria (2023). "EU Taxonomy Basics". https://eu-taxonomy.info/de/info/eu-taxonomy-basics

EPO – European Patent Office (2019). "Climate change mitigation technologies". November 25, 2019. https://www.epo.org/de/node/447280 (Download dd.mm.2023).

EPO – European Patent Office (2023). "Innovative power unbridled: patent applications in Europe will continue to increase in 2022". March 28, 2023. https://www.epo.org/de/news-events/news/innovationskraft-ungebremst-patentanmelden-europa-gehen-2022-weiter- zu (Download dd.mm.2023).

Erlach, Berit, Sabine Fuss, Oliver Geden, Ulrich Glotzbach, Hans-Martin Henning, Karen Pittel, Jürgen Renn, Simona Rens, Dirk Uwe Sauer, Christoph M. Schmidt, Indra Spiecker called Döhmann, Christoph Stemmler, Cyril Stephanos and Jessica Strefler ( 2022). "What are negative emissions and why do we need them? (Briefly explained!)", academy project "Energy Systems of the Future" (ESYS). https://doi.org/10.48669/ESYS_2022-2.

European Commission (2023). European Battery Alliance. https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/european-battery-alliance_en (Download dd.mm.2023).

European Commission (2022). “Batteries for Energy Storage in the European Union”. https://setis.ec.europa.eu/batteries-energy-storage-european-union_en (Download dd.mm.2023).

IEA (2021). “Net zero by 2050”. https://www.iea.org/reports/net-zero-by-2050 (Download dd.mm.2023).

IEA (2022). “World Energy Outlook 2022”. https://www.bing.com/search?FORM=RA75DF&q=IEA+(2022)%3A+World+Energy+Outlook&PC=RA75 (Download dd.mm.2023).

IEA (2023). “Hydrogen Patents for a Clean Energy Future”. https://www.iea.org/reports/hydrogen-patents-for-a-clean-energy-future (Download dd.mm.2023).

ifo Institute (2019). “What the energy transition will really cost us.” July 12, 2019. https://www.ifo.de/medienteil/2019-07-12/was-uns-die-energiewende-really-cost-will (Download dd.mm.2023).

IRENA (2019). *Future of wind. Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation paper).* International Renewable Energy Agency. Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf?rev=c324896ba0f74c99a0cde784f3a36dff (Download dd.mm.2023).

Roland Berger GmbH (2021). *GreenTech made in Germany 2021. Environmental technology atlas for Germany.* Published by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Berlin.

WIPO Green (2023). “About WIPO GREEN”. https://www3.wipo.int/wipogreen/en/aboutus/ (Download December 4, 2023).

## Address | Contact

Bertelsmann Foundation
Carl-Bertelsmann-Strasse 256
33311 Gütersloh
Telephone +49 5241 81-0
bertelsmann-stiftung.de

Daniel Posch
Project Manager
Sustainable social market economy
Telephone +49 30 275788-173
daniel.posch@bertelsmann-stiftung.de
https://www.bertelsmann-stiftung.de/de/unsere-projekte/nachhaltig-wirtschaften