B 1 New Technologies for Sustainable Agriculture

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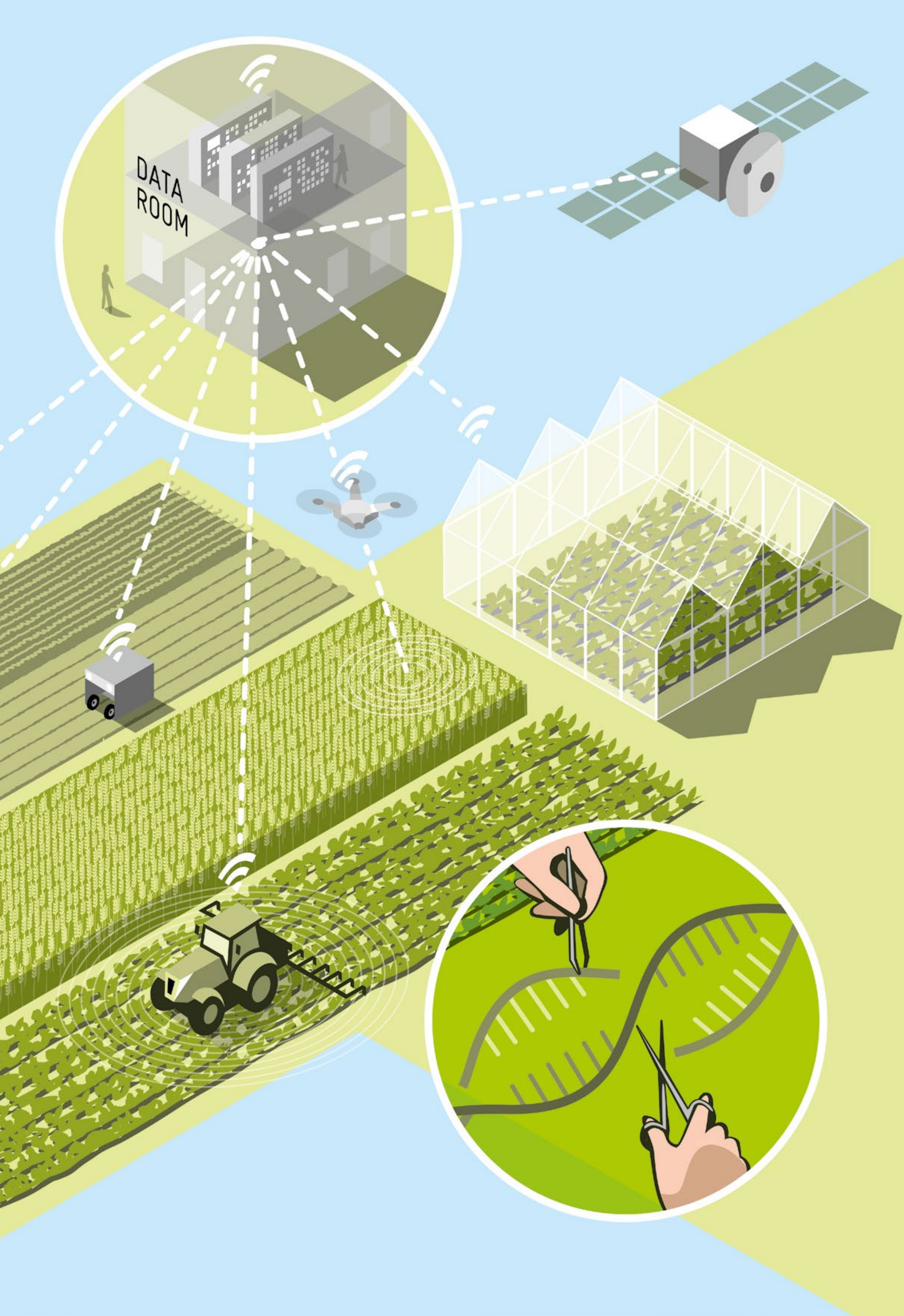
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B 1 New Technologies for Sustainable Agriculture

Agriculture is facing major challenges worldwide. The Sustainable Development Goals (SDGs) formulated as part of the United Nations 2030 Agenda call for the fight against hunger on the one hand and the sustainable use of the natural environment, the preservation of biodiversity and the fight against climate change on the other. Agriculture, which is itself affected by climate change, must by tendency produce larger quantities of food with less environmentally harmful inputs such as pesticides and fertilisers while at the same time arable land is decreasing.[115] To master this balancing act, a major transformation of the agricultural system will be necessary – and certainly also a change in dietary habits. A major technological change is likewise required in crop farming, which is the focus of this chapter.[116] The use of digital and smart technologies, in particular resource-saving precision technologies, but also green genetic engineering methods that enable the cultivation of plants that are both more climate-resistant and richer in nutrients, offer opportunities here.

However, the use of these innovative technologies is still restricted by many barriers. With regard to digital and smart technologies, digital infrastructure and interoperability between hardware and digital applications are lacking. There are still insufficient incentives for the use of resource-saving precision technologies to reduce environmentally harmful inputs. However, the cultivation of new crops using genetic engineering also faces numerous hurdles in Europe and Germany in terms of the legal framework and acceptance. The Commission of Experts therefore calls on the Federal Government, and in particular the Federal Ministry of Food and Agriculture (Bundesministerium für Ernährung und Landwirtschaft, BMEL), the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Naturschutz, -nukleare Sicherheit und Verbraucherschutz, BMUV) and the Federal Ministry for Digital and Transport (Bundesministerium für Digitales und Verkehr, BMDV), to provide stronger incentives for the use of digital and smart agricultural technologies and to solve the necessary infrastructure problems, and to actively support the European Commission’s proposal to reform the process-based regulations for the use of new genomic techniques. In the long term, method-based regulation should be converted to regulation of the characteristics of the bred plants.

B 1-1 Challenges for Agriculture

Population growth, climate change, the decline in arable land and the negative effects on the environment caused by agriculture itself, such as biodiversity loss and groundwater pollution, constitute major challenges for agriculture.

Food Security as a Challenge for Agriculture

One of the goals formulated by the United Nations in the SDGs is to eradicate all forms of hunger and malnutrition by 2030. This goal is to be achieved by increasing production and productivity in agriculture, adapting to climate change and at the same time making farming methods more sustainable in order to protect natural ecosystems and maintain soil quality.[117] The challenge, therefore, is to transform existing intensive agricultural practices into more sustainable forms of farming and at the same time ensure that the demand for food[118] is met for a growing world population.[119]

Climate Change as a Challenge for Agriculture

Extreme weather events have increased significantly in Germany over the past 20 to 30 years.[120] According to the forecasts of the Intergovernmental Panel on Climate Change (IPCC), this trend is highly likely to continue in Central and Western Europe in the future. The greatest climate-related challenges for agricultural production in Germany are the increase in winter precipitation with an increased risk of erosion and nutrient leaching as well as the increase in dry periods during the main growth season.[121] Climate change affects different crops differently from region to region and across the vegetation periods.[122] Climate change also influences the habitat conditions of harmful organisms that indirectly affect agricultural production.[123] The consequences are losses in the quality and yield of agricultural products.[124]

Agriculture as a Cause of Climate and Environmental Damage

Agriculture is not only affected by climate change, but also contributes significantly to climate change through emissions (especially methane and nitrous oxide) and land-use changes (especially the conversion of forests and peatlands into agricultural land). In addition, agriculture has negative impacts on groundwater and surface water as well as on neighbouring natural ecosystems, particularly their biodiversity, through the use of nutrients and the application of pesticides.[125] Abundant biodiversity plays a key role in the resilience of agroecosystems and the productivity of soils. It promotes an optimal interplay of processes in nature,[126] which in turn has a positive effect on agricultural production.[127]

Finally, the withdrawal of groundwater and surface water for irrigation purposes is a major problem in many parts of the world. Even if agriculture in Germany has played a minor role in water withdrawal to date, this may change in the future due to longer periods of drought.[128] In large parts of Germany, groundwater resources are already in a critical state today.[129]

To meet the challenges of climate change and biodiversity loss and to ensure food security, a major technological change in agriculture is required. Digital and smart technologies, in particular resource-saving precision technologies, as well as green genetic engineering methods for breeding climate-resistant plants with improved pest resistance and improved nutrient uptake offer innovative solutions. However, the extent to which the potential of these technologies can be utilized depends not least on the incentives, skills and overall conditions in the agricultural sector.[130]

B 1-2 Digital and Smart Technologies in Agriculture

The following section looks at digital and smart technologies and their potential for the transformation of agriculture. In addition, obstacles that currently stand in the way of widespread use are identified. Digital and smart technologies include digital hardware and software as well as their connectivity so that data can be received and sent.[131] The various technologies are components of the concepts of precision agriculture and smart farming, which are explained in greater detail below.

Box B 1-1 German Agricultural Sector

The gross domestic product (GDP) of the agricultural sector amounted to around €28.9 billion in 2021, which corresponded to 0.8 percent of Germany's total GDP.[132] In 2020, 937,900 people were employed in agricultural holdings.[133] This corresponded to approximately 2 percent of the labour force in Germany.[134] Approximately 50.5 percent of the total area in Germany is used for agriculture, 70.3 percent of which is arable land.[135] Agriculture was responsible for 7.4 percent of greenhouse gas emissions in 2022.[136] The public contribution to the funding of agriculture in Germany is essentially made via the Common Agricultural Policy (CAP) of the European Union (EU). The German CAP Strategic Plan 2023-2027 provides, among other things, funds totalling €12.8 billion for basic income support and €8.7 billion for additional direct payments.[137]

B 1-2 a Potential and Challenges of Digital and Smart Technologies

Precise Farming of Specific Areas Possible

Precision farming is the site-specific, targeted and variable application of agricultural inputs such as seeds, plants, fertilisers, pesticides and water. The quantity of inputs used is adapted exactly to the current specific requirements of the respective agricultural sub-area.[138] Precision farming can reduce the amount of fertiliser and pesticides applied. This allows for savings in operating costs while reducing negative environmental impacts.[139] Satellite-based navigation technologies, which enable precise positioning, are key to the application of precision farming. The information obtained via sensors can be processed in geographic information systems, so-called field maps.[140] Work processes and the use of resources can be optimized with the help of such field maps and carried out by automated agricultural machinery.[141]

Better Farm Management Made Possible by Digital and Smart Technologies

Smart farming is looser defined than precision farming and utilizes both the data collected by interconnected devices on the Internet of Things and the processing of this data with other context-specific data to support farmers in making operational decisions or to automate these decisions. The spectrum of tasks ranges from automated data collection and optimization of farm planning to the automation of accounting.[142] In addition to farms, the agriculture 4.0 network also includes manufacturers of inputs, retailers and consumers. The aim is to improve organization and processes along the entire value chain.[143]

Wide Range of Applications for Digital and Smart Agricultural Technologies

Digital (partially) automated agricultural machinery, robots or drones can be used in precision farming. (Partially) automated agricultural machinery includes, for example, tractors with track guidance or part-width section control for the site-specific application of inputs.[144] Robots are autonomously operating machines that are able to register their environment, process information obtained via sensors, make decisions and derive suitable work steps from this.[145] Compared to (partially) automated agricultural machinery, robots are significantly smaller and gentler on the soil. However, they are still largely at the research and development stage.[146] The currently targeted areas of application range from the determination of plant characteristics and health, soil cultivation, weed control and maintenance work in fruit growing to sowing and harvesting.[147] Drones, as part of remote sensing,[148] are human-controlled or semi-autonomous aircraft that use sensors to monitor plant growth, pest infestation, soil structure, water shortages, erosion and storm damage. Drones can also apply inputs such as pesticides in rough terrain.[149] Thanks to falling costs and simplified operation and control, their use is becoming increasingly widespread in some areas.[150]

The functionality of (partially) automated agricultural machinery, robots and drones is largely based on sensors and actuator technology. Sensors record information and convert it into electrical signals that can be digitally recorded and processed. Recording this data makes it possible, for example, to differentiate between crops and weeds.[151] Actuators such as motors, section control, robotic arms and display elements convert the processed sensor data into customized agricultural processing.

Farm management and information systems (FMIS) and decision support systems (DSS) assist agricultural holdings through the automated collection and processing of data that enables better planning, monitoring, documentation and optimization of operational processes, e. g. through the automated creation of field maps.[152] Both internal farm data and data from external sources are processed and artificial intelligence (AI) is used.[153]

Widespread Use of Farm Management Systems

In a non-representative survey[154] conducted on behalf of the Commission of Experts between May and June 2023, 40.9 percent of the participating farms and contractors stated that they use FMIS or DSS (cf. figure B 1-2). This is followed at a slight distance by the use of digital technologies for agricultural machinery. Digital information platforms are used by approximately one in three and drones by one in four of the farms surveyed. While detection and sensor technology still play a role for one in five farms, field robots are only used by 4.2 percent of the farms surveyed. However, 12.7 percent of those surveyed stated that they were planning to use field robots.[155]

Continued Development in Agricultural Technologies Required

As precision technologies are used in vastly different environments, correct status detection and environment recognition requires the combination of sensors and integrated sensor systems or the linking of data from different sensors. Significant development steps are still needed here, especially for autonomous systems. In addition, the use of advanced applications requires integration into the Internet of Things and, consequently, suitable network structures for fast data transmission, which are still insufficiently established in many rural areas.[156]

Analyzing the practical suitability of precision technologies is an important development step. To this end, the BMEL has launched 14 'Digital Experimental Fields'.[157] These are projects within which the funded actors investigate how digital technologies can be optimally used to protect the environment, increase animal welfare and biodiversity and facilitate work.[158] These experimental fields offer interested users the opportunity to learn more about digitalization in agriculture. In addition, cooperation between agriculture and research takes account of practical requirements in the development and testing of new applications to ensure a two-way transfer of knowledge.

Fig. B 1-2 Use of digital and smart technologies 2023 in percent

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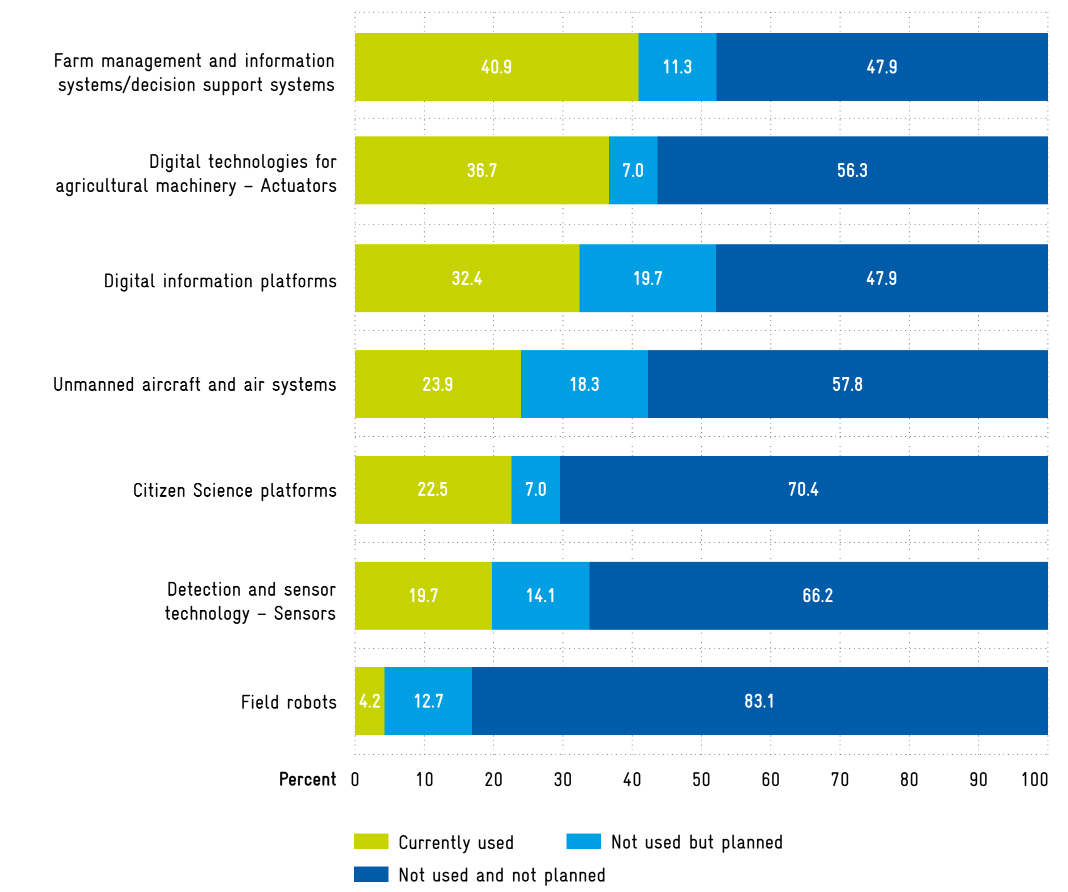

Legend: 40.9 percent of the farms and contractors surveyed stated that they currently use farm management and information systems or decision support systems. 11.3 percent of respondents plan to use them in the future; number of observations: 71; Question text: "Which digital and smart technologies do you use for your activities?"
Bars do not always add up to 100 percent due to rounding.
Source: Own evaluations based on Geppert et al. (2024).

Incentivizing Use of New Technologies Essential for Sustainability

New digital and smart technologies are often still at a competitive disadvantage compared to powerful conventional agricultural machinery developed for intensive farming. There are three main reasons for this: first, some of these technologies, such as robots, are not yet mature in their development. Second, they are still comparatively expensive due to their limited distribution and therefore small numbers. Third, the negative environmental impacts of conventional agricultural practices are not reflected in the production costs of farms.

To make robots and drones competitive, for example, their area coverage, duration of use and precision must be further increased. Switching to cultivation concepts with significantly differentiated and smaller-scale cultivation of land, such as spot farming,[159] would also increase their competitiveness.[160] However, the development costs of robots in particular are very high, so that relatively small numbers of units are likely to result in high acquisition costs for farms.[161] In the above-mentioned survey, 60.0 percent of respondents who already use digital and smart technologies cited the high acquisition costs as a (very) major obstacle to their use (cf. figure B 1-3). Due to a lack of experience with the new technologies, the economic benefits for agricultural holdings are also initially uncertain. However, as these new technologies become more widespread and thus larger numbers of units are produced, the acquisition costs are

Fig. B 1-3 Barriers to the use of digital and smart technologies 2023 in percent

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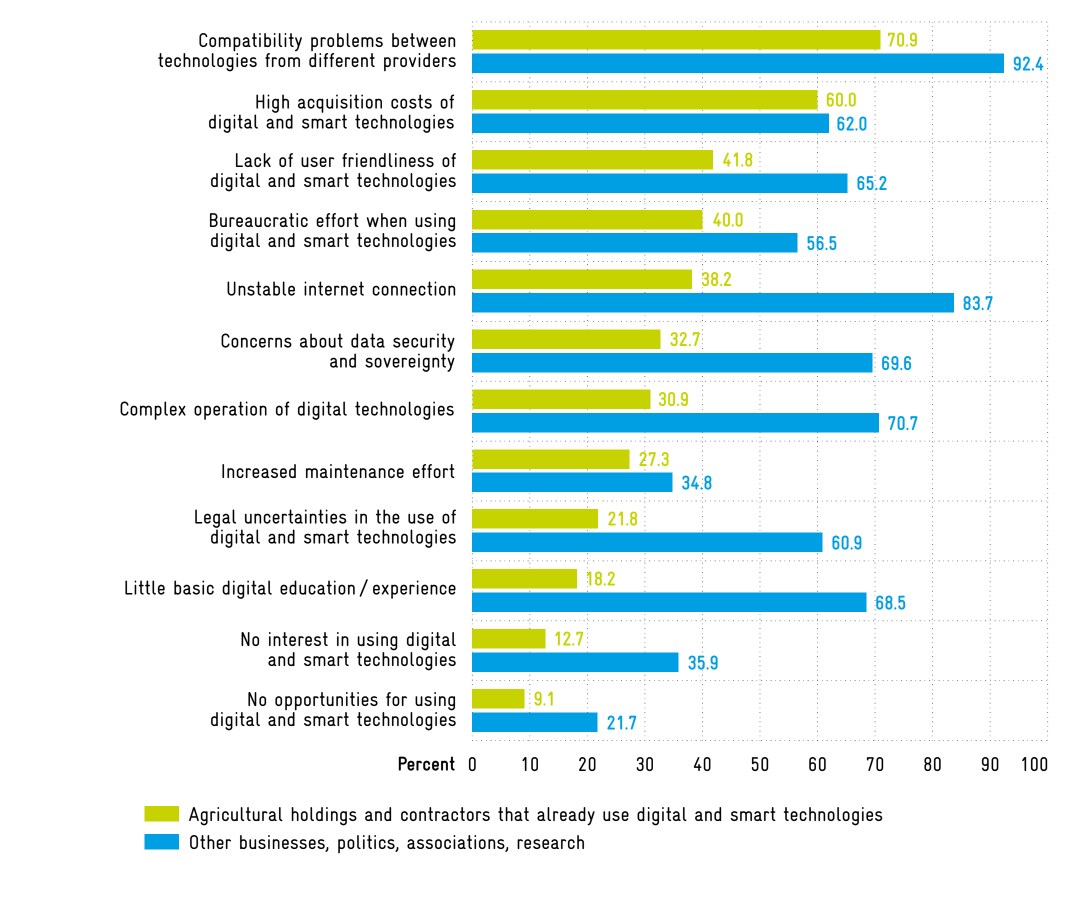

Legend: 70.9 percent of the agricultural holdings surveyed that use at least one of the digital and smart technologies surveyed themselves view compatibility problems between technologies from different providers as a major or very major barrier to using digital and smart technologies. Question text: "In your opinion, what factors impede or prevent the use of digital and smart technologies in agriculture?" Possible answers: no barrier, minor barrier, major barrier, very major barrier. The bars show the sum of "major barrier" and "very major barrier".
Source: Own evaluations based on Geppert et al. (2024).

likely to fall making the technologies even more attractive.

The survey conducted on behalf of the Commission of Experts also showed that both farmers and representatives from politics, associations, research and industry attribute high potential to digital and smart technologies in the field of sustainability and environmental protection, especially in protecting biodiversity and reducing soil pollution (cf. figure B 1-4). According to a survey of 500 farmers in Germany conducted by Bitkom Research in 2022, 92 percent of respondents believe that digital and smart technologies can save on fertilisers, pesticides and other operating resources.[162]

However, the at times massive environmental impacts caused by the application of fertilisers and pesticides is generally not considered by farms in their cost accounting. The incentives to use new, environmentally friendly precision technologies are therefore still too low.

This would change if the use of polluting inputs were subject to a tax or levy. This is already the case in Denmark.[163] The use of old, unsustainable agricultural technologies would thus become more expensive and newer (precision) technologies would become competitive.

Another alternative would be the introduction of a quota trading system for fertilisers and pesticides like the European emissions trading system for CO_2 certificates (EU ETS). However, a quota trading system for fertilisers and pesticides runs the risk of some agricultural holdings buying up large quantities of quotas. This would concentrate the application of fertilisers and pesticides at certain locations and lead to excessive pollution there. A tax or levy is therefore preferable to quota trading.

Fig. B 1-4 Potential of digital and smart technologies 2023 in percent

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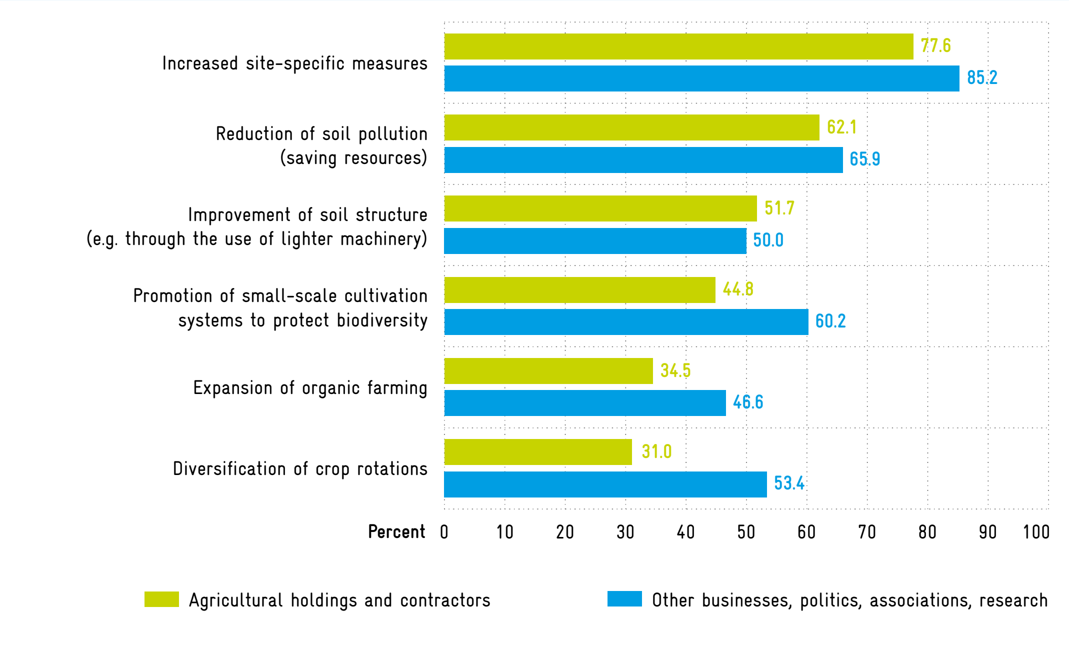

Legend: 77.6 percent of the agricultural holdings surveyed consider digital and smart technologies to have a high or very high potential for implementing more site-specific measures. Question text: "How high do you estimate the potential of digital and smart technologies in agriculture for sustainability and environmental protection in the next 10 years?". Possible answers: no potential, low potential, high potential, very high potential. The bars show the sum of "high potential" and "very high potential".
Source: Own evaluations based on Geppert et al. (2024).

New Skills Needed in the Use of Digital and Smart Technologies

Precision farming and smart farming also require new skills and competences from agricultural workers.[164] Of those surveyed on behalf of the Commission of Experts who use digital and smart technologies, more than 80.0 percent stated that advisory, training and continuing education programmes would facilitate the use of such technologies (cf. figure B 1-5).[165] For example, the use of certain sensors demands the competence to carry out special calibrations, while complex FMIS and DSS require sufficient skills in handling data and software. In the survey, 31.0 percent of farms cited the high complexity of operating digital technologies as a (very) major obstacle to their use (cf. figure B 1-3).

Insufficient Compatibility of Systems

A prerequisite for the combined use of digital and smart technologies is the exchange of data. This requires suitable interfaces and data standards, which are currently only available to a limited extent. As a result, there are still considerable compatibility problems when exchanging data between products from different manufacturers, such as individual sensors, robots, drones and FMIS, as well as between different FMIS. This increases farmers' lock-in to one provider. In the survey conducted on behalf of the Commission of Experts, 70.9 percent of the farms surveyed that already use digital and smart technologies stated that such compatibility problems are a (very) major obstacle (cf. figure B 1-3). In addition, the lack of availability of agricultural data is often a further obstacle. In the Bitkom Research survey of 500 farmers in Germany in 2022, 56 percent of respondents consider political measures as (very) important for establishing a centralized agricultural platform for farm data management. As many as 95 percent of respondents consider user-friendly and free geodata, farm inputs and weather data to be (very) important.[166]

Practical Legal Framework Required

A transparent and widely communicated legal framework[167] for the use of autonomous vehicles

Fig. B 1-5 Measures for facilitating the use of digital and smart technologies 2023 in percent

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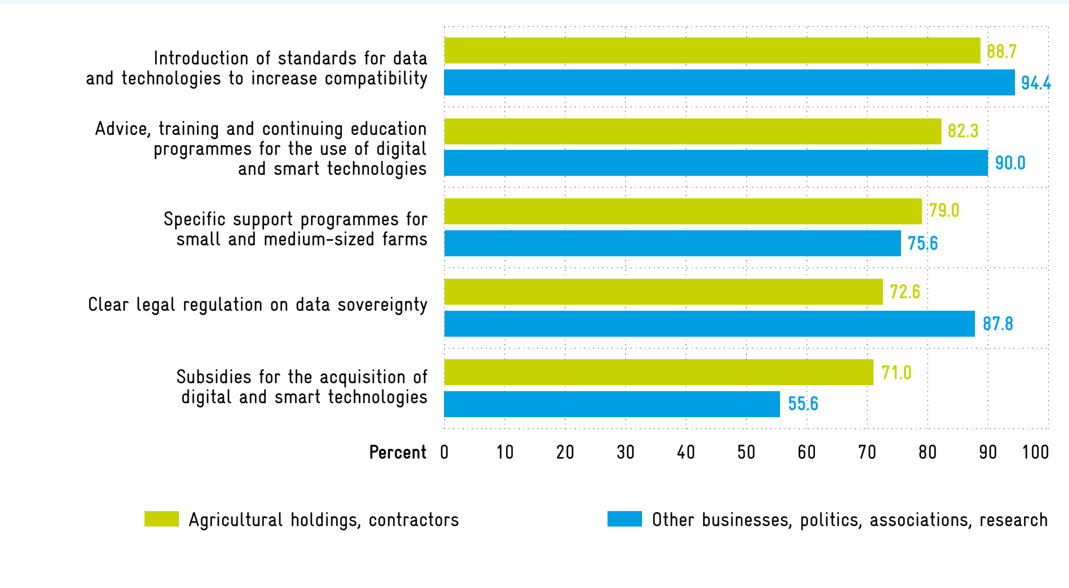

Legend: 88.7 percent of the farms surveyed consider the introduction of standards for data and technologies to increase compatibility to be an important or very important measure to enable the use of digital and smart technologies on farms.
Question text: "How important do you consider the following measures to enable the (increased) use of digital and smart technologies on farms?" Possible answers: not important, rather unimportant, rather important, very important.
The bars show the sum of "rather important" and "very important".
Source: Own evaluations based on Geppert et al. (2024).

Fig. B 1-6 Transnational patent applications for digital and smart agricultural technologies in selected countries and regions 2000–2020

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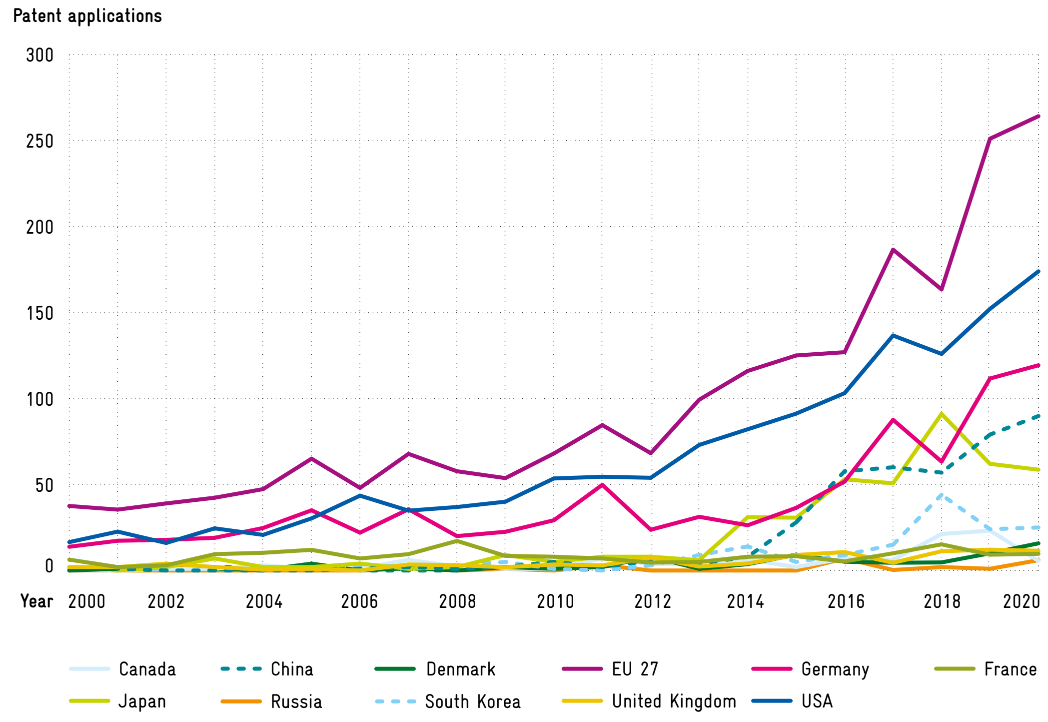

Source: PATSTAT. Own calculations.

such as robots, drones and autonomous agricultural machinery is needed to reduce farmers' reservations about using them and to create investment security. The Autonomous Driving Act (Gesetz zum autonomen Fahren), which came into force in 2021, is an important first step in this regard. Some drone applications require the use of larger devices,[168] which can drop materials such as pesticides. In addition, large-scale drone operations also require flights beyond visual range. Such operations require complex authorizations from the relevant authorities or the European Aviation Safety Agency.[169]

The exchange and processing of a comprehensive database, including internal data, is a prerequisite for the use of precision and smart farming technologies. However, concerns about data security and data sovereignty in internal company processes inhibit the use of FMIS, which is also reflected in the survey results (cf. figure B 1-3). One of the aims of the Data Act (Datenverordnung), which came into force in January 2024, is to address the unresolved legal issues in this area, thereby reducing existing reservations.[170]

B 1-2 b International Comparison of the Development of Digital and Smart Agricultural Technologies

An increase in the number of transnational patents[171] filed in the field of digital and smart agricultural technologies can be observed in the period from 2000 to 2020 (cf. figure B 1-6). In the same period, the share of these patents in all agricultural patents also rose continuously – in the EU and Germany from 5.0 percent and 3.5 percent respectively in 2000 to over 15 percent in 2020. This reflects the increasing importance of these technologies in the agricultural sector. Over the entire period, there were more patent applications from the EU than from the USA.

Europe Leading in Actuators, Sensors and Robotics

Patent applications can be broken down into the areas of sensor technology, robotics, actuator technology, drones, AI, decision support and automated systems.[172] Patent applications in the field of sensor technology account for the largest share, and their number has increased significantly more since 2012 than in the years before (cf. figure B 1-7). Although patent applications in the other areas are at a much lower level, they more than doubled worldwide between 2015 and 2020.

In the fields of actuators, robotics and sensors, most patent applications originate from the EU (cf. figure B 1-8). Patent applications from China dominate in the field of drones. Most patent applications in the field of AI come from the USA.

B 1-3 Green Genetic Engineering in Agriculture

In addition to digital and smart technologies, green genetic engineering can also contribute to solving the challenges in agriculture. The following section outlines green genetic engineering methods, their potential and risks, as well as research activities in the field of genome editing.

B 1-3 a Methods, Regulation and Application of Green Genetic Engineering

In green genetic engineering, the genetic material of a plant is modified in such a way that new characteristics are created. Possible modifications range from the alteration of individual bases to the incorporation of longer gene sequences into the plant genome. When altering gene sequences, four different

Fig. B 1-7 Transnational patent applications for digital and smart agricultural technologies worldwide by technology area 2000–2020

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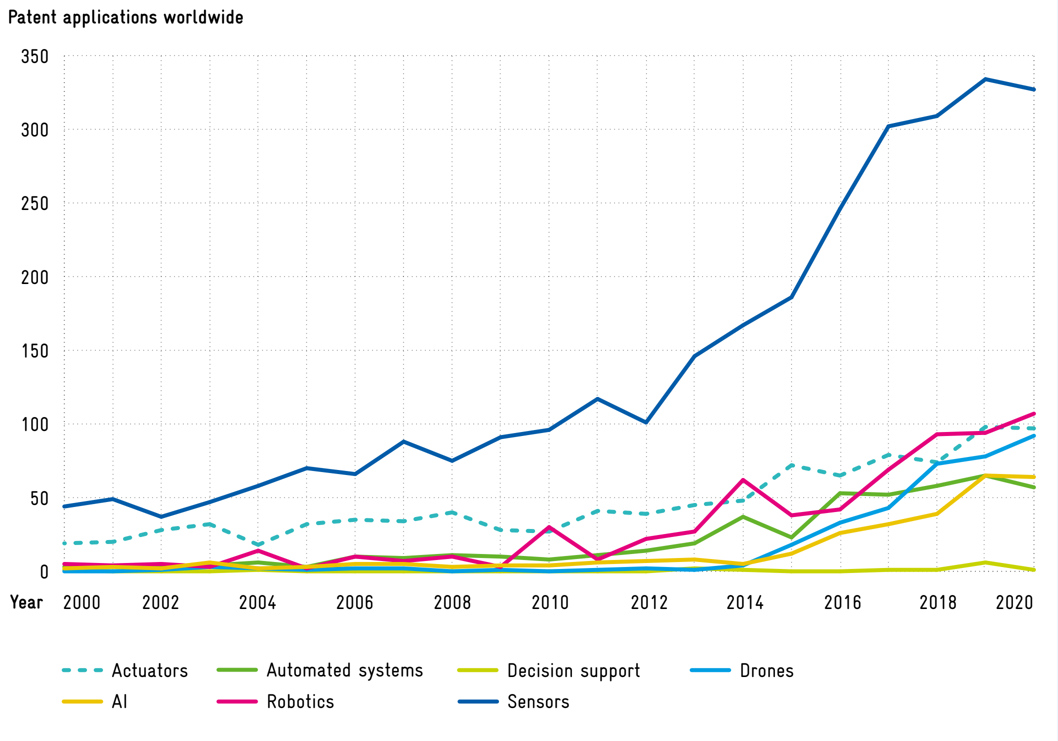

Source: PATSTAT. Own calculations.

Fig. B 1-8 Percentage of selected countries and regions in transnational patent applications worldwide by technology area 2000–2020

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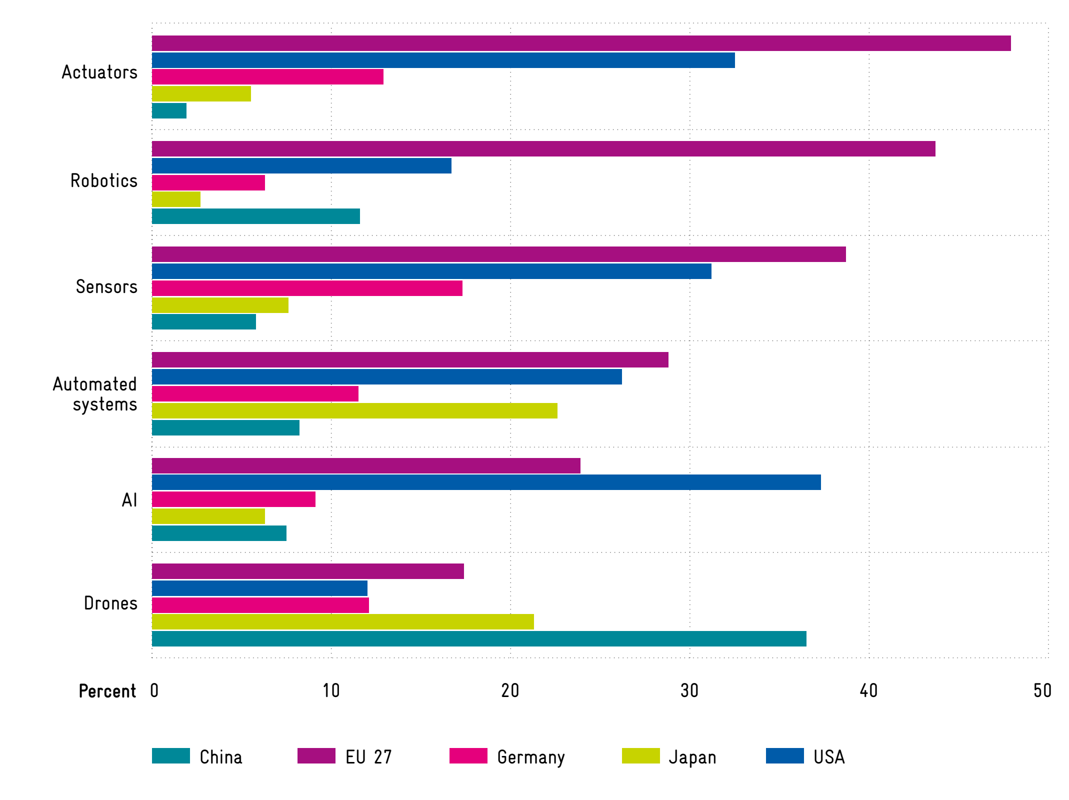

Source: PATSTAT. Own calculations.

genetic modifications are distinguished: mutagenesis, cisgenesis, intragenesis and transgenesis (cf. figure B 1-9).[173] These modifications can be produced by various methods. The three methods discussed below are genome editing,[174] conventional genetic engineering and mutation breeding. In addition, there are other methods of genetic engineering, such as synthetic biology, which shall not be discussed here,[175] as well as methods of conventional plant breeding that do not utilize genetic engineering. In this report, conventional plant breeding primarily refers to techniques such as crossbreeding and selection.[176]

Mutagenesis Possible by Several Methods

In mutagenesis, a mutation is created based on the plant's own genetic material without introducing genetic material into the organism. Organisms produced by mutagenesis can therefore also be the result of conventional plant breeding or by natural means.[177] There are essentially two different methods by which mutagenesis can be carried out: untargeted or random mutation breeding and targeted mutagenesis by means of genome editing. In random mutation breeding, the gene sequence is damaged by chemicals or radioactive radiation, for example. In this method, the location where the plant's DNA[178] is damaged cannot be determined in advance, resulting in plants with many mutations. The plants that have the desired mutation must then be selected in a complex process. In genome editing, the gene sequence is damaged by a targeted (double-strand) break.[179] The so-called CRISPR[180] genetic scissors are the most frequently used genome editing method. In both random mutation breeding and targeted mutagenesis, the damaged gene sequence is repaired by the cell's own system, resulting in mutations.[181]

Fig. B 1-9 Overview of modifications and methods of green genetic engineering and their current regulation

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Process / Modification	Mutagenesis	Cisgenesis	Intragenesis	Transgenesis
Genome editing	targeted Mutagenesis (red)	red	red	red
Conventional genetic engineering	grey	red	red	red
Mutation breeding	green	grey	grey	grey

Red means that the plants from this method fall under the strict regulations of the Genetic Engineering Act (Gentechnikgesetz), i.e. they are subject to mandatory labelling as a genetically modified organism (GMO), they are subject to risk assessment and the plants are not permitted in organic farming.
Green means that the plants from this method are not subject to the strict regulations of the Genetic Engineering Act, i.e. there is no labelling requirement as a GMO, the risk assessment does not apply and the plants are permitted in organic farming.
Grey means that this modification cannot technically be carried out using the method.
Source: Own representation.

Versatile Modifications with Introduced Genetic Material

Whilst in mutagenesis no genetic material is introduced into the organism, in cisgenesis, intragenesis and transgenesis gene sequences of different origins are inserted into the genome of a plant.[182] In cisgenesis, DNA from the plant itself or from closely related, cross-compatible plants is used. The organisms produced in this way could also be obtained by conventional breeding. In intragenesis, fragments of gene sequences from the plant's own species or from a cross-compatible species are recombined and introduced into the plant. These organisms cannot be produced by conventional plant breeding. In transgenesis, gene sequences from foreign organisms are introduced into the plant. These plants are also not produced by conventional plant breeding.[183]

Cisgenic, intragenic or transgenic plants can be produced by two methods: genome editing and conventional genetic engineering. In genome editing, a break is created at a specific location and, in contrast to targeted mutagenesis, a gene sequence is inserted that the cell's own system can use to repair the targeted break. In conventional genetic engineering, gene sequences are inserted into the genetic material of a plant in an untargeted manner, e.g. using transport bacteria or a gene gun. The location and frequency of the insertion cannot be determined.[184]

Transgenesis can be used to create new characteristics in plants. Mutagenesis, on the other hand, is limited to the natural diversity of the plant genome. Cisgenic and intragenic organisms are located between these two extremes.[185]

Genome Editing Not a Complete Substitute for Other Methods

The advantage of genome editing methods is that they can shorten the time it takes to develop a modified plant characteristic by years or decades.[186] Since nowadays many genes and their functions have been sequenced, genome editing offers the possibility of implementing changes faster and more precisely than untargeted methods such as conventional genetic engineering and mutation breeding. The prerequisite for realizing the full potential of genome editing is the sequencing of a plant's genome. Reference genomes[187] are available for most of the world's economically important crops.[188] Genome editing allows for precise prediction of genetic modification and potentially results in time and cost savings. It can also be used by small and medium-sized enterprises (SMEs), which are typical of the European seed market, which can have a positive impact on product diversity and competition in the seed market.

By contrast, untargeted mutagenesis produces many mutations at random, which means that a considerable amount of time and money is required to select the few desired plants. However, knowledge of the gene sequences is not a prerequisite here.

Mutation breeding results in a large number of changes in the plant genome, the consequences of which are unknown. In rare cases, genome editing can also lead to changes in non-target sequences, which are known as off-target effects and are considered undesirable. However, since genome editing is a more precise procedure, such unintended mutations occur much less frequently than with untargeted methods.[189]

Genome editing is a valuable tool for expanding the genetic variation of cultivated plants. It is already being used worldwide in plant breeding for various crops. However, only a few genes can be specifically modified at the same time. Yet many characteristics are only formed through the interaction of numerous genes. As not all plant species have been sequenced to date and there are still technical difficulties in using genome editing for transgenesis, the methods of conventional genetic engineering, mutation breeding and conventional breeding will remain indispensable in the future.

Genetic Engineering Strictly Regulated in the EU

Genetically modified organisms (GMOs) are defined in the EU as organisms whose genetic material has been modified in a way that does not occur naturally by crossbreeding or natural recombination. This means that all organisms that have not been created through conventional breeding are considered GMOs.[190]

To be approved for cultivation or as food and feed in the EU, GMOs must undergo complex and lengthy approval procedures.[191] These procedures include a comprehensive risk assessment and environmental impact assessment. The necessary data must be provided by the developing companies and is reviewed by, among others, the European Food Security Agency (EFSA).[192] Approval as food or feed or for cultivation is granted at EU level and applies to all Member States. In the case of approval for cultivation, the Member States nevertheless have the option of prohibiting cultivation on their territory.[193] In addition, GMOs are subject to labelling requirements. Products labelled as GMOs must not be used in organic farming.[194]

The EU takes a method-based approach to the regulation of genetic engineering.[195] All organisms created using mutation breeding, genome editing or conventional genetic engineering are considered GMOs. However, organisms resulting from mutation breeding are treated differently from organisms resulting from targeted mutagenesis by means of genome editing. Organisms resulting from mutation breeding do not have to undergo an approval procedure or risk assessment. They are not labelled as GMOs and can therefore also be used in organic farming.[196]

GMOs Rarely Cultivated in the EU

The first two GMOs were placed on the market in the EU in 1996. Currently, 140 specific combinations of genetically modified crops and characteristics are approved in the EU. Of these, only one crop, the insect-resistant maize MON810, is approved for cultivation, while the other approvals relate to the use of imported feed or food.[197] Within the EU, MON810 maize is only cultivated in Spain and Portugal, while all other Member States have banned its cultivation despite EU approval.[198] Globally, however, GMOs are grown on about 12.5 percent of arable land – mainly in Argentina, Brazil and the USA.[199] The dominant and commercially successful trait categories of genetically modified plants are herbicide tolerance and insect resistance. These two characteristics are currently being developed primarily using conventional genetic engineering.[200] Genome editing does not yet play a significant role in application. To date, only a few plants produced primarily with genome editing are on the market, including a soya bean with an optimized fatty acid composition (cf. box B 1-10).[201]

B 1-3 b Potential of Green Genetic Engineering in Agriculture

Green Genetic Engineering Helps Achieve Food Security

A key objective in plant breeding is to increase yields or maintain them in extreme weather conditions and organic farming, thereby ensuring food security even as agricultural land decreases. This can be achieved through higher yields, but also through resistance to various pests.[202] Furthermore, crops can be modified to be more nutritious, thereby helping to improve nutrition.[203] Such characteristics can be created using green genetic engineering methods.[204]

The development of many plant characteristics is geared towards target markets in industrialized countries. Crop species from developing countries, where food security is a problem, have so far only been genetically modified to a relatively small extent. As cultivation conditions and practices vary greatly between countries, the products of green ge-

Box B 1-10 Case Studies for Green Genetic Engineering Products

Field Pennycress As Catch Crop

The US start-up CoverCress has developed an optimized field pennycress that can be used both as a winter cover crop in a soya-maize rotation and for the production of vegetable oil for biofuels. It is thus adapted to the regional growing conditions. Various methods were used for its development: mutation breeding, selection, conventional genetic engineering and genome editing. Aspects such as soil conservation, soil quality and agrobiodiversity are taken into account with this field pennycress. Since 2013, CoverCress has received US$ 58 million from private and public investors in several rounds of financing for its development. Bayer AG is now the largest shareholder. It remains to be seen whether this field pennycress will be successful on the market. Extensive field trials are currently underway.[205]

Soya Bean Optimized for Fatty Acid Composition

The US company Calyxt has used genome editing to develop a soya bean with an optimized fatty acid composition that can be used to produce a more nutritious and longer-lasting oil. The responsible US authority decided in 2015 that the plant did not need to undergo an approval process, meaning it could be cultivated as early as 2018 and marketed as oil in 2019. The business was discontinued in 2020, as several breeding companies were already offering seeds for such soya oil qualities, both from conventional breeding and conventional genetic engineering, on the market and acceptance among farmers was additionally low because of low yields.[206]

Drought Tolerant Wheat

The Argentinian company Indear has used conventional genetic engineering to breed a drought and herbicide-tolerant wheat that, depending on the location, yields about 6 percent more under drought stress and is comparable to other varieties under normal growing conditions. The combination of drought stress and herbicide tolerance is aimed primarily at markets in South America and the USA. After more than 15 years of development, approval for cultivation and as food in Argentina was granted in 2020, with both the development using untargeted methods and the approval process taking a long time.[207]

netic engineering cannot be cultivated everywhere, and developing countries are often excluded from innovative products. Here, genome editing offers developing countries an opportunity to work on the development of plant characteristics themselves.[208]

Green Genetic Engineering Facilitates Climate Adaptation

Climate change is causing stress in Central Europe through drought, but also through extreme rainfall, a shift in the vegetation period and the influx of harmful organisms. Plant breeding is attempting to counteract these influencing factors by modifying plant characteristics. Genetic engineering in particular can help to adapt plants to climate change by developing drought stress tolerance or resistance to harmful organisms. As complex characteristics for climate adaptation often involve the interaction of several genes and the changes are necessary in a relatively short period of time due to the rapidly changing conditions, the methods of conventional genetic engineering and genome editing offer advantages over conventional breeding methods. Besides drought stress tolerance and resistance to harmful organisms, initial efforts are underway to prevent seed germination before the harvest to account for the shift in the vegetation period, and to increase the burst resistance of rapeseed pods to protect the harvest from extreme weather conditions such as wind, hail and heavy rain. This provides various options for adapting plants to new climatic conditions. However, comprehensive climate adaptation can only be achieved holistically by combining different breeding methods, cultivation techniques and crop management.[209]

Green Genetic Engineering Supports Biodiversity and Crop Diversity

Green genetic engineering can improve the pest resistance, nutrient use efficiency and stress tolerance of plants. As a result, green genetic engineering can reduce the input of pesticides and fertilisers into the ecosystem and thus contribute to the biodiversity conservation and other Green Deal objectives. For example, a meta-analysis found that the amount of pesticides used could be reduced by 42 percent in insect-resistant plants.[210] To develop corresponding products, incentives for the industry and suitable farming concepts are necessary to enable the cultivation of such products.[211]

Moreover, green genetic engineering methods can contribute to increasing crop diversity and thus to biodiversity. As only a few different crop species have been used in genetic engineering to date, the genetic engineering of neglected crop species or the domestication of wild plants[212] by means of genetic engineering can provide a remedy. This can make agriculture more climate-resistant and less dependent on pesticides and promote agrobiodiversity.[213]

B 1-3 c Risks of Green Genetic Engineering

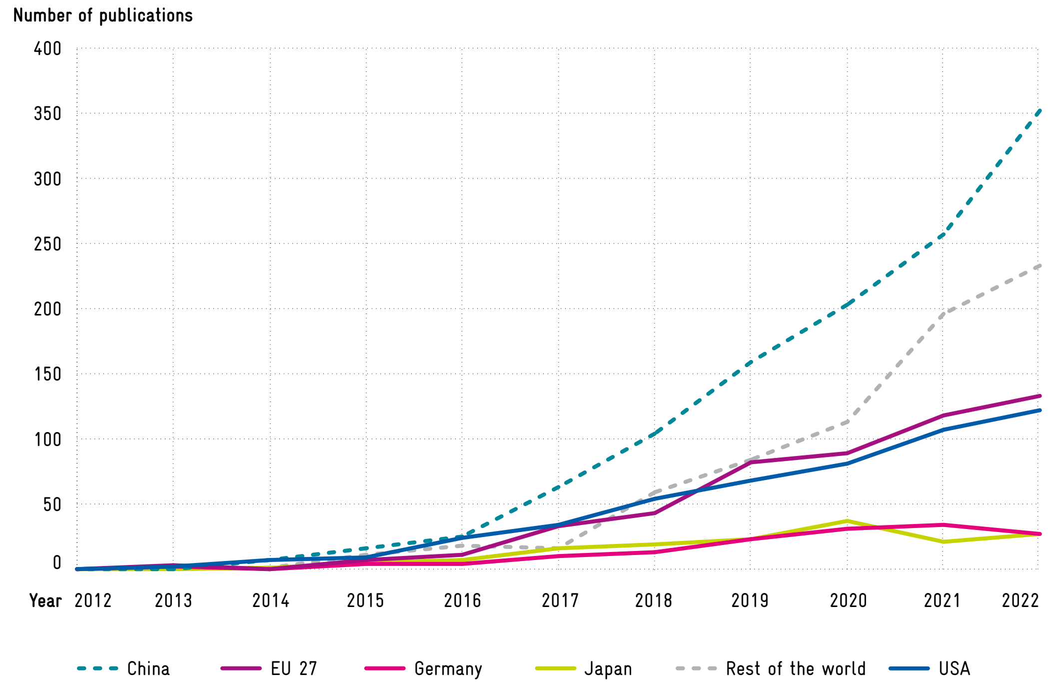
Two categories of risks can be distinguished: risks associated with the breeding method itself and risks associated with the bred characteristics of the plants.[214] Since the latter depend on the specific application, it is not possible to compile a general risk profile for genetically modified plants.

No Method-related Risks Identified in Green Genetic Engineering

In over 30 years of research and application, no method-related risks for humans, animals or the environment have been identified in conventional genetic engineering.[215] Even though genome editing cannot yet look back on such a long history of safe applications, there are no indications of method-related risks here either. In particular, the EFSA has not identified any new risks for targeted mutagenesis compared to conventional and mutation breeding.[216] On the contrary: targeted mutagenesis significantly reduces the risk of random mutations. The risks associated with cisgenesis, which involves the introduction of species-specific gene sequences, are also comparable to those of conventional breeding, regardless of the method.[217] Risks associated with the bred characteristics of the plant can therefore only be assessed on a case-by-case basis and independently of the method.

Fig. B 1-11 Number of CRISPR publications in the field of crops for selected countries and regions 2012–2022

Download Data



Source: Own representation based on Zyontz (2024).

Variety of Measures to Minimize Potential Risks

In the EU, as in some non-EU countries, a key element of the approval procedure for GMOs is a risk assessment.[218] This examines environmental compatibility and safety for humans and animals. The risk assessment analyzes all plant characteristics with potentially undesirable effects and develops strategies for dealing with the risks.[219] In addition, field trials play an important role not only in the development of a breeding objective, but also in testing the bred plants under different environmental conditions. Based on this data from cultivation, EFSA can issue a recommendation on the risk potential of a plant. Such field trials must be approved and registered in the EU.[220]

Specific regulations also apply to the cultivation of genetically modified organisms, which enable the coexistence of agriculture without and with genetic engineering. These include, for example, the rules of good farming practice for the cultivation of GMOs,[221] which are intended to prevent the exchange of genetic material between genetically modified and GMO-free plants. In addition, there is a site register for the cultivation of GMOs in Germany.[222]

B 1-3 d Research and Innovation Activity on Genome Editing in Crop Plants

The following section uses a publication and patent analysis to examine how research and innovation activities in the field of cultivated crops have developed utilizing CRISPR and where Germany and the EU stand in an international comparison. The focus on CRISPR is appropriate because it is the most widely used genome editing method[223] and the data availability is particularly good.

Fig. B 1-12 Cumulative number of CRISPR publications in the field of crops in top scientific publications for selected countries and regions 2012–2022

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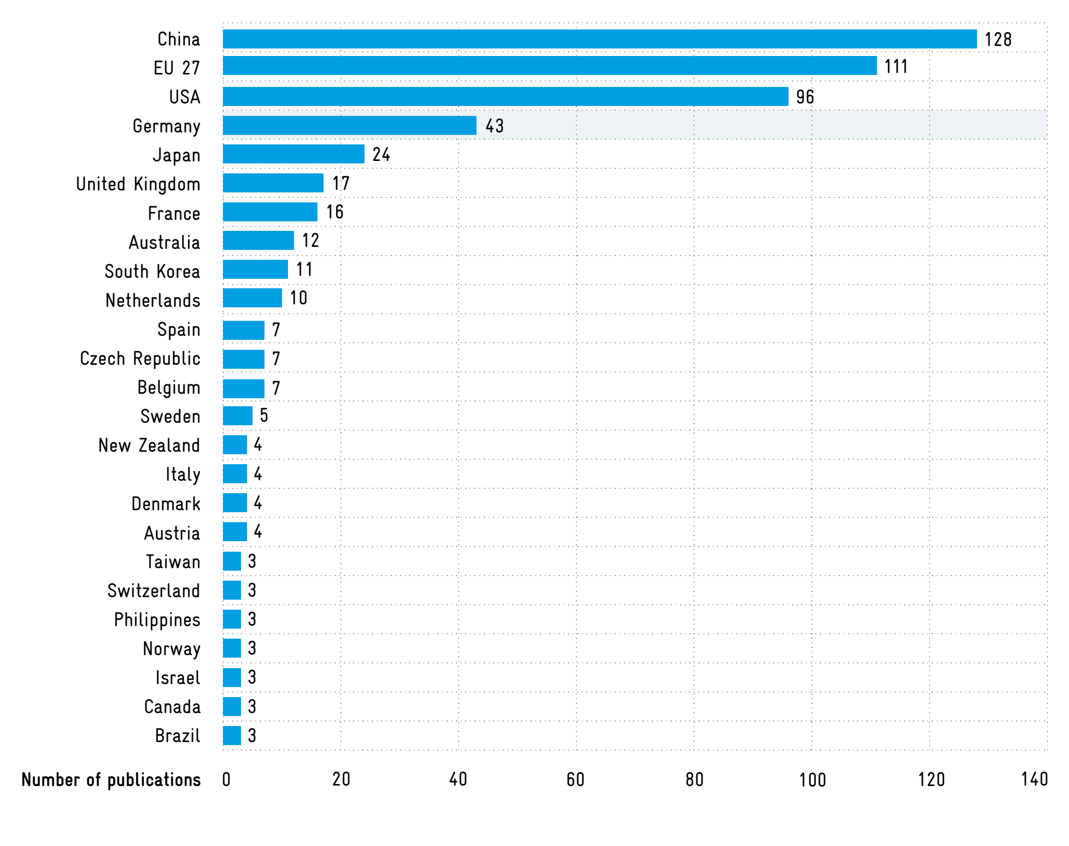


Legend: China has a total of 128 publications in the top 10 percent of journals in the period 2012–2022.
Source: Own representation based on Zyontz (2024).

China Leads in Publications and USA in Large Patent Families

A study requested by the Commission of Experts shows a continuous increase in scientific CRISPR publications since 2012 (cf. figure B 1-11).[224] China dominates this development. In terms of cumulative publications in the top journals over time (cf. figure B 1-12), however, China, the EU and the USA rank much closer to each other.

China is also well ahead of the USA and the EU in terms of CRISPR patent applications in the crop sector (cf. figure B 1-13). However, when looking at the applications of the largest patent families, the US is far ahead of China with more than twice as many patent family applications (cf. figure B 1-14), while the EU and, even more so, Germany are clearly lagging behind.

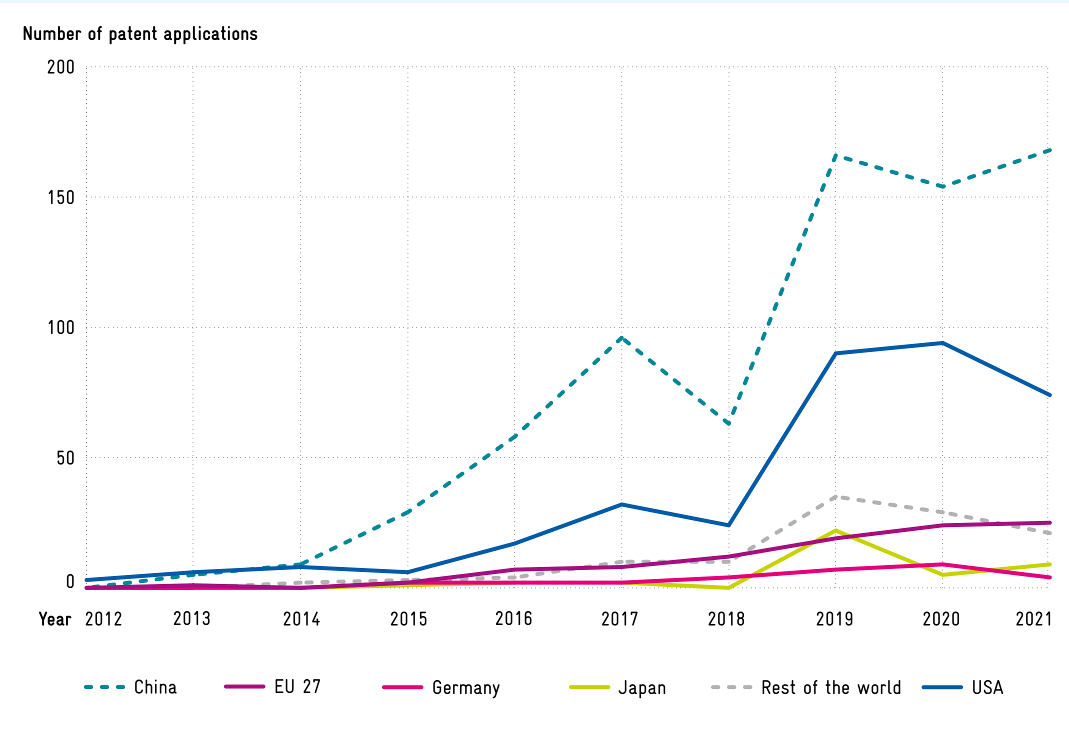
B 1-3 e Barriers to Green Genetic Engineering in Germany

Method-based Regulation Not Up to Date

The current regulation of green genetic engineering does not do justice to the scientific developments of recent decades. Green genetic engineering products are subject to method-based regulation in the EU, even though no method-related risks of green genetic engineering have been identified to date.[225] This method-based regulation focuses on the method and not on the modified plant characteristic that could potentially pose a risk. Since the development of genome editing, there has been a problem of inconsistency in method-based regulation. This is because method-based regulation means that, for example, plants from untargeted mutation breeding and targeted mutagenesis with the same characteristics are regulated differently.[226]

Fig. B 1-13 Number of CRISPR patent families in the field of crops for selected countries and regions 2012–2021

Download Data



Patent families can have applicants from more than one country. The patent family is counted once for each country represented; therefore some patent families are counted twice.
Source: Own representation based on Zyontz (2024).

While the plant resulting from mutation breeding does not have to undergo an approval procedure with risk assessment, the same plant from targeted mutagenesis is subject to a strict approval procedure and mandatory labelling as a GMO. In addition, not all plants created through targeted mutagenesis and cisgenesis via genome editing can be distinguished from conventionally bred plants and plants from mutation breeding. This complicates the implementation of regulation.[227] The current regulation leads to considerable uncertainty among plant breeders and may discourage companies, especially SMEs and start-ups, from engaging in research and development.[228] Some countries, including agricultural exporters such as Argentina, Australia, Canada and the USA, have already facilitated the approval of plants developed using new genomic techniques (NGT),[229] including genome editing, through changes to the regulatory framework. This increases the pressure on the EU to adapt the existing GMO regulation for such NGT plants.[230]

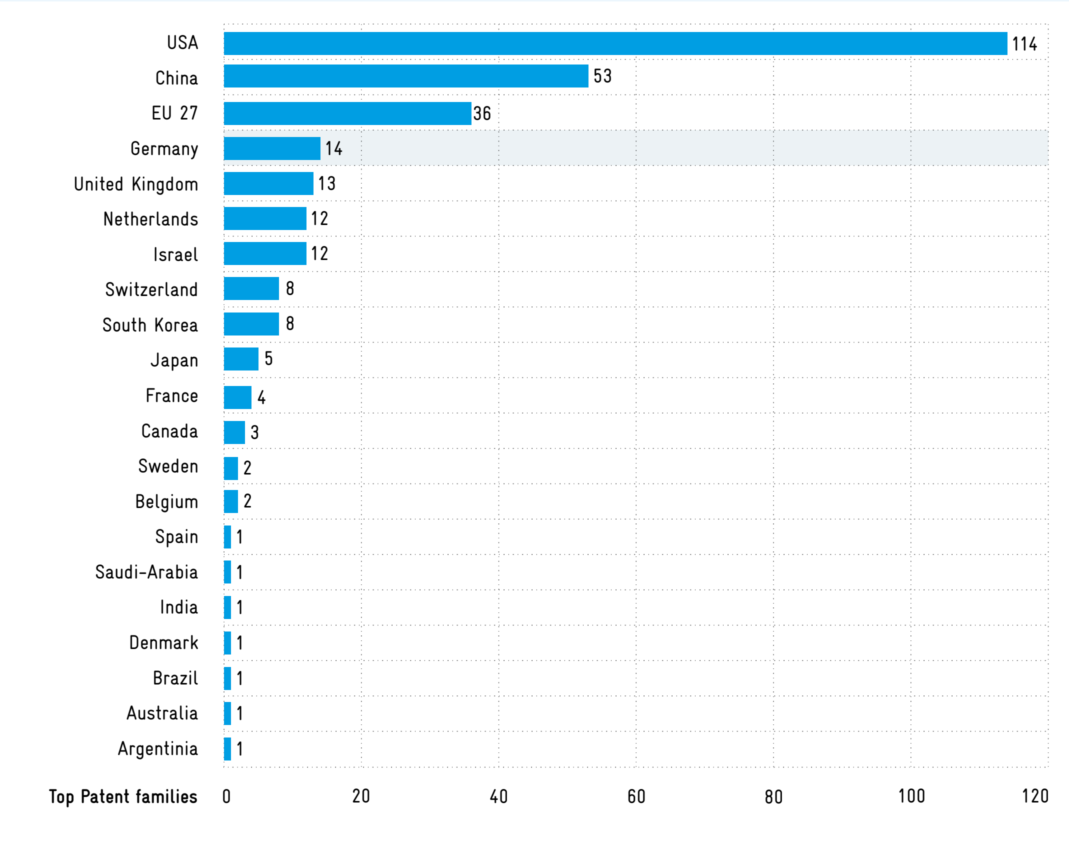
Another point of criticism of the current regulation is the lengthy and costly approval procedures. Only larger companies can afford these, which can result in a highly concentrated market structure in the seed and plant breeding market.[231] Start-ups and SMEs are thus severely impeded in their innovation activities in these areas.[232] In addition, the current regulation does not recognize whether the bred plants can contribute to the EU's sustainability goals and therefore does not provide any incentives for the development of corresponding plants.[233]

Strict Regulation Limits Research in EU

Research into genetic engineering and new genomic techniques is restricted in the EU by current regula-

Fig. B 1-14 Cumulative number of largest CRISPR patent families in the field of crops for selected countries and regions 2012–2021

Download Data



The largest patent families contain three or more applications. Patent families can have applicants from more than one country.
The patent family is counted once for each country represented; therefore some patent families are counted twice.
Source: Own representation based on Zyontz (2024).

tion and the resulting lack of practical relevance.[234] For example, no field trials with GMOs have taken place in Germany since 2013,[235] and there have been no field trials at all with genome-edited plants to date. Research projects at European research institutions are also being abandoned or relocated outside Europe. A career in agricultural biotechnology in the EU has also become less appealing.[236]

Proposal for New EU Regulation

The European Commission's proposal for the new regulation of NGT plants created by mutagenesis and cisgenesis could be a partial solution to the aforementioned obstacles.[237] The proposal does not cover NGT plants created by transgenesis and intragenesis. The NGT plants covered by the proposal are divided into two categories, which differ in the extent of the changes made in order to take account of different risk profiles. The first category includes plants that can also arise naturally or through conventional breeding and have been modified in less than 20 base pairs[238] – so-called NGT-1 plants. This also includes plants resulting from targeted mutagenesis. All other plants covered by the proposal fall into the second category (NGT-2). According to this proposal, NGT-1 plants are to be labelled as such, but not as GMOs. NGT-1 plants are moreover exempt from the requirements of the GMO regulation regarding risk assessment and approval. A simple notification to the national authorities is sufficient for field trials.

NGT-2 plants, on the other hand, are still subject to the approval procedures, risk assessments and GMO labelling requirements that also apply to plants from conventional genetic engineering. However, depending on the risk profile, simplified approval and safety procedures may apply. Simplified approval procedures also apply to plants that can contribute to the sustainability goals of the Green Deal.[239] The option for Member States to restrict or prohibit cultivation, such as is possible for GMOs, is to be dropped for NGT-2 plants.[240]

However, even with this new proposal, the problem remains that regulation is method-based. Nevertheless, the proposal is a pragmatic approach to at least adapt the regulation of plants created by mutagenesis and cisgenesis using new genomic techniques in line with current scientific developments.

An earlier version of the European Commission's proposal contained a so-called free movement clause, which would have expressly prohibited Member States from banning or restricting the release or marketing of NGT-1 plants or related products.[241] Since this clause has been removed, it cannot be ruled out that individual Member States will still restrict the release and marketing of NGT-1 plants after all and that innovation potential will not be exploited.

GMOs Excluded from Organic Farming

The EU Organic Regulation excludes all plants labelled as GMOs from organic farming.[242] However, just like organic farming, GMOs can contribute to the sustainability goals of the Green Deal and the SDGs. Synergies between organic farming and green genetic engineering, such as the reduction of the yield gap in organic farming and the reduction of pesticide use through resistant varieties, remain untapped due to the regulatory incompatibility.[243]

Because of the inconsistency of the method-based regulation of green genetic engineering in the EU, plants from mutation breeding do not have to be labelled as GMOs, whereas plants with the same characteristics from targeted mutagenesis are subject to such a labelling requirement. This means that plants from mutation breeding can currently be used in organic farming. In contrast, plants from targeted mutagenesis are not approved for use in organic farming. According to the European Commission's proposal, this ban also applies to NGT-1 plants.

Low Public Acceptance of GMOs

The population in Germany is sceptical about genetic modification of crops.[244] When asked about the potential long-term risks of new genetic engineering methods, 79 percent of respondents in a study by the BMUV agree that the long-term consequences cannot be assessed. Similarly high is agreement with the statement that humans have no right to deliberately genetically modify plants and animals.[245] However, the study also shows that agreement with these statements fell significantly between 2019 and 2021. Due to the still low level of consumer acceptance, various food retailers are against differentiating between GMOs from conventional genetic engineering and NGT and are in favour of GMO-free production.[246]

Yet various studies have also shown that the acceptance of genetically modified plants depends on the type and objective of the modification. If a genetic modification is associated with a specific positive benefit for consumers or the environment, acceptance is higher. Acceptance is also greater for minor changes through genome editing than for transgenic plants. Overall, the level of information among the population in Germany about genetic engineering and genome editing as well as the benefits of genetically modified plants for agriculture is low.[247]

Complex Balancing of Patent Law and Plant Variety Protection

The protection of intellectual property in plants is governed by biopatent law and plant variety protection.[248] Plant varieties are excluded from patentability. Their protection is regulated by the Plant Variety Protection Act (Sortenschutzgesetz). According to this law, plant variety protection can be granted if the variety is new, differs from other varieties in decisive characteristics, these characteristics are uniformly expressed during propagation and remain unchanged after each propagation.[249]

Patents can be granted for technical processes[250] for modifying the genome of a plant, so-called process patents, as well as for plants that are bred using such technical processes, so-called product patents. The effect of process and product patents also extends to the offspring of the patented plant obtained by propagation if they too have the characteristics specified in the patent. The effect of a process or product patent therefore also extends to the varieties produced in this way. However, if the technical implementation of an invention is limited to a specific plant variety, the invention is not patentable. Plants that have been created using biological processes or by natural means are not patentable.[251]

The question of whether genetically modified plants should be patentable or whether plant variety protection is sufficient is controversial.[252] The argument in favour of plant variety protection, with the comprehensive breeder's privilege it provides, is that small and medium-sized plant breeders can freely use and further develop genetically modified plant varieties for breeding without being burdened by licence fees for patents. The argument in favour of patent protection is that it can provide the necessary incentives to invest in research and development activities to breed certain desired characteristics using complex genetic engineering methods. A balance must therefore be struck between easy access to genetic material for small and medium-sized breeders and the creation of incentives for costly research. The European Commission has therefore undertaken to evaluate the impact of patenting plants on breeders' access to genetic material, on the availability of seeds for agriculture and on the competitiveness of the EU biotechnology sector by 2026.[253]

B 1-4 Recommendations for Action

The use of digital and smart technologies as well as green genetic engineering offer agriculture numerous opportunities to increase productivity, make farming practices more sustainable and improve resilience to climate change. Although digital and smart technologies can significantly reduce negative environmental impacts, farms currently have little incentive to use such technologies as they are still comparatively expensive. The opportunities offered by green genetic engineering cannot be fully utilized due to restrictive legislation and a lack of acceptance and information among the public and politicians.

The Commission of Experts therefore recommends the following measures, to the Federal Government and, in particular, to the Federal Ministry of Food and Agriculture, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection and the Federal Ministry for Digital and Transport:

Introduce a Levy on Pesticides and Fertilisers as an Incentive for the Use of New Technologies

— The use of pesticides and fertilisers should be subject to a levy based on the Danish model. This measure promotes the increased use of digital and smart technologies for sustainable farming. It also creates incentives to breed crops that lead to less use of pesticides and fertilisers. The impact of the levy needs to be evaluated and its implementation design adjusted if necessary.

Expand Digital Infrastructure

A corresponding digital infrastructure is required to accelerate the use of digital and smart technologies. In addition, sufficient compatibility between systems from different vendors is required to avoid dependencies on individual manufacturers.

- The digital infrastructure must also be expanded in rural regions to enable the integration of digital and smart agricultural technologies into the Internet of Things, among other things.
- The Federal Government should create a standardized data space for agriculture across the Länder to share and utilize data for knowledge sharing and enable the use of innovative technologies.
- The Government should lobby both the Deutsches Institut für Normung (German Institute for Standardization, DIN) and the EU to further develop interface standards for digital technologies to ensure the interoperability of the various systems for both hardware and software across manufacturers.

Promote Experimental Fields as well as Education and Training for Digital and Smart Technologies

Because of the reluctance to adopt digital and smart technologies to date, uncertainties exist regarding both economic and ecological benefits.

- More use should be made of experimental fields to test the practical feasibility of new digital and smart agricultural technologies and their effectiveness in specific applications and to make them visible to potential users.
- The Federal Government should expand and financially support training and continuing education measures in the use of digital and smart technologies.[254] To this end, corresponding curricula in training centres should be adapted and supplemented.

Clarify the Regulatory Framework

A clear regulatory framework is needed to ensure legal certainty in the development and use of new digital and smart agricultural technologies.

- Clear regulatory conditions and simple procedures for approving the use of fully automated and autonomous agricultural machinery, robots and drones need to be developed. In particular, the dropping ban related to weight restrictions for drones in agriculture should be reformed.
- Clear regulatory conditions in the field of data protection and data sovereignty must be created to enable the legally secure use of digital and smart agricultural technologies and to prevent unauthorized use of data.
- Increased use should also be made of regulatory sandboxes to enable regulatory learning and pave the way for the widespread use of digital and smart agricultural technologies.

Better Educate and Inform the Public on Green Genetic Engineering

The public and politicians have reservations about new genomic techniques and genetic engineering in general, some of which are difficult to justify and are due to a lack of information.

- There is a need for a scientifically sound and coordinated communication strategy on the part of the Federal Government, which is also reflected in political action. It is important to inform the public about the potential contribution of green genetic engineering to achieving sustainability goals and to dispel scientifically unfounded fears.

Agree to EU Proposal, Develop Method-independent Regulatory Framework

The regulatory framework in which green genetic engineering operates in the EU not only inhibits research and development in this field, but also the innovation-based transformation of agriculture.

- In the European Council, the Federal Government should approve the proposal submitted by the European Commission on the differentiated regulation of genome-edited plants. This proposal contains measures for the differentiated labelling of so-called NGT-1 plants and for the simplified approval of plants that can contribute to the EU's sustainability goals.

- The Federal Government should not restrict the release and placing on the market of NGT-1 plants approved in the EU.

- The Federal Government should support the approval of plants labelled as NGT-1 in organic farming, as already envisaged in an earlier draft of the European Commission's proposal.

- In the long term, the Federal Government should lobby the EU to revise the regulation of green genetic engineering so that decisions on the approval of genetically modified plants are primarily based on the properties of a plant rather than the method used.

Evaluate Patent Law and Plant Variety Protection

Patent law and plant variety protection strike a balance between free access to breeding material and the protection of investments in the development of new plants through patents. This is a complex issue for which there is not yet sufficient empirical evidence.

- The status quo of patent protection for genetically modified plants should not be changed for the time being. However, the Federal Government should lobby the EU to evaluate the effects of patent law and plant variety protection on the use of genetic engineering methods and on the registration of genetically modified plants and, if necessary, to modify the existing regulations.

- In addition, the market for seeds should be monitored regarding market foreclosure effects in order to introduce measures under competition law if necessary.