

Geppert, Frauke; Krachunova, Tsvetelina; Bellingrath-Kimura, Sonoko Dorothea

Research Report

Digital and smart technologies in agriculture in Germany: Identification of key recommendations for sustainability actions

Studien zum deutschen Innovationssystem, No. 4-2024

Provided in Cooperation with:

Expertenkommission Forschung und Innovation (EFI)

Suggested Citation: Geppert, Frauke; Krachunova, Tsvetelina; Bellingrath-Kimura, Sonoko Dorothea (2024) : Digital and smart technologies in agriculture in Germany: Identification of key recommendations for sustainability actions, Studien zum deutschen Innovationssystem, No. 4-2024, Expertenkommission Forschung und Innovation (EFI), Berlin

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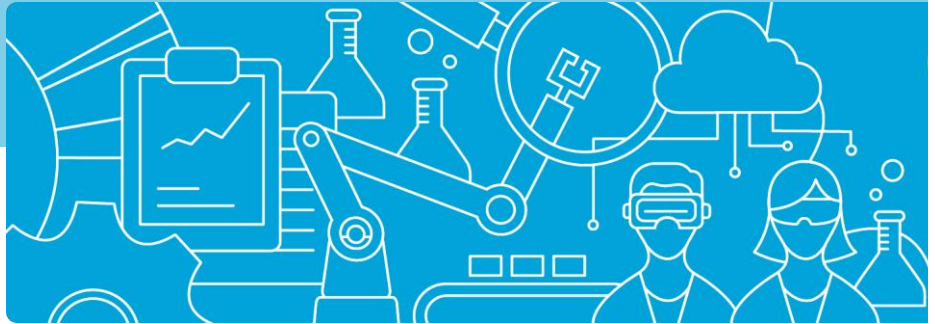
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Studie zum deutschen Innovationssystem | Nr. 4-2024



Frauke Geppert, Tsvetelina Krachunova, Sonoko Bellingrath-Kimura

Digital and Smart Technologies in Agriculture in Germany

Identification of Key Recommendations for Sustainability Actions



Leibniz-Zentrum für
Agrarlandschaftsforschung
(ZALF) e.V.

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Durchführendes Institut

Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e.V.
Eberswalder Straße 84, 15374 Müncheberg
www.zalf.de

Studien zum deutschen Innovationssystem

Nr. 4-2024
ISSN 1613-4338

Stand

Februar 2024

Herausgeberin

Expertenkommission Forschung und Innovation (EFI)

Geschäftsstelle

Pariser Platz 6 | 10117 Berlin
www.e-fi.de

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Kontakt und weitere Informationen

Prof. Dr. Sonoko Bellingrath-Kimura
Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e.V.
Eberswalder Straße 84, 15374 Müncheberg
T +49 (0)33432 82-207
M belks@zalf.de

Impressum

Institution	Leibniz Centre for Agricultural Landscape Research (ZALF) e.V.
Last updated	October 2023
Authors	Frauke Geppert, Tsvetelina Krachunova, Prof. Sonoko Dorothea Bellingrath-Kimura

Frauke Geppert
Leibniz Centre for Agricultural Landscape Research (ZALF) e.V.
Eberswalder Straße 84, 15374, Müncheberg, Germany
frauke.geppert@zalf.de

Tsvetelina Krachunova
Leibniz Centre for Agricultural Landscape Research (ZALF) e.V.
Eberswalder Straße 84, 15374, Müncheberg, Germany
tsvetelina.krachunova@zalf.de

Prof. Dr. agr. Sonoko Dorothea Bellingrath-Kimura
Leibniz Centre for Agricultural Landscape Research (ZALF) e.V.
Eberswalder Straße 84, 15374, Müncheberg, Germany
belks@zalf.de

www.zalf.de

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List of abbreviations

AI	Artificial intelligence technologies
ANN	Artificial Neural Networks
BD	Big Data
BFG	Berufsgruppe/ Occupational category
BfN	Federal Agency for Nature Conservation / Bundesamt für Naturschutz
BLE	Federal Office for Agriculture and Food / Bundesanstalt für Landwirtschaft und Ernährung
BMEL	Federal Ministry of Food and Agriculture/ Bundesministerium für Ernährung und Landwirtschaft
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection / Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz
BMWK	Federal Ministry for Economic Affairs and Climate Action / Bundesministerium für Wirtschaft und Klimaschutz
CAN	Controller Area Network
CAP	Common European Agricultural Policy
CH₄	Methane
CLRTAP	Convention on Long-range Transboundary Air Pollution
CNN	Convolutional Neural Networks
CO₂	Carbon dioxide
CO₂-eq	Carbon dioxide equivalent (metric measure)
CS	Citizen Science
CSO	Civil Society Organisations
DBV	German Farmers' Association / Deutscher Bauernverband
DEHSt	German Emissions Trading Authority / Deutsche Emissionshandelsstelle
DESI	Digital Economy and Society Index
Destatis	Statistisches Bundesamt
DIP	Digital Information Platforms
DL	Deep Learning
DLG	German Agricultural Society / Deutsche Landwirtschafts-Gesellschaft
DNN	Deep Neural Networks
DSS	Decision Support System
DTDS	Digital Technologies for Driving and Steering
DTN	Digitale Technologien und Naturschutz / Digital technologies and nature conservation
DüV	Düngeverordnung

List of abbreviations

DWD	Deutscher Wetterdienst
ECSA	European Citizen Science Association
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FMIS	Farm Management Information System
FRL ÖBL	Förderrichtlinie Ökologischer/Biologischer Landbau
FRM	Farmer
FUA	Funding Agency
GAP	Good Agricultural Practice
GHG	Greenhouse Gases
GIS	Geographical Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GWP	Global Warming Potential
HNV	High Nature Value
ibid.	ibidem
IE	Industry Employee
IFAD	International Fund for Agricultural Development
IoT	Internet of things
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IT	Information Technology
kt	kilotonnes
LfULG	Landesamt für Umwelt, Landwirtschaft und Geologie
LULUCF	Land use, Land Use Change and Forestry
mg l⁻¹	Milligrams per liter
Mio	Millions
ML	Machine Learning
MS	Microsoft
N	Nitrogen
N₂	Molecular nitrogen
N₂O	Nitrous oxide/laughing gas
NABU	Naturschutzbund Deutschland e.V.
NGO	Non-Governmental Organisation
NH₂OH	Hydroxylamine

List of abbreviations

NH₃	Ammonia nitrogen
NH₄⁺	Ammonium nitrogen
NIR	National Inventory Report
Nmin	Mineral content of nitrogen in the soil available to plants
NO	Nitric oxide
NO₂	Nitrogen dioxide
NO₃⁻	Nitrate nitrogen
NO_x	Nitrogen oxides
NUE	Nitrogen use efficiency
P	Phosphorus
PDT	Potenziale digitaler Technologien/ Potentials of digital technologies
PM	Policy Maker
Q	Question
RGB	Red, Green, Blue - additive colour model
RLZ	The German Red List Centre / Rote Liste Zentrum
Robot/s	Robotic technologies
RS	Researcher
RTK	Real Time Kinematic
SDG	Sustainable Development Goals
SDN	Software-Defined Networking
Sensor/s	Sensing and sensor technologies
UAA	Utilised Agricultural Area
UAV/AUS	Unmanned Aerial Vehicles and Unmanned Aerial Systems
UBA	German Environment Agency / Umweltbundesamt
UFZ	Helmholtz Centre for Environmental Research
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
URL	Uniform Resource Locator
VDT	Vorerfahrung digitale Technologien/Experiences with digital technologies
WEF	The World Economic Forum
WFP	World Food Programme
WHO	World Health Organization
WP	Work Package
ZALF	Leibniz Centre for Agricultural Landscape Research

Executive Summary

This study provides an inventory of the environmental impact of agriculture and an inventory, categorisation, and assessment of commercially available digital and smart technologies in Germany. Agriculture in Germany currently accounts for 8.35% of the country's greenhouse gas emissions:

- With 1.200 kilotonnes, agriculture is the largest driver of methane emissions in Germany.
- Agriculture is most important contributor to nitrous oxide emissions in Germany: about 53,000 tonnes out of a total of 91,000 tonnes of national nitrous oxide emissions in 2022.
- Sixty-six per cent of the nitrous anthropogenic emissions are attributed to agricultural soils.
- Although it has been constantly reduced over the past 30 years, the yearly carbon dioxide emissions of drained organic soils was 50.5 million tonnes in 2014, which accounted for 6.6% of the German greenhouse gas emissions.
- Drained peatlands make up approximately 5% of the total agricultural area of Germany, but they account for nearly 6.7% of the German greenhouse gas emissions, and more than 90% of the gases are carbon dioxide.

Furthermore, critical thresholds of other pollutants are still exceeded:

- The total use of nitrogen in German agriculture was 1.265 million tonnes alone for 2020–2021.
- North-west Germany and small regions in central and east-southern Germany show very high nitrogen surpluses of 120–162 kilogrammes nitrogen per hectare.
- In the period between 2016 and 2019, high nitrate concentrations (> 50 miligrammes/litre) were significantly more frequent at the agriculturally dominated monitoring sites, with a share of 26.7%, compared with the non-agriculturally dominated monitoring sites, with a share of approximately 5%.
- Agriculture is by far the main contributor of ammonia emissions in Germany (95%), with total emissions of 629 kilotonnes in 2016. So far, Germany has not reached its nitrogen-related environmental quality and actions targets.
- Eighty per cent of the total phosphorus demand comes from the agricultural sector; 192,000 tonnes of phosphorus in commercial fertilisers were applied in the crop year 2020/2021. Currently, 67.3% of the German groundwater bodies are in a good chemical condition, whereas 32.7% are not in a good chemical condition.
- In the year 2014, there was an average application of 8.8 kilogrammes of pesticides, meaning 2.8 kilogrammes of substances per hectare.

In addition, biodiversity and peatlands are experiencing severe damage from agriculture in Germany:

- Insect biomass has been reduced by 75% in 63 nature conservation areas surrounded by agricultural land within the last three decades. In grasslands, there was a 67% decline in the insect biomass and a 34% decline in species within 10 years.
- The aggregated high nature value indicator was reduced from 13.1% of total German farmland in 2009 to 11.5% in 2017, with a slight overall increase in 2017 versus 2015.
- The German agricultural sector is responsible for the transformation and use of more than 70% of the land that was once considered peatland soils.

As of March 2023, we identified a total of 230 digital technologies on the German commercial market. Digital technologies in agriculture rarely contain only a few components; they also consist of various other technologies that have many common interfaces. Therefore, a clear classification into only a few groups is difficult. For this study, we classified these technologies based on their type (complex systems for data processing, software-based technologies, and hardware-based technologies) and mode of operation (farm management information systems/decision support systems, digital technologies for guidance and steering, digital information platforms, citizen science applications and platforms, sensors, field robots, and unmanned aerial vehicles). Digital technologies require hardware as well as complex systems for data collection and processing that create a cognitive system and ensure the software functions properly before it reaches the users. There are three systems that process large amounts of data in digital technologies. Machine learning describes the generation of knowledge from data based on mathematical algorithms, which creates a cognitive system. Machine learning only refers to the learning process of a computer (or other digital technology) from gathering data through hardware. Artificial intelligence is the digital-based ability of a mechanical being to perform very specific tasks related to intelligent beings in the field of computer science. Artificial intelligence systems recognise pattern and offer solutions for problems and use logic for planning, educating, communicating, and imaging. Artificial intelligence is based on the algorithm knowledge obtained from machine learning. Big Data is a complex system in computer science; it provides an overview of real-time situations, thus enabling a user to make a “smart” decision. Big Data systems work with a huge amount and great variety of data at a high speed compared with artificial intelligence. Software-based technologies are available for users in practice and some of them are available free of charge, while users always have to pay a fee to use hardware technologies.

1 Introduction

Digitalisation within the agricultural sector is already being used to optimise procedures and processes (Hennes et al., 2022). Digital technologies offer new opportunities that can facilitate coordination among different stakeholders (WEF, 2020). Due to rapid technological progress, technological innovations can significantly increase resource use efficiency and reduce greenhouse gas (GHG) emissions (Basso & Antle, 2020; Finger et al., 2019). Moreover, digital technologies could significantly improve nature conservation, although nature conservation and ecosystem service provisioning are currently not the primary goal of digitalisation in agriculture. These technologies are mainly used as yield-increasing and effort-reducing tools for production and economic optimisation (Kliem et al., 2023).

To date, fears that agricultural production will not be able to keep pace with population growth have not materialised, as agriculture has been able to show significant increases in productivity due to chemical-technological progress and economies of scale. However, these productivity increases are accompanied by significant environmental impacts. For example, methane (CH₄) is the second most common GHG, and among CH₄ sources, livestock farming is the most significant contributor in terms of volume (Kuhla & Viereck, 2022). In addition, nitrate (NO₃⁻) and other nutrient inputs from agriculture place a significant burden on ecological sinks such as standing and flowing waters, oceans, and groundwater (Kirschke et al., 2019; Klages et al., 2020). Likewise, the use of insecticides, fungicides, and herbicides, but also the extensive conversion of rainforests into agricultural land, are among the main drivers of biodiversity loss (Köthe et al., 2023; Leeb et al., 2020; Liess et al., 2022).

Changes in land use, pesticide application, and crop rotation can contribute to the conservation of nature in agricultural landscapes. The reduction of synthetic pesticides, in particular those containing hazardous compounds such as heavy metals, can make a decisive contribution to protect soil and species richness biodiversity on arable fields (European Environmental Agency, 2015; M. Kumar et al., 2021; Uwizeyimana et al., 2017). The diversification of crop varieties and species as well as the cultivation of mixed, cover crops and flowering fields also contribute to agrobiodiversity conservation (Elhakeem et al., 2019; Fiorini et al., 2022; Gayer et al., 2021). Although there are legal frameworks as well as strategies and action plans for biodiversity protection, their implementation has been incomplete and insufficient (European Commission, 2015). However, the future use of digitalisation in agriculture to promote nature conservation has been set as a goal in Germany (Deutscher Bundestag, 2019a).

Digitalisation of agricultural management has given rise to new, different challenges and risks, such as rebound effects assessing the energy efficiency of digital tools. Therefore, there is an urgent need for research on the practical implementation of digital technologies that promote biodiversity protection and conservation. Indeed, the ambitious goals set regarding digitalisation as a solution for ecological problems have not been fulfilled and whether potentials or risks will predominate depends heavily on agriculture, social acceptance, and economic and political conditions.

This study assesses the potentials of digital and smart technologies in terms of sustainability and productivity gains, as well as challenges and risks driven by agriculture; political, economic, and

technological aspects; and social acceptance. The overall aim is to identify key recommendations for action for advancing digitalisation in agriculture regarding sustainability in Germany based on a three-stage analysis (literature research, survey results, and expert discussion).

First, we prepared an inventory of the current environmental impact of agriculture in Germany. We measured the environmental impact with various indicators, including CH₄; carbon dioxide (CO₂); and nitrogen (N: NO₃⁻ and ammonia [NH₃]-N), phosphorus (P), and pesticide pollution from agriculture. In addition, we considered the scale of biodiversity over time and the current condition of agricultural land in Germany. The review covers biotic impacts such as species richness and abiotic impacts such as a reduction in GHG emissions and fertiliser use.

We used objective criteria to identify and categorise innovative digital and smart technologies that can potentially contribute to sustainable agriculture. For this purpose, we compiled a list of all commercially available digital technologies in Germany. Based on the available information, we evaluated the identified technologies in terms of their technological maturity, application in Germany, effectiveness, cost efficiency, and contribution to the transformation of agriculture and the reduction of negative externalities.

Furthermore, we identified barriers that may hinder the diffusion, application, and development of the (effective) technologies. Therefore, we gathered and analysed the experience and knowledge of relevant stakeholders. We applied quantitative and qualitative research methods to develop a comprehensive and representative picture of the status quo. We distributed a nationwide online survey via different networks among stakeholders from agriculture (farmers as well as custom farming operators); politicians; researchers; and employees of administrations, associations, nongovernmental organisations, and other industries via email between 23 May and 30 June 2023. The survey collected demographic characteristics, previous experiences, and the participants' views on the barriers and expected potentials of digital and smart technologies. Based on this online survey, we conducted an online discussion with 13 invited experts from politics (federal agricultural ministries), civil society, and two farmers on 3 July 2023. We presented the participants with the relevant results of the literature searches (Chapters 4 and 5) and the online survey and then asked targeted questions to determine the most significant barriers and possible potentials for digital and smart technologies in German agriculture. To integrate the outcomes of the previous sections of this study into a larger context, we identified, listed, and characterised best-practice examples for the use of technologies from other European countries. These best-practice examples could also be applied in Germany.

2 Challenges in agriculture

2.1.1 Nutrition for the world's growing population

Agricultural land use and food production for a sufficient and healthy human diet are facing enormous ecological challenges. Among the greatest challenges are certainly the impacts of climate change as well as the continuous and severe loss of biodiversity. Since 1970, human-driven actions have significantly affected whole ecosystems within and outside agricultural landscapes (IPBES, 2019). These negatively influencing factors are accompanied by further external shocks such as wars (e.g., the Russo–Ukraine War), pandemics (e.g., COVID-19), and economic inflation. As an industrial sector interacting closely with nature, intensive high-yield agriculture, characterised mainly by monocultures and immense fertiliser and pesticide inputs, is affected by climate change (e.g., extreme weather conditions) and is also a significant contributor to negative environmental developments, such as desertification, water scarcity, and the loss of sensible biotopes and species (BMEL, 2022g; FAO, IFAD, UNICEF, WFP & WHO, 2022; IPCC, 2023). In parallel to the increasing environmental problems, the world's population continues to grow. Between 1950 and 2020, the world's population has tripled to almost 7.8 billion people, and it is expected to rise to 8.5 billion in 2030 and to around 10.4 billion between 2080 and 2100 (United Nations Department of Economic and Social Affairs, Population Division, 2023).

In the context of these environmental and sociodemographic developments, the demand for a high quantity of high-quality food products is continuously increasing. Therefore, the question of whether the food supply will accommodate the rising population continues to be on the agenda of agriculture and politics. Set by the United Nations (UN), the Sustainable Development Goals (SDG) 2.1 and 2.2 address the purpose to end hunger and all forms of malnutrition and to provide nutritious and sufficient food for all people throughout the world. At the same time, necessary food production needs to be performed in a sustainable and environmentally friendly way (SDG 2.4 and 2.5) (United Nations, 2023). Therefore, multidimensional, and multi-layered approaches are necessary to tackle this complex situation and to protect the natural resources while providing affordable and sufficient food products for all people, especially the poorest.

2.1.2 Protecting the environment

Since 1970, land-use change to agriculture has had the largest negative impact on the environment, in particular biodiversity and ecosystems, throughout the world (IPBES, 2019). Two thirds of ecosystems worldwide have been so severely damaged that their ability to provide beneficial services for humans and society has drastically decreased (Millenium Ecosystem Assessment, 2005; Secretariat of the Convention on Biological Diversity, 2020). In addition, the diversity of floristic and faunistic species in Germany continues to decline. Of the 97 mammalian taxa assessed in Germany, 30 are listed as endangered, including well-known species such as the brown hare (*Lepus europaeus*) and the polecat (*Eliomys quercinus*) (Meinig et al., 2020). A considerable proportion of a wide range of insect species in Germany are affected by long- and short-term population declines (Deutsche Akademie der Naturforscher

Leopoldina e.V., 2020a, 2020b; Ries et al., 2019). The populations of half of the bird species are continuously declining (BfN, 2015). One of the main reasons for these events is the increasing intensification of agriculture and land-use changes. However, the protection of biodiversity is both a key component of nature conservation as well as an important basis for the continuity of Germany's food production (Deutsche Akademie der Naturforscher Leopoldina e.V., 2020b).

2.1.3 Compliance with government regulations

Characterised by fertile soils and favourable climate conditions – moderate temperatures and sufficient precipitation – Germany is a prime location for agriculture in Europe. For hundreds of years, agricultural land use has shaped the landscape in Germany and has created a unique cultivated landscape with distinct ecosystems (UBA, 2023d). Today, agriculture still has an enormous influence on the German landscape. However, production systems have changed over time: extensive, low-input, pasture-based farming systems have turned into intensive, farming systems with high fertiliser input and predominantly stall feeding for livestock (BMEL, 2020d). This transformation has had and still has a significant effect on the environment and prevalent ecosystems that have developed over the centuries. The intensive farming and production systems are a major source of environmental impacts and pollution and, consequently, a threat to plant and animal species (BfN, 2017). To avoid these negative environmental externalities, German farmers must comply with standards regarding environmental conservation and animal welfare, including regulations on administering animal feed, medicinal drugs, and plant protection products (BMEL, 2020d). Examples of appropriate instruments to restrict the negative environmental developments are the National Agricultural and Environmental Law as well as the drafting of the Common European Agricultural Policy (CAP) (European Commission, 2022e). The environmental law presents the totality of legal norms aimed at protecting the functioning of ecosystems and consists of several laws, regulations, directives, and agreements on a national level in Germany and at the European and international levels. At present, there is no environmental protection law in Germany (BMUV, 2023a). Historically, environmental law has developed in response to different environmental problems in Germany. In its core areas, it is geared towards specific environmental media or pollution factors (BMUV, 2023a). The classic environmental laws include the water protection law (WHG, 2009/3. Juli 2023), the emission control law (BImSchG, 1974/19.10.2022), the soil protection and contaminated sites law (BBodSchG, 1998/25.2.2021), the nature conservation law (BNatSchG, 2009/8.12.2022), and the waste law (KrWG, 2012/2.3.2023 Nr.56). The National Agricultural and Environmental Law contains the minimum standards of environmental protection, which are legally obligatory for farmers. It is one of the main instruments in Germany to implement the requirements of European agri-environmental policy (European Union [EU] directives) (UBA, 2023d). At the federal level, this law includes, for example, the fertiliser law (DüV, 2017/10.8.2021) and the plant protection act (PflSchG, 2022/06.02.2012). The federal soil protection and contaminated sites law (BBodSchG, 1998/25.2.2021) determines the codes of Good Agricultural Practice¹

¹ Good Agricultural Practice is the level of ecological and safety protection farmers must adhere to when using their land in different regulatory context – at their expense, and without compensation according to Heller (2000).

(GAP) and also requires agricultural practices for sufficient soil protection (UBA, 2023d). Due to lack of additional EU requirements, the soil protection act currently contains only national guidelines. One of the measures of the newly developed Arable Farming Strategy 2035 is to reduce administrative hurdles, and, to minimise regulatory efforts for participation in biodiversity-promoting measures (BMEL, 2019a, 2021). While farmers understand the purpose of the above-mentioned laws and guidelines, additional public, financial, and administrative support could enable them to apply agricultural practices more actively and thus limit environmental impacts (Jantke et al., 2020).

Another point of contention for German farmers involves the adequate use of pesticides. In Germany, the use of pesticides (herbicides, insecticides: fungicides, molluscicides, acaricides, rodenticides and growth regulators) are regulated by EU as well as national laws. At the EU level, the four most important regulations are (1) regulation EC No 1107/2009, 2009 (2009), on testing and approval of plant protection products and their active substances (Verordnung (EG) Nr. 1107/2009 des Europäischen Parlaments und des Rates vom 21. Oktober 2009 über das Inverkehrbringen von Pflanzenschutzmitteln und zur Aufhebung der Richtlinien 79/117/EWG und 91/414/EWG des Rates); (2) directive 2009/128/EC. on the application of pesticides in the EU member states (RICHTLINIE 2009/128/EG DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 21. Oktober 2009 über einen Aktionsrahmen der Gemeinschaft für die nachhaltige Verwendung von Pestiziden); (3) regulation EC No 1185/2009, 2009 (2009) on sales and the application of plant protection products in the EU member states (VERORDNUNG (EG) Nr. 1185/2009 DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 25. November 2009 über Statistiken zu Pestiziden); (4) guideline 2009/127/EC, 2009 (2009) on the required norms and standards for machinery used for pesticide application within the EU (RICHTLINIE 2009/127/EG DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 21. Oktober 2009 zur Änderung der Richtlinie 2006/42/EG betreffend Maschinen zur Ausbringung von Pestiziden) (BMEL, 2019d).

At the national level, 13 guidelines and regulations stipulate the application of pesticides in German agriculture. They span from the plant protection law to the bee protection law to special control regulations. The objective of these guidelines and regulations is an appropriate application and handling, as well as required proof of expertise of pesticides and special regulations on the application of pesticides with regard to bee protection (BMEL, 2019c). Violations of the plant protection law (PflSchG, 2022/06.02.2012), for example, can lead to penalty charges of up to 50.000 euros according to §68.

2.1.4 Adaptation to rapidly changing weather conditions due to climate change

The increase in exceptional or even extreme weather events as a consequence of climate change, require appropriate adaptation strategies in agricultural land use and food production in order to secure a sufficient supply of food products in the long term (FAO, 2021b). These adaptation strategies are no longer only of concern for countries in the Global South, but also for Europe and Germany. Exceptional and extreme weather events such as extremely hot and dry summers or heavy rainfalls and even floods have clearly increased in Germany over the last two to three decades (DWD, 2022b). Although food

security is not seriously threatened in Germany, the consequence of climate change related crop failures are estimated at 4.4 billion euros for the years 2018 and 2019 (BMEL, 2022f).

The major climate challenges farms are facing in Germany are increasing winter precipitation along with a higher risk of erosion and nutrient (especially nitrate [NO₃⁻]) leaching, an increase in dry periods during the main growth stage, and heavy rainfall events that lead to soil erosion and floodings (BMEL, 2022f).

These changing weather conditions entail other negative consequences. If, for example, upper soil layers are still dried out, post-harvest processing can only be conducted under unfavourable conditions together with higher fuel consumption and material wear. Furthermore, sowing of cover crops and winter rapeseed (*Brassica napus* L.), possibly even winter cereals, would become difficult due to a lack of essential water for germination and juvenile development of the plants. A reduction in precipitation during summer increases the risk of rising NO₃⁻ concentration in the leachate, especially at loess sites and in soils with a high organic matter content. Therefore, there could be reduced nutrient availability during dry periods and reduced availability of mineral fertilisers to plants. In addition, higher air and soil temperatures promote the risk of gaseous ammonia (NH₃) losses during fertilisation and increased nitrogen (N) mineralisation from organic matter (BMEL, 2022f; Deutscher Bundestag, 2019b). Established cultivars in Germany such as potatoes (*Solanum tuberosum* L.), corn (*Zea mays* L.), (winter) wheat (*Triticum aestivum* L.), sugar beets (*Beta vulgaris* L.), and rapeseed (*Brassica napus* L.) respond differently to the changing climate conditions. Potatoes, corn, and sugar beets react very sensitively to water shortages during their growing period. The result is a noticeable reduction in profits (BMEL, 2022f; UBA, 2023d).

In addition, winters that are too mild can cause a delay or shift of vernalisation in plants. Hence, plant species such as winter wheat may shift their main growth stage and yields can decline in July and August (Deutscher Bundestag, 2019b).

Adequate climate change adaptation responses in agriculture include on-farm water management, water storage, soil moisture conservation, and irrigation, among others (IPCC, 2023). The response options include improvements of cultivars, agroforestry, and farm; a change in crop rotation; and landscape diversification. To reduce inland flood risks, early warning systems, enhancement of natural water retention such as restoration of wetlands and rivers, as well as adjusted land-use planning like no build zones or upstream forest management are effective measures. Adaptation actions such as improved soil organic carbon management, ecosystem conservation and land restoration, reduced deforestation and degradation, and reduced food loss and waste are valuable adaptation strategies that can also have mitigation co-benefits. Any adaptation measures that increase the resilience of biodiversity and ecosystem services to climate change – for example, reduced fragmentation or extending natural habitats – can allow species to persist (IPCC, 2023).

The German government has developed a targeted strategy to improve the climate resilience of agrarian systems: “Program of measures for the implementation of the agenda Adaptation of agriculture, forestry and fisheries and aquaculture to climate change” (BMEL, 2020b). The programme covers recommendations for actions and allocation of responsibilities between the federal and the state governments for the following categories: risk management, research, transfer into practical experience

and back, breeding/choice of species/provenance, water, information and data management, and monitoring (BMEL, 2020b).

In addition to this programme, the federal government has established research funding targeted at the further development of the cultivation systems (BMEL, 2022f). The main requirements are alterations in crop management, establishment of erosion control strips, adaptation of tillage methods and irrigation technology, and a significant increase in biodiversity in agroecosystems and thus diversifying crop rotations. To reach this goal, the funding aims to broaden the crop spectrum by identifying suitable companion crops and undersown crops for various main crops and further developing existing methods for sowing and cultivating main crops, catch crops, and undersown crops. This includes in detail (BMEL, 2022f):

- (1) to broaden the range of crops to include adapted crop varieties and species with good heat and drought stress tolerance, high nutrient mobilisation and enrichment, and good preceding crop value in the rotation. In this regard, although cultivation of established crops from other climate zones such as chick peas (*Cicer arietinum*), quinoa (*Chenopodium quinoa*), and sweet potatoes (*Ipomoea batatas*) is still a niche market, more and more pioneer farmers are starting to grow them;
- (2) to optimise the arrangement of crops in the crop rotation design to maximise water use efficiency and to minimise the nutrient leaching potential, among other things;
- (3) to eliminate the temporal and spatial separation of main and catch crops² in the form of mixed or strip³ cropping with species-diverse mixtures;
- (4) to better integrate undercrop⁴ and intercrop mixtures in conventional cropping systems across the entire rotation;
- (5) to expand and further develop species-rich intercrop and undersown mixtures suitable for this purpose;
- (6) to further develop and adapt production systems and techniques in practice (BMEL, 2022f).

2.1.5 Limited resources - agricultural land and water

Together, water and land are crucial to produce crops that are used for both human and animal consumption. The amount of precipitation and the quantity and quality of land are significant factors in agricultural yields (Renner et al., 2021) In Germany, the agriculture and forestry sectors account for the largest percentage of land use (81%, see Figure 1).

² A catch crop is a fast-growing crop plant species grown between the main crops to keep the soil surface covered Anonymous (2023b).

³ Strip cropping is a succession of narrow, cultivated, and uncultivated field strips, which reduce erosion Anonymous (2020).

⁴ Undercropping and undersowing (used as synonyms in this study) refer to the situation where an appropriate plant species is drilled into a main crop plant or failing pastures to prevent weed infestation and to cover the soil surface Anonymous (2023a).

Land use in Germany (31.12.2021)

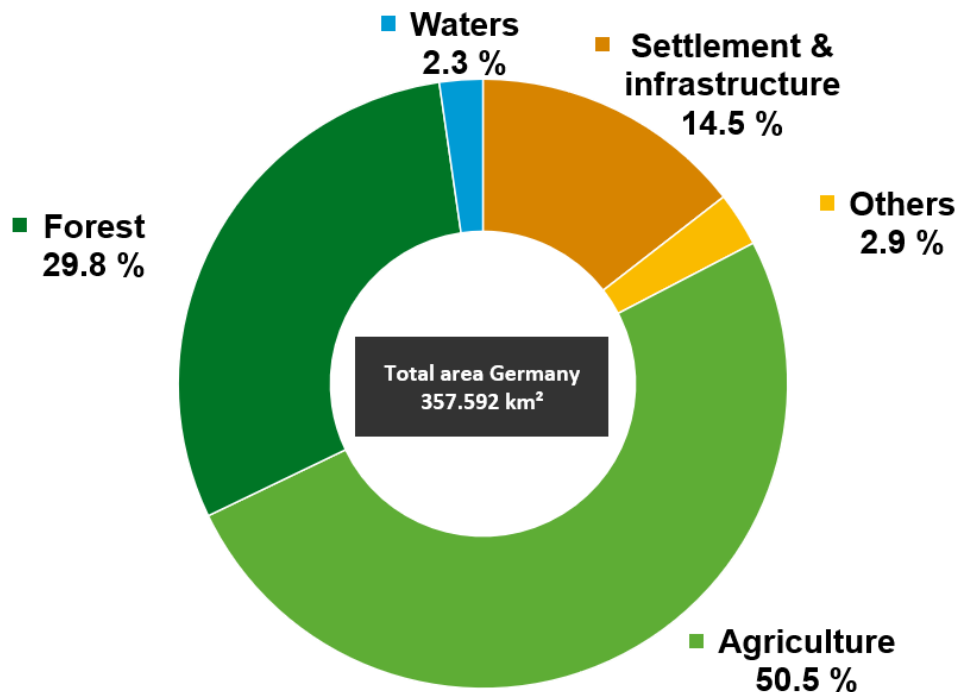


Figure 1. Land use in Germany (the results of the land survey by type of actual use as of 31 December 2021). Adapted from Destatis (2022a).

From 2016 to 2021, the share of agricultural land decreased by 2,047 km² from 51.1% to 50.5% of the total area. The loss is even greater: since 2016, 1,487 km² of heath and moorland are no longer reported under agricultural land, but rather under “other land” (UBA, 2022g).

Agricultural land must compete with other land uses such as forests, grasslands, conservation areas, resource extraction and human settlements. Based on Figure 2, land under permanent crops and land use as meadows and pastures has seen a steady decline from 1961 to 2020. The main reason for this decline is the marked 2.559 km² increase in land used for settlements and transport, as well as a growth in forests and wooded areas (UBA, 2022f). The German Farmers’ Association (Deutscher Bauernverband [DBV]) claims that there is an agricultural land loss of 70 hectares per day and demands policy implementation to address this issue (Kirschke et al., 2021). Other factors such as greening, policies to promote more biodiversity, and environmentally sustainable land management practices have contributed to making agricultural land scarcer, thus affecting land markets and prices (Kirschke et al., 2021).

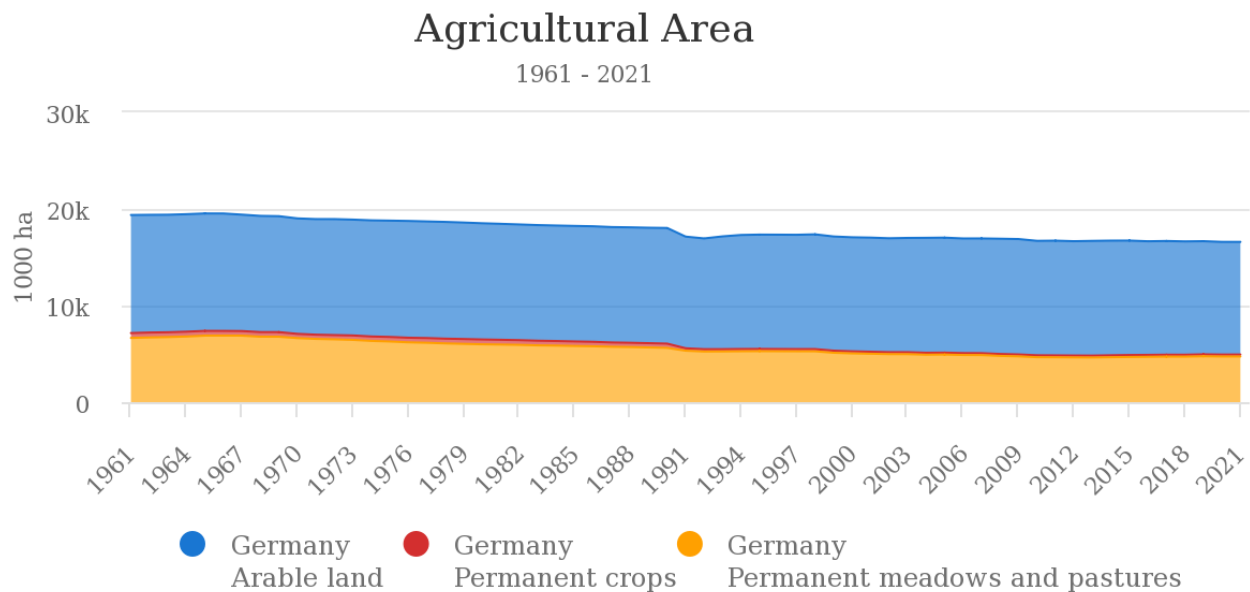


Figure 2. Agricultural area (1000 ha) development categorised by arable land, permanent crops⁵ and permanent meadows and pastures in Germany for the period 1961–2021. Adapted from FAO (2021a).

Besides available land, the quantity of water has become an issue in different parts of Germany. Extremely dry weather in Germany between 2018 and 2020 has affected farming outputs and has caused large economic losses. A water quantity study of the federal states in north-eastern and central Germany showed that cereal production in Brandenburg and Saxony Anhalt was under water stress between 1996–2000. Additionally, plant growth in more than 40% of the agricultural land in this area is expected to be affected by drought (Schindler et al., 2007).

Generally, German agriculture is not reliant on irrigation infrastructure. As of 2016, the German Federal Statistical Office (Destatis) reported that only 1.4% of yearly freshwater extraction is attributed to agriculture (ZKL, 2021). However, the effects of climate change may be causing German agriculture to adapt to meet its water needs. Results published in the national water strategy (2023) showed that farming methods have already very well adapted to drier climate and implemented sustainable irrigation systems or humus formation adapted to local conditions (BMUV, 2023b). In the long run, a framework strategy that aims to permanently maintain a semi-natural and functional water regime must be developed in dialogue with representatives of agriculture, forestry, water, soil, and nature conservation (BMUV, 2023b). Agricultural droughts are events in which there is less water in the soil than the long-term average causing yield losses and/or decline in yields (Thoer et al., 2018). The record year 2014 showed exceptional droughts events in march 2014, which captured the attention of research (Figure 3).

⁵ Permanent crops are crops that are not included in the crop rotation and remain on the land for a period of at least 5 years and which provide recurrent yields, including nurseries. Perennial crops listed in Article 2(d) of Regulation (EC) No 795/2004 and nurseries of such perennial crops are excluded. Source: Article 2(c) from (Comission Regulation (EC) No 795/2004 of 21 april 2004 laying down detailed rules for the implementation of the single payment scheme provided for in Council Regulation (EC) No 1782/2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers, 2004)

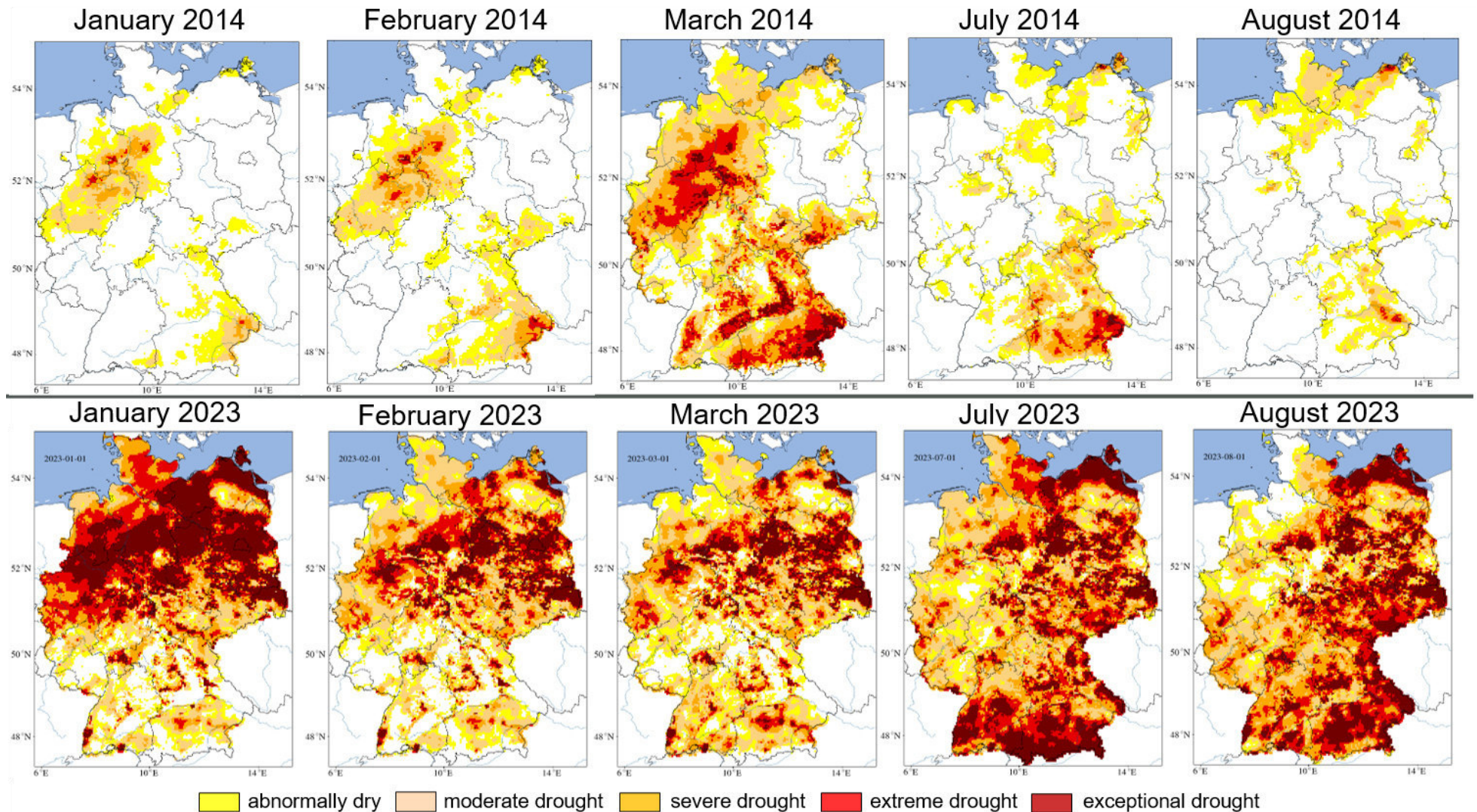


Figure 3. Drought development in a total soil column depth of 1.8 m for January, February, March, July, and August 2014 compared to 2023. Original data from UFZ (2023).

The reduction in water availability is mainly driven by changes in temperature, as projected annual precipitation hardly changes. A higher air temperature leads to the atmosphere being able to absorb more water. Thus, evaporation from the land surface increases with global warming (Thober et al., 2018). The trend of months with soil moisture deficit has been increasing all over Europe in the past decade, which is associated to global warming (Grillakis, 2019; Markonis et al., 2021). Figure 3 shows very clearly how the agricultural drought in Germany has developed - from a few exceptional drought points in January 2014 to larger parts of northern Germany being severely affected in January 2023.

Figure 4 a) shows exemplary of 21st of June 2023 drought monitoring maps of the total soil column for Germany. Especially the eastern parts of Germany already indicate severe drought stresses for 2023. Figure 4 b) provides additional information on the usable field capacity for the plants (plant-available water development) in the uppermost 25 cm of the soil. Compared to the drought status of the total soil column, the condition of the water availability for plants is even more tense in most parts of Germany Figure 4 b) (UFZ, 2023).

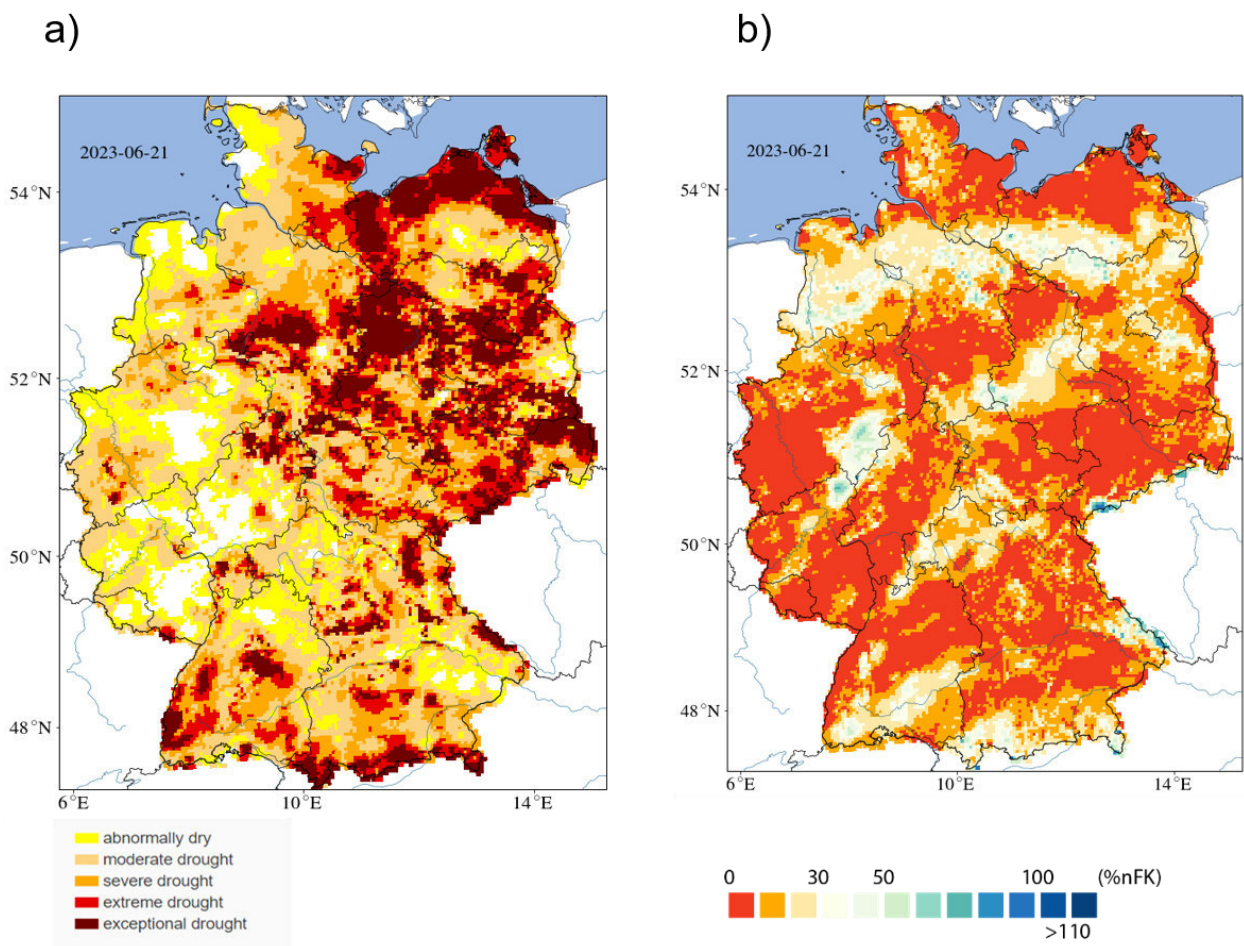


Figure 4. Drought and soil moisture monitoring maps throughout Germany as of 21 June 2023. (a) The total soil column (1.8 m). (b) Plant-available water in the uppermost 25 cm of the soil. Adapted from (UFZ, 2023).

Prospectively, the German Weather Service (Deutscher Wetterdienst) predicts that the period between 2021 and 2026 will also be very dry (ZKL, 2021). Together with the situation displayed in the drought

monitoring maps (Figure 4), this climate perspective underlines the need of agricultural practices to adapt to drier climate conditions.

2.1.6 Increasing production and labour costs

Similarly to every industry, agriculture relies on resources. Food production requires natural resources such as fertile soils, water, and sufficient temperature, as well as additionally purchased means of production including fodder, fertilisers, pesticides, petrol, electricity, and other maintenance costs for machinery and buildings. Another considerable factor is the lease most farmers have to pay for the land they cultivate (BMEL, 2022b).

All of these material means of production are one part of the production costs farmers must invest in their business as advanced payments. The prices of these producer costs are subject to fluctuations, mainly caused by external shocks such as the COVID-19 pandemic and the Russo–Ukrainian War (BLE, 2022a). Considering the price tendencies of producer costs in German agriculture in general, over the last six years there was a constant upward trend between 2017 and 2019 as well as a very significant increase between 2020 and 2022. Between 2019 and 2020, the prices showed a slight decrease of almost 3% (Destatis, 2022b). Looking at the different sectors, plant production costs increased by 17 percentage points (from 109.4% in 2012 to 129.4% in 2020) compared with livestock production (110.1% in 2012 and 2020). Between 2021 and 2022, the total increase in plant production costs rose even more and even higher (from 129.4% to 165.3%) compared with livestock production (from 110.1% to 150.6%) (Destatis, 2022b).

Figure 5 shows the price development of different agricultural advanced payments from 2009 to 2019. While prices for products such as fertilisers and energy and lubricants between 2010 and 2015 were still higher than the general consumer price index, they fell below the general consumer price index in 2015. Whereas the price for fertilisers was still below the general consumer price index in 2019, the prices for energy and lubricants began to rise again above the general consumer price index at the beginning of 2018 (Haß et al., 2020).

The prices for maintenance and new acquisition of machinery for the construction of new buildings were below the general consumer price index between 2009 and 2014. Compared with the prices for fertilisers and energy and lubricants, the prices for machinery, buildings and construction of new buildings began to rise constantly at the beginning of 2016 (Figure 5).

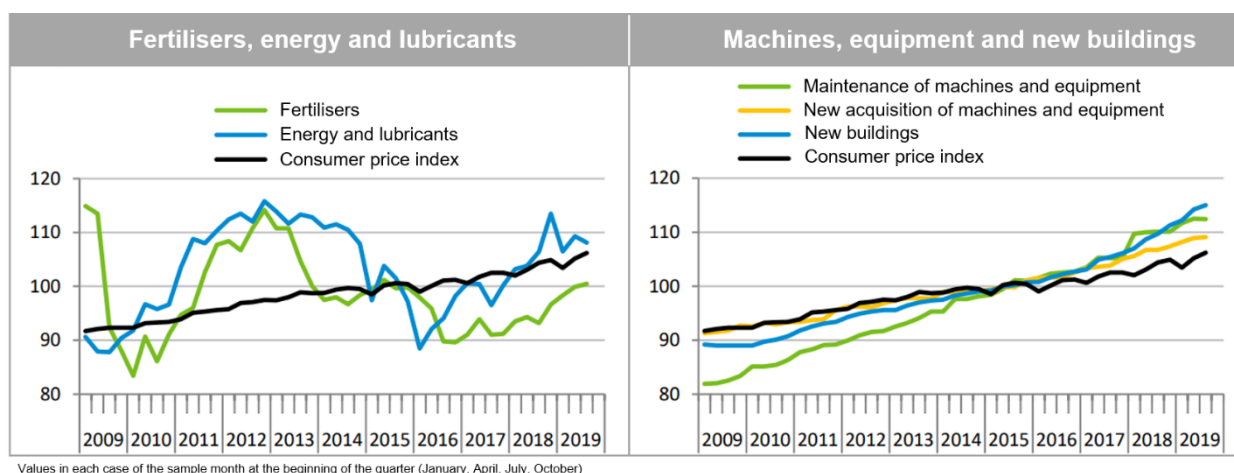


Figure 5 The development of purchase prices for selected agricultural inputs compared with the consumer price index from 2009 to 2019 (index in 2015 was 100). Adapted from Abbildung 2.2 in Haß et al. (2020).

The fodder prices for livestock had been relatively stable in Germany until 2020. Since 2021, they have increased tremendously; they reached a record level in May 2022 with a price index of 174.4 (this means an increase of 74.4% compared with the index year 2015). In April 2023, fodder prices still showed an index of 146 and therefore are on average 46% higher compared with the average in 2015 (Statista, 2023b).

One reason for the overall trend of increasing production costs is the general inflation rate, meaning the general price increase in Germany. Over the past 10 years, the inflation rate fell from 1.5% in 2013 to 0.5% in 2015, 2016, and 2020. Then, it jumped significantly to 3.1% in 2021 and 6.9% in 2022 – with the latter being the highest inflation rate in reunified Germany (Statista, 2023a).

The factors that have significantly influenced the general German inflation rate are the effects of the COVID-19 pandemic and the Russo–Ukrainian War. The increase in fodder prices can be attributed to the Russo–Ukrainian War and the associated shortage of certain resources as well as impaired supply chains (Bundesinformationszentrum Landwirtschaft, 2023).

Regarding leases, prices began to rise significantly in 2007. This trend continued between 2016 and 2020. In 2020, the price per hectare was 329 euros rent per year, an increase of 14% compared with the price farmers had to pay per hectare in 2016 (288 euros) and an increase of 62% compared with rent in 2010 (204 euros). On the regional scale, rent prices have risen more strongly in the new federal states (East Germany) compared with the western part of the country (BMEL, 2022b). Nationwide, the purchase price per hectare rose from 11.854 euros in 2010 to 22.310 euros in 2016 to 26.777 euros in 2020 (BMEL, 2022b).

In addition, not only have production costs (costs for material means of production) increased, but labour costs have shown a significant increase in all performance groups since 2010. In Germany, agriculture is one of the business sectors in Germany that is characterised by a high percentage (almost 50%) of temporary, assistance employees, or employees of unknown qualification. Simultaneously, the proportion of employees with an academic qualification is comparatively low (9%) (BMEL, 2020a).

The agreed wages have increased equally for all performance levels. Thereof, employees in managerial positions have received the highest collectively agreed wages over the entire period: in 2013/2014 the figure of 20 euros per hour was exceeded. In comparison, the wages of the assistance employees was 9.78 euros per hour in 2015/2016 (BMEL, 2020a).

As a consequence of the increased producer prices, in 2022 consumer prices reached the highest level in Germany for the past 60 years. In February 2023, consumer had to pay 20% more for food products and beverages compared with February 2022 (Bundesinformationszentrum Landwirtschaft, 2023).

Despite the increased production costs, on balance most farm types in Germany have benefited from the market development. According to the latest accounting results, the business profit of the main commercial farms increased by more than 26,000 euros per farm in the 2021/22 marketing year across all farm types. This corresponds to an increase of 49%. Dairy farms were the biggest winners regarding the price development, with an increase of 68% (38.800 euros) compared with the previous year. With a total profit of 95,000 euros per farm on average, milk production earned the most. Arable farms (+ 42%) and fattening farms (+ 41%) also benefited from the favourable price trend (Bundesinformationszentrum Landwirtschaft, 2023).

2.1.7 Shortage of skilled labour

Once being one of the most important labour market in Germany, agriculture has become less important since the 1950s. The reasons are increasing industrialisation together with better wages and working conditions. Accompanied by a continuous decline of agricultural farms, the entire sector has been subject to a significant structural transformation (Stratmann, 2019).

Currently, agricultural field work is perceived as difficult, low paid, and lacking incentives for apprentices. Working in the agricultural sector is not viewed as an attractive career in Germany (Bundesinformationszentrum Landwirtschaft, 2023; Stratmann, 2019).

In a nationwide comparison of sectors, the first sector is characterised by the longest weekly working time. In contrast, employees in the agricultural sector earn only 80% of the nationwide average earnings. A further unfavourable characteristic is the low level of participation by agricultural enterprises regarding additional training opportunities compared with other branches and sectors (Reckinger, 2023).

Several jobs on organic farms, such as weed control in vegetable and sugar beet crop rows, are very labour intensive. Due to the prohibition of pesticide use, this work is still mainly done by hand (Achilles et al., 2017; BMEL, 2023b; Wilhelm et al., 2011). One way to improve the overall situation is the establishment of organised working time models, especially for work peaks during the season, to limit daily working hours or to enable weekly working hours and to adjust the working conditions in agriculture so that they are similar to other branches (ZKL, 2021). For organic farms, the development and use of specialised machinery for weed control in various crops is increasingly encouraged (Wilhelm et al., 2011).

Of note, a 2019 study found that there was no indication that poor working conditions in East Germany were the main reason for the shortage of skilled labour in the agricultural sector. At this point other influencing factors matter, such as general satisfaction with life in rural areas (Jantsch et al., 2019).

Labour shortages, which have been extreme in the context of mobility restrictions in Europe due to the COVID-19 pandemic, are causing farmers to consider new production methods, such as the use of robots for picking fruits and vegetables (Mitaritonna & Ragot, 2020). In a recent study, farmers stated that difficulties in finding skilled labour was a key motivation for investing in robotics and other automated machinery (Prause, 2021).

On the other hand, ongoing digitalisation in agriculture has led to a profound transformation of the labour market and work processes in this sector. Machinery and robots will continue to replace manpower. As a consequence, fewer workers are necessary for work in the field or stables, but new skilled workers are needed to manage and maintain these technologies (Stratmann, 2019).

2.1.8 Increasing consumer demands

Within the last 20 years in Germany, there has been a shift in what food products consumers are demanding and a decline in the percentage of income spent on food. Not only are consumers demanding more food options, they are also demanding food that is, fresh, produced regionally with environmentally friendly practices, and with a stronger focus on vegetarian and vegan diets (ZKL, 2021). However, the actual price paid for these food products does not translate to better payments for farmers. Farmers argue that there is a *citizen–consumer gap* regarding the expectations of consumers and the prices they are willing to pay for their food products. Farmers think that their role as food production experts are not taken seriously and that the general public has alienated themselves from the food production process (ZKL, 2021).

Food retailers, in an effort to meet the high-quality standards that they believe consumers want, offer products with a certain size, weight, appearance, and shape. This results in farmers discarding large amounts of their produce. For European fruit and vegetable production, such as potatoes, the Food and Agriculture Organization of the United Nations (FAO) estimates losses at harvest and in the immediate downstream area (e.g., sorting) at around 25% of the quantity produced. The FAO cites quality standards of the trade as an important reason for these losses (Meyer et al., 2018; Schmidt et al., 2019).

At the same time, the dairy sector reports food waste through technical issues with their machinery (Göbel et al., 2015). Farmers may also feel the effects of consumer demands in the retail space as there is a desire to have store shelves that are constantly filled with food products at all times, leading to over-ordering and overstocking of food products (Horoś & Ruppenthal, 2021).

There has been a noticeable increase in consumer demand for food products that trace the impact of food production practices on the environment (Zaharia et al., 2021) and on animal welfare as well as where the food is produced (International Trade Administration, 2022). While consumers may be demanding food from production practices that address environmental stewardship, some consumers are not willing to pay a food premium to farmers who use environmentally friendly practices (Moon et al., 2002). However,

other studies show that German consumers may be willing to pay a premium for certified agricultural farming practices (Nocella et al., 2010) and quality and safety measures in meat production (Enneking, 2004; Lewis et al., 2017). A consumer preference study with the participation of the faculty of organic agricultural sciences at the University of Kassel in Witzenhausen showed that Germans prefer buying products labelled “produced locally” as they attribute this label with fewer food miles, increased traceability and transparency, supporting the local economy and with having the animal feed sourced locally (Greibitus et al., 2013; Wägeli et al., 2016). A survey of German consumers on behalf of the Federal Ministry of Food and Agriculture (BMEL) published in 2020, showed that nearly 50% of respondents expressed concern about pesticide residues on their food (BMEL, 2020d). In another survey, 60% of respondents stated that they have made changes regarding their items purchased for environmental reasons (Statista, 2020). In addition to an increased demand for environmentally friendly production methods, there has been a noticeable increase in consumer preference for regionally grown foods as well as a shift from meat consumption towards more peas (*Pisum sativum* L.), lentils (*Lens culinaris*), and soybeans (*Glycine max* L.) (Ketteler, 2021).

3 Methodology

3.1 Overall study structure

The following study explores the potentials of digital and precision farming technologies in terms of sustainability and increasing yield, as well as their contribution to solving food supply issues driven by challenges such as climate change, increasing population, biodiversity decline, ecosystem provisioning, and yield fluctuation. For this purpose, this study was structured based on four work packages (WP), which were first developed separately and then placed in a collective context. The study was conducted between November 2022 and August 2023. Figure 6 illustrates the overall structure of the study and short descriptions of the individual WPs.

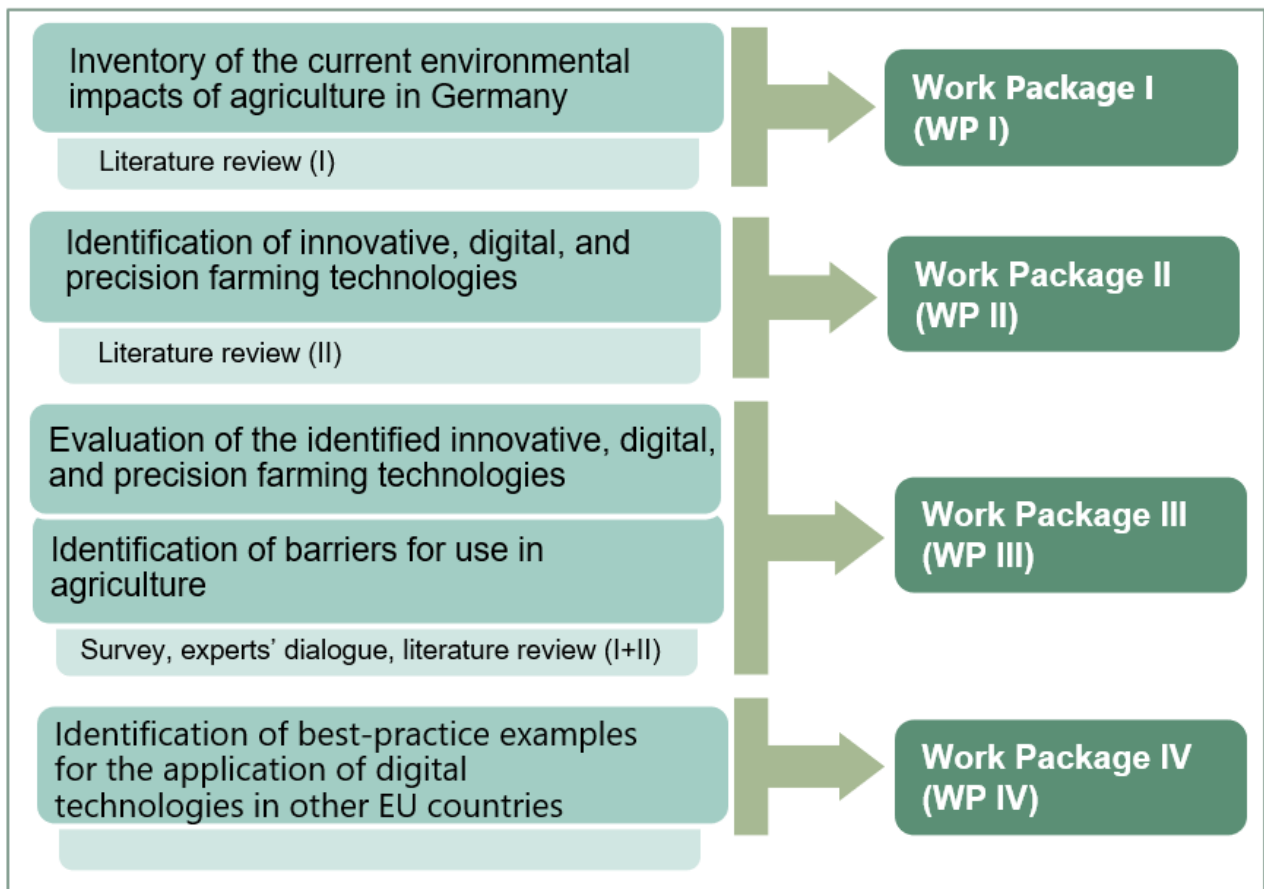


Figure 6. Overall structure of the study. Our illustration.

3.2 Literature reviews

3.2.1 WP I Systematic literature research

WP I focuses on the current environmental impacts of agricultural land use in Germany. To get a comprehensive overview of the recent various impacts agricultural land use in Germany has on the environment, an extensive search of the literature was conducted at the beginning of the study. To focus on the latest available data and results regarding the topic, only sources and files published from January 2019 to July 2023 were included. The applied languages were German and English. The topics were

searched individually by keywords in both German and English (Figure 7). The search yielded articles, reports, publications, press releases from authorities, brochures, statistical data (processed and not processed), regulations, laws, directives, and sector programmes. The resilience of the information was estimated based on the reputation of an institution, expert knowledge, how frequent it was mentioned, and how current the datasets were.

The search was quite broad. One essential element was large academically established databases like Web of Science, Scopus, and Google Scholar; the online databases of the library of the Humboldt University Berlin; and the databases of the library of the Leibniz-Institute for Agricultural Landscape Research (ZALF e.V.). The databases were searched mainly for peer-reviewed articles to gain an overview of the latest scientific insights. In addition to the databases, online published reports, publications, and data of representative administrative bodies of the United Nations (UN) within the EU and Germany – for example, the Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCCC), the FAO, the European Commission, BMEL, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), the German Environment Agency (UBA), and the Federal Agency for Nature Conservation (BfN) – were used. Reading over these sources, publications as well as the information provided under various headings on the homepages was included (see Appendix Table 1 to Appendix Table 3).

Furthermore, relevant associations of agriculture in Germany, for example, the DBV and the German Agricultural Society (DLG), were considered. These sources were used in the same way as the websites of authorities. The Google search engine was an important resource for a keyword search of press releases and fact sheets or brochures from the relevant authorities.

Although the time frame for the literature review was set as 2019–2023, there are some sources that are highly relevant to certain disciplines but were published before 2019. These are mainly regulations, laws, guidelines, directives, federal reports, peer-reviewed manuscripts on long-standing studies.

For the purpose of this study, peat soils were not considered in detail in the assessment of digital technologies. However, from our point of view it is important to point out the problems with organic soils in Germany regarding the current environmental impacts of agriculture and to describe the current condition of peatlands to have a complete view of the agricultural land in Germany.

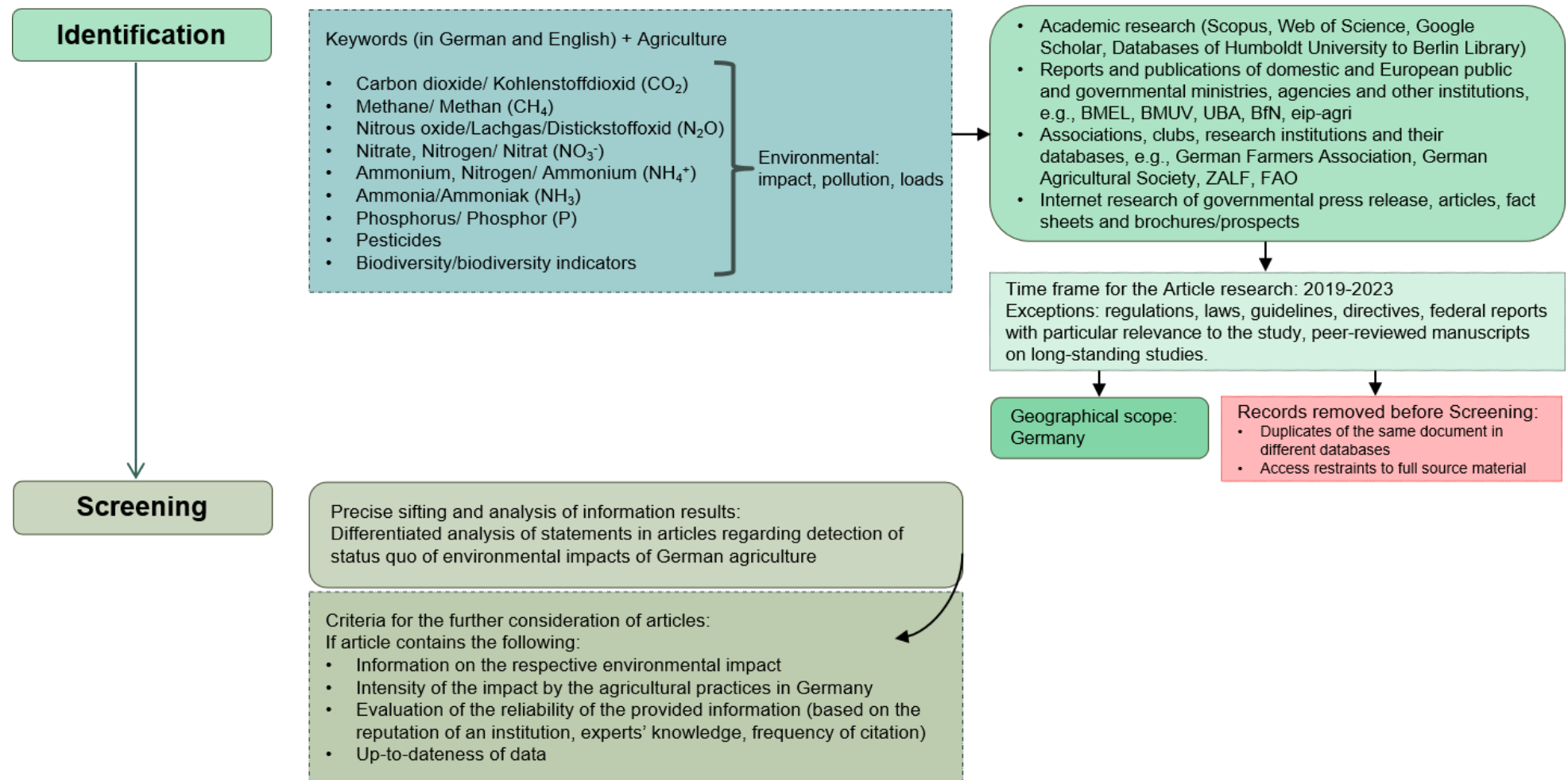


Figure 7. Structure of the literature search for WP I. Our illustration.

3.2.2 WP II: Identification of innovative, digital, and precision farming technologies

The focus of WP II was the identification of currently commercially available smart and precision-farming digital technologies and their actual and potential impacts to shape sustainable agriculture. For this purpose, academic, non-academic (internet research), as well as a combination of academic and non-academic searches were conducted from November 2022 to September 2023.

Considering that many of the commercially available digital products have been investigated in research on a limited scale or not at all, an internet search via Google was used to complement the technology list. In the next step, the data portals of ministries, authorities, agricultural research institutes, and associations of the individual federal states in Germany were browsed. Individual search queries were performed for each technology group (using the keywords “Agriculture” in combination with “Big Data”, “Machine Learning”, “Artificial Intelligence”, “Farm Management Information Systems”, “Decision Support Systems”, “Digital Technologies”, “Guidance”, “Steering”, “Digital Information Platforms”, “Citizen Science”, “Sensors”, “Field robots”, “Unmanned Aerial Vehicles”, and “Unmanned Aerial Systems”). This resulted in an extensive technology list with a total of 201 entries (Figure 8). The keywords used in the academic search were in English, while the keywords used for the other two searches were the same as used in the academic search but translated into German. In the identification process, technologies listed in project reports prior to 2019 were reviewed for their current availability on the market.

With an increasing range of digital technologies, more and more interfaces are emerging between technology providers who network their digital products with software and hardware from other providers. This makes it increasingly difficult to define technology categories because of the multitude of possible combinations. During the search process, it became apparent that there is rarely a uniform categorisation of digital technologies, because of the diversity of the products on the market. Digital technologies can collect a lot of data in the shape of physical parameters of the environment (e.g., temperature, precipitation, soil moisture, humidity, global radiation, etc.) or relevant measurements of plant populations (e.g., chlorophyll content, canopy, etc.). These data can be available in a numerical format and/or as images. The data collected by digital tools (remote, *in situ*, or vehicle-mounted sensors) can be fed into a system, processed, and/or analysed by models as well as used by machine learning and/or then by artificial intelligence (AI) algorithms to identify optimal application rates and dates for fertilisers, pesticides, and irrigation, among other factors. Features of management documentation usually include monitoring the overall activities at the farm level (e.g., for regulation compliance). Such documentation modules might include farm economics and stock as well as machinery and production management activities. We were also aware that a large number of categories describing digital technologies would facilitate the implementation of the online survey. Therefore, in this study, three categories were elaborated that relate to the original mode of operation of the technologies listed: complex software- and hardware-based systems for data collection and processing were collected from a previous study conducted by the ESS working group at ZALF e.V. for the period of 2021–2022 (Kliem et al., (2023). Three overlapping sub-areas characteristic of digitalisation in agriculture according to the Federal Ministry of Education and Research were used as a starting point: (1) the use of software-driven

equipment (drones, automated field robots, Global Positioning System [GPS]-controlled machines, etc.), (2) the use of farm management software; and (3) the collection, storage, and networking and analysis of data (Pflanzenforschung, 2019). The classification of the screened digital technologies in agriculture was carried out on two levels based on technology type and mode of operation (Figure 8). The first category represents complex systems for data collection and data processing, which are essential for the functioning of all other digital technologies in the software- and hardware-based categories. The additional classification refers to the primary difference between physical components and devices (hardware) and operating programmes (software). For the purpose of this study, the sub-categories were expanded to a total of 10.

Technologies that solely aim at the economic optimisation of agricultural production and administration were not considered. Farm management information systems (FMIS) were included in the list if they contain and/or offer modules for sustainable land management. Digital technologies used for indoor livestock management and farming were excluded (e.g., milking robots, cleaning robots, feeding robots, etc.). Virtual fencing sensor technologies were incorporated into the study because of their relevance to sustainability and nature conservation (see chapter 5.4.1). Software-based technologies, such as FMIS and decision support systems (DSS), which are available in the German language but only on the market in Austria and Switzerland, were sorted out.

Due to the very dynamic nature of the commercial technology market, we do not claim that the list of digital technologies provided in this study is exhaustive. We are aware that the market for digital technologies in agriculture is constantly evolving, so the lists presented in this study represents a snapshot of the research period.

The academic research for the assessment of the digital technologies (Chapter 8) targeted mostly peer-reviewed literature (Figure 8). It was conducted in two rounds with a total of 937 peer-reviewed articles. On 16 November 2022, a total of 515 articles with a primary focus on the keywords “Digital Technologies” and “Agriculture” were identified. On 5 December 2022, another 422 articles with the additional keywords “Sustainability” and “Nature Conservation” were obtained. The abstracts were reviewed to select the articles that deal with digital technologies in agricultural practice relevant for Central Europe. In the end, 46 articles with explicit relevance to digital technologies in agriculture and sustainability/nature conservation were selected.

Based on the study’s objectives, the potentials of sustainable agricultural practice are presented. It is important to point out that there is currently limited empirical evidence of the potentials in practice, especially regarding long-term studies, and that the potentials are presented based on the current state described in the literature. Furthermore, the barriers and risks for the sustainability of agriculture are discussed. When available, best-practice examples are integrated. During the review process of the identified digital technologies, sub-categorisation based on the application area of the technologies was conducted. The application of some technologies could not be allocated to only one area. Consequently, in addition to individual areas of application, sub-categories with combinations of two or three applications were defined (Figure 8). Additional information on the access (subject to charge/free of

charge), country of origin, and manufacturer name and/or brand are also available. A list of all the identified technologies is available in the Appendix Table 8 to Appendix Table 22.

We are aware that the use of digital technologies for crop cultivation in the context of nature conservation and biodiversity protection is currently based on examples from the literature and case studies. The technologies and the potentials presented in this study may be difficult or impossible to implement in practice in the short term. Digitalisation in agriculture is advancing rapidly, and the market as well as the motivations for the use of technologies are changing dynamically. Therefore, it is important to set goals for nature conservation and to identify potentials as well as the barriers that currently prevent the realisation of these potentials.

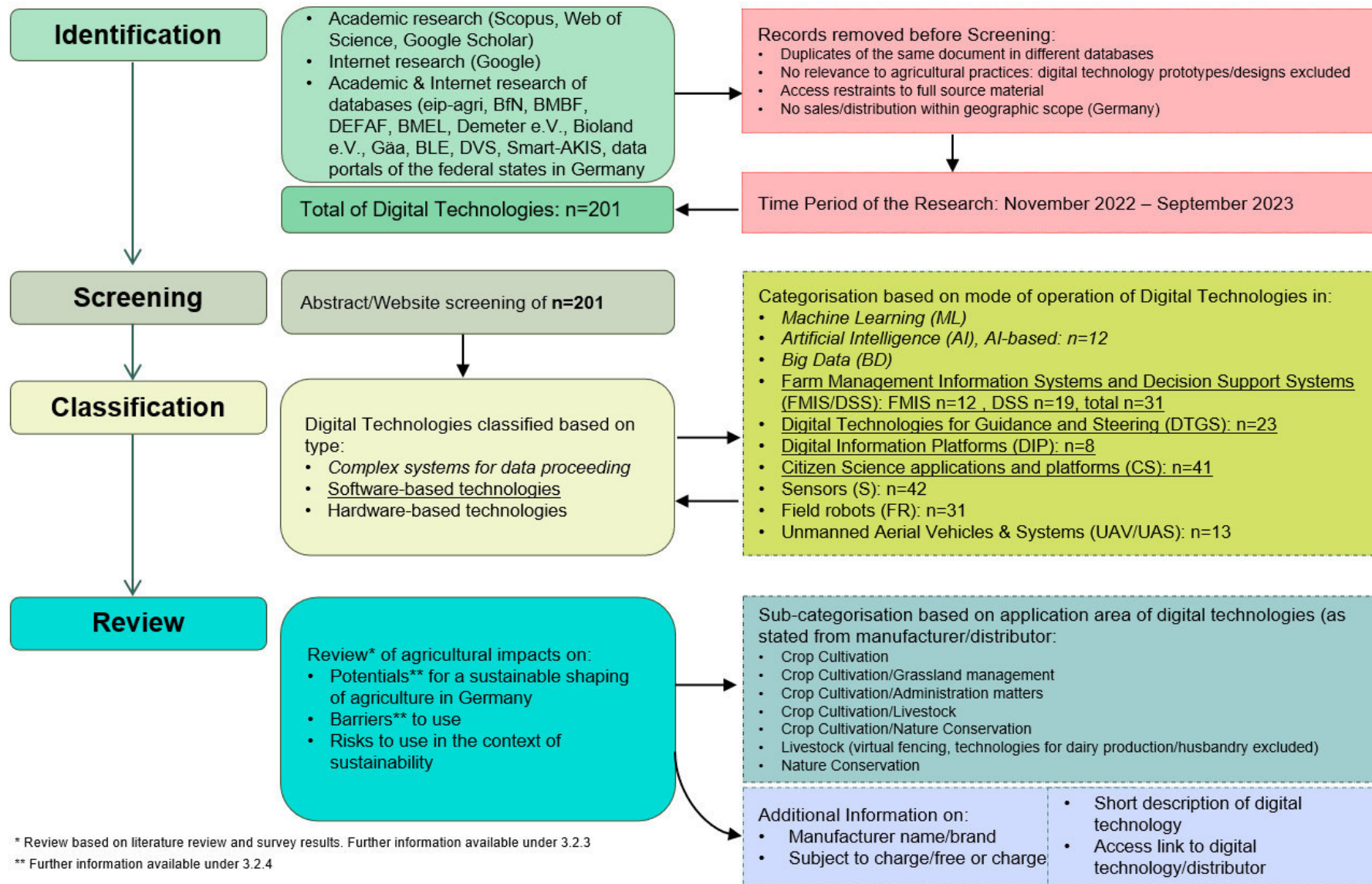


Figure 8. Literature review process for the identification of currently commercially available smart and precision-farming digital technologies in Germany. Our illustration.

3.2.3 WP III: Online survey and discussion among experts for the identification and evaluation of digital technologies and barriers

3.2.3.1 Online survey

In the interest of involving experts in the evaluation of digital technologies and to specify the most prevalent barriers regarding their broader use, we collaborated with the EFI commission to create an expert list and to develop an online survey.

In the first step, we defined three relevant stakeholder groups for this study and divided them into different sub-groups. The first group includes farmers and custom farming operators. We distinguished three different categories of farming practices for the analysis of the results: traditional commercial farming, commercial farming with reduced input of fertilisers and pesticides, and a strong orientation along the codes of good farming practice (with organic farms as a final category). The second stakeholder group includes representatives from politics/administration, associations, and nongovernmental organisations (NGOs). The third group includes experts from research/science and other businesses. The list also included already available contacts from our ZALF team and the EFI commission. The final number of potential participants was 337.

The EFI commission and ZALF developed the questionnaire. It comprises four main sections: (1) assignment of the stakeholder group and specific working field (question group “BFG”); (2) questions about previous experiences with digital technologies, including barriers experienced in the use of digital technologies (question group “VDT”); (3) expected potentials for the use of digital technologies (question group “PDT”), along with a special question group for farmers focusing on the expected potential of digital tools with regard to nature conservation (question group “DTN”); and (4) sociodemographic data (question group “D”) (Appendix Figure 1).

We created the survey with multiple paths, including particular professional questions directed at each stakeholder group. The first path was for farmers; the second path was for custom farming operators; the third path was for policy stakeholders and administrative staff as well as employees of associations and nongovernmental organisations; the fourth path was for researchers and scientists; and the fifth path was for specific professional participants working in the category “other businesses”.

The main question types were multiple choice and matrix. We used multiple choice questions to collect demographics. Except for the question on gender, all demographic questions had to be answered. We used matrix questions (with a Likert scale) for the content. We configured these questions with thematically different response options as multiple choice questions. Except for the complex multiple choice matrix questions, all content questions were mandatory. We added comment boxes to six of the questions for the participants to provide details of individual situations as well as additional answers. We randomised the order of the listed digital technology categories to prevent the respondents from becoming accustomed to them.

The survey was distributed among the experts via LimeSurvey (LimeSurvey Expert, Cloud version 5.6.25, released 2023). The first launch of the survey to the first 100 participants on our list took place on

16 May 2023. In consultation with the EFI commission, we conducted this soft launch to respond to any noticeable difficulties or to phase out any repetitive questions. Because there were no major issues, the second invitations were sent out on 23 May 2023, followed by the next invitations on 5 June 2023 and 16 June 2023.

We set the general settings in LimeSurvey so that we could determine who had completed the survey and who we would need to remind at a later date. We stored the date stamp, the IP address, the referrer URL, and cookies. By storing cookies, it was possible to prevent a participant from participating in our survey twice. We deleted these data 2 weeks after the end of the online survey.

After expiry of the survey, we considered the first 60 completely answered questionnaires for detailed data analysis. We exported the data from LimeSurvey and transferred it to a Microsoft Excel file, where we edited and graphed the data.

3.2.3.2 Discussion with relevant experts

There were two aims of the discussions with experts: (1) to get a critical review of the results from the literature search on environmental pollution and digital technologies in agriculture; and (2) to discuss the results of the first 60 online questionnaires and to gather personal experiences from the experts. We compiled a list of experts from different disciplines to gather their perspectives. We invited 30 people to the discussion; they represented politics, civil societies, industry, research, and agriculture. Finally, 13 experts took part in the discussion, which was held online via Zoom on 3 July 2023 in German. The group of 13 experts comprised five researchers (R), two representatives from civil society organisations (CSO), three policy makers (PM), one farmer (F), one representative from a funding agency (FU), and one employee from industry (I). We have kept the identities of the experts in this study anonymous. However, the opinions are categorised according to the participant's area of expertise.

Prior to the discussion, we introduced the overall aim of the study as well as the background and problem. We gave a 45-minute presentation including the results of the literature reviews described in Chapters 2, 4 and 5, and selected results of the first 60 completed online surveys (presented graphically). We used four survey questions, including their results, to prepare the discussion questions. After the introductory presentation, we conducted the online discussion, which lasted for 75 minutes. The participants were also given the opportunity to express their opinions and experience in written form in a shared Excel file. A critical point for the discussion concept was the time period we chose to contact the participants. Because many of the experts contacted did not have time in July, it was not possible, for example, to find more farmers with different forms of cultivation management experience.

We analysed the experts' answers qualitatively and developed inductive categories. We collected all text passages relevant to the research question from the discussion transcripts and paraphrased them. For the evaluation, we also considered the comments from the chat. The resulting paraphrases were subsumed by generalisation. We then compared the subsumption of the paraphrases with the original transcription. We also provide direct quotes of expert statements and arguments that were particularly relevant and informative.

3.2.4 WP IV: Best-practice examples for the application of digital technologies in other EU-countries and experts' dialogues

We conducted research to identify countries that use digitalisation intensively to identify best-practice examples on the use of new digital technologies (with a focus on the European Union [EU] member states). We determined Germany's position regarding digitalisation in agriculture by comparing to other European countries. We used the official EU website (European Commission, 2023a) and its database of publications, factsheets, reports, and projects for this endeavour. Since 2014, the European Commission has developed a monitoring programme for all EU member states to record their progress in digitalisation. The results are published annually in the Digital Economy and Society Index (DESI) reports. With a 2022 DESI index value of 52.9. Germany was in the middle of the EU countries (average for the EU: 52.3) regarding a digital economy and society (European Commission, 2022d). Germany is currently in 13th place among the EU member states. The first three places are taken by Finland, Denmark, and the Netherlands (European Commission, 2022c). Northern European countries lead the way, which is why we used the keywords "digitalisation" and "agriculture" in combination with "Norway", "Sweden", "Denmark", and "Finland". Furthermore, we searched the database of the rural development programmes by country (European Commission, 2023b) to identify additional best-practice examples of digitalisation in agriculture. We searched the eip-agri Agriculture and Innovation database (current a part of EU CAP Network; eip-agri (2023)) for best-practice examples. Separately, we searched the database of Horizon Europe, the EU's key funding programme for sustainable development, for projects and/or living labs relevant for this study.

In addition, the Food and Agriculture Organization of the United Nations (FAO) published in cooperation with the International Telecommunication Union (ITU) a status report of the digitalisation of 18 European and Asian countries (ITU & FAO, 2020). They especially considered the parts and countries of Europe that are somewhere in the process of EU accession and/or have suffered the most from underinvestment in the digitalisation of their agricultural sector. Based on these two documents, which narrowed the range of countries to be considered for the identification of best-practice examples in Europe, we conducted an internet search on available digital and smart farming technologies in the European countries with the highest DESI index. Moreover, we drew from our knowledge of the strongest and leading agronomically countries within the EU. We conducted the search with Google, adding the keywords "digital farming tools" and "sustainable agriculture" to the respective country. The results are shown in Chapter 10 under Table 3 to Table 5.

4 Inventory of the current environmental impact of agriculture in Germany

Within the context of the current ecological challenges such as climate change, environmental pollution, and the ecological footprint of economic sectors, the impacts of high-input agriculture are strongly debated. Along with other industrialised nations around the globe, German agriculture is known as one of the main contributors to Germany's greenhouse gas (GHG) emissions (8.3%). Moreover, it contributes to other serious environmental problems, such as groundwater contamination by NO_3^- leaching or loss of valuable biodiversity (Figure 9). Germany has shown its commitment to mitigate its GHG emissions and to mitigate air and environmental pollution by signing international protocols: the UN Framework Convention on Climate Change (United Nations, 1992); the Kyoto Protocol (United Nations, 1998); the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) (UNECE, 1979); and, within the European Union, the Directive of the European Parliament and of the Council on national emission ceilings for certain atmospheric pollutants (EU 2016/2284, 2016/14.12.2016). As a part of the UNFCCC since 1994, Germany has been obliged to prepare, publish, and regularly update national GHG emission inventories. All parties listed in ANNEX I of the UNFCCC are required to prepare and submit annual National Inventory Reports (NIRs) containing detailed and complete information on the entire process of preparation of such GHG inventories (UBA, 2021a).

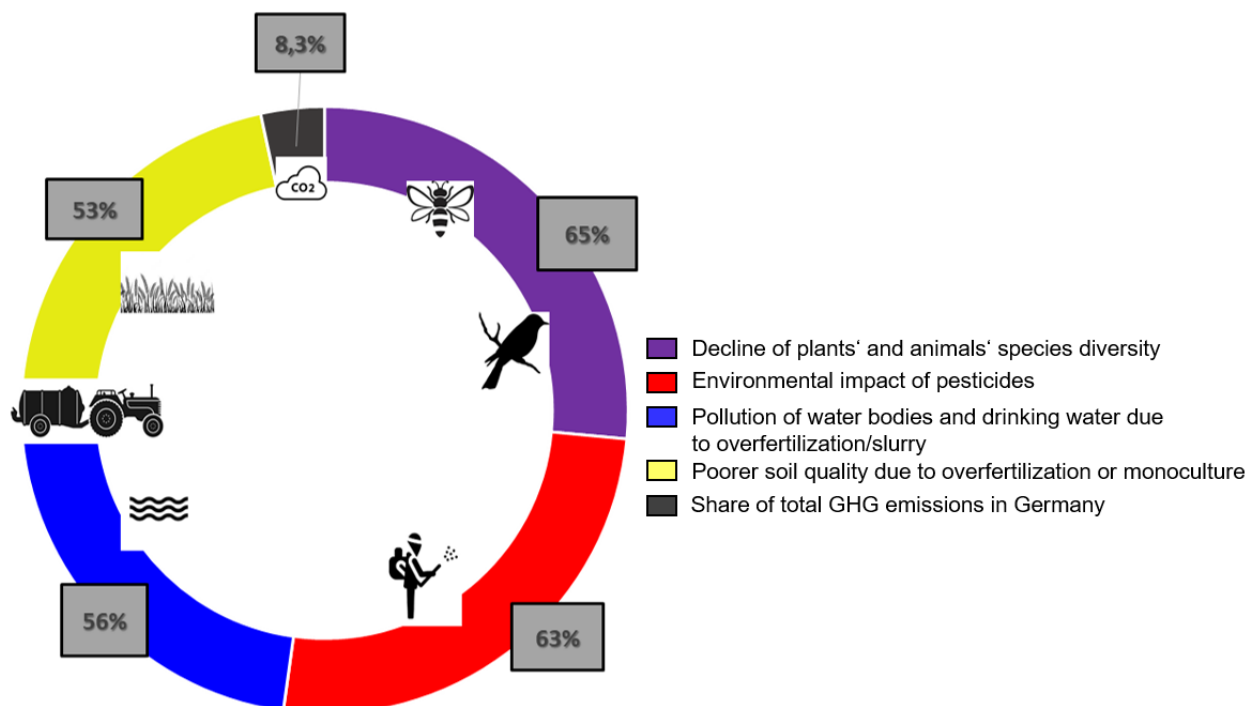


Figure 9. The environmental impacts of agriculture in Germany. Our illustration based on data from BMU and UBA (2019)⁶.

⁶ Data were gathered in 2018. It relies partly on a long-term survey since 1996 with biennial data collection rhythm.

Subscription to these conventions requires constant monitoring and screening of environmental- and biodiversity parameters as well as the relevant pollutants (Vos et al., 2022). In Germany, several directives specify the critical thresholds of pollutants from agriculture on the environment. These include among others the fertiliser law (DüV, 2017/10.8.2021), the Water Framework Directive (2000/60/EC, 2000/23 October 2000); the EU's biodiversity strategy (COM(2020)380, 2020) and the agreements and standards of the CAP (European Commission, 2022e). Despite these agreements, negative environmental impacts of agricultural land use in Germany have persisted and have even increased (BfN, 2023).

4.1 Gas emissions from agriculture and their negative impact on the environment

Agriculture accounts for almost 8% of Germany's total GHG emissions (BMEL, 2022g). Cultivation of soils, N fertilisers, and animal husbandry are crucial sources of climate-damaging GHGs such as methane (CH₄) and nitrous oxide (N₂O). In 2021, 65% of the total CH₄ and 77% of the total N₂O in Germany came from agricultural activities (UBA, 2022d). Figure 10 provides an overview of the development of the GHG emissions of carbon dioxide (CO₂), CH₄, N₂O, and NH₃ (converted to kt CO₂ equivalents a⁻¹)⁷ from German agriculture over the past 30 years. The graph shows a slight decline in GHG emissions of about 15.000 kt CO₂ equivalents a⁻¹ (-20.5%) from 1990 to 2020 (Figure 10).

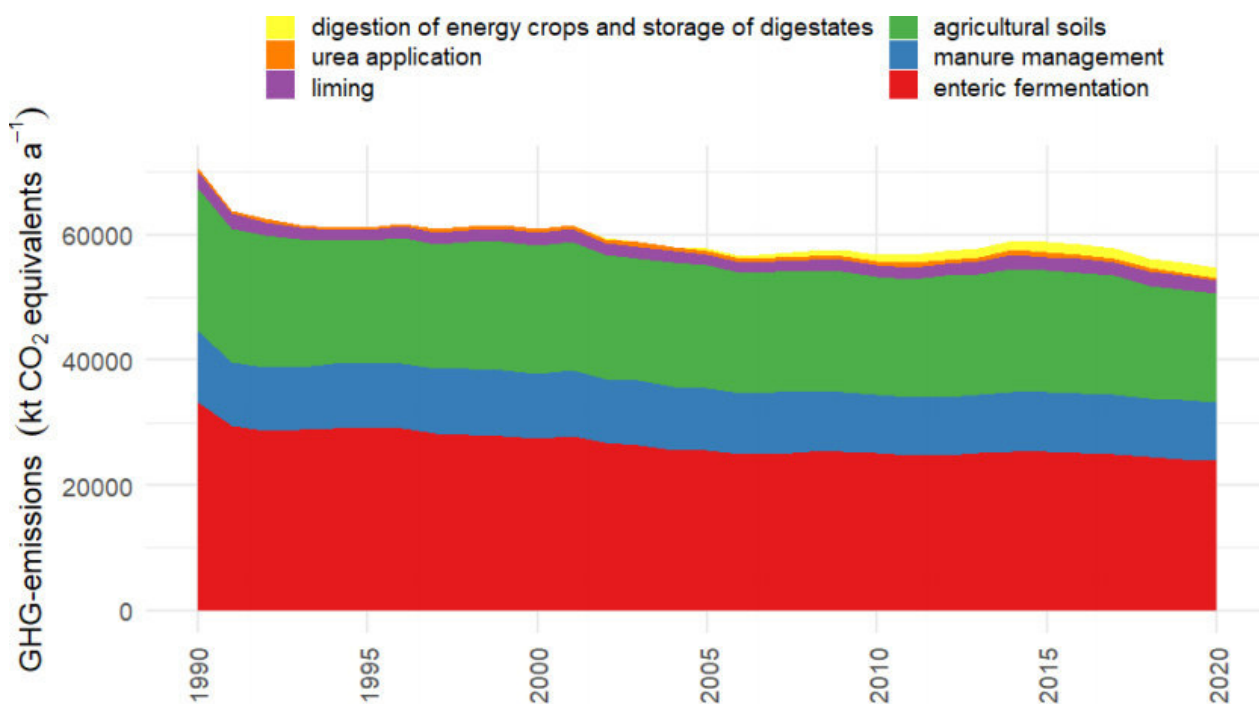


Figure 10. Annual greenhouse gas (GHG) emissions from German agriculture. Not included in the graph: emissions from mobile and stationary combustion in agriculture and forestry and emissions from intermediate inputs (e.g., fertiliser production). CH₄ and N₂O inputs were converted into CO₂eq units by multiplying GWP by 25 kg kg⁻¹ for CH₄ or by 298 kg kg⁻¹ for N₂O. CO₂ emissions from liming also include CO₂ emissions from liming in the forestry sector (Submission 2022). Adapted from Figure 2-1 in Vos et al. (2022).

⁷ Conversion factors: GWP_{CH₄} = 25; GWP_{N₂O} = 298

The negative environmental impacts of CO₂, CH₄, N₂O, and NH₃ emissions include, among others, the acidification and eutrophication of ecosystems, the near-surface heat balance of the atmosphere, and the adverse effects on human health. Therefore, there is an urgent need to follow the directives of the international conventions, such as the Kyoto Agreement (entered into force in 2005) (United Nations, 1998) and the CLRTAP (UNECE, 1979) to reduce total GHG emissions and to pursue the goal of the German climate protection law (KSG, 2019/Art. 1 G v. 18.8.2021 I 3905) to achieve GHG neutrality by 2045 (Vos et al., 2022).

Of note, the aforementioned 8% that agriculture contributes to Germany's GHG emissions does not include the upstream sectors like the production of operating supplies as well as other relevant material and energy flows in terms of fuels, fertilisers, and pesticides; additionally purchased concentrated feed; and other operating supplies (BLE, 2022b). The inclusion of fodder imports (soybeans) alone would add another 3.8–24 million t CO₂ equivalents a⁻¹ (depending on the land-use change in place) (Grethe et al., 2021). Therefore, the calculation of GHG emissions emanating from agriculture requires a comprehensive analysis of all involved factors.

Based on the categorisation of the NIR (UBA, 2021a), the relevant direct emission sources from agriculture originate from: enteric fermentation, manure management (including manure digestion and storage of manure digestates), use of agricultural soils, liming and use of urea. An additional origin of emissions analysed and presented in the NIR is emissions originating from the digestion of energy crops. (UBA, 2021a). Other important agricultural GHG sources like emissions from rice cultivation are not considered in the NIR, because they do not occur in Germany. Furthermore, slash-and-burn cultivation is not practiced in Germany and the burning of fields and crop stands is prohibited in Germany by law (UBA, 2021a).

The basis of all emission calculations of livestock is the feed intake of the animals. It is calculated as a function of the maintenance and performance-related energy demand. This results in the CH₄ emissions of enteric fermentation (3.A) and the excretion of carbon and N for the emissions from farm manure and digestate management. Management of digestates is also an important component for the calculation of N input into agricultural soils (UBA, 2022a). For an in-depth analysis of emissions, all animal husbandry is also categorised into sub-categories, according to their performance and housing systems. The key factor characteristic of the housing system is manure management.

The overall constant decrease in agricultural emissions since 1990, amounting to over 19.2%, is primarily due to reductions in livestock populations. Other factors are the reductions in emissions from agricultural soils and fertiliser use. The downward trend was partly interrupted by an increase in the total GHG emissions from agriculture in the mid-2000s. This increase is attributable to rising N₂O emissions as a consequence of higher N fertilisation. The increased N application was mainly caused by digestates of biogas production. The decrease since 2015 is the result of a notable decline in livestock populations and reduced application of synthetic fertilisers (UBA, 2021a; Vos et al., 2022).

Total GHG emissions from German agriculture decreased from 70.6 Tg CO₂ equivalents in 1990 to 56.1 Tg CO₂ equivalents in 2020 (-20.5 %) (see Appendix Table 4) (Vos et al., 2022). The main factors

influencing the modifications of GHG emissions are mostly a decrease in animal numbers after German reunification and a decrease in cattle numbers up to the middle of the first decade of the current century due to the limiting effect of the milk quota system and a subsequent recovery of cattle numbers after cancellation of the milk quota system on 31 May 2015 (Vos et al., 2022). The recorded increase in GHG emissions since the middle of the 2010s is due to an increase in N fertilisation, which is mainly caused by increased application of digestates from biogas production (Vos et al., 2022).

The gas emissions from agriculture and their impacts are presented below in descending order according to their share of total GHG emissions.

4.1.1 Methane (CH₄)

CH₄ emissions are the second largest contributor to global warming. The global warming potential of CH₄ is 28 times higher than CO₂ and 84 times more potent on a 20-year timescale (European Commission, 2021; Kuhla & Viereck, 2022). Figure 11 illustrates the share of agriculture of the total German CH₄ emissions between 1990 and 2022. Overall, the CH₄ emissions in Germany have decreased over the past 30 years, from 4.736 thousand tonnes in 1990 to 1.608 thousand tonnes in 2022. Because the share of other contributing sectors such as diffuse emissions from combustibles and CH₄ emissions from waste and waste water have been constantly decreasing since 1990, the share of agricultural contribution has become more and more significant. With over 1.200 kilotons, agriculture is the biggest driver of CH₄ emissions in Germany. CH₄ emissions from German agriculture emanate primarily from digestion processes of ruminants (especially of bovine and sheep), farm manure storage, as well as storage of fermentation residues of renewable natural resources (see Figure 11) (UBA, 2023a, 2023e).

The total contribution (thousand tonnes) of CH₄ emissions from agriculture has decreased by 25% since 1990 (Figure 11). This can mainly be attributed to a reduction in livestock populations, notably cattle. Their population has decreased by 42% from 1990 to 2020. In contrast, CH₄ emissions from enteric fermentation have only decreased by 28% in the same period. As single animal performance has increased significantly, part of the overall agricultural CH₄ reduction has been compensated for by better single animal performance (Appelhans et al., 2022).

Methane emissions by category

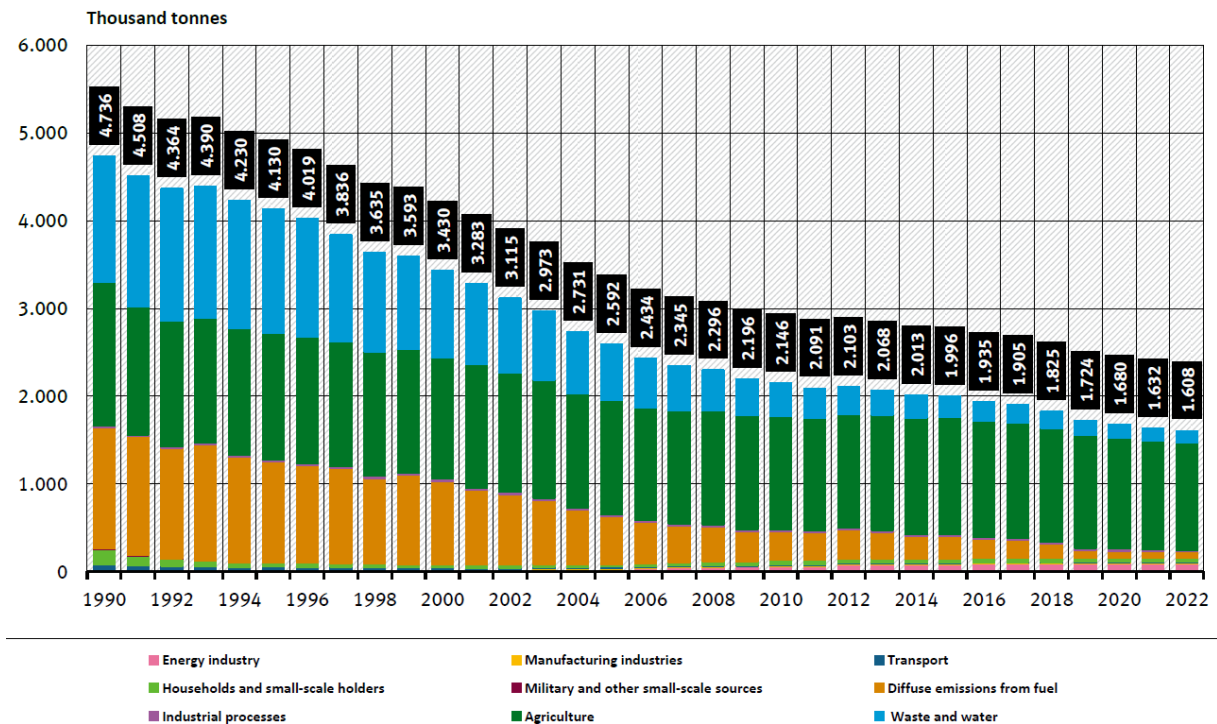


Figure 11. Methane emissions in Germany from 1990 to 2022 (in thousand tonnes) by category: energy industry, manufacturing industries, transport, households and small-holders, military and other small-scale sources, diffuse emissions from fuel, industrial processes, and agriculture. Translated and adapted from UBA (2023e).

In 2022, 61.6% of German agriculture emissions were CH₄. Thereof, 47.2% came from enteric fermentation (Figure 15). Emissions from digestion have been stagnant for years. In comparison, emissions from farm manure management fell by 28% between 1990 and 2020, as more manure is now used in biogas plants. On the other hand, new CH₄ emissions from the fermentation of energy crops have been added compared with 1990 (Appelhans et al., 2022).

Due to the relatively short mean residence time of CH₄ in the atmosphere (about 9–12 years), CH₄ mitigation can make an important contribution to mitigate global warming in the short term (Appelhans et al., 2022).

Hence, regarding agriculture, recommendations for mitigation actions include a reduction in CH₄ from animal digestion, in particular by reducing the number of animals, including import of meat or livestock products and their overall consumption. Other valuable aspects to reduce CH₄ emissions from livestock is to exploit the potential for reducing CH₄ emissions per unit of product via feed additives and by improving animal feeding, breeding, welfare, health, and longevity (Appelhans et al., 2022). Further, an expansion of manure fermentation in biogas plants and gastight storage of fermentation residues could substantially lower CH₄ emissions in agriculture. However, an expansion of farm manure fermentation should not lead to increased farm manure production capacities (Appelhans et al., 2022).

4.1.2 Laughing gas (N₂O)

N₂O has the most heat-trapping potential with respect to other GHGs and damages the ozone layer in the atmosphere. Given that other economic sectors, such as industrial processes, reduced their N₂O emissions significantly between 1990 and 2008, agriculture remains the most important contributor to N₂O emissions in Germany: about 53,000 t out of a total of 91,000 t in 2022 (Figure 12). The FAO estimates the direct and indirect agrifood shares of N₂O emissions in Germany was almost 80% in 2020 (Figure 13) Figure 13 and Figure 15 clearly show the importance of the agricultural sector for the overall N₂O emissions in Germany (FAO, 2020b).

According to the German Environment Agency (UBA, 2019), N-based fertilisers and livestock farming are some of the main point sources of N₂O. Within intensive livestock production, N₂O emissions are one of the byproducts of the use of N (Chmelíková et al., 2021). Figure 15 shows that the main part of N₂O emissions from the agricultural sector come from cultivation and management of agricultural used soils (29.0%). Moreover, 4.2% is from the management of organic fertilisers and 0.4% is from the atmospheric deposition of storage of fermentation residues of renewable raw materials.

Nitrous oxide emissions by category

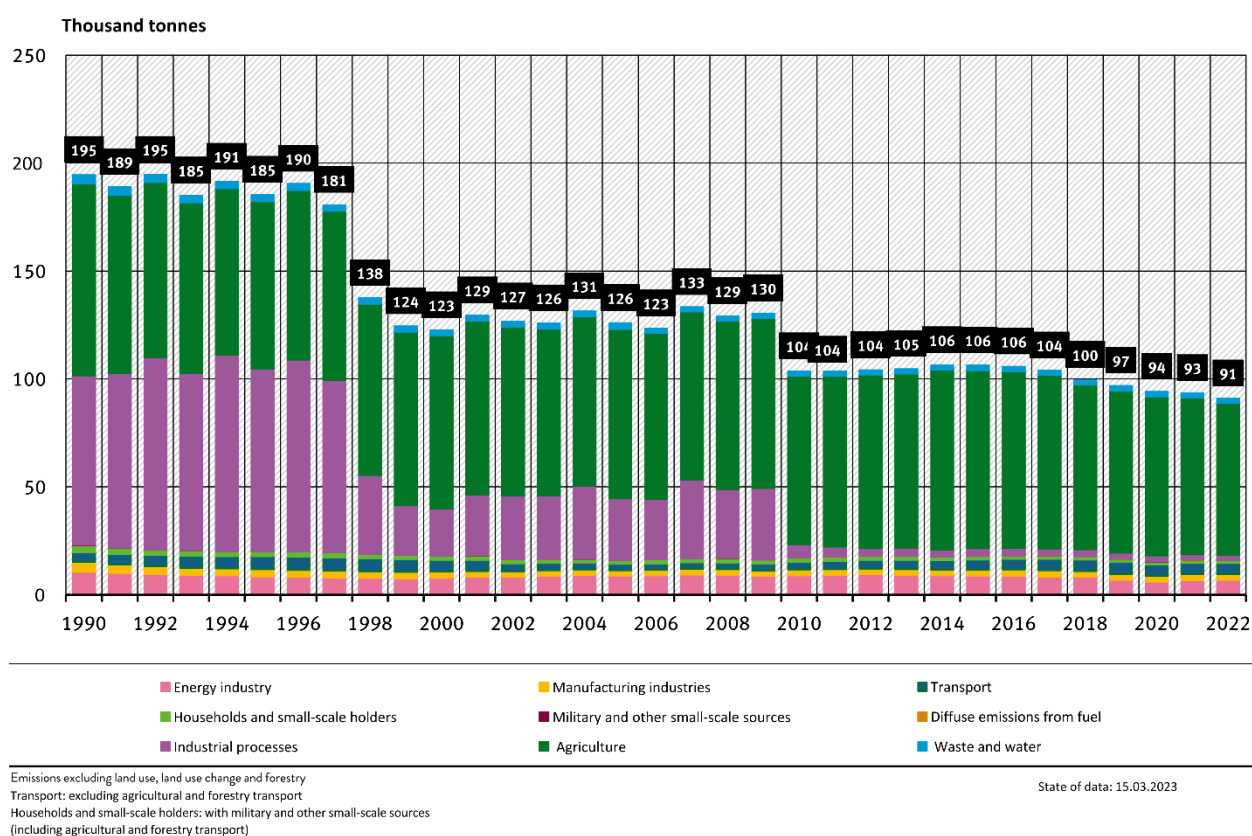
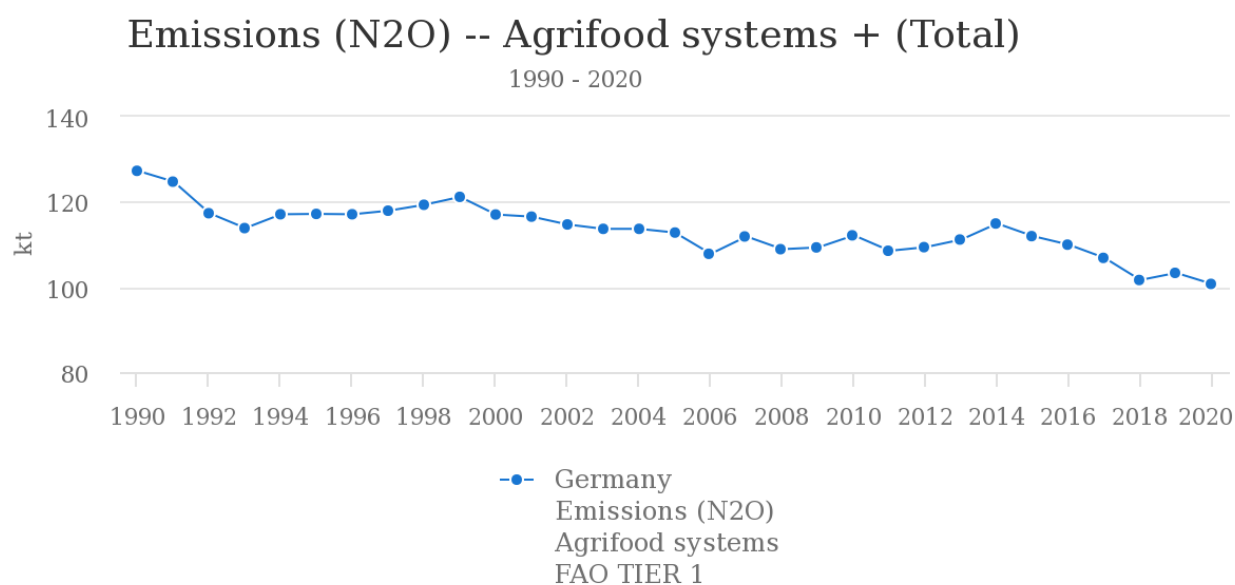


Figure 12. Nitrous oxide emissions in Germany from 1990 to 2022 in thousand tonnes by category: energy industry, manufacturing industries, transport, households and small-holders, military and other small-scale sources, diffuse emissions from fuel, and industrial processes. Translated and adapted from UBA (2023b).



Source: FAOSTAT (Oct 16, 2023)

Figure 13. Emissions of nitrous oxide in kilotons of agrifood systems in total emission in Germany. Graphical image extracted from FAO (2020b) by using the Items “Emissions Totals (N₂O)” and Agrifood systems” for Germany within the period 1990–2020. State of the image data: 16. October 2023.

It is important to note that there are direct and indirect sources of these emissions. Direct sources include farming activities such as N fertiliser application, atmospheric deposition of N in the soil, and N fixation by leguminous plants. The indirect sources include N₂O transformation from NO₃⁻ and ammonium (NH₄⁺) that are present in surrounding natural areas (UBA, 2019). Figure 13 presents the agrifood (direct and indirect) sources of N₂O and shows that the agricultural sector is largely responsible for its emissions in Germany (FAO, 2020b). According to BMWK (2023a), in Germany, N₂O emissions account about 3.2 % of total GHG emissions. Over a period of 100 years, it has 265 times the climate impact of CO₂. The concentration of N₂O in the atmosphere has increased sharply, especially in the past 20 years. The main sources are nitrogenous fertilisers and agricultural animal husbandry, because the gas is produced in particular when microorganisms break down nitrogenous compounds in the soil (BMWK, 2023a).

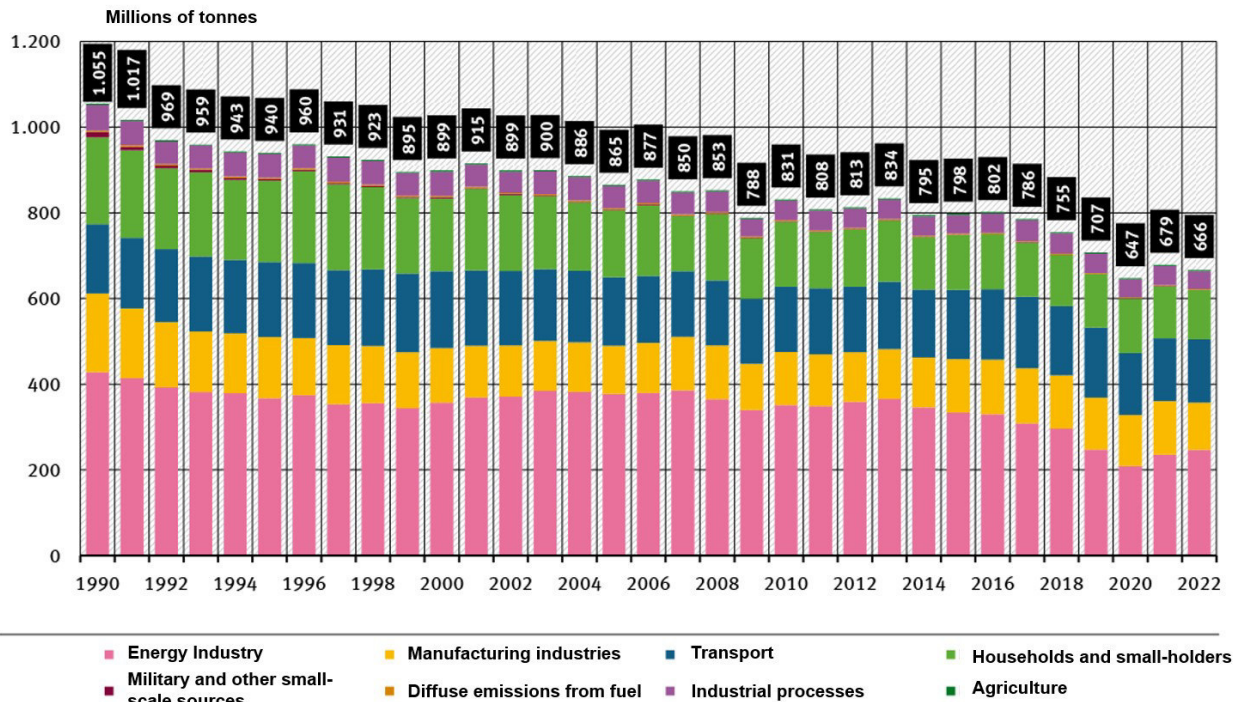
In addition, the yearly release of N₂O from soils under various agricultural crops is correlated with surplus N fertilisation (Guzman-Bustamante et al., 2019). Specific agricultural sectors such as drained peatlands and managed grasslands, are other significant areas of N₂O emissions – ranking second in terms of most important GHG emissions (Offermanns et al., 2023).

4.1.3 Carbon dioxide (CO₂)

Seventy-five per cent of global GHG emissions are believed to be attributed to the CO₂. This gas is viewed as the primary culprit for climate change (Mohammed et al., 2019). Figure 14 shows the overall CO₂ emissions in Germany per year (from 1990 to 2022) divided by the contributing sectors. For Germany, agriculture contributes the smallest amount to the overall CO₂ emissions. Most of the CO₂ emissions from agriculture are related to the livestock sector and soil use. In total, the CO₂ emissions from agriculture represent 4.6% of the overall agricultural GHG emissions (see Figure 15). These

numbers do not include the emissions from land use, land-use change, and forestry (LULUCF) (UBA, 2023a).

Carbon dioxide (CO₂) emissions by category



CO₂ emissions: excluding land use, land use change and forestry
 Transport: without agricultural and forestry transport
 Household and small-holders: with military and other small-scale sources
 (including agricultural and forestry transport)

Current state of data: 15.03.2023

Figure 14. Total carbon dioxide (CO₂) emissions in Germany from 1990 to 2022 (in million tonnes) by category: energy industry, manufacturing industries, transport, households and small-holders, military and other small-scale sources, diffuse emissions from fuel, industrial processes, and agriculture. Translated and adapted from UBA (2023c).

Shares of GHG in agricultural emissions (calculated in carbon dioxide equivalents) 2022

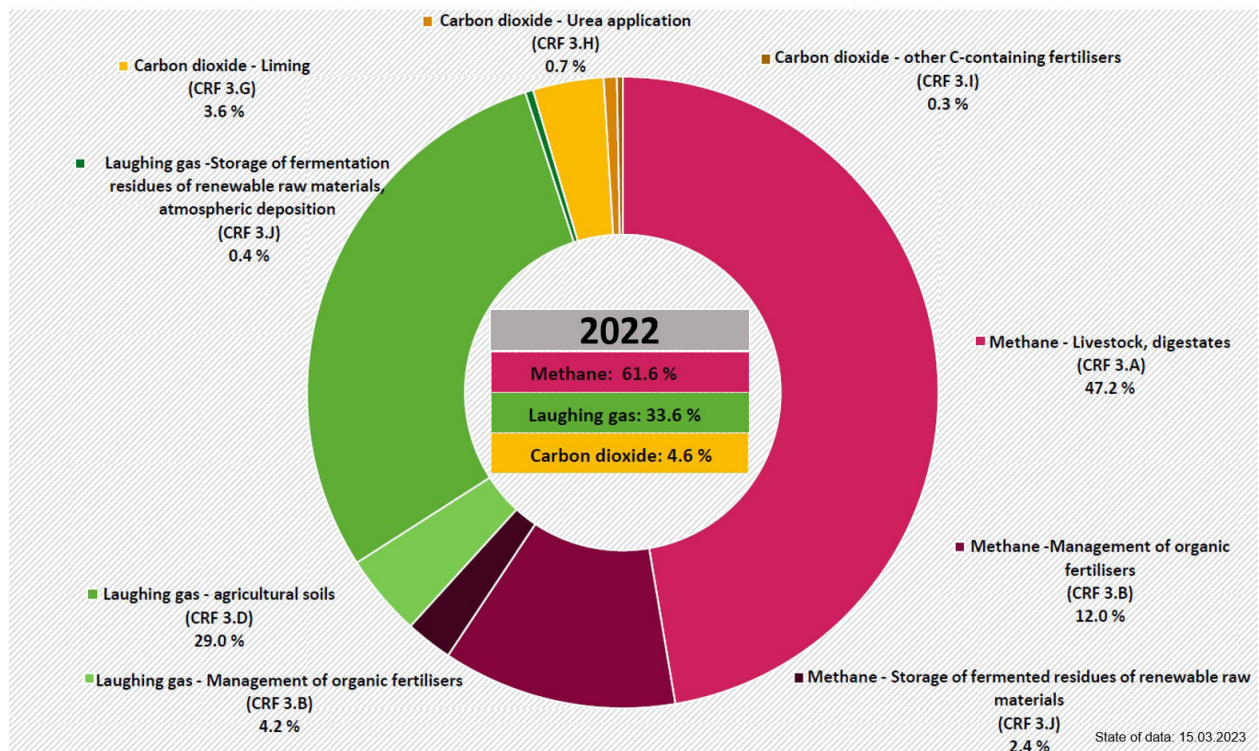


Figure 15. Share of individual greenhouse gases (GHGs) of the total agricultural GHG emissions. Translated and adapted from UBA (2023a).

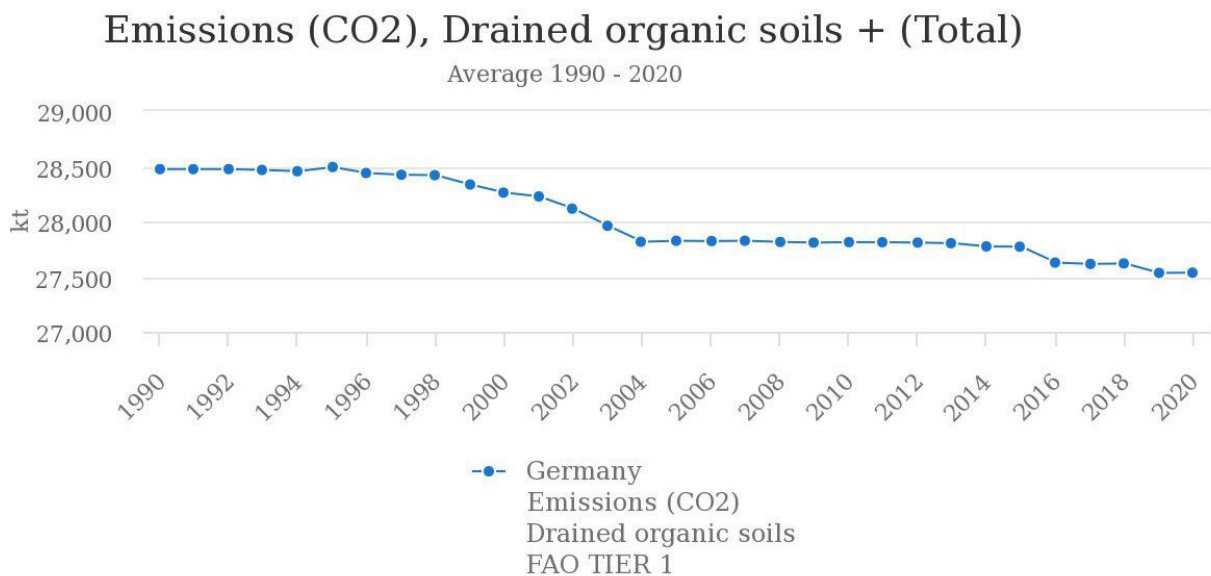


Figure 16. Carbon dioxide (CO₂) emissions from drained organic soils. Extracted from FAO (2023a) by using the Items “Emissions (CO₂)” and “Drained organic soils” for Germany in 1990–2020. State of the image data: 13 July 2023.

Figure 16 shows the German CO₂ emissions from drained organic soils⁸ over a 30-year period, calculated by the TIER 1 method of the IPCC (FAO, 2023a). From 1990 to 2004, CO₂ emissions from drained organic soils were reduced by almost 700 kt, followed by another 500 kt reduction until 2016. Nevertheless, the total emissions are still high and indicate the ongoing activity of land conversion and land-use changes. Tiemeyer et al. (2020) described and applied the German approach for measurement, reporting, and verification (MRV) of anthropogenic GHG emissions from drained organic soils. They calculated the yearly CO₂ emissions of drained organic soils as 50.5 million t. As of 2014, this accounted for 6.6% of the national German GHG emissions (Tiemeyer et al., 2020).

The amount of carbon stock available in the soil and the amount released due to agricultural activities depends on the context. Mayer et al. (2019) demonstrated that there is a strong relationship between the generic soil type, topography, land use, and organic carbon stocks. The results from a German soil condition survey by the Thünen Institute show that after oceans, soils are the second largest carbon sinks, storing more than 2 billion tonnes (BMEL, 2022a). However, agricultural practices like converting grasslands into arable land or draining peat soils for agricultural purposes have become a source of CO₂ emissions (BMEL, 2022a). While drained peatlands only make up approximately 5% of the total agricultural area of Germany, they account for nearly 6.7% of the German GHG emissions. Data from 2021 show that of these emissions, more than 90% are CO₂ (Thünen-Institut, 2023). While agriculture and land-use change have a negative effect on CO₂ emissions, mitigation strategies like flower strips and hedgerows act as a carbon sink. Harbo et al. (2023) concluded that converting 1% of the agricultural land in Germany to flower strips, which increases the soil organic carbon stocks, could mitigate 0.24 Tg CO₂ per year, which is equivalent to 0.4% of the current German GHG emissions. Increasing the organic carbon in the soil is important as it benefits the soil ecology and can prevent the carbon from being oxidised and converted to CO₂. Hedgerows established in cropland have also proved to be an excellent mitigation strategy for sequestering carbon in the soil while simultaneously promoting soil protection and biodiversity (Drexler et al., 2021).

4.2 Nitrogen pollution from agriculture and its negative impact on the environment

N is an essential component of living organisms; for plants, N is a component of amino acids from which proteins are made (Evans, 1989; Gruber & Galloway, 2008). Furthermore, N is a component of chlorophyll in plants and hence important for photosynthesis. Therefore, it plays a major role in agriculture, especially when it comes to achieving high crop yields.

⁸ Organic soils are wet soils ecosystems, characterised by very high levels of organic matter, which accumulates under the anoxic conditions that exist in the presence of water. They include tropical and boreal peatlands, high-latitude bogs, ferns, and mires. While organic soils cover globally a mere 3 percent of the terrestrial land area, they represent up to 30 percent of the total soil carbon, playing an important role in maintaining the earth's carbon balance. Drainage of organic soils releases large quantities of carbon dioxide (CO₂) and nitrous dioxide (N₂O) into the atmosphere and for several decades after the drainage event, due to the increased oxidation rates of the underlying organic matter. Source: FAO (2020a).

However, N also plays a major role regarding the environmental impacts of agriculture. Too much N input into agricultural fields can have wide-ranging negative consequences for the surrounding ecosystems (see Figure 17). In the form of NO_3^- , high N input leads to contamination of groundwater bodies and acidification of soils and waterbodies, changes that reduce biodiversity and promote eutrophication of forests, peatlands, heathlands, surface waters, and oceans (UBA, 2022e).

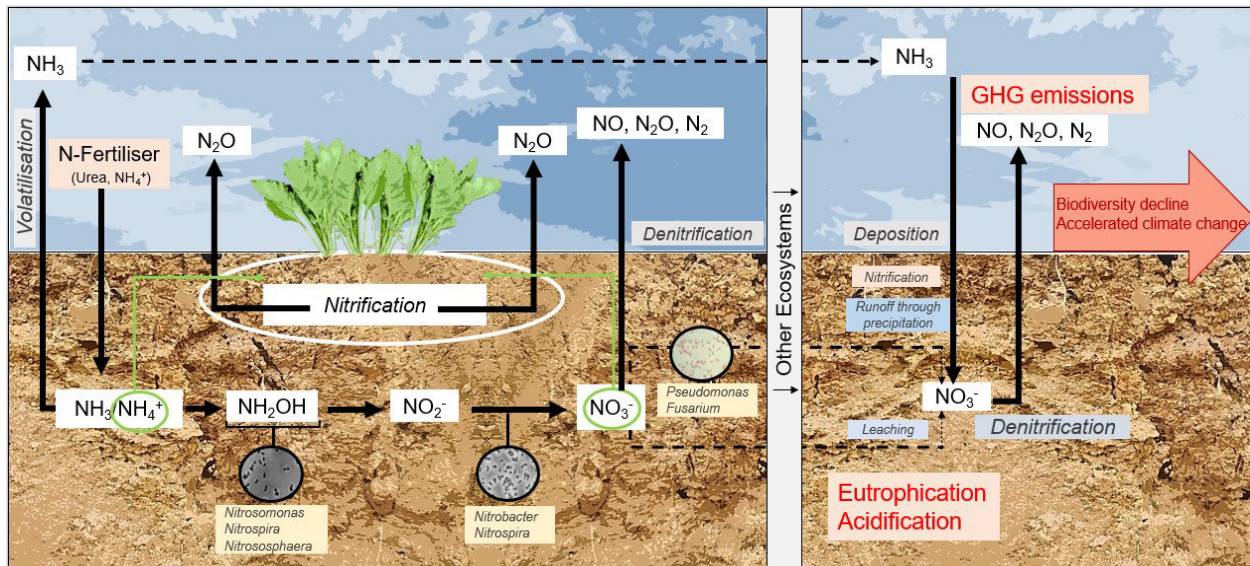


Figure 17. The cycle of nitrogen fertilisers applied to agricultural systems (adapted from Figure 2 in Coskun et al. (2017) with additional information from Galloway et al. (2003)).

Figure 18 shows the total fertiliser consumption (nutrient N, phosphate, and potassium [potash]) in German agriculture from 1961 to 2020. The graph shows a clear decline around 1990. This overall decline can mainly be attributed to the reduction of livestock in the new federal states of Germany after German reunification and efficiency gains in N use (yield increases in crop production and higher feed conversion in livestock) (UBA, 2022e). Nevertheless, a total use of 1.9 million t fertilisers (N: 1.265 million t; phosphate: 192.000 t; potassium: 446.00 t (see Appendix Table 5, Appendix Table 6, Appendix Table 7) in German agriculture in 2020/2021 is still a high input for the environment (Figure 19) (BMEL, 2022k).

Fertiliser consumption in nutrients 1961 - 2020

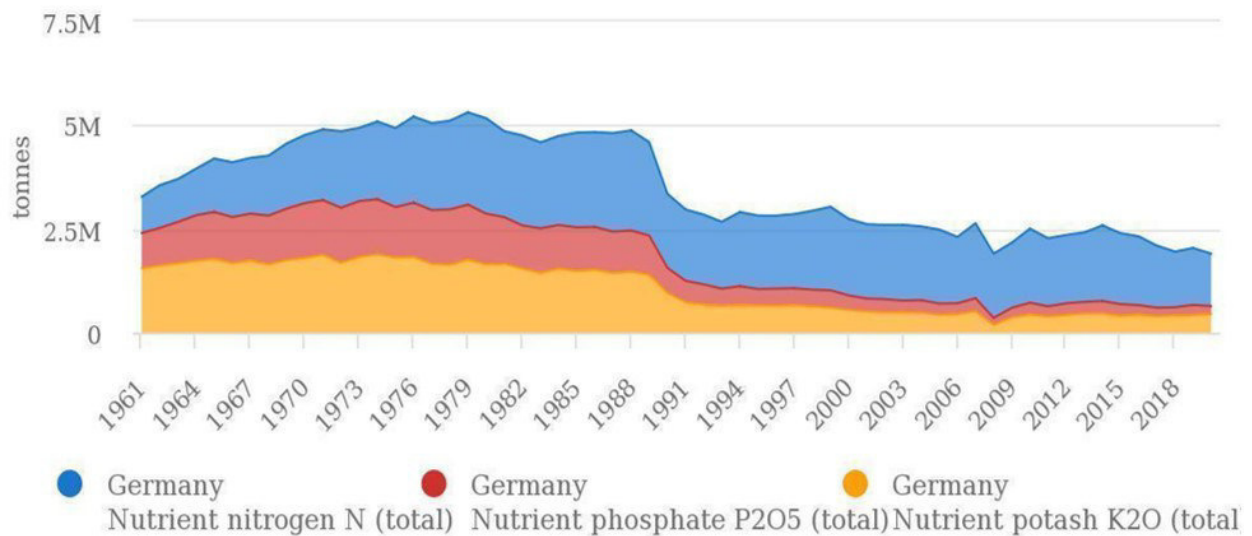
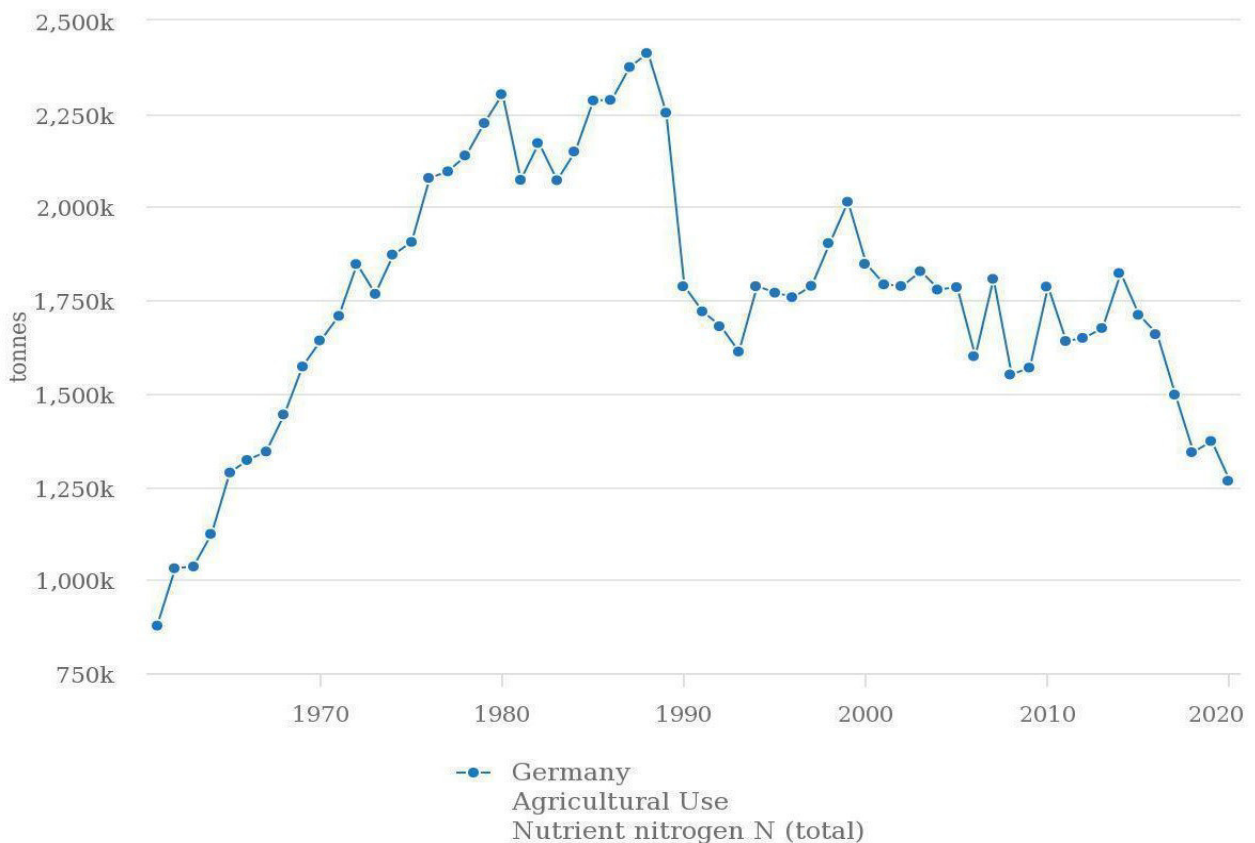


Figure 18. Fertiliser consumption in Germany (nitrogen, phosphate, potash; in tonnes) from 1961 to 2020. Extracted from FAO (2023b) by using the items “Nutrient nitrogen N (total)”, Nutrient phosphate P₂O₅ (total)”, and “Nutrient potash K₂O (total)” for Germany for the period of 1961–2020. State of the image data: 26 January 2023.



Source: FAOSTAT (Jan 26, 2023)

Figure 19. Nitrogen (N) use (in tonnes) in Germany between 1970 and 2020. Extracted from FAO (2023b) by using the items “Nutrient nitrogen N (total)” and “Agricultural Use” for Germany for the period of 1961–2020. State of the image data: 26. January 2023.

In addition, between March 2019 and February 2020, 209 million t farm manure was applied to cropland and grassland (Bundesinformationszentrum Landwirtschaft, 2022). The overall positive trend of a reduced fertiliser consumption in German agriculture has still led to negative environmental consequences. In particular, the actual N surplus loads for environmental elements such as waterbodies is still too high and exceeds the critical thresholds.

Table 1 shows the yearly accruing N excretion per livestock species in Germany between 1990 and 2019 (UBA, 2021a). Except for horses and sheep, the yearly N excretion per animal species has increased over the years. Table 2 presents the origin of N (farm manure) depending on the respective stable or grazing system. The total amount (in kg N ha⁻¹) is obviously decreasing. When considering the different systems indicates this trend applies to the slurry-based, straw-based, and grazing systems (Table 2). For the deep bedding and especially the digestion systems, N excretions has increased⁹ significantly (UBA, 2021a). With a yearly input of 76 kg N ha⁻¹ agriculturally used area in 2020/2021, the actual input of N still lies beyond the mean target value of 70 N ha⁻¹ agriculturally used area of the national sustainability strategy (BMEL, 2022k; Die Bundesregierung, 2020).

The overall positive trend of a reduced fertiliser consumption in German agriculture has still led to negative environmental consequences. In particular, the actual N surplus loads for environmental elements such as waterbodies is still too high and exceeds the critical thresholds.

Table 1. Nitrogen (N) excretion per animal species and year for the four management systems – slurry based (without digestion), straw based (without deep bedding and without digestion), deep bedding (without digestion) and digestion¹⁰ – as well as grazing. Adapted from Table 236 in UBA (2021a).

[kg place ⁻¹ a ⁻¹]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dairy cows	92.0	97.9	103.8	108.9	110.3	111.0	111.3	110.7	111.8	113.1	114.5	114.3	116.8	120.0
Other cattle	38.1	40.4	41.9	41.8	42.6	42.4	42.4	42.5	42.5	42.8	42.7	42.9	43.1	43.5
Swine	12.1	12.6	12.7	12.8	12.9	12.9	12.9	13.0	13.0	13.0	13.1	13.2	13.3	13.3
Sheep	7.7	7.7	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Horses	48.2	48.1	49.0	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8
Poultry	0.69	0.66	0.69	0.74	0.77	0.75	0.72	0.69	0.71	0.72	0.73	0.73	0.74	0.74

Table 2. Annual nitrogen (N) excretion separated by manure management systems and grazing systems. Adapted from Table 237 in UBA (2021a).

[kt a ⁻¹]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	1534.9	1328.1	1298.8	1256.1	1255.3	1259.9	1279.4	1294.3	1310.1	1305.3	1297.6	1293.2	1275.1	1265.1
Slurry-based ^a	849.3	806.9	794.4	740.7	636.6	615.5	616.6	602.8	605.7	597.6	597.4	594.9	586.8	580.7
Straw-based ^b	421.9	293.6	284.7	275.5	281.0	283.8	289.5	293.9	297.1	297.2	295.1	294.4	294.1	292.4
Deep bedding ^a	49.5	52.4	57.1	67.3	70.6	67.7	67.4	68.0	68.0	66.6	65.9	64.7	62.9	61.5
Digestion	0.04	0.56	4.8	32.4	132.7	161.6	175.3	197.7	206.1	209.6	206.2	207.3	201.2	201.2
Grazing	214.2	174.7	157.8	140.2	134.3	131.2	130.6	131.9	133.3	134.3	133.0	132.0	130.0	129.2

^a Without digestion

^b Without deep bedding and without digestion

⁹ In solid-manure systems, additional nitrogen enters the system via the bedding material. In BMEL (2020c), this nitrogen is taken into account in calculation of laughing gas and nitrate nitrogen oxide emissions from manure management.

¹⁰ According to UBA (2021a), the digestion category includes all animals whose manure is digested.

Considering the spatial distribution of N surpluses in Germany, Figure 20 a) shows the shift of the mean N surpluses (a) and the N use efficiency (NUE) (b) in Germany between 2015 and 2017. The NUE is defined as the quotient of N uptake/harvest removal and N supply. Notably north-western Germany shows very high N surpluses of 120 – 162 kg N ha⁻¹ agriculturally used area. Likewise, a small region in east-central southern Germany display similar mean N surpluses. There are very low mean N surpluses of 26–60 kg N ha⁻¹ agriculturally used area in the diagonal axis from north-eastern to south-western Germany (Figure 20). The majority of the hot spot areas with the highest mean N surpluses of 120–162 kg N ha⁻¹ agriculturally used area show a poor mean NUE of 0.53 to 0.60 (equivalent to 53%–60%). The same poor NUE applies to the hot spot areas in southern Germany (Figure 20 b). For the north-eastern/south-western axis with a lower N surplus, the mean NUE is comparatively diverse. There is a very good NUE in north-central Germany of 75%–79% and a worse NUE of 70%–75% in the northern parts of Mecklenburg-Western-Pomerania; the corner of Saxony-Anhalt, Lower Saxony, and Thuringia; and the border area between Hesse and Rhineland-Palatinate. There is an even lower NUE of 65%–70% in the northern parts of Bavaria and Baden-Wuerttemberg, at the border area of Brandenburg and Saxony-Anhalt, the northern part of Hesse, southern Rhineland-Palatinate and Saarland, the south-eastern parts of Baden-Wuerttemberg, and the central parts of Bavaria (Figure 20).

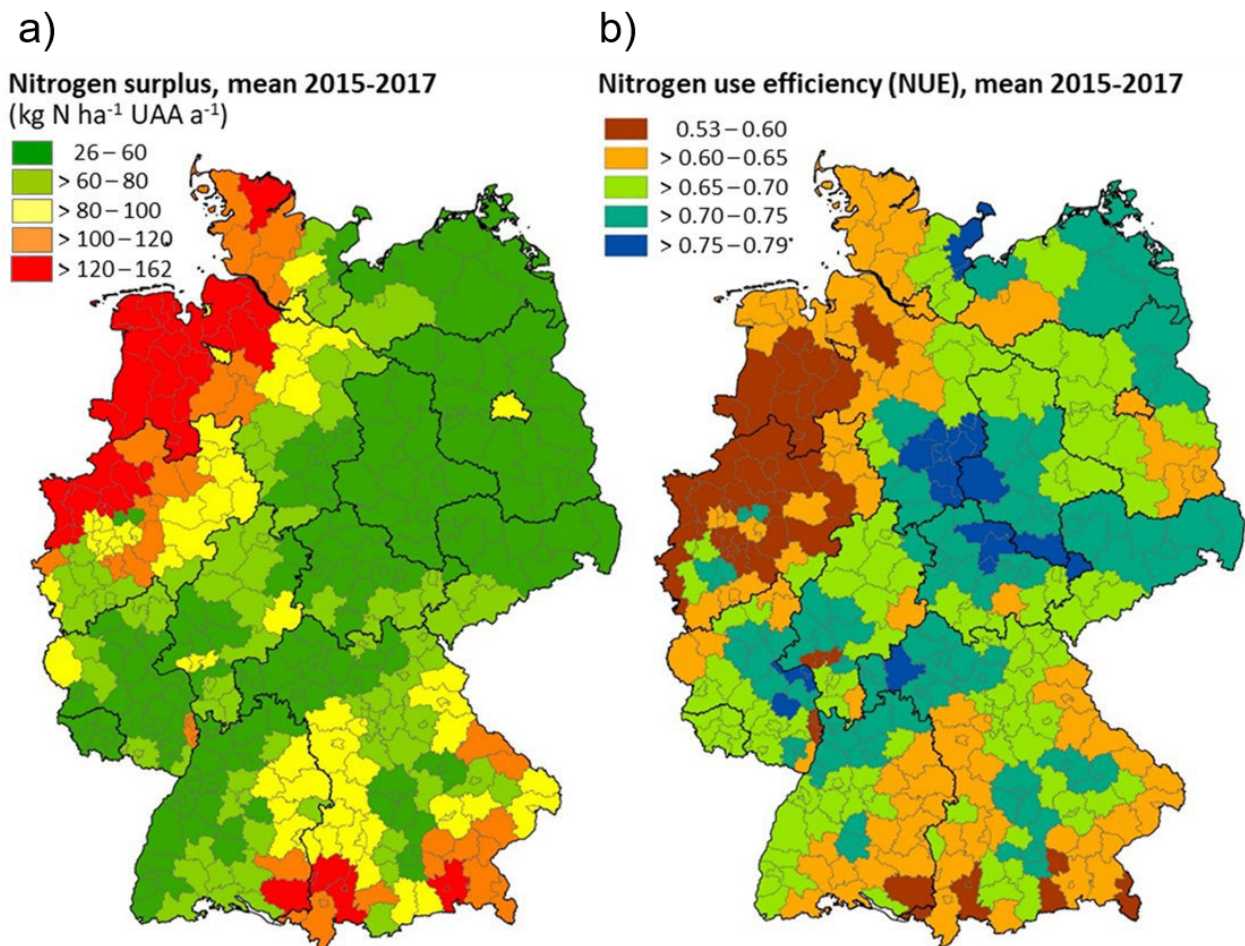


Figure 20. a) Nitrogen budget surplus of nitrogen soil surface budgets of districts in Germany. Means for the period 2015–2017. b) Nitrogen use efficiency (mean 2015–2017). Original image (Fig.3) from source Häußermann, Klement, et al. (2020).

The NUE is a critical parameter as well as for the soil fertility as for the environment. The ideal NUE for preservation of the soil fertility and a clear mitigation of environmental impacts, ranges between 75 and 90%. A NUE higher than 90% means a too high harvest removal of N and leads to a significant loss of soil biodiversity. A NUE lower than 75% means too high N to the environment such as eutrophication of water bodies or increased N₂O emissions by denitrification of non- absorbed nitrogen from fertilization (Osterburg, 2017; Ratjen & Kage, 2012). A low NUE can be the result of the cultivation of crops, which do not absorb high amounts of N (e.g., oilseed rape or silage maize), deficits in fertilizer management/lack of codes of good practice or application of fertilizers with a high content of organic N or mineral carbamide N, which cannot be completely absorbed by the plants and not be converted into biomass (Osterburg, 2017). The discussed hot spot areas in northwest Germany (western Lower Saxony and northern North Rhine-Westphalian) are characterised by intensive livestock farming and biogas plant operations. Therefore, high export volumes of N (farm manure) are indispensable for these regions. Since farm manure cannot be exported to the Netherlands or Belgium, as they are themselves affected by high N surpluses due to intensive livestock farming, long farm manure export distances must be added to the environmental impacts of these regions (Osterburg, 2017).

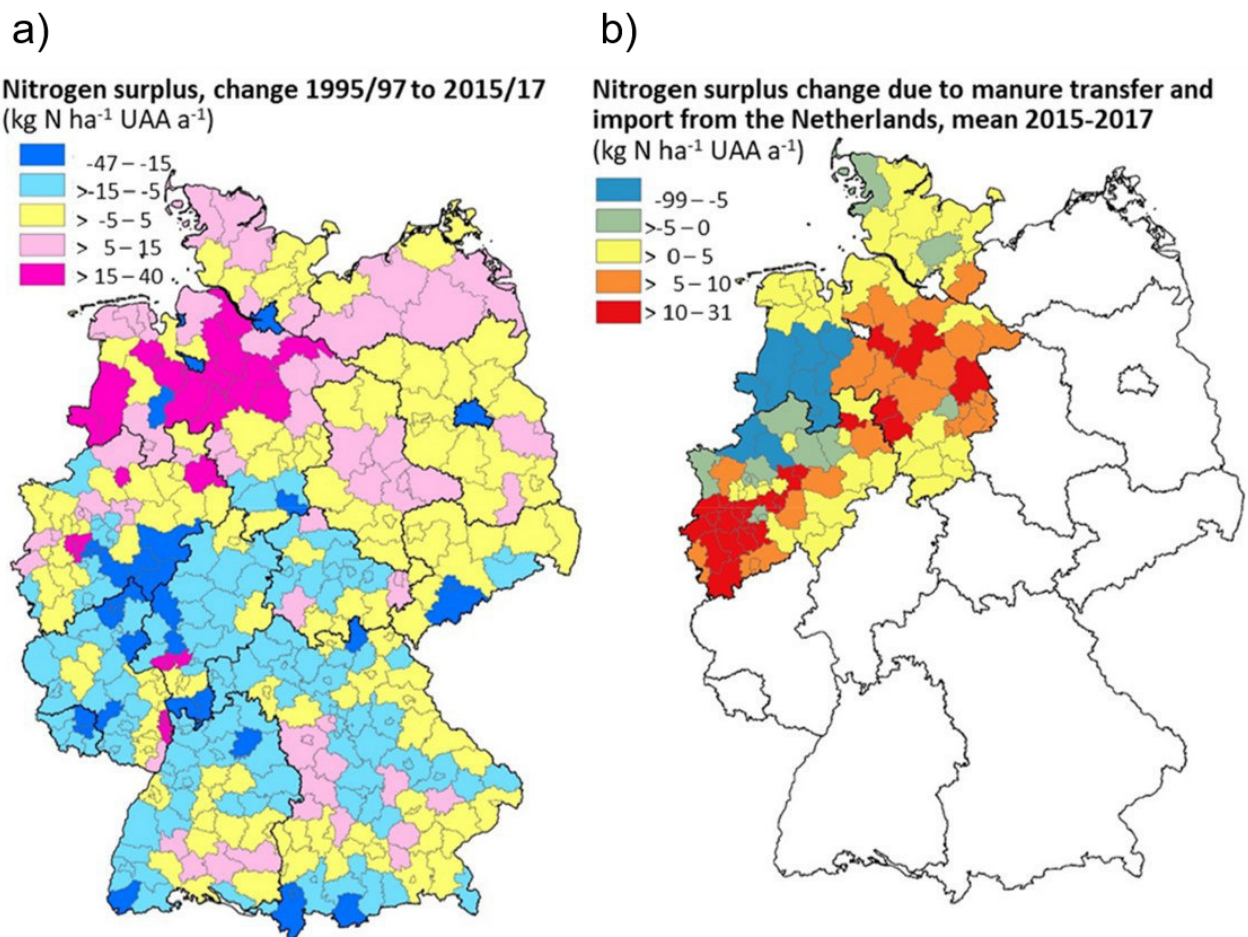


Figure 21. (a) Change in the mean nitrogen surplus from 1995/97 to 2015/17 per utilised agricultural area (UAA). (b) Change in the mean nitrogen surplus due to manure transfer and import from the Netherlands in 2015–2017. Adapted from Figure 3 in Häußermann et al. (2020).

Figure 21 a) shows the mean N surplus changes (kg N ha⁻¹ agriculturally used area) in Germany from 1995/97 to 2015/17. The results are consistent with Figure 20 high surpluses in north-western Germany, where the mean N surplus was also high in 2015/2017. There is not a significant increase or change in the N surplus for the southern parts of Germany, where the mean N surplus in 2015/17 was also 120–162 kg N ha⁻¹ agriculturally used area. These regions seem to have had a relatively stable N surplus over the last 20 years. Figure 21 b) shows the amount of manure (N) import from the Netherlands. Based on the displayed transfers and imports of manure (N), the overall high mean N surplus in north-western Germany is not just the result of high domestic N surpluses. It is also a consequence of manure imports and transfers from intensive livestock farming regions in the Netherlands (compare Figure 21 (b) and Figure 20 (b)).

4.2.1 Nitrate (NO₃⁻)

NO₃⁻ losses through leaching are extremely low in natural and stable ecosystems. This phenomenon is not only due to a continuous uptake of N mineralised in the soil by existing vegetation; it is also because oxidation of the NH₄⁺ formed is specifically prevented by inhibition of nitrification by various plant species that cover the ground (Subbarao et al., 2006). In agriculture, NO₃⁻ enters the soil either by direct

application in the form of mineral fertilisers (potassium, calcium, sodium, and ammonium NO_3^-) or by the degradation (nitrification) of added organic fertilisers such as farm manure (slurry or solid manure) (UBA, 2022c). Soil NO_3^- values that are too high due to over-fertilisation or inadequately adapted fertilisation (especially beyond 70 kg N ha^{-1} agriculturally used area) cannot be taken up by the plant roots and will be leached out of the soils and reach the surrounding ecosystems including ground-waterbodies (Figure 17) (Ortmeyer et al., 2022). As specified by the EU Groundwater Directive, the maximum NO_3^- concentration within groundwater bodies in Germany is 50 mg l^{-1} (GWRL 2006/118/EC, 2006/12.12.2006). Figure 22 clearly shows the negative influence of agriculture on the abundance distribution of NO_3^- in German near-surface groundwater bodies. Groundwater bodies close to agriculturally used areas show a NO_3^- concentration that is ≥ 160 percentage points higher than the 50 mg l^{-1} limit compared with groundwater bodies without the influence of agriculture (Figure 22). BMEL (2020c) reported that for 2016–2019, high NO_3^- concentrations ($> 50 \text{ mg l}^{-1}$) occurred significantly more frequently at the agriculturally dominated monitoring sites, with a share of 26.7%, compared with the non-agriculturally dominated monitoring sites, with a share of approximately 5%. Only a slight decrease in NO_3^- levels in agriculturally influenced groundwater has been recorded since 2015. Therefore, the NO_3^- contamination of groundwater bodies in Germany is still classified as too high (BMEL, 2020c).

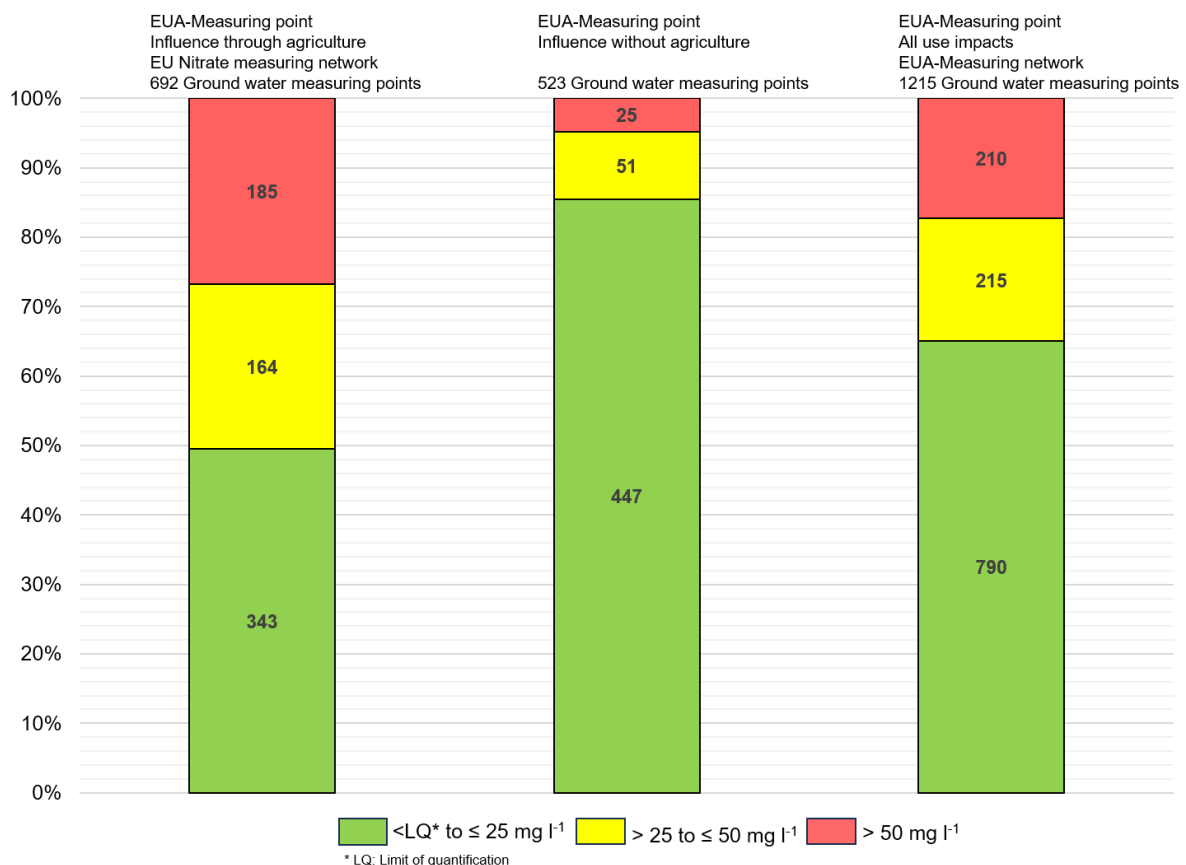


Figure 22. Abundance distribution of the nitrate (NO_3^-) concentration (%) in near-surface groundwater bodies at European Environment Agency (EUA) measurement sites between 2016 and 2018 according to the Nitrate Report 2020. Adapted from Abbildung 7 in BMEL (2020c).

Figure 23 shows the spatial distribution of NO_3^- input loads ($\text{kg N ha}^{-1} \text{ a}^{-1}$) transported across the unsaturated zone to the groundwater in Germany for the period of 2007-2016. The situation is consistent with the situation displayed in Figure 20. The highest NO_3^- loads ($> 40 \text{ kg N ha}^{-1} \text{ a}^{-1}$) occur predominantly in the areas with intensively managed agricultural systems in north-western Germany (the southern parts of Lower Saxony and the northern parts of North Rhine-Westphalia) as well as in the eastern parts of Baden-Wuerttemberg and southern Bavaria (Figure 23). There are also some hot spot areas in the triangle of eastern Lower Saxony, Brandenburg, and Saxony-Anhalt; southern Rhineland-Palatinate; and north-eastern Baden-Wuerttemberg (Figure 23). However, it should be noted that these are the loads and not the groundwater NO_3^- concentrations and therefore cannot be linked to the limit value of $50 \text{ mg NO}_3^- \text{ l}^{-1}$ (Knoll et al., 2020).

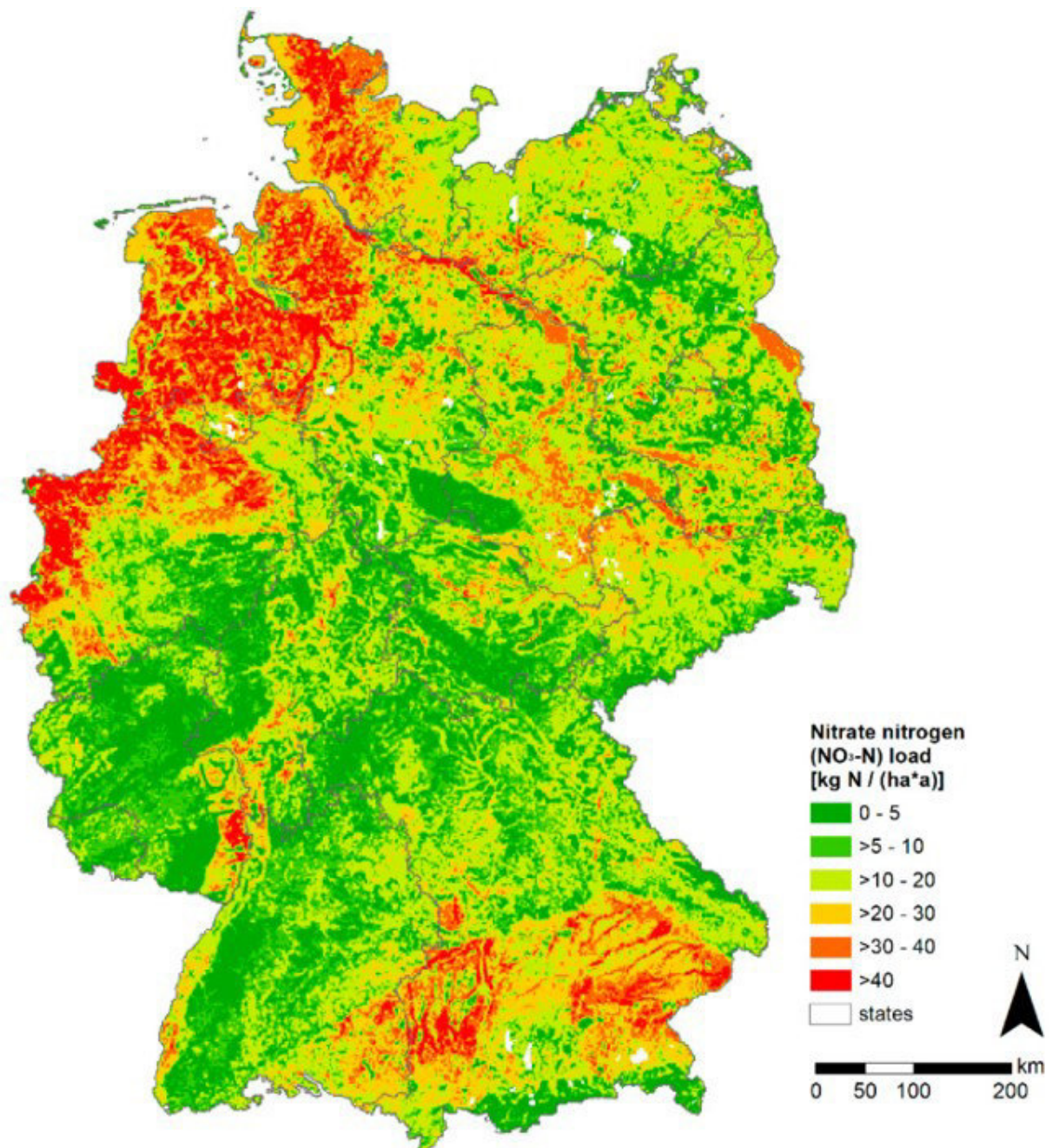


Figure 23. Nitrate-nitrogen input load in the groundwater (NO₃-N_loadinput_gw) based on a 1 × 1 km grid map of Germany for the period of 2007–2017. Adapted from Figure 3 in Knoll et al. (2020).

Figure 24 presents the actual N pollution as mg NO₃⁻ l⁻¹ in German groundwater bodies. Again, the distribution of the hot spot areas with NO₃⁻ concentrations > 50 mg l⁻¹ are in the north-western, south-eastern, and central regions of Germany around Magdeburg, Erfurt, and Leipzig, areas characterised by intensive managed agricultural systems.

Mitigation measures are clearly required to reduce the total input load and concentration of NO₃⁻ in groundwater bodies. One essential control parameter is site-adapted and economical fertilisation. However, local hydrogeological characteristics have a substantial influence on the potential to reduce NO₃⁻ in the respective waterbodies (Knoll et al., 2020; UBA, 2018).

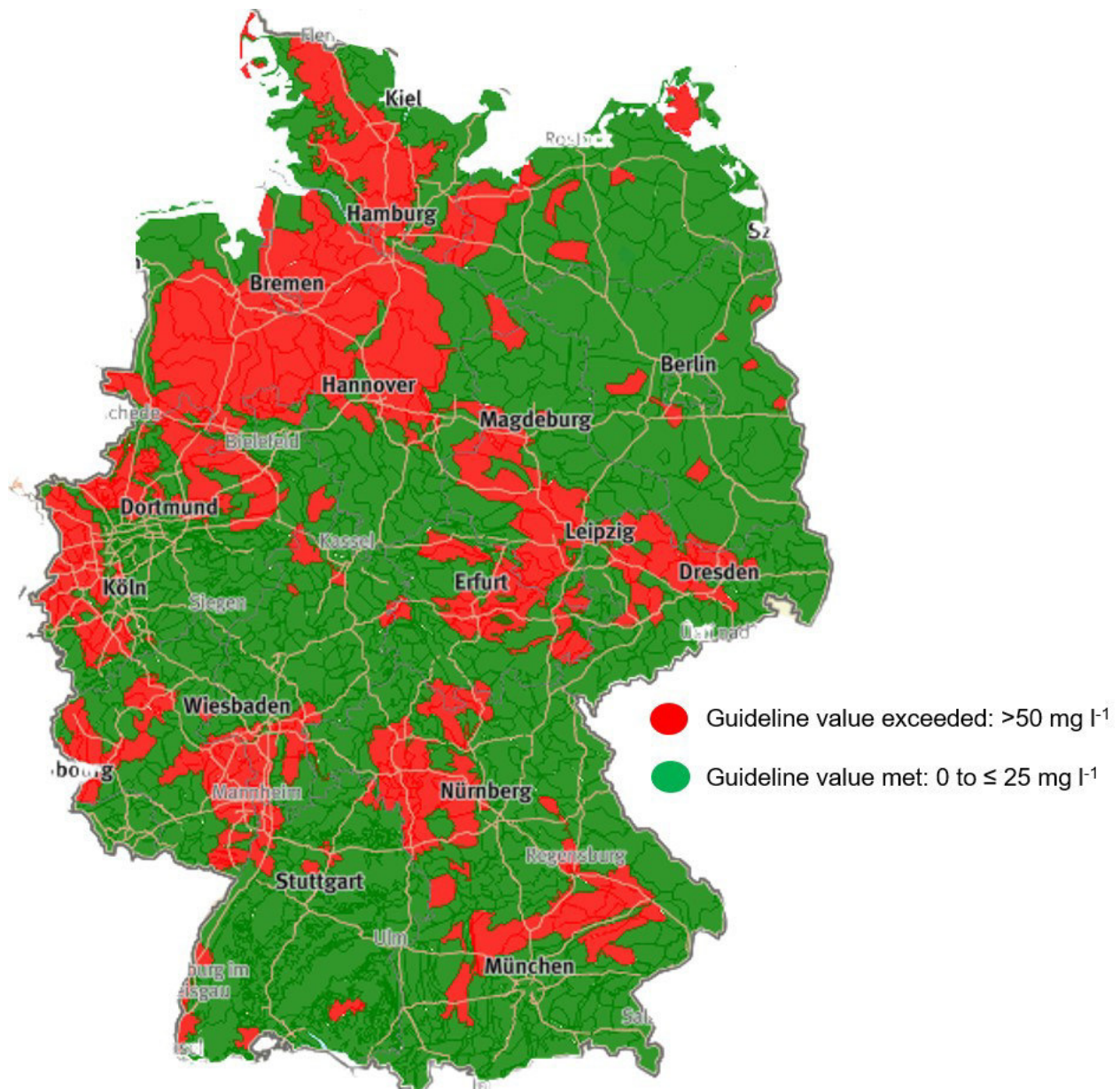


Figure 24. Nitrogen (N) pollution of groundwater bodies in Germany in 2020 derived from UBA (2020). The map data are from OpenStreetMap contributors (Esri©).

4.2.2 Ammonia (NH₃) and ammonium nitrogen (NH₄⁺)

Agriculture is the main contributor of NH₃ emissions in Germany: in 2016, agriculture accounted for a total emission of 629 kt NH₃, representing 95% of the total German NH₃ emissions (Häußermann, et al., 2020). The air pollutant NH₃ originates primarily during N management of livestock feeding strategies, animal housing techniques, manure storage techniques, manure application techniques, fertiliser application techniques, and other measures related to agricultural N (Bittman et al., 2014). A particularly large amount of NH₃ escapes during the application of liquid manure, solid manure, and fermentation residues, especially in summer at high temperatures and when these products are only spread superficially. There is much lower NH₃ released during mineral fertilisation. The problem exists in the long term: the N for mineral fertilisers is obtained from the air (see Figure 17). In the long term, regular and non-site-adapted application of mineral fertilisers together with imported fodder add more N to local

N circles. Because the majority of agricultural areas in Germany already have a high N cushion, more NH_3 escapes to the air (Stroh et al., 2018). When NH_3 reaches the atmosphere (see Figure 17), it starts reacting with other particles and can form harmful particulate matter, which promotes acidification and eutrophication of water and soils. Gaseous N compounds are precursors of ground-level ozone and secondary particulate matter and thus pose a risk to human health. NH_3 itself only stays in the atmosphere for several hours to a few days. Most of it is chemically transformed to NH_4^+ and its salts. These compounds stay in the atmosphere for a long time and are transported by wind over long distances. They are deposited mainly under wet and humid conditions such as precipitation or are removed from the atmosphere by plant needles and leaves (Stroh et al., 2018).

Other possible environmental consequences are a loss of biodiversity or, at very high concentrations such as around large livestock facilities, direct damage to the surrounding vegetation due to high NH_3 concentrations (Häußermann, et al., 2020; Sorg et al., 2021). Via NH_4^+ , NH_3 can be transformed into NO_3^- and N_2O and encourage the development of fine particles, which negatively affect the environment and human health (Sorg et al., 2021). Figure 25 breaks down the German NH_3 emissions within the agricultural sector. The black diagonal line at the right of the graph represents the National Emission Climate (NEC) plan directive targets to which Germany has committed (BMF, 2021). For NH_3 , the NEC Directive (EU 2016/2284, 2016/14.12.2016) provides for reduction targets of 5% from 2020 and 29% from 2030 and compared with NH_3 emission in 2005, which, according to the 2018 emissions reporting, corresponds to maximum levels of 594 kt NH_3 in 2005. According to the 2018 emissions reporting, these targets correspond to a maximum level of 594 kt NH_3 in 2020 and 444 kt NH_3 in 2030. So far, Germany has not reached its N-related environmental quality and action targets (Fuß et al., 2023; Häußermann et al., 2020).

Ammonia emissions in Germany 1990 to 2021

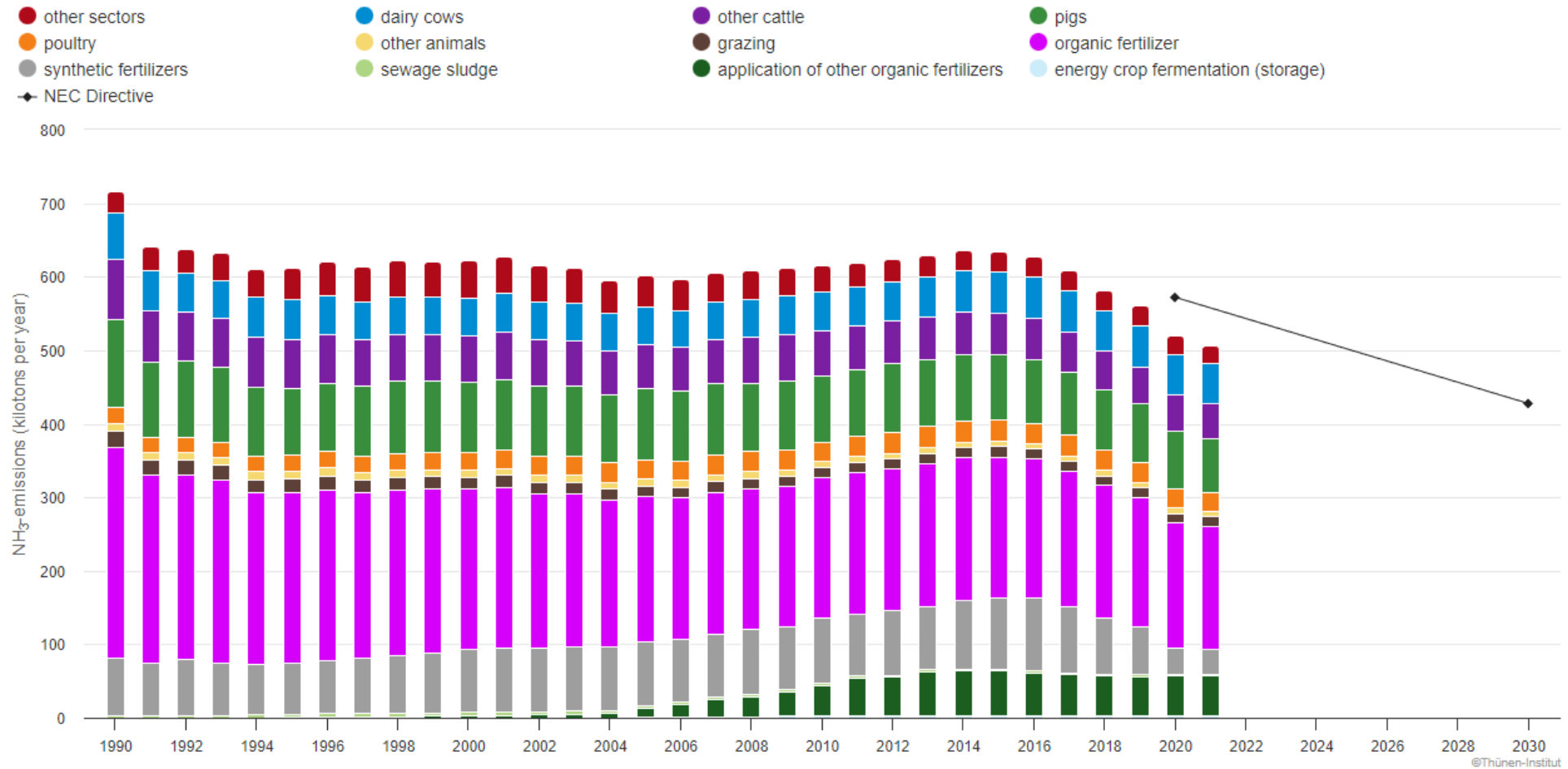


Figure 25. Ammonia (NH₃) emissions (kt per year) from agriculture in Germany for the period of 1990–2021. Adapted from Fuß et al. (2023).

4.3 Phosphorus (P) pollution from agriculture and its negative impact on the environment

P is an essential nutrient element for plant growth and a major limiting factor for crop production worldwide (Sharpley et al., 2018). Agriculture is highly dependent on P, which is a non-renewable resource (derived from phosphate rock) (Cordell et al., 2009). However, excessive P can lead to eutrophication of waterbodies, resulting in negative health effects for aquatic species and humans (UBA, 2021b). Soils are naturally P poor (Cordell et al., 2009). Therefore, the nutrient needs to be added to cultivated soils to prevent serious deficiencies for plant growth (Schnug et al., 2019).

In Germany, close to 80% of the total P demand comes from the agricultural sector (Mayer & Kaltschmitt, 2022). In total, 192,000 t of P commercial fertilisers were applied in the 2020/2021 crop year. In Germany, a quarter of the P used for agricultural production originates from finite fossil repositories of only a few regions/countries such as North Africa and the Near East. Almost two thirds (Heyl, 2023) of the required P is covered by farm manure such as stable manure or slurry (BMEL, 2022k; Leinweber, 2019; Schnug et al., 2019).

Because P added to soil has very little mobility, plants cover their P requirements from previous P fertilisations. Due to this remaining P reservoir in soils, the P requirement for the current crop must be estimated. If the soil displays greater concentration grades than A (B–E), then additional P fertilisation has no additional benefit and does not increase the yield of the current crop. Instead, it can have negative environmental impacts, such as eutrophication of neighbouring ecosystems¹¹ (Leinweber, 2019; Schnug et al., 2019).

German agricultural activities contribute to half of the total P load in water bodies (Heyl, 2023; Ta et al., 2020). Specifically, excessive P inputs from agriculture, mostly from the livestock sector, have resulted in eutrophication of various ground water bodies and other waterbodies such as the Baltic Sea (Heyl, 2023) and the North Sea (see Figure 26) (BMEL, 2020c; Steidl et al., 2022). The EU groundwater directive (GWRL 2006/118/EC, 2006/12.12.2006) stipulates the thresholds for all EU member states. As mentioned in Chapter 4.2.1, the limit for NO₃⁻ and pesticides is 50mg l⁻¹ (BMEL, 2020c; GWRL 2006/118/EC, 2006/12.12.2006). The P load of water bodies is regularly investigated at the monitoring sites of the state monitoring networks (BMEL, 2020c).

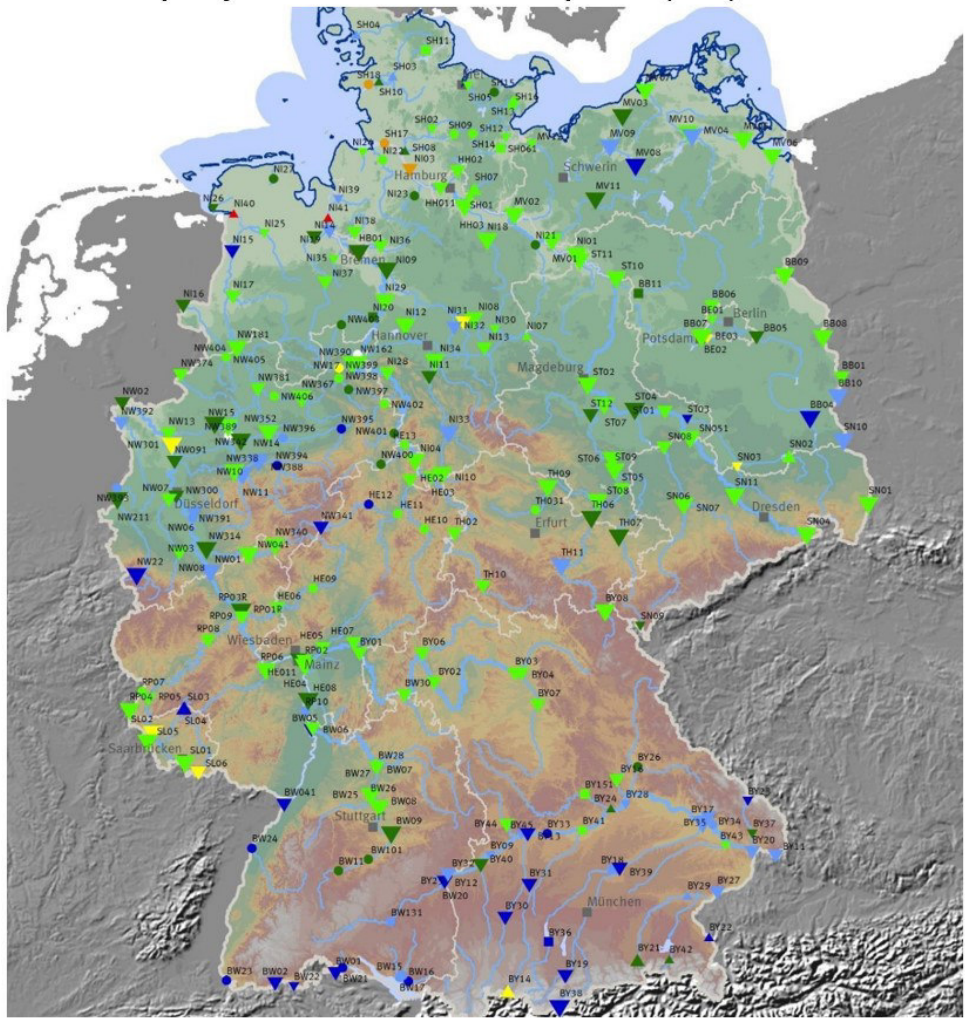
Currently, 67.3% of the German groundwater bodies are in a good chemical condition, whereas 32.7% are not in a good chemical condition. A good chemical condition is defined as adherence to environmental quality standards (limit values) and threshold values according to EU specifications at all measurement points of the waterbody (UBA, 2022b). Figure 26 shows of waterbodies not in a good chemical condition; they mainly occur in regions where N surpluses are also very high (Figure 20 and Figure 21 in Chapter 4.2). The Nitrate Report 2020 (BMEL 2020c) provides a detailed overview of the current P pollutions in German water bodies (flowing waterbodies and surface waters [with a focus here on lakes]). For quality

¹¹ The P saturation (plant available P) in the soil is classified in five categories: from A (very low) to E (very high), source: Schnug et al. (2019)

classification, flowing waters are categorised and critical environmental thresholds for the evaluation of their condition are determined (Figure 26) (BMEL, 2020c).

Figure 26 shows the national distribution and development of the trend and quality classification of flowing waterbodies in Germany in 2018. The overall trend is a decline in the total P concentration of > 50% or 25%–50% (Figure 26 and 27). Flowing waters showing a total P increase of > 25% occur mainly in the north-western regions of Germany, where high N surpluses can be found (Figure 20 and Figure 21 in Chapter 4.2).

Trend and quality classification 2018: Phosphorus (total)



- Trend**
- ▽ Decrease > 50%
 - ▽ Decrease 25 to 50%
 - ▽ Decrease 5 to 25%
 - No trend
 - △ Increase 5 to 25%
 - △ Increase > 25%
 - Data set not sufficient
- Quality classification using the example "no trend"**
- I
 - I - II
 - II
 - II - III
 - III
 - III - IV
 - IV
 - No classification in 2018 possible

Data source: Geobasisdaten: DLM1000,2012, BKG
 Expertise: Federal Environment Agency (UBA)
 according to the Working Group of the Federal
 States on Water (LAWA), 2019
 Data editing: Federal Environment Agency (UBA),
 2019

Water body type*	I	I - II	II Target value	II - III	III	III - IV	IV
1.1, 1.2, 2.2, 3.2, 4, 5, 9, 9.1, 9.1K, 9.2, 10, 14, 15, 15g, 16, 17, 20, 23	≤0.05	≤0.075	≤0.1	≤0.2	≤0.4	≤0.8	> 0.8
12, 19	≤0.05	≤0.1	≤0.15	≤0.3	≤0.6	≤1.2	> 1.2
22.1, 22.2, 22.3	≤0.1	≤0.2	≤0.3	≤0.6	≤1.2	≤2.4	> 2.4
T1, T2	≤0.03	≤0.0375	≤0.045	≤0.09	≤0.18	≤0.36	> 0.36
12 with high retention	-	-	≤0.1	≤0.2	≤0.4	≤0.8	> 0.8

* Water body types available under Table 7, p. 30 Nitrate report 2020

Figure 26. Trend (1991–1994 and 2015–2018) and quality classification of flowing waterbodies in Germany in 2018: total phosphorus. Adapted from Abbildung 12 and Tabelle 8 in BMEL (2020c).

The overall trend of the environmental P condition in selected lakes in Germany is shown in Figure 28. 11 out of 12 measurement points showed a decline of >50%, 5 out of 12 a decline of 25%–50% of the total P concentration (BMEL, 2020c).

Phosphorus concentration (total) 2015-2018 compared to 1991-1994 data

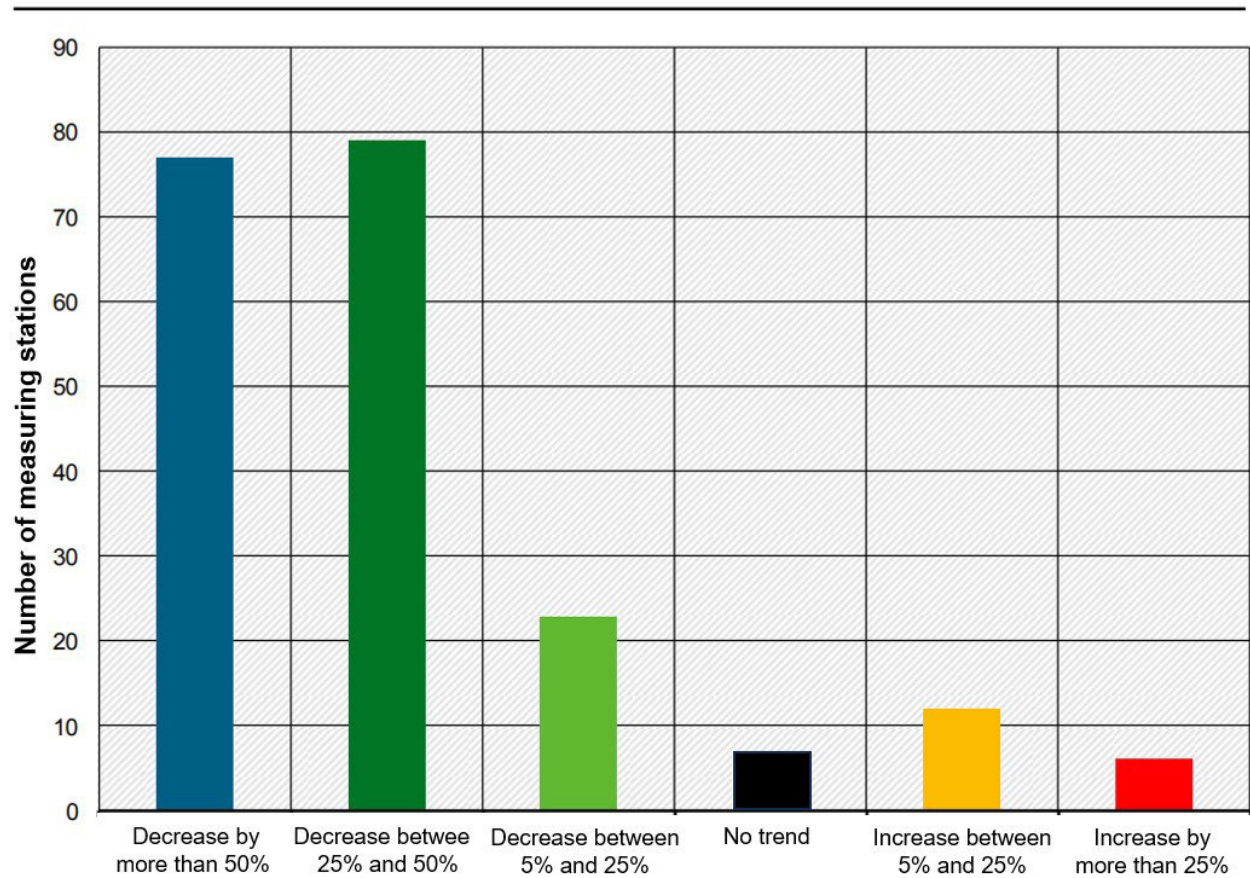


Figure 27. Change in the total phosphorus concentration in surface waters in Germany for the period of 2015–2018 compared with the period of 1991–1994. Adapted from Abbildung 14 in BMEL (2020c).

Phosphorus concentration (total) in selected lakes 2015-2018 compared to 1991-1994 data

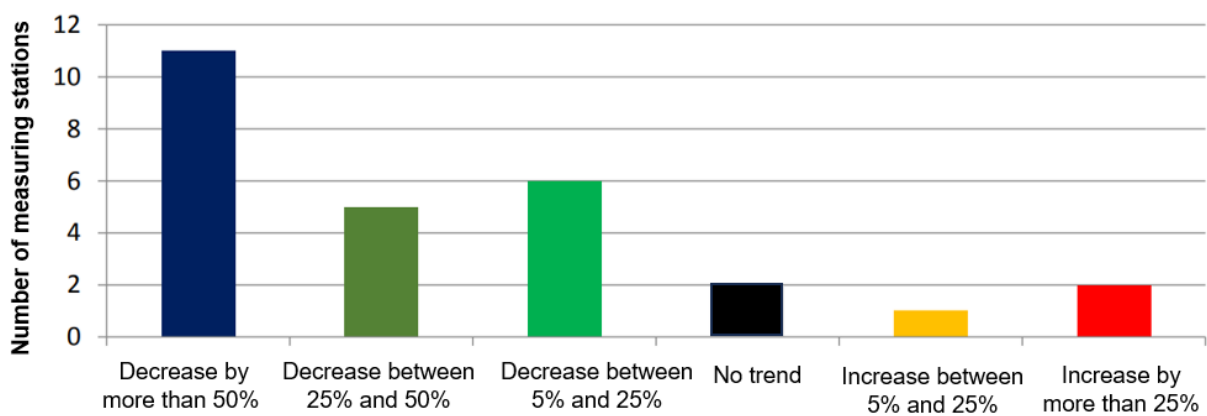


Figure 28. Change in the total phosphorus concentration in lakes in Germany for the period of 2011–2014 compared with the period of 2015–2018. Adapted from Abbildung 18 in BMEL (2020c).

A summary by the UBA (2021b) revealed that considering total P in 2019, 43% of monitoring sites had an annual mean concentration below the target value (quality class II and better), 52% of monitoring were in quality class II–III, and 3% of monitoring sites were in quality class III. Twenty-seven surface waterbodies were classified based on their P quality. Figure 29 illustrates that analogous to the trend of flowing waterbodies, 11 out of 12 of the results from measurement points in surface waterbodies showed a > 50% decline in total P (BMEL, 2020c). The findings of the Nitrate Report 2020 show that the overall condition of waterbodies in Germany regarding the P concentration has decreased within the last 20 years, but there is still an urgent need to contain P loads transferred to the environment (UBA, 2021b).

Too high P concentrations in flowing water bodies can lead to eutrophication, excessive oxygen consumption, and shifts in species composition although nutrients are constantly transported. Increased algae and plant growth and highly fluctuating oxygen levels due to photosynthetic oxygen production during the day and oxygen depletion due to plant respiration at night can harm small organisms (LFU, 2023).

When P concentrations are too high in flowing waterbodies, eutrophication, excessive oxygen consumption, and shifts in species composition can occur, even though nutrients are constantly transported. Increased algal and plant growth and highly fluctuating oxygen levels due to photosynthetic oxygen production during the day and oxygen depletion due to plant respiration at night can harm small organisms (LFU, 2023).

Other problems can occur because P nutrients are particularly effective for a long time, as they often remain in the lake for years and are converted several times in the material cycle (LFU, 2023). Figure 29 shows the potential for addressing P flows within the livestock sector by using sustainable management technologies. Improved fertilisation practices and improved soil conditions – that is, erosion control – are recommended measures to reduce P inputs (Ta et al., 2020).

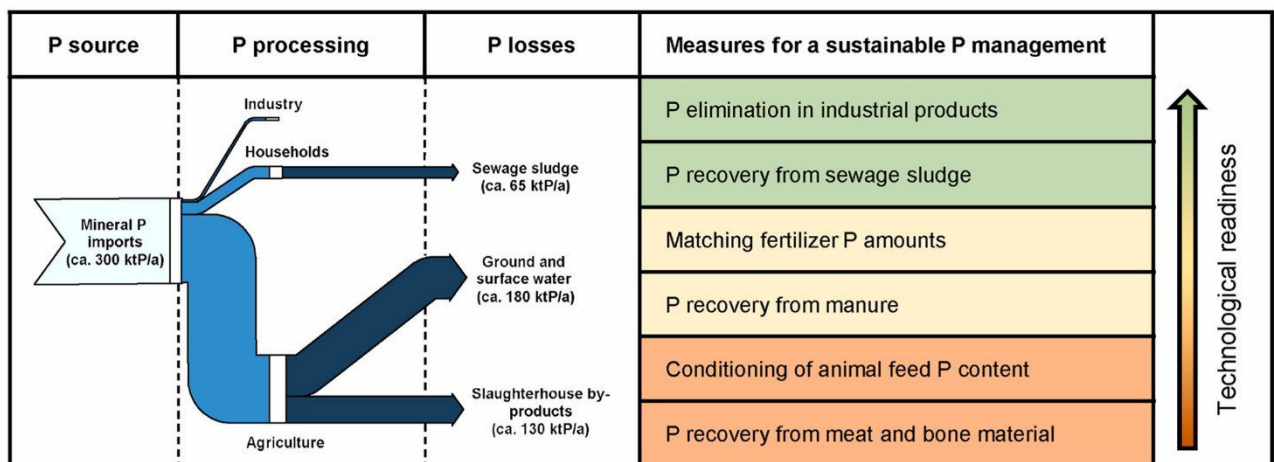


Figure 29. Phosphorus (P) source, processing, losses, and measures for sustainable P management. Adapted from Mayer and Kaltschmitt (2022).

4.4 Pesticide pollution and its negative impact on the environment

Pesticides are used in the agricultural sector to control weeds, diseases, and pests that may inhibit growth or cause crop plant death. Applied pesticides are distinguished between herbicides, insecticides, fungicides, molluscicides, acaricides, rodenticides, and growth regulators. In Germany, the sale and use of pesticides is regulated by European as well as national laws (see Chapter 2.1.3).

The 2021 domestic sales of pesticides was 28.945 t of active substances (without inert gases) (BMEL, 2022j). According to the UBA (2023g), 50.6% of the sales of pesticides are herbicides. However, sales alone cannot be used as an indicator for the actually applied amount of substance per hectare. Based on calculations, in 2014 there was an average application of 8.8 kg of pesticides, meaning 2.8 kg of substances per hectare (UBA, 2023g).

Figure 30 shows the worldwide use of pesticides between 2017 and 2020 in terms of gradations. Germany is among the countries with the highest agricultural use of pesticides (> 11.915 t).

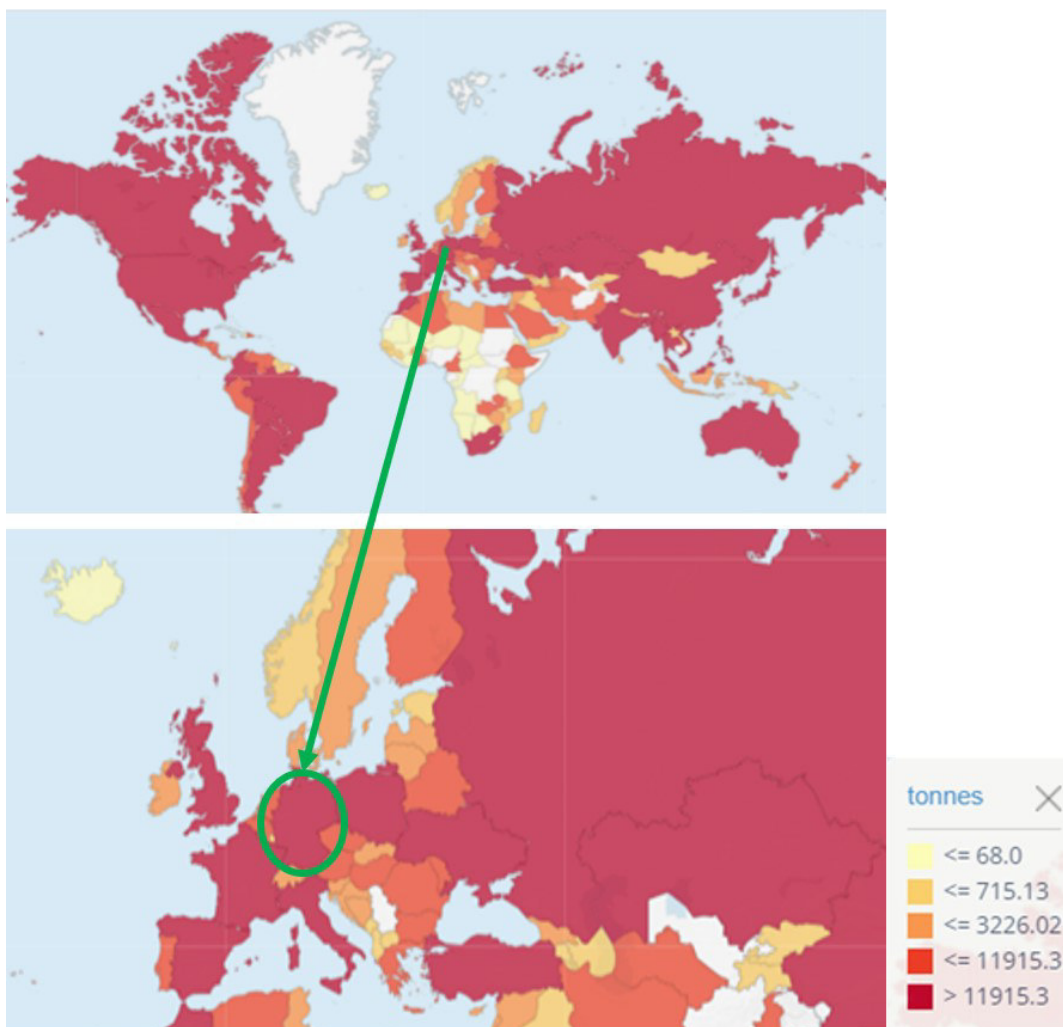


Figure 30. Total pesticide application worldwide and in Germany (in tonnes) between 2017 and 2020. Extracted from FAO (2023c) by using the Items “Pesticides total”, “Agricultural use” and “world” within the period of 2017-2020. State of the image data: 14. January 2023.

Figure 31 shows the domestic sales of individual pesticide active substances in Germany between 1995 and 2021. The overall domestic sales of pesticides have declined by slightly more than 1,000 t, from 30,467 t in 1995 to 29,027 t in 2021. The figure also shows that considering just the active ingredients, herbicides represent more than 50% of pesticide sales (UBA, 2023g).

Domestic sale of individual active substances of pesticides

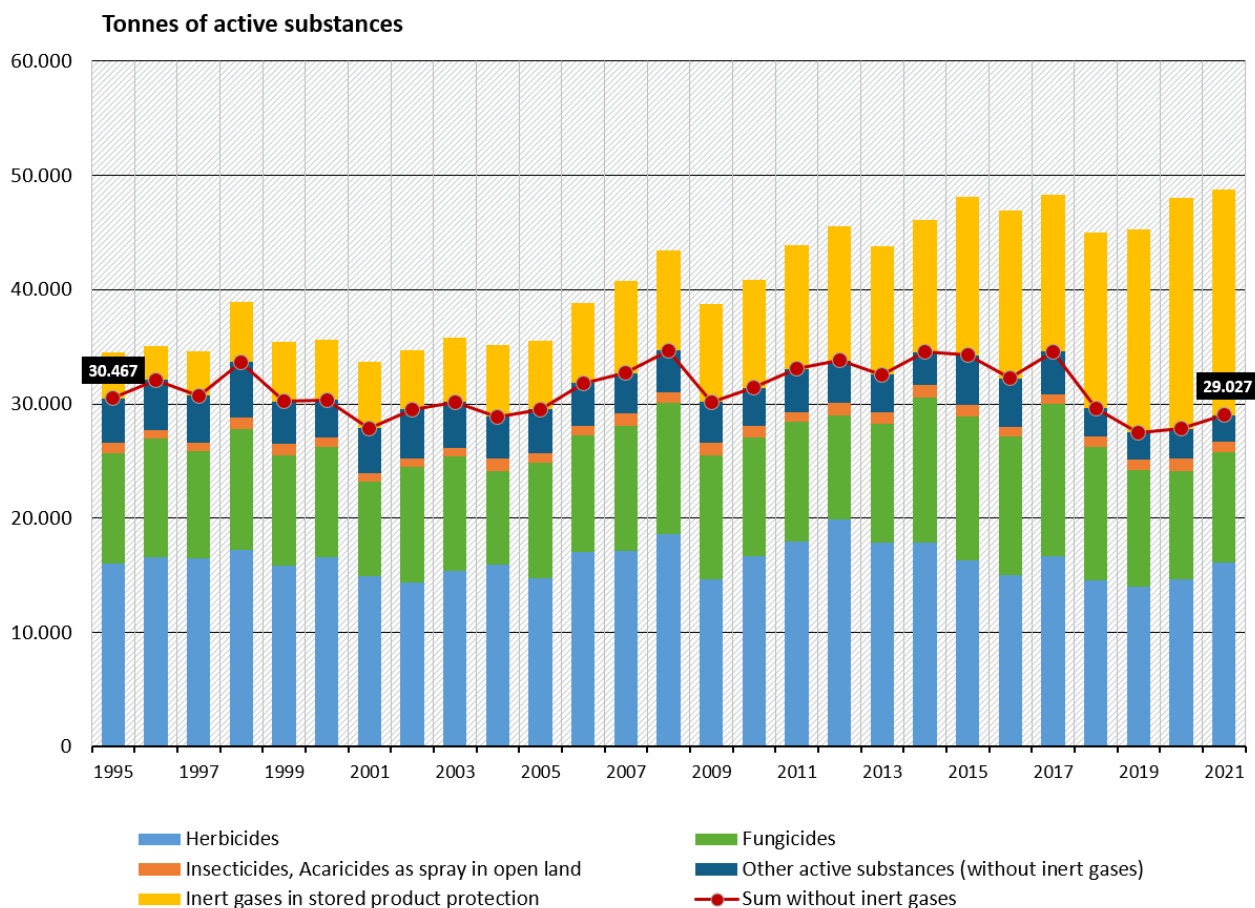


Figure 31. Domestic sales of individual pesticide active substances in Germany between 1995 to 2021 by category: herbicides, fungicides, insecticides and acaricides as sprays in open land, other active substances (without inert gases), inert gases in stored product protection, and sum without inert gases. Adapted from UBA (2023g).

Although pesticides are applied to crops, they still enter the surrounding ecosystems. In non-target ecosystems, pesticides cause considerable environmental impacts, such as biodiversity loss, bee deaths, and impacts on surrounding aquatic systems and their inherent invertebrates and macrozoobenthos¹² (Liess et al., 2022). Furthermore, pesticides can enter the soil microbiome and, groundwater and can be dispersed to nearby water bodies (Willkommen et al., 2021; Wolfram et al., 2023), or they can remain in the soil and harm a mix of different species. In a study carried out over 13 different agricultural sites in Germany, the researchers detected 44 of the 98 commonly applied pesticides in soil samples. The pesticide load was significantly above the average based on EU standards (Bakanov et al., 2023). Similarly, Tauchnitz et al. (2020) reported that pesticides can remain in the soil over long periods of time

¹² Macrozoobenthos is the living invertebrate community of seabeds (=benthos). Source: Asmus and Asmus (1985)

and even more importantly, the pesticide detections in the study were not consistent with the application data from the farmers. In terms of pesticides in waterbodies, Halbach et al. (2021) showed evidence of 76 pesticides exceeding acceptable regulatory concentrations in small streams under various weather conditions.

Due to fluvial transport, pesticides have also been detected in nature conservation areas (Wolfram et al., 2023). As pesticides enter nature conservation areas and/or waterbodies, both the macro- and micro-biome are affected. Even at pesticide concentration levels that are considered safe by European legislation, pesticide pollution has been shown to trigger species adaptation in crustaceans, leading to reduced survival, growth, and mating (Siddique et al., 2020). Agricultural pesticide pollution is the leading factor in reducing vulnerable insect populations in aquatic communities (Liess et al., 2021) and in negatively affecting the breeding population of toads (Leeb et al., 2020).

The application of pesticides on arable land can also have unintended consequences on nearby plant life. When assessing the pesticide residues on field edges (also known as buffer strips), Köthe et al. (2023) observed that the number of plant species decreased as the proximity to agriculture fields increased. While buffer strips added by farmers at the edges of their field are exposed to pesticides, they also serve a vital function: to prevent pesticides from entering nearby waterbodies. Researchers have concluded that adding buffer strips adjacent to agricultural fields is the strongest measure to prevent pesticide pollution in nearby waters (Köthe et al., 2023; Leeb et al., 2020; Vormeier et al., 2023). Specifically, the wider the buffer strips, the greater the protection against pesticide pollution in nearby water bodies (Lorenz et al., 2022). There have been numerous studies demonstrating the potential benefits that technology can play in reducing the quantitative number of pesticides used and reducing the effects on the environment. Further information is available in Chapter 8.2.

4.5 Scale of biodiversity over time

Natural biodiversity and agrobiodiversity play an important role in the function and productivity of agricultural soils and their production. Rich biological diversity fosters the optimal functioning of natural processes and important ecosystem services, which are of great significance for agriculture, such as natural pest control, pollination of crop and wild plants by insects and the generation and degeneration of biomass (Deutsche Akademie der Naturforscher Leopoldina e.V., 2020a; Pfiffner, 2022). There is worldwide consensus that natural biodiversity and agrobiodiversity are in decline. This is also the case in Germany. Numerous studies and expert committees have illustrated that the reduction in overall biodiversity is caused, inter alia, by agriculture intensification (Deutsche Akademie der Naturforscher Leopoldina e.V., 2020a; IPBES, 2019; Tschardt et al., 2021). Agriculture once functioned as a promoter of structurally rich cultivated landscapes with crop fields (and field margins), meadows, hedges, vineyards, standard and field trees. As agriculture has intensified, it has started causing a massive loss of biodiversity and species richness, rather than providing valuable habitats for various plant and animal species (Pfiffner, 2022). For Germany, there are no national long-term data on biodiversity of a broad range of plants, animals, and fungi. Monitoring is only conducted in specific programmes for flora, fauna,

habitats, and farmland of high nature value (HNV). In addition, there are data from various scientific analysis of species numbers, frequency, and biomass for birds, selected insect groups, and plants at regional levels (Deutsche Akademie der Naturforscher Leopoldina e.V., 2020a).

Within the last three decades, the insect biomass has been reduced by 75% in 63 nature conservation areas surrounded by agricultural land. For grassland, there has been a 67% decline in insect biomass and a 34% decline in insect species over the past 10 years. A decline in insect biomass and species is a crucial point because their existence affects other species in the food chain and crucial pollination processes of plants (Pfiffner, 2022). In one of the most important German scientific studies on the condition of the insect biomass, Hallmann et al. (2017) followed a standardised protocol to measure the total insect biomass with malaise traps, deployed over 27 years in 63 nature protection areas in Germany. Their results showed an 82% decline in the mid-summer of aerial insect biomass (Figure 31 A) and a 76% loss in the seasonal biomass (Figure 31 B).

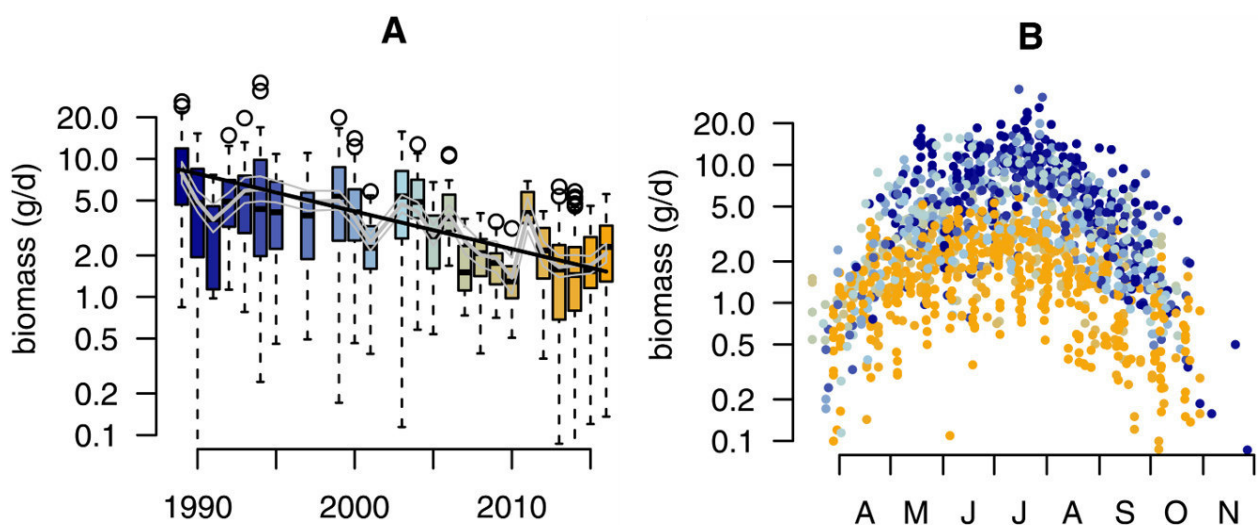


Figure 32. A) The boxplots depict the distribution of the insect biomass (gram per day) pooled over all traps and catches for each year ($n = 1503$). Based on the final model, the grey line depicts the fitted mean (+95% posterior credible intervals) considering weather, landscape, and habitat effects. The black line depicts the mean trend as estimated with the basic model. (B) Seasonal distribution of the insect biomass showing that the highest insect biomass catches in mid-summer show the most severe declines. The colour gradient in both panels range from 1989 (blue) to 2016 (orange). Adapted from Fig. 2 in Hallmann et al. (2017).

Regarding specific species, 53% of the almost 600 wild bee species in Germany are currently endangered (Deutsche Akademie der Naturforscher Leopoldina e.V., 2020a). In addition, common farmland bird species are affected: the number of skylarks (*Alauda arvensis*), starlings (*Sturnidae*) and lapwings (*Vanellus vanellus*) decreased by more than 36% between 1998 and 2009. Within the EU, common farmland birds have dropped to an average of 68.5% since 1990 (considered=100%) (Figure 33) (eurostat, 2022a). Figure 34 illustrates the development of bird species in Germany according to their main habitat comparing the status quo of 1998-2009 with the status quo of 2004-2016. Overall, bird species of agricultural landscapes are significantly more endangered than bird species found in woodlands or settlements (Deutsche Akademie der Naturforscher Leopoldina e.V., 2020a).

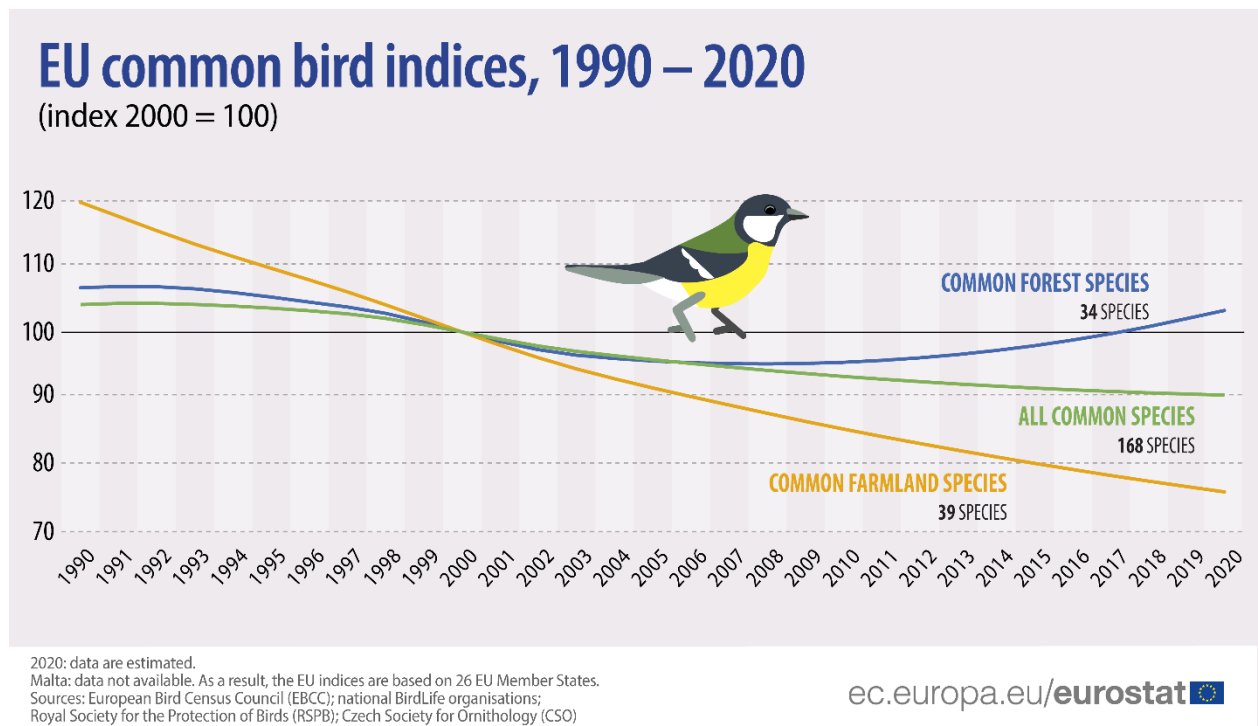


Figure 33. Decline in common bird species in the European Union (EU) from 1990 to 2015. Adapted from eurostat (2022a).

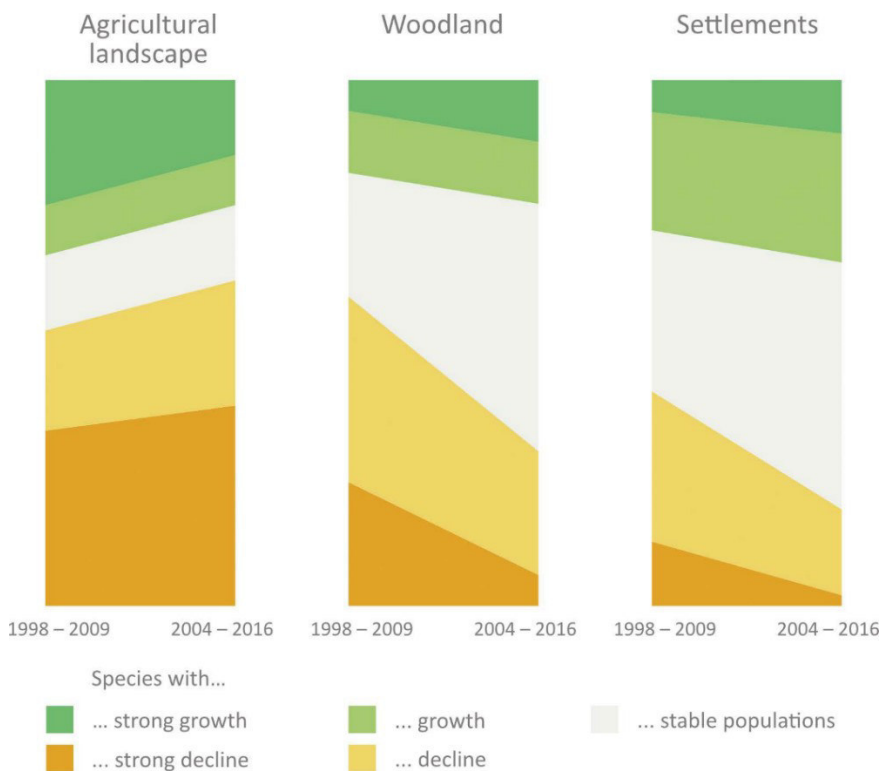


Figure 34. The trend of breeding bird species in Germany grouped according to their main habitat comparing 1998-2009 with 2004-2016. The graphs show the proportions of the bird species' populations in agricultural, woodland, and populated habitats, which are in severe decline, declining, and greatly increasing or stable. Compared with other habitats, an increasing number of bird species in agricultural landscapes are declining or in severe decline. Adapted from Deutsche Akademie der Naturforscher Leopoldina e.V. (2020a).

There are no systematic long-term data for Germany regarding plant species decline. However, regional studies – for example, in Baden-Württemberg and southern Germany – have revealed that the decrease in herbaceous plants growing wild in farmland is particularly acute. In general, there has been a shift in species distribution: synanthropic species that respond positively to the increasing use of N on farmlands show positive growth and replace slower growing species. For vascular plants, there has been a long-term decline for 129 out of 254 wild farmland plant species and a short-term decline for 108 of 230 species (Deutsche Akademie der Naturforscher Leopoldina e.V., 2020a).

It is worth noting that several policy measures have been implemented to address biodiversity loss. One of the key points of the 2013 **Greening** approach adopted by the EU CAP calls for concrete action to be taken by the farming sector with respect to biodiversity (BMEL, 2023a). Furthermore, the expansion of the joint task “Improvement of Agricultural Structure and Coastal Protection” (GAK) (BMEL, 2022i) and the agri-environmental climate measures implemented in the second pillar of the CAP are important instruments to preserve the biodiversity of agricultural ecosystems (BMEL, 2019b).

At the national level, the German government has adopted several acts and strategies to protect and foster biodiversity and species richness in agricultural landscapes. Among them are following strategies for agro-biodiversity:

- the National Technical Programme for the Conservation and Sustainable Utilisation of Plant Genetic Resources (BMEL, 2015);
- the National Technical Programme for the Conservation and Sustainable Utilisation of Animal Genetic Resources (BMELV, 2008);
- the National technical programme on the conservation and sustainable use of aquatic genetic resources (BMEL, 2022e);
- the National Technical Programme "Concept for the Conservation and Sustainable Use of Forest Genetic Resources in the Federal Republic of Germany" (BMELV, 2010).

One important project funded by the government is the Future Resources, Agriculture & Nature Conservation (F.R.A.N.Z.) Project, which was initiated to identify new ways to promote biodiversity in agricultural landscapes. It brings farmers, research institutions, and government agencies together to promote effective biodiversity measures that farmers can easily integrate into their practices (Umweltstiftung Michael Otto & Deutscher Bauernverband e.V., 2023).

4.6 Condition of the agricultural land in Germany

Land is a limited and scarce natural resource, especially in a densely populated country like Germany. Intensive agriculture accounts for a high share of land use conflicts with nature and natural resource use protection. Considering the land scarcity and the negative impacts of intensive agriculture on biodiversity and species' diversity, the German government has developed (on the basis of the bird index) a biodiversity and landscape quality indicator within the context of its Sustainability Strategy (Figure 35) (Kirschke et al., 2021)

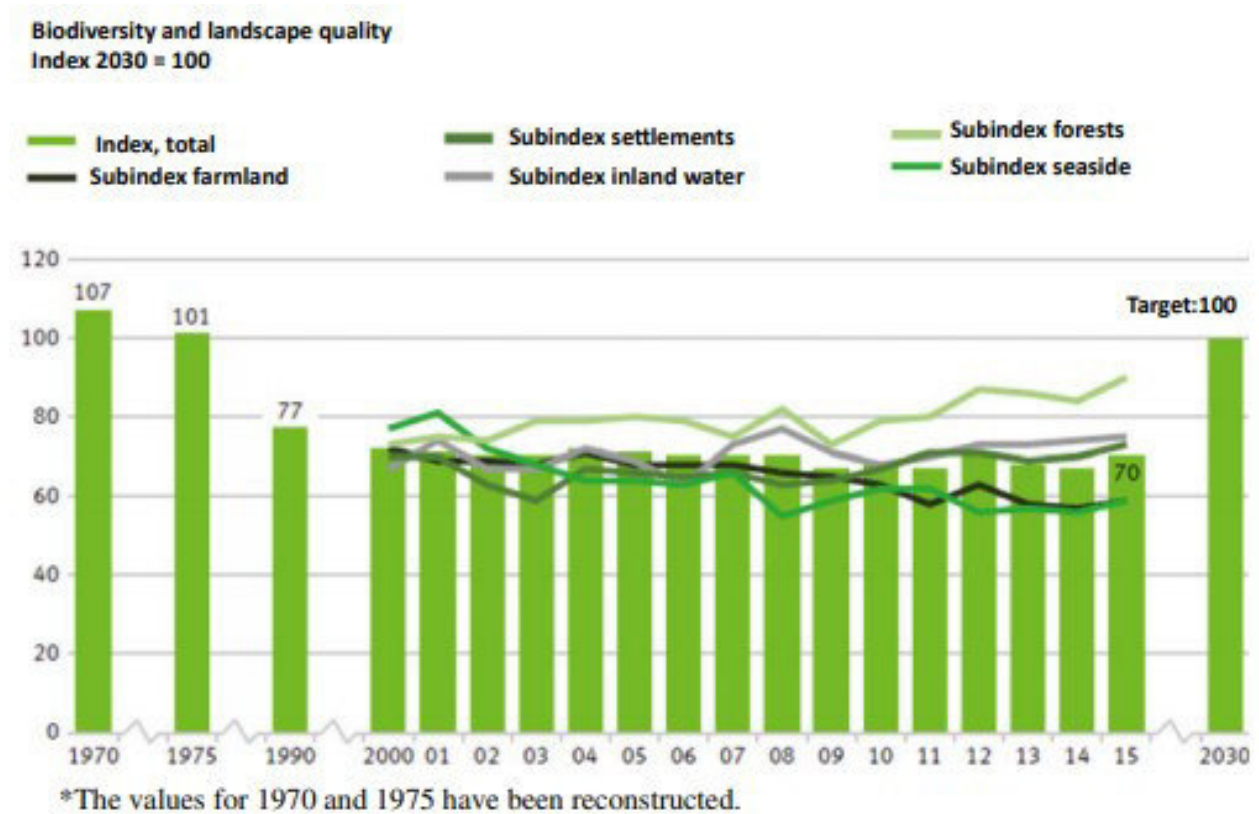


Figure 35. Biodiversity and landscape quality in Germany, 1970-2015, where 2030 is set at 100. Original image (Fig. 3.4) in Kirschke et al. (2021).

Figure 35 indicates that there has been a drastic decline in biodiversity since 2000 with no improvement. Looking at the specific land-use activities, except for forests, where biodiversity has even improved, agricultural land has shown an almost constant decline in biodiversity. In terms of analysing the condition of the agricultural land in Germany, one metric used is HNV. This indicator relates to the quality of farmland for nature and is used to evaluate farming impacts on biodiversity. HNV metrics are broken down into three levels: I, II and III, where the highest quality of land is designated HNV I, followed by HNV II and III. Figure 36 shows that the aggregated indicator has declined from 13.1% of total German farmland in 2009 to 11.5% in 2017, with a slight overall increase in 2017 versus 2015. In addition, the largest decrease has been in HNV III farmland, indicating that land with a lower HNV has been affected by intensive agricultural production. There have been small but stable intensive agricultural impacts on HNV I and II farmland.

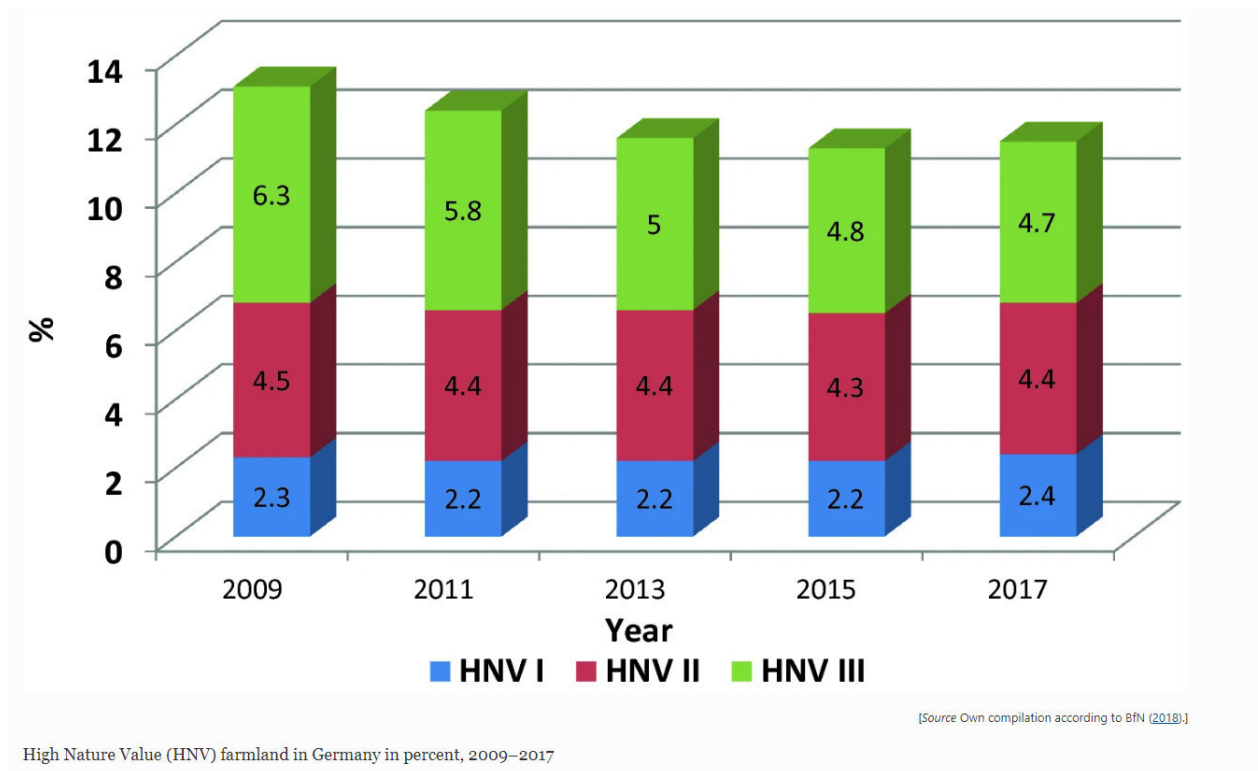
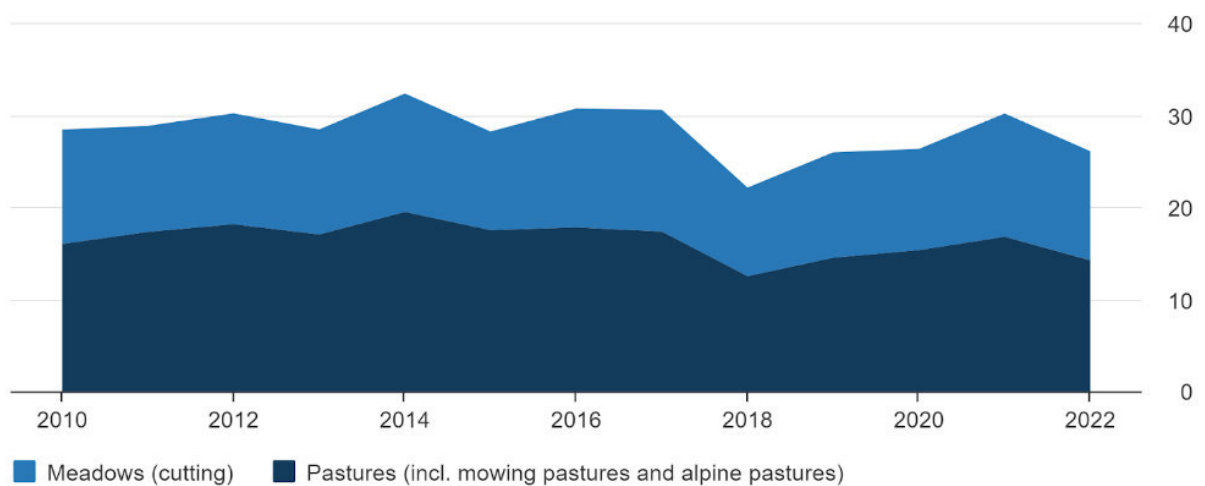


Figure 36. High nature value (HNV) farmland in Germany (%), for 2009-2017. Original image (Fig. 3.5) in Kirschke et al. (2021).

Harvested quantities of permanent grassland
in million tonnes



© Statistisches Bundesamt (Destatis), 2023

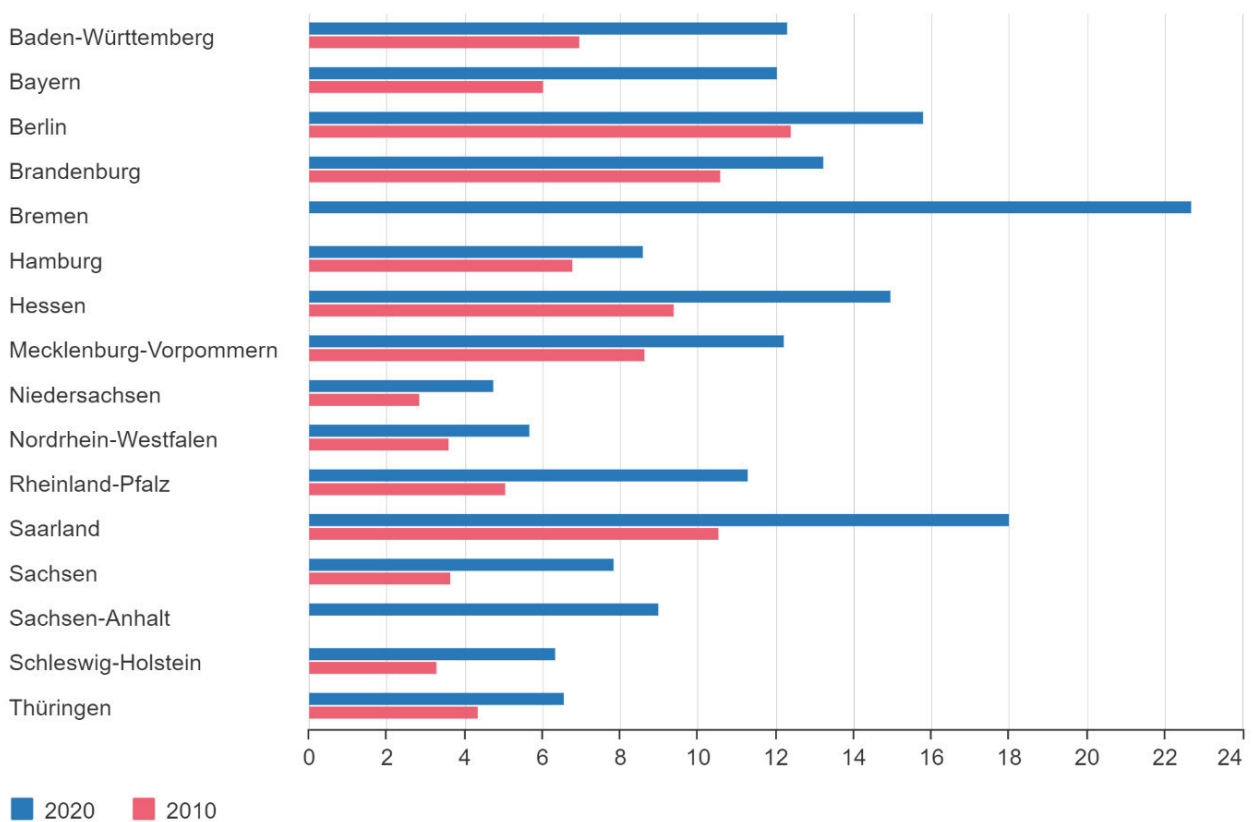
Figure 37. Harvest quantity of permanent grasslands in Germany between 2010 and 2022 in million tonnes. Original image from Destatis (2023).

Figure 37 shows the harvested quantities of permanent grassland over the course of 12 years. Although there was a 13.5% decrease in the harvest volume from 2021 to 2022, the harvest quantity is between the

12-year range. Aside from weather conditions, the factors that affect harvest quantities are how intensely the meadows are used: the frequency of cutting, fertilisation, and animal stocking rates (Destatis, 2023). Conventional use of agricultural land versus organic farming is another way in which the condition of agricultural land can change. Data from the period of 2010–2020 show that the area of agricultural land used for organic agriculture has increased from 6% to 10%, and there has been a 58% increase in organic farm holdings Figure 38 compares the development of the total organically used agricultural area for each federal state of Germany between 2010 and 2020. There is a noticeable overall increase in organically used agricultural area. Moreover, more than half of the organic holdings are in Bayern and Baden-Württemberg (Destatis, 2021b).

Organic area

Percentage of the total utilised agricultural area



The 2010 figures for Bremen and Sachsen-Anhalt are subject to statistical confidentiality

© Statistisches Bundesamt (Destatis), 2023

Figure 38. Development of total organically used agricultural area in the German federal state in 2010 compared with 2020. Original image from Destatis (2021b).

Intensive agriculture is considered to be the main driver for the loss of biodiversity and species richness. Various studies over the last 30 years have proved that organic agriculture has had a significant positive impact on biodiversity and species richness in agricultural landscapes (Figure 39) (Stein-Bachinger et al., 2020).

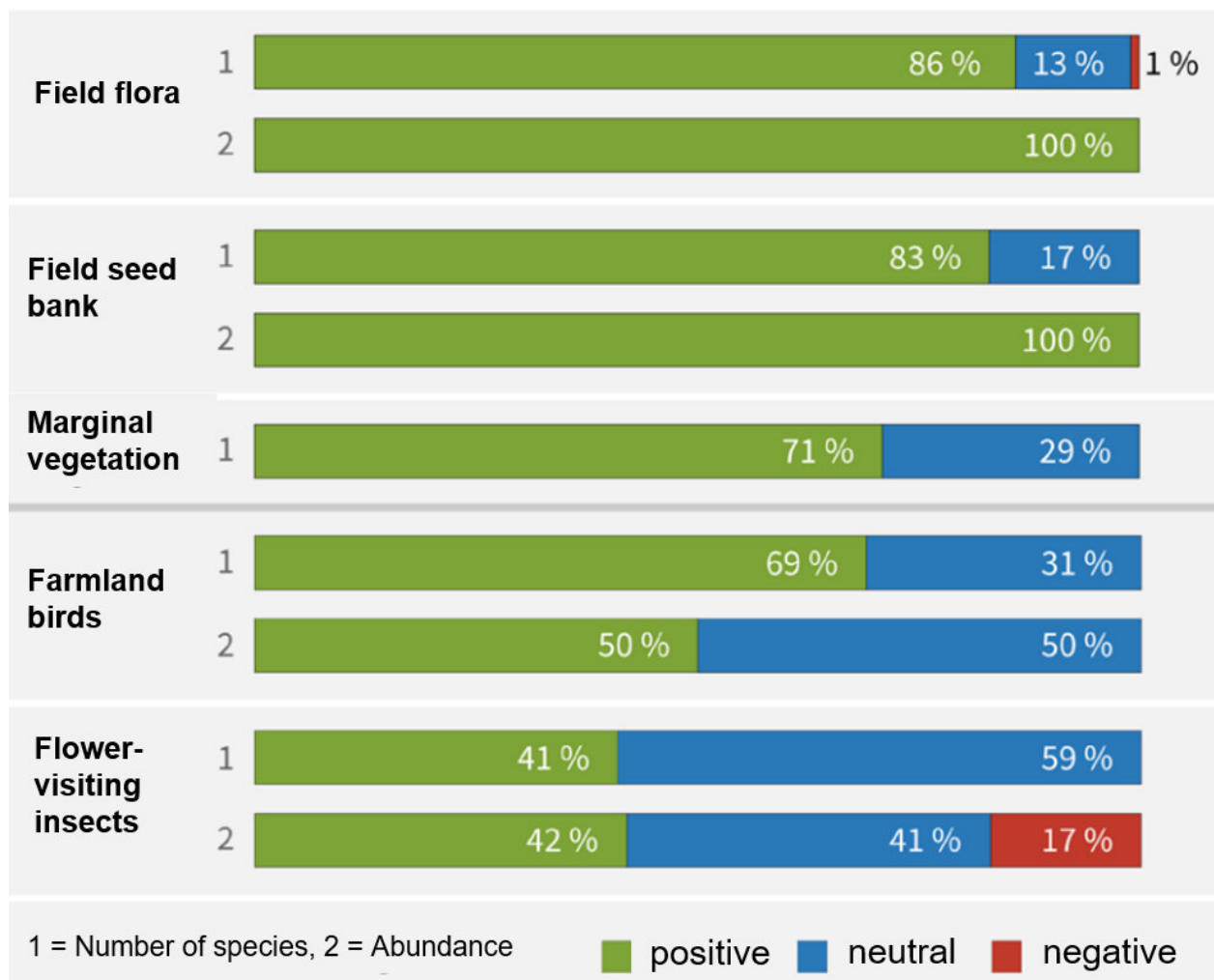


Figure 39. The effects of organic farming on the average number of species and the abundance of different organism groups compared with conventional (intensive) farming. Green: higher performance by organic farming; blue: comparable performance of both farming systems; red: decreased performance by organic farming. Original image from Stein-Bachinger et al. (2020).

Field flora benefitted the most from organic farming systems (Figure 39). Animal species showed a 49% benefit in organically managed fields compared with conventionally managed fields. In addition, the occurrence of farm bird species was 35% higher with organic farming. The main reasons for the positive ecological impact of organic farming is the abandonment of pesticides and mineral fertilisers (Stein-Bachinger et al., 2020). Furthermore, the number of livestock per area is smaller compared with conventional farming systems, and less additional fodder is purchased. Therefore, the overall nutrient level in organic farming systems is generally lower. Another aspect is the more diversified and regularly established crop rotation in organic fields. This practice benefits the soil composition and maintains the health of the cultivated crops (Stein-Bachinger et al., 2020).

In terms of changes to the soil composition and chemistry, organic farming methods enhance humus formation and soil biota. Fields and meadows operated under organic farming methods have a greater amount of biomass and microbial activity. Therefore, natural soil fertility also increases. Losses of topsoil caused by erosion is largely avoided (BMEL, 2022h).

4.6.1 Peatlands

Peatlands play a critical role in the regulation of Earth's climate. They can help slow down the effects of climate change as they naturally trap and prevent carbon from being converted into CO₂. Figure 40 displays the distribution of organic soils (peatlands and small peat layers) throughout Germany. Data from the German Emissions Trading Authority (DEHSt) indicated that 90% of the peatlands throughout Germany have been drained. As of 2018, only 2% of the peatlands in Germany still exist in their near-natural state (UBA & DEHSt, 2023; Zak et al., 2018).

According to DEHSt, one of the main reasons for draining peatlands is for food production (regarding food security). In 2020 alone, the emissions from drained peatlands used for agriculture were estimated to be about 40 million t CO₂ equivalents, which represents close to 7% of Germany's total CO₂ emissions. Aside from the problems with GHG emissions, drained peatlands also lose their soil structure and nutrients, causing land subsidence and loss of unique biodiversity (UBA & DEHSt, 2023).

Distribution of organic soils in Germany

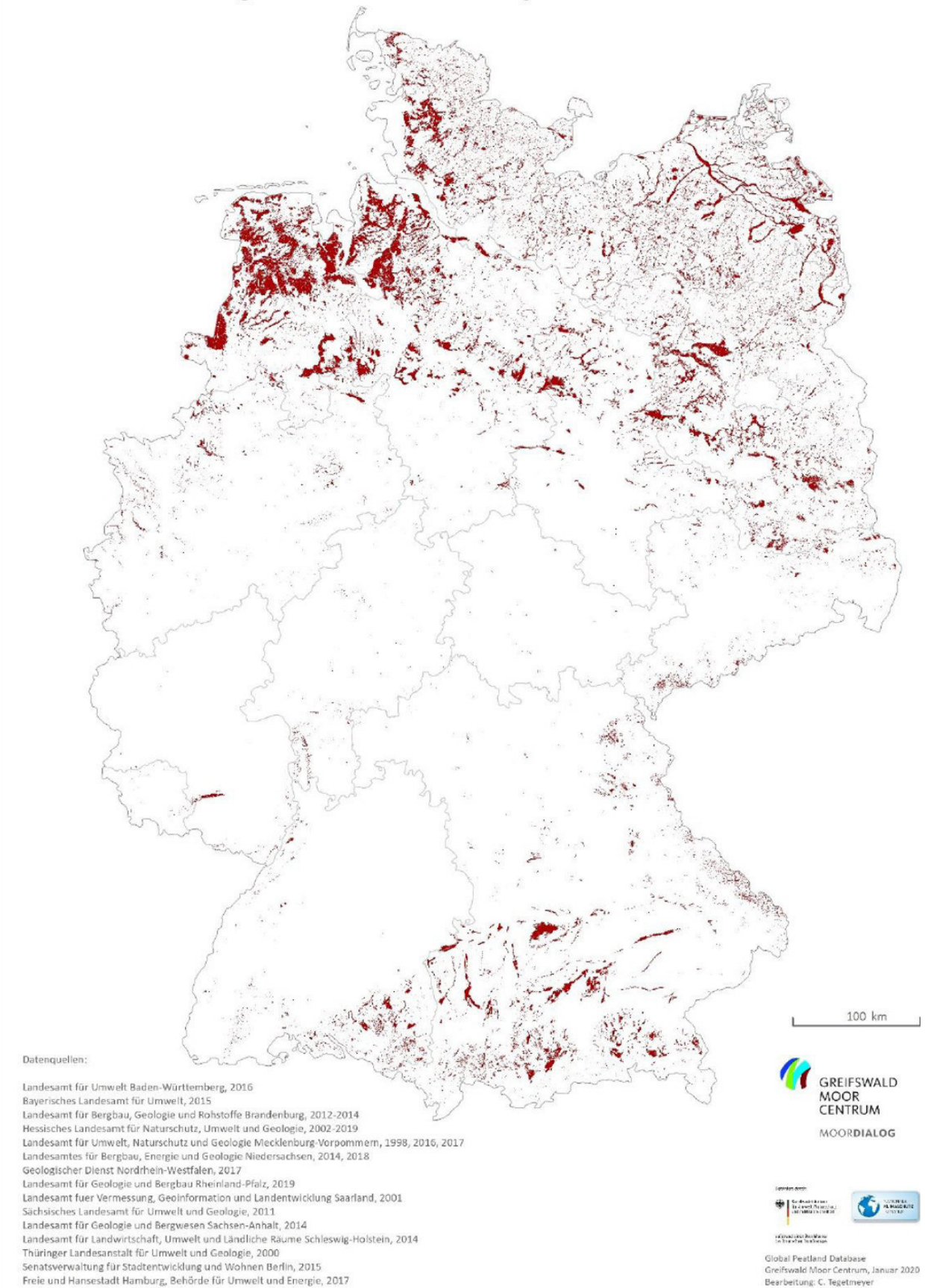


Figure 40. Map of the distribution of organic soils in Germany (peatlands and small peat layers). Original image from Tegetmeyer et al. (2020).

Use of peatland soils in Germany

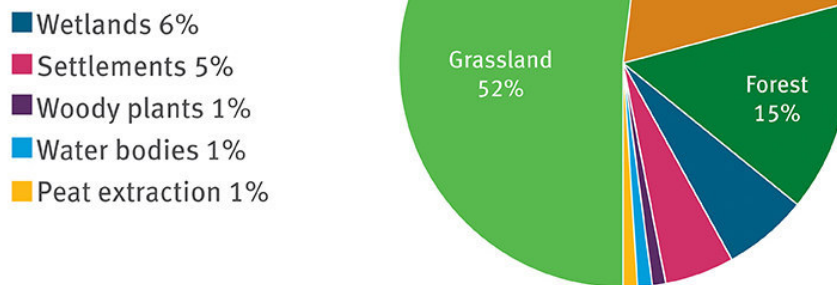


Figure 41. Use of peatland soils in Germany (%). The categories “woody plants” and “wetlands” are based on the vegetation and use of the areas. These categories include the few preserved near-natural peatlands, as well as unused drained peat soil. Original image from UBA and DEHSt (2023).

The German agricultural sector is responsible for the transformation and use of more than 70% of the land that was once considered peatland soil (Figure 41, Figure 42 and Figure 42). As a mitigation and restoration strategy, rewetting peatlands has been proposed and studied over many years. Using paludiculture – growing crops on rewetted peatland – has been proposed as a mitigation strategy for peatland loss (Tanneberger et al., 2020; UBA, 2023f). However, Kreyling et al. (2021) showed that rewetting does not necessarily return peatlands to their original state: there are marked differences in vegetative biodiversity, hydrological and geochemical functioning, and land cover characteristics.

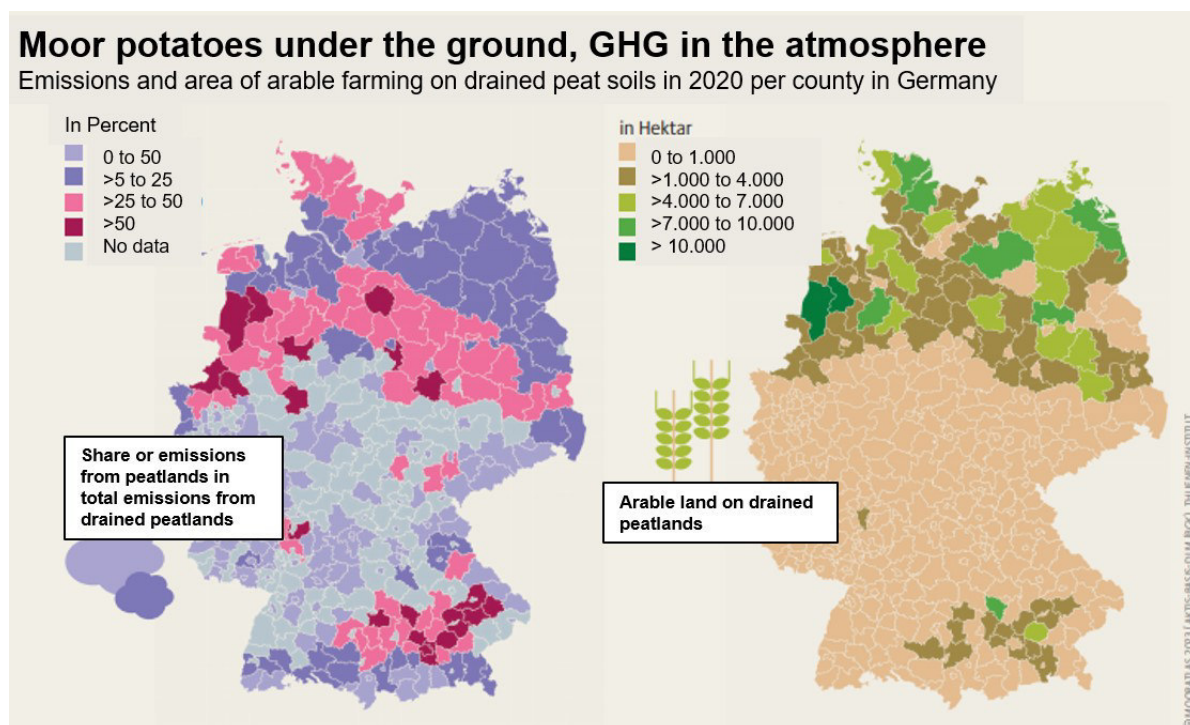


Figure 42. Share of agriculture on drained peatlands in Germany (per county) in 2020. Original image by Dewitz et al. (2023).

5 Digital technologies in agriculture

5.1 Trends in digital technologies

Since the late 20th century, some large-scale farmers have adopted modern technologies to control weeds. These technologies range from the use of robotics, sensors, and unmanned aerial or terrestrial vehicles systems (drones), to digital reference works, digital land machines, and FMIS software because older techniques are time-consuming and require higher labour costs (Bakhshipour et al., 2017). The digitalisation of agriculture describes the application of new information technologies to create agricultural value, with optimisation of agricultural processes is in the foreground (Pflanzenforschung, 2019). While some authorities use keywords like “Agriculture 4.0”, “precision farming” (PF), and “smart farming” (SF) as synonyms (Pflanzenforschung, 2019), in practice they are defined in a different hierarchy (Figure 43).

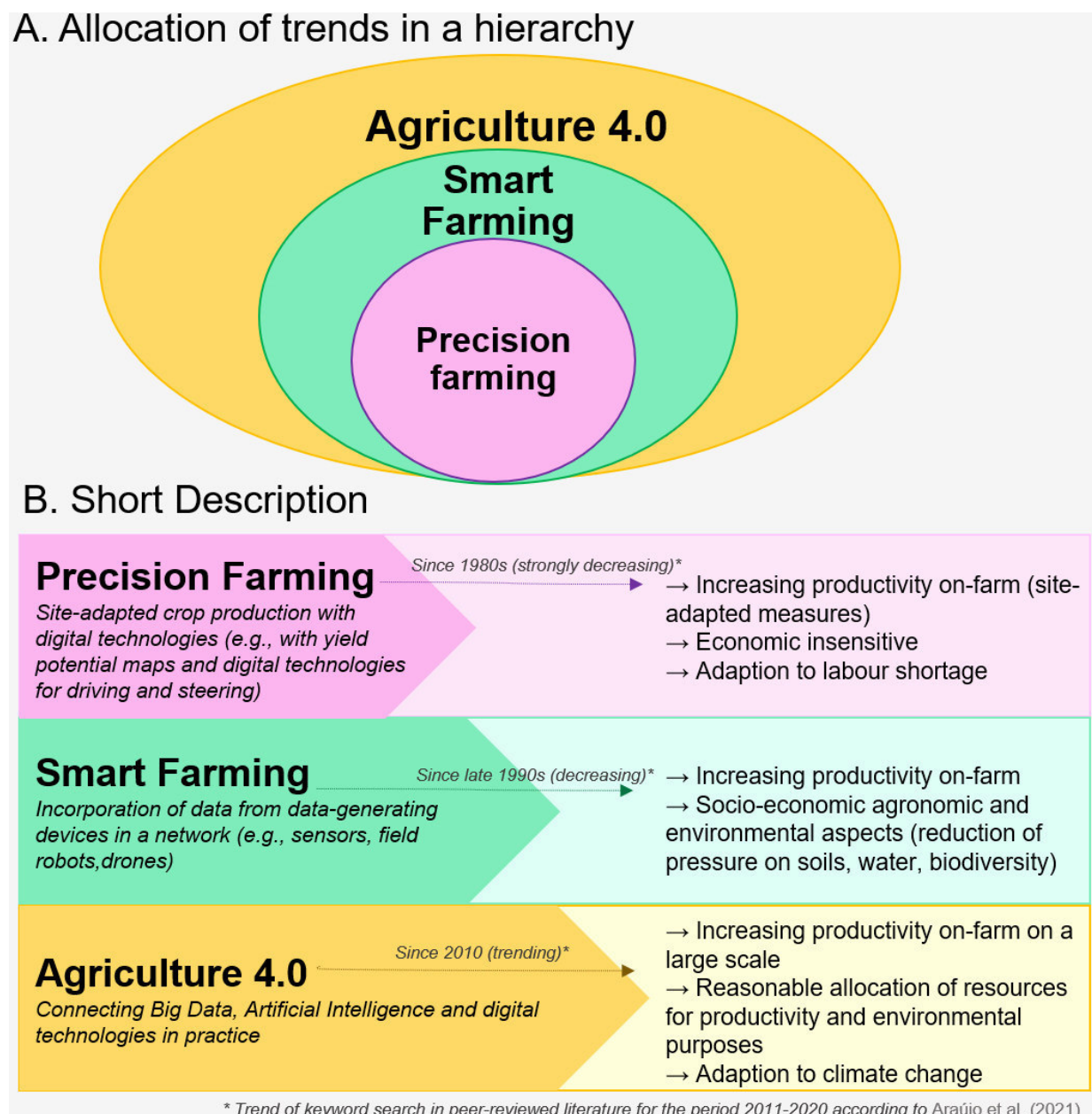


Figure 43. Development and trends in the digitalisation of agriculture. Our illustration.

The trends of digitalisation in agriculture are described and conceptualised in scientific, political, and other discourses by different stakeholders and thus from different points of view. Therefore, the definition and concept behind a trend used in research and industry are not always conceptually clear (Kliem et al., 2023). Hence, the trends Agriculture 4.0, PF, and SF must be considered and understood in the context of the diversity of the stakeholders. Many of the digital technologies presented in this report are not new to agriculture – indeed, many concepts emerged in the 1980s and have continued to be developed since then. However, especially in the last 10 years, there has been a push towards digitalisation in agriculture, as illustrated by the many commercially available technologies. In the context of this study, we do not equate the three trends; rather, we distinguish them according to their scope of function in agriculture. The main reason for the clear separation of the terms in this study is the fact that the three trends have different objectives and sustainable management, in particular nature conservation, is not defined as the main objective for each trend (Figure 43).

5.1.1 Precision farming (PF)

The collective application of new technologies has improved agricultural management practices and has given rise to PF (Di Cicco et al., 2017). Based on an official definition, PF is a collective term for new production and management techniques in crop cultivation that make intensive use of data for the specific location and plant population (Pflanzenforschung, 2002). The trend started emerging in the 1980s, when field sizes started increasing and farmers wished for a technological framework that provides better control of arable management (Blackmore, 1994). With the available techniques, it is possible to carry out site-specific and site-adapted crop production, which, considering environmental conditions and actual plant needs, is more resource efficient than conventional methods (Irias & Castro, 2019) PF is not only about technology; it also concerns the management of arable variability (temporal and spatial). PF also links field information acquisition and analysis strategies and the application of inputs according to established parameters through intelligent systems; a main factor is site-specific management for optimised and efficient field crop production (Sonntag et al., 2022). Well-known PF technologies include auto-guidance and yield measurements through yield potential maps¹³ (Kutter et al., 2011). PF concentrates entirely on economic incentives, leaving environmental and social factors in the background (Kutter et al., 2011). PF is no longer a common keyword in the peer-reviewed literature, but precision agriculture is a more common term (Araújo et al., 2021).

5.1.2 Smart farming (SF)

SF encompasses PF but goes beyond it by expanding the application focus of digital technologies, connecting different “sub-areas” in a farm and helping farmers to incorporate the data from the network of individual data-generating devices with each other and their networking with executive devices in the Internet of Things (IoT) (Bacco et al., 2019; Kliem et al., 2023). This process generates a large amount of

¹³ Yield potential maps have been used in agriculture for the past 25 years. Yield potential maps are using satellite remote sensing data and mathematical and evaluation models to estimate the yield potential of a field crop based on the biomass detected from the satellite imagery.

real-time and context-specific data in addition to spatially related data, on the basis of which, processes can be automated (Kliem et al., 2023). Therefore, PF can be described as a sub-category of SF. SF is narrowly connected to the term IoT, which is crucial for the communication and computing of data-generating devices, such as sensors, with software technologies. The IoT describes the integration of multiple devices with their internal and external states through the embedded technology of the IoT (for the collection of information). More specifically, the IoT provides the components for SF (Farooq et al., 2019).

SF has the potential to support more productive and sustainable agriculture through a more precise and resource-efficient approach on-farm. Only one fifth of farmers in Europe use SF approaches on a daily basis, while up to 80% of farmers in the United States of America use SF tools for crop production. The Council of the EU officially recognised the potential of SF for a sustainable digital future with a declaration in 2019 (Council of the European Union, 2019). Economic as well as environmental aspects are mentioned as a part of the smart transformation of agriculture.

5.1.3 Agriculture 4.0

Agriculture 4.0 is an industry trend that is transforming the production capabilities of the agricultural domain. Agriculture 4.0 connects Big Data, AI, and digital technologies in practice (European Commission, 2017). All data from all fields can be gathered, processed, and then used by farmers to optimise field management (Zhai et al., 2020). Agriculture 4.0 is a fairly new trend – it emerged around 2010 – and promises to bring major global improvements, such as increasing productivity, a reasonable allocation of resources, and adaptation to climate change (Araújo et al., 2021; Zhai et al., 2020). In the peer-reviewed literature the new term “Agriculture 5.0” has begun to appear. Agriculture 5.0 is the next industry trend, which uses sensors, Big Data, IoT, robots and artificial intelligence, but the main difference is, that the application area are extended. Digital technologies, such as field robots can make a difference between crops and weed plants, and more specifically differ between different weed species. Agriculture 4.0 is expected to strongly affect the nature of farmer work and the employment of labour, since Agriculture 4.0 promises labour-saving technologies (Rose et al., 2021).

5.2 Complex systems for data proceeding

The variety and volume of data in agriculture that is available through different sources, such as satellite imagery, networked sensors, and monitoring, are constantly increasing. Therefore, management and processing of such data requires systems that can structure it in a useful way for agriculture. At this point, we want to clarify that the term complex systems for data processing refers to the objectives of this study and only includes the areas of machine learning (ML), artificial intelligence (AI), and Big Data (BD), and does not describe computing systems or computer languages in detail. Figure 44 schematically illustrates the hierarchy of complex systems for data processing and software- and hardware-based technologies. In the middle is ML and AI, which are the cornerstones for the extensive functions of software-based technologies. ML and AI are independent concepts (see 5.2.1 and 5.2.2), whereby the ML processes have

hardly any points of contact with the everyday life of farmers – it is a task for computer and mathematics experts. The branch of mathematics that deals with theories appropriate for dynamic systems is one example (Jong & Boer, 2009). Farmers provide the input for the ML algorithms, but they do not design these algorithms themselves. AI is a form of data processing that relies on farmer input, but is also rooted in the field of computer science. In everyday life, there are now some AI-based online tools that are very well known: ChatGPT, DeepL, FireFlies.ai, Murf, genei.ai, Jenny.ai, All Search.ai, ContGPT, and ExplainThis.ai are but a few. There are currently only a few AI-based tools that farmers can use directly. However, it can be assumed that most of the technologies that support decision-making are AI-powered, although the manufacturers rarely mention this fact on their websites. The difference between AI-based and AI-powered digital technologies is described in Chapter 5.2.2.

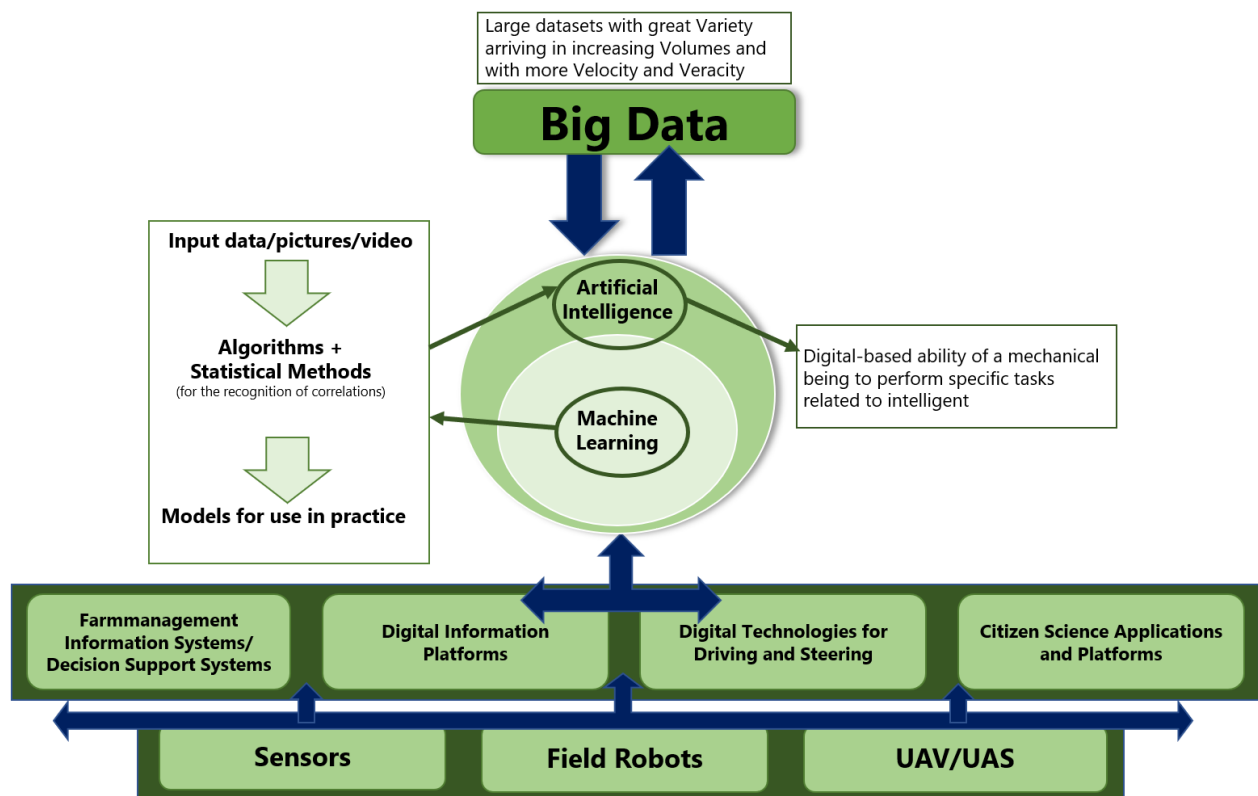


Figure 44. Definitions and relationships between Big Data, Artificial Intelligence and Machine Learning in the context of software- and hardware-based digital technologies. Our illustration with definitions from Aggarwal et al. (2022), Berkeley (2022), Oracle Cloud (2022) and Russell and Norvig (2021).

Above AI, Big Data is a term for the processing of very large and heterogeneous data volumes at high speed (Figure 44). Therefore, it is combining both machine learning and artificial intelligence as predictive analytics and as an important component of business intelligence (Bhat & Huang, 2021). Machine learning and artificial intelligence are closely related to all software-based technologies - they form the basis that the technologies need to perform various functions, e.g., pattern recognition, forecasting or recommendations. The hardware-based technologies, especially sensors, collect information in their environment, feed it via the software-based technologies to machine learning and accordingly to artificial intelligence, which in turn is used in the software-based technologies, such as

farm management information systems and decision support systems, to make recommendations to farmers. In the sections below (5.2.1 to 5.2.3, and 5.4.1 to 5.4.3) the individual terms from Figure 44 are discussed more in detail.

5.2.1 Machine Learning (ML)

ML is not equal to AI: it is a preliminary stage of it, in which training data are classified based on algorithms (Aggarwal et al., 2022; Liakos et al., 2018). ML describes the learning process of technologies from gathering data through hardware to using them in the more complex context of AI and/or BD (Berkeley, 2022). The process of using ML algorithms to build specific models from datasets is called learning or training (Zhou, 2021). The first ML-based approaches were developed for description and classification purposes between the 1950s and early 1970s (Saitta, 2009; Zhou, 2021). These concepts were presented as decision trees¹⁴, or logical formulae, in a propositional or restricted first order logic (Saitta, 2009). Decision ML models can use regression models, clustering, probabilistic graphical models, memory-based models, decision trees, artificial neural networks (ANN), support vector machines or ensemble learning (Benos et al., 2021; Berkeley, 2022; Liakos et al., 2018).

The term deep learning (DL) is often used together with ML. The use of ML in science has advanced a lot and is characterised through more sophisticated learning algorithms and efficient pre-processing techniques. The evolution of ANN towards increasingly deep neural network (DNN) structures with improved learning capabilities is the official definition of DL (Janiesch et al., 2021). In the hierarchy of ML, DL takes the lowest place, followed by ANN and ML learning algorithms. ANN have a flexible structure and can be modified for a wide variety of contexts across all ML types. ML algorithms produce superior results, which can be better interpretable than DNN results (Janiesch et al., 2021).

According to Araújo et al. (2021), “machine learning” was the second most used term in peer-reviewed literature in agricultural topics between 2011 and 2020. Throughout the world, maize and wheat are the most common crop plants that are being investigated by ML models (Benos et al., 2021).

ML is an indispensable part of digital technologies, but the responsibility for this area falls on technology developers and researchers – farmers can only provide input through digital technologies as end users and do not have a part in the learning process of a ML model.

5.2.2 Artificial intelligence (AI) technologies

The definition of AI has been greatly debated in science since the first conversation about it published by Turing (1950) who asked can computers think? Because computer programs cannot completely act and think like human beings, the definition and aims have been extended and adapted by Russell and Norvig (2021) and other authors as the digital-based ability of a mechanical being to perform very specific tasks related to intelligent beings in the field of computer science (Martin et al., 2022; VanderZaag et al., 2018). AI can recognise patterns and offer solutions for problems and uses logic for planning, educating,

¹⁴A decision tree refers to a non-parametric supervised learning algorithm used for both classification and regression tasks. It has a hierarchical tree-like structure, consisting of a root node, branches, internal nodes, and leaf nodes. Source: IBM (2023b)

communicating, and imaging (Aggarwal et al., 2022). Aggarwal et al. (2022) explained, that the aim of AI is to obtain the most suitable solution from a variety of answers, while ML focuses on one answer to the question: is this solution optimal or not. According to Araújo et al. (2021), “artificial intelligence” is the sixth most used term in peer-reviewed abstracts.

In the recent years, AI-powered solutions have been extensively applied in agriculture throughout the world; they are integrated in certain software-based technologies or used for software-based predictions in agriculture (Javaid et al., 2023). Because AI-based solutions are not simply designed for end users (farmers), their direct adoption in agriculture is limited (Javaid et al., 2023). The distinction we make between AI-powered and AI-based digital technologies lies in the user area. AI-powered technologies refer to those technologies whose functions and/or recommendations arise from AI. In this sense, the end user does not have access to AI and only uses the “end product” in the form of software. AI-based technologies are those that can be used directly by end users, or in our study context farmers, or end users can participate in the “learning” process. We offer the following examples to make this difference even more understandable. NVIDIA Deep Learning AI Software¹⁵ is a well-known and very advanced AI platform for the development of analytics based on different ML algorithms. Through this AI-powered technology, a manufacturer or developer can create a chip for edge computing. This chip could be installed on a field robot and act as the robot’s “brain”; thus, the robot would be AI powered by NVIDIA¹⁶. The farmer has no direct access to this process – the farmer uses the “end” product as an AI-based field robot. AI-powered chips can work independent of servers and clouds, a difference from other software-based technologies.

According to the information platform “There’s an AI for That”,¹⁷ there are 3,600 AI solutions for farm management software, which can perform 609 different tasks, including task automation, time management, health monitoring, workflow management, pattern generation, three-dimensional (3D) images, problem solving, and product recommendation. AI-based technologies offer AI-powered data processing on platforms and applications, but farmers can use them directly. A famous example for a quick question check is agriGPT (www.agrigpt.de), which is derived from the famous ChatGPT AI-based tool. Another example is heliopas.ai. This AI platform offers quick analytics on a daily basis, when the user enters individual relevant parameters (e.g., soil homogeneity, soil moisture, crop type, land usage, plant health, and floor-bearing capacity). Other examples are available under Appendix Table 8.

5.2.3 Big Data (BD)

BD provides an overview of real-time agricultural situations, enabling farmers to make “smart” decisions in field (Dhanaraju et al., 2022). The term “Big Data” was established around 2015 in science as the volume of data generated increased markedly (Emani et al., 2015). The Federal Ministry of Education and Research in Germany (BMBF), BMBF (2023) has established two competence centres for BD in

¹⁵ Information available from <https://www.nvidia.com/en-us/ai-data-science/>

¹⁶ Example taken from Zauberzeug GmbH (www.zauberzeug.com)

¹⁷ Source: <https://theresanaiforthat.com/job/farm-manager/?ref=suggest>

Germany: the Berlin Big Data Center (BBDC) and the Competence Center for Scalable Data Services (ScaDS) in Dresden. The Federal Ministry of Education and Research claims to have set itself the goal of providing targeted support for research into the intelligent handling of large, heterogeneous datasets in Germany. A competence centre for AI and BD that focuses on agricultural food production will be established in 2025. The Federal Ministry of Economic Affairs and Climate Action (BMWK), BMWK (2023b) states that the general conditions for BD in agriculture in Germany are ideal and offer great potential for sustainability. Currently, the keyword “Big Data” is the 10th most common in the peer-reviewed literature on agriculture (Araújo et al., 2021).

BD analysis has been used very successfully in other industrial sectors, but it is a new term in agriculture and its adaptation has started only recently (Lokers et al., 2016). The complexity of BD is described by three “Vs”: volume, variety, and velocity (Lokers et al., 2016; Oracle Cloud, 2022). Volume stands for the immense amount of data that is being generated and collected from digital technologies. Terabyte¹⁸ to petabyte¹⁹ size volumes are easily reached when attempting to capture natural variability on detailed spatial and temporal scales (Lokers et al., 2016). Variety refers to the heterogeneity of the data, which is not only relevant, but can be incorporated into the decision-making process. Velocity describes the pace at which new data can become available, for example, through real-time streaming, but it also refers to usually high requirements regarding processing time to make data available at all (Lokers et al., 2016). Veracity is often mentioned as the fourth “V” characteristic of BD and relates to the accuracy and credibility of the data (Coble et al., 2018). Other authors go further and report up to 10 “Vs”: volume, variety, velocity, veracity, validity, value, variability, venue, vocabulary, and vagueness (Bhat & Huang, 2021). According to Bronson and Knezevic (2016), BD is a concept that is actively framed and interpreted by people. Hence, BD is not solely a technical accomplishment; rather, it is also a social and ethical concept.

It is often not clear which technologies are BD based – only certain functions or the whole technology – as the manufacturers themselves do not provide information on this aspect. Large-scale manufacturers are using BD tools (Bronson & Knezevic, 2016). Osinga et al. (2022) concluded that BD solutions are not yet able to work “out-of-the-box” yet, when the application domain is being changed, and additional technology development is necessary.

Digital tools based on BD could play an important role in the adaptation of agriculture to climate change, as the assessment of large datasets could provide short- or long-term predictions (Luyckx & Reins, 2022). However, there are still open questions of ethical, cultural, political, ecological, and material significance that need to be addressed when using BD in agriculture (see Chapter 0). Currently, some of the main drivers for BD use are the prevention of food safety incidents, the development of field robots, and optimisation of crop yield forecast (Osinga et al., 2022).

¹⁸ 1 terabyte = 1.000 gigabyte = 1.000 000 megabytes = 10.000 000 000 000 bytes

¹⁹ 1 petabyte = 1.000 terabytes

5.3 Software-based technologies

Data networks are becoming more and more software-based. By moving from a hardware- to software-based environment, network services become easier to deploy and enables more complex functions (Wood et al., 2015). This trend is described as software-defined networking (SDN) (Farhady et al., 2015). A software-based system is centred on the intercommunication of components through software, which is only possible through a combination of hardware (such as routers) and software (Zehir et al., 2020). Software-based technologies are commonly known under the term cloud-computing, which applies for all industry sectors. According to IBM (2023a) cloud-computing is also often referred to “the cloud” and describes the on-demand provisioning of information technology (IT) resources, which can be applications or whole data centres over the internet with usage-based fees. Remote computers from a certain service provider usually run cloud computing. Users can connect to these remote computers via the internet and a browser or from a certain application or platform and use the data or the services of a certain technology. In software-based technologies in agriculture, the Shapefile (.shp) format for data is common. This format was originally created by the ESRI²⁰, it is a simple, nontopological format for storing the geometric location and attribute of geographic features. Such features can be shown as points, lines, and polygons (ESRI, 2021). The other common format for data in agricultural software solutions is ISO-XML; it refers to a communication protocol for agricultural machinery based on the CAN bus. ISO-XML is the data format for the exchange of data between machine terminals (MICS) and agricultural software (farm management information systems [FMIS]). It can contain customer and product information as well as application cards. When returned from the MICS terminal, machine data are also retrievable. For the customer is it then possible to create grids or to code their (Wiebeler, 2022).

In this study, we sorted the software-based technologies into four sub-categories. The term platforms refers to software solutions available via a browser and not as an application. FMIS and decision support systems (DSS) are Internet of Things (IoT)-based digital technologies that use plausible relationships between data from all other technologies (such as sensors) to optimise agricultural processes (Figure 45). FMIS and DSS are related to MICS and the use of ML algorithms. The FMIS and DSS technologies listed in Appendix Table 9 and Appendix Table 10 are software solutions available to end users. Digital technologies for guidance and steering (DTGS) refer to GNSS²¹-based digital technologies for precise steering and driving, which usually enable semi-automatic machine guidance and precision of the actuators (Figure 45). The list of DTGS technologies includes an overview of the software solutions, available to end users, and does not go in detail about the hardware of steering systems (e.g., touchscreen monitors, tablets, steering wheel motors, antennas, steering angle sensors or cable harnesses). In some cases, the offered DTGS technology is combined with hardware (Appendix Table 11 and Appendix Table 12).

²⁰ ESRI is an US-American software manufacturer of geoinformation systems

²¹ GNSS refers to Global Navigation Satellite System and is a collective term. GPS (Global Positioning Service) is a part of GNSS. There is nationwide network of more than 240 permanently registering GNSS reference stations in Germany BKG (2023)

Digital information platforms (DIP) are digital platforms for digital collaboration, networking, and knowledge-sharing (Figure 45). DIP can provide data for various applications that can be applied and developed at a higher software level, such as FMIS and DSS. Citizen science (CS) applications and platforms collect and can provide large amounts of data, which can be used to develop and enhance ML algorithms. Additional details about each software-based technology group are available in Chapters 5.3.1 to 5.3.4.

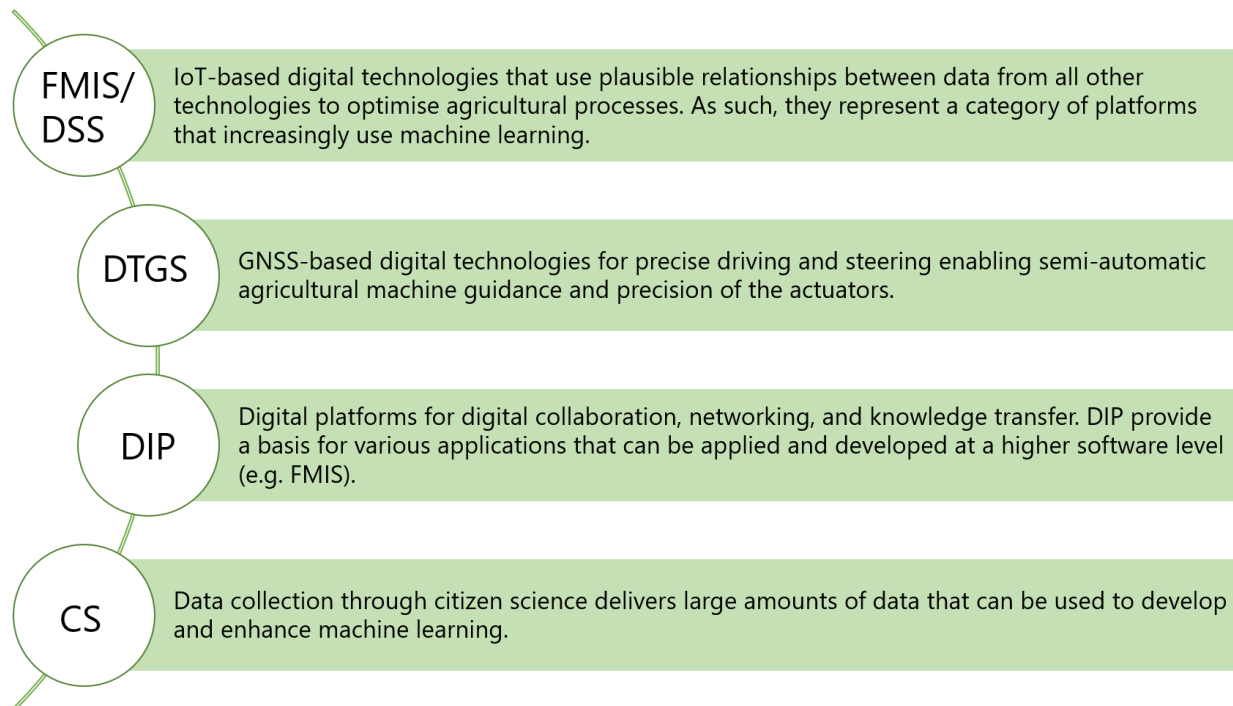


Figure 45. Overview of software-based technologies in sub-categories. Our illustration.

5.3.1 Farm Management Information Systems (FMIS) and Decision Support Systems (DSS)

FMIS are IoT-based technologies that can use plausible correlations between data from all digital technology categories in order to optimise agricultural processes at administration and operational levels. Thus, they represent a category of platforms that increasingly use machine learning. From the integrated analysis of farm-specific data, such as yield quantities, the application rates of fertilisers and crop protection products, machine data and site-specific data, and soil data, it is possible to improve processes to make them more efficient (Kuhwald et al., 2020). Fountas et al. (2015) distinguished the purposes of FMIS from academic and commercial points of view. In their market study, Eckelmann (2020) reported that most FMIS entered the market after 2010. FMIS developed in academia tend to analyse more complex systems, including the integration of spatial and temporal management and distributed systems including the IoT and web services. On the other hand, commercial FMIS seek to facilitate farm management and operational planning. As planning must take place separately for each field, digital technologies can facilitate the process by collecting and partially analysing the necessary data to help decide which crops to plant. In 2020, the average size of agricultural farms in Germany was 63 ha of

utilised agricultural area per farm (Destatis, 2021c). The application of FMIS is partly cost-intensive and often complex, which is why their use is still limited (Munz et al., 2020).

FMIS can become more comprehensive when data collection and processing are included to support farm management decisions in the field, an approach referred to as DSS (Boehlie & Eidman, 1984; Tummers et al., 2019). The main difference between FMIS and DSS is the group of people targeted by the technologies within a farm or company. FMIS optimise the farm as a whole and not just parts of it – this is achieved by offering everything on one platform – including crop and livestock management, machinery management, payroll and administrative work and reports, as well spatial and temporal management (Henningsen et al., 2022; Streimelweger et al., 2020). DSS support human decision-makers by identifying and clearly preparing relevant information for operational and strategic tasks; therefore, DSS are used in the production process. Jones et al. (1980) provided the first definition of DSS: “a computer-based support system for decision makers who deal with semi-structured problems to improve the quality of decisions”. DSS can be integrated into FMIS (Murr et al., 2018). Some authors describe FMIS as software solutions that record large amounts of data within farms and are used to make decisions. However, we explicitly use the original definition of FMIS. Therefore, we categorised software solutions, which are referred to as an “electronic field diary” or a digital field index, as DSS (Appendix Table 10).

Research has shown that FMIS and DSS providers develop mobile and web applications that are cost money to use. DSS developed in cooperation science (CropSAT and EcoPay) and DSS for simpler tasks (Magic Scout) are free for customers but offer only limited functions compared with the technologies that cost money to use. FMIS providers often offer a demo version for farmers to try; the price for the full version depends on the module selection of the farm. FMIS and DSS cannot be developed in a general and uniform way for small- to large-scale farms (LfULG, 2020) because of the great variety of farm needs and goals. NEXT Farming also offers the purchase of a hardware weather station for farms connected to their FMIS (Bosch, 2019).

In addition to the common DSS for crop production and administration, the free to use FAIRshare tool was developed with EU funding. Farm advisors can search for a suitable digital tool based on defined criteria. Within five steps, criteria in different application areas are selected and the user receives concrete suggestions for digital tools available on the market.

Below we provide two examples of an FMIS and a DSS and briefly present their modules. A full list is available Appendix Table 9 and Appendix Table 10.

CLAAS TELEMATICS is a DSS of networked sensors for data recording, transmitting, operating, and processing. The data are stored on a web server, where it can be accessed by various actors for different purposes and used to optimise working processes (Drewel et al., 2017; Kielbasa et al., 2018). Another function of the telemetry system is to export the data located on the web server to FMIS, such as the 365FarmNet Platform, for further processing (Drewel et al., 2017; Kluge & Hardie, 2020). CLAAS TELEMATICS offers three different licences for users: basic (a 1-year licence for 275 euros), advanced (a 1-year licence for 450 euros), and professional (a 1-year licence costs 665 euros). The 365FarmNet

Platform provides three modules for users: the first two modules are free to access and include basic modules. For the third model, the company provides prices upon individual requests.

5.3.2 Digital technologies for Guidance and Steering (DTGS)

DTGS are the pioneers of precision agriculture and the most used digital technologies in crop cultivation. Their functions are based on spatial data from global navigation satellite systems (GNSS) (geographic information system [GIS] and/or GPS), which are used by farmers to optimise field operations through precise driving and steering. According to the survey by Gabriel and Gandorfer (2022), the most used digital technologies in the federal state of Bavaria are based on spatial data: automatic steering systems (30%), GPS-based technologies (21%), satellite-based map data (18%), and optical steering tools (11%). The usage of spatial data enables semi-automatic machine guidance and operations for farmers, which are mainly used to reduce the workload of the driver and to work more precisely. The input for DTGS is spatial data collected by sensors, satellites, unmanned aerial vehicles, and FMIS/DSS. DTGS offer the greatest potential for implementing site-specific measures to reduce pesticides and fertilisers, allowing resource use efficiency. At the same time, there are high risks for use that is too precise – for example, in the marginal field areas – without allowing sufficient habitats for flora and fauna. The acquisition costs of software for DTGS are low, compared with other digital technologies, and some services are also provided free of charge (Rohleder et al., 2020; Söderström et al., 2016). A full list is available under Appendix Table 11 and Appendix Table 12.

5.3.3 Digital Information Platforms (DIP)

The guidance from FAO for the transition to sustainable agricultural systems indicates that sharing knowledge as the second most important aspect to achieve agroecological aims (FAO, 2019). Sharing knowledge is a very important part of designing sustainable agriculture. DIP provide both formal and non-formal education for farmers and are closely connected to building synergies in food systems. Coordination and communication among different stakeholders are important both in the development of new digital tools and in the collection and analysis of data, in order to design sustainable agricultural systems (BMEL, 2022c). Beside their technically integrative capacity, DIP serve as intermediaries between different stakeholders, for example, as a simple supply–demand relationship. By coordinating actions between different stakeholders in a commercial setting, DIP can create new economic value. DIP are an example of mediating transactions along the entire value chain in agriculture and are of an emerging interest for the design of a sustainable agriculture (Kliem et al., 2022).

A full list is available under Appendix Table 13.

5.3.4 Citizen Science platforms and applications (CS)

CS describes the active engagement of the general public in scientific research tasks (Vohland et al., 2021). CS is a flexible concept that can be adapted within diverse situations and disciplines (ECSA, 2022). The trend of CS emerged in the 1990s, as Irwin (1995) postulated that there is a linkage between

science, technical knowledge and the wider population. The first noteworthy examples of the application of CS are from Austria, Germany, and Spain (Vohland et al., 2021). The application of CS databases in natural sciences, such as agriculture, produces long-term societal outcomes. CS platforms and apps support innovations and promote new learning as an important source of data for science (Koffler et al., 2021). CS are often accessible free of charge and usually involve unpaid volunteers in the data collection process (Koffler et al., 2021). In 2015, the European Citizen Science Association set key principles for good practice in CS; these principles cover the outcome, benefits, participation, data issues, and research approaches (ECSA, 2022). In the form of image and/or sound and short film recordings, data are used as the basis for analyses and for the development and expansion of other digital tools (Steward et al., 2019). Most CS databases have a spatial reference from geo-tagged photographs or location information from a smartphone. CS data collection by citizens may take place in hard-to-reach locations, which is an advantage compared with traditional data sources. CS comprises denser and more frequent observations as well as a diversity of subject areas (Fritz et al., 2019). CS has the potential to contribute to reporting SDGs, such as achieving food security (Fritz et al., 2019). Frigerio et al. (2021) stated that nationwide monitoring schemes for agricultural areas support research regarding the influence of agricultural production, land use, and agricultural change on biodiversity.

Currently, the use of CS data is limited, as it is only in the last 10 years that scientists have considered the potential of CS. Therefore, it is not yet common for peer-reviewed articles to use CS databases (Koffler et al., 2021). Koffler et al. (2021) noted in their review that the number of publications containing CS data on bee species has continuously increased and can be used as an instrument to involve different stakeholders. However, CS relies on financial resources, some of which could be high. Successful CS projects require pertinent experts who control the data processes and communicate regularly with the data collectors (Frigerio et al., 2021).

Most well-known CS projects in Germany are supervised by experts (Franzoni & Sauermann, 2014). The large interactive CS platforms Deutschlandflora and The German Red List Centre (Rote Listen- Zentrum [RLZ]) are directly funded and managed by the Federal Agency for Nature Conservation, as indicated on their official websites (www.deutschlandflora.de and www.rote-liste-zentrum.de, respectively). RLZ specifies on their website that relevant data may be available, for example, from the nature conservation authorities of the federal states, professional societies, natural history museums, regional mapping projects, planning offices, or researching individuals. Additional findings can be obtained from the evaluation of individual publications, museum collections, or through targeted searches of earlier sites. In many cases, data from CS projects are also available, which are included in the data collection after examination and confirmation by experts. According to the Deutschlandflora website, the aim of the data portal is to bring together observation and collection data on vascular plants from Germany. This is intended to provide an overview of historical and current occurrences of species. The offer to contribute to Deutschlandflora is aimed equally at official and voluntary organisations, as well as interested individuals. Verified data are used for nature conservation purposes; scientific evaluations; and to compile the Red Lists of endangered animals, plants, and fungi of Germany. Another well-known

platform for CS data collection and volunteer engagement as well as knowledge-sharing is Naturschutzbund Deutschland e.V. (NABU; www.nabu.de). NABU has various platforms and apps that can collect data. For example, the well-known Naturgucker app (www.naturgucker.de) is managed by NABU. Here, public observation campaigns are made that relate to different animal species, among other things. They also organise observation competition events to attract as many participants as possible. Currently, a campaign is underway to collect the locations of hedgehogs (*Erinaceus europaeus* L.) and moles (*Talpa europaea* L.), as there are no reliable data collections on them so far. Hedgehogs are now on the RLZ's list of endangered species (RLZ, 2023). Observations together with pictures and videos are mandatory for the observation campaigns of NABU. A full list is available under Appendix Table 14 to Appendix Table 16.

5.4 Hardware-based technologies

Hardware is the generic term for the physical components of a data processing system; it serves as a complement to software. Hardware is the part that can be touched and includes all components from a simple capacitor to a completely assembled circuit board; the device; accessories such as a mouse, keyboard, screen, and printer; and data carriers such as hard disk drives or USB memory sticks and servers (IT-Service.Network, 2023).

The three sub-categories of hardware-based technologies in this study include sensors (S), field robots (FR) and unmanned aerial vehicles (UAV) (Figure 46). S are physical devices that collect information from their environment through observation. Sensors can be stationary (i.e., satellites) and help agriculture with mapping and data collection. As mobile tools, sensors can measure a wide range of physical parameters, including soil and air temperature, humidity, the amount of precipitation, evaporation, the chlorophyll content, and light intensity, among others. Field robots are semi-autonomous or autonomous machines that are built and programmed (e.g., through a robot brain; see Chapter 5.2.2) to perform specific tasks for agricultural production. Field robots use sensors and AI to perceive and assess their environment through augmentation and can make decision in the field based on previously gathered information (e.g., weed control in crop plants). Unmanned aerial vehicles and systems (i.e., drones) refer to semi-autonomous or autonomous aerial vehicles that are controlled by humans. They have an integrated computer and are used for different tasks, such as monitoring, image-capturing, and laser measurements. Drones can be combined with tools and sensors and used for spraying, seeding, transport of seeds or materials, surveillance, 3D modelling, or acoustic recording of areas (Figure 46). All hardware technologies are subject to charge. The prices can vary greatly among the different manufacturers of field robots and unmanned aerial vehicles and systems, depending on the features that are mounted to the field robot (e.g., camera, sensors, hacking tools, spraying tools, stun gun) or to the drone (e.g., camera, sensors, spraying tools, transport devices).

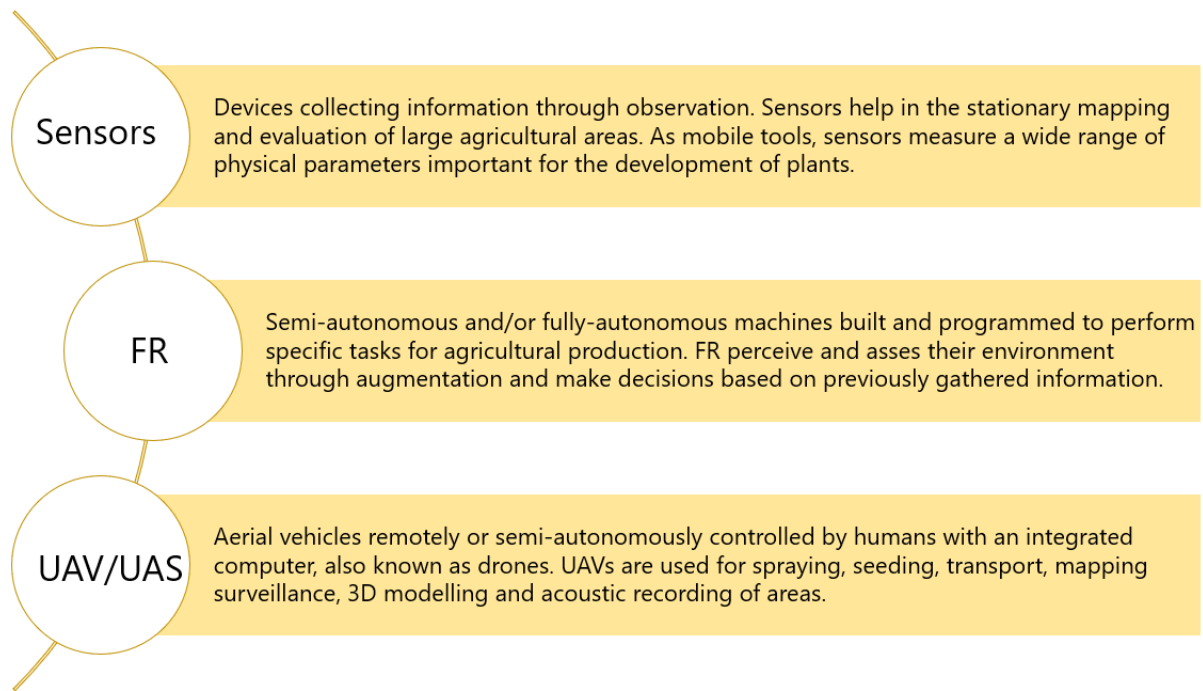


Figure 46. Overview of hardware-based technologies in sub-categories. Our illustration.

5.4.1 Sensor technologies (S)

S are devices that collect information through observation (Saiz-Rubio & Rovira-Más, 2020). Sensors help stationary mapping and assessment of large agricultural areas (Adão et al., 2017; Li et al., 2017). Sensors are often used in combination with robotics (Bellon Maurel & Huyghe, 2017; Tansey et al., 2009).

As mobile tools, sensors are used in the reduction of fertilisers and pesticides as well as in the determination of forage quality traits (Ali et al., 2017; Duckett et al., 2018a). Multispectral images from sensors can also be useful for monitoring and assessing agroecosystems. Passive sensors reflect sunlight and cannot emit any radiation of their own. Their measurements take place in the visible and infrared range of the electromagnetic spectrum (Erdle et al., 2011). Active sensors can emit radiation and receive it at the same time. They transmit radiation in the microwave range (ibid.). Passive sensors help stationary mapping and assessment of large agricultural areas (Adão et al., 2017). As mobile tools, passive sensors are used in the reduction of fertilisers and pesticides as well as in the determination of forage quality traits (Noack 2018). The use of active sensors is also aimed at reducing fertiliser quantities. The perceived light reflection of the plant stands provides an indication of the current chlorophyll supply, enabling nitrogen supply to be tailored to requirements (Bogue, 2017; Reckleben, 2014).

In this study, solely a few examples of virtual fencing technologies for cows are implemented, because a fenceless pasture-feeding of bigger ruminants has a proven positive effect not only on the welfare of the animals, but also significantly on the surrounding environment and ecosystems. Wild animals are not jeopardised by inappropriate built fences and can move around the area according to their natural behaviour. Due to the free movement of cows (or other livestock), the landscape gets shaped much more

naturally (for example browsing of ruminants on herbaceous and shrub vegetation) and the influence of the human induced agricultural land use becomes a lot distributed and decentralised.

A full list is available under Appendix Table 17 to Appendix Table 19.

5.4.2 Field Robotic Technologies (FR)

A field robot is a machine in terms of the European Machinery Directive (Directive 95/16/EC, 2006), described under Article 2 (a) as “an assembly, fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application”. Robotic technologies in agriculture refer to semi-autonomous and fully autonomous machines that are built and programmed to perform certain tasks for farming production (Cheng et al., 2023). Robots can sense and evaluate their environment by extension, and make decisions (“think”) based on the collected information with the help of AI-algorithms (Bekey, 1998; Kliem et al., 2023). Robots are associated with improved efficiency for specific tasks as well as for overall performance (Ghobadpour et al., 2022). There are two development paths of robots in agriculture –integration of automation solutions into existing technologies/machineries and the development of smart, new, smaller robot concepts (Gaus et al., 2017).

Robotic technologies in agriculture are most commonly deployed for dairy production (Blockhahn & Terry, 2022; Duckett et al., 2018b). The survey by Rohleder and Meinel (2022) showed that 19% of 500 surveyed farmers in Germany use milking robots, while only 3% employ robots for field work. However, the impact of robots used in animal husbandry of cows indoors is closely related to milk yield (milking robots) and improved ruminants’ health (e.g., AI-based robots for health detection) as well as the performance of mechanical work for animal welfare reasons (camera- or laser-guided robots for mechanical feeding, water supply, and/or removal of manure (Leinweber et al., 2019; Ruckelshausen, 2023). Therefore, we did not consider them to be relevant for the sustainable development of agriculture in the strict context of this study and have not examined them further.

The development of field robotic technologies for crop production has focused mainly on the agricultural side to address the yield-reducing problem of weeds by using common mechanical and chemical methods (Botta et al., 2022). However, other methods for field robotic weed regulation such as thermal and electrical methods are currently under development for automation (Steward et al., 2019). Field robots still need to be refined before they can be used successfully in large-scale farms (Bručienė et al., 2022). The major problem of robotic technologies is their working speed and area (Fountas et al., 2020). The working speed of robots is 1–4 km/h (Gil et al., 2023). Furthermore, the effectiveness of weeding can vary greatly among field robots, depending on the site, soil type, weed infestation, weed composition, and weeding time (Ahmad et al., 2014; Bručienė et al., 2022; Fountas et al., 2020). Field robots can also facilitate work and take over additional tasks in agriculture and horticulture such as fruit picking (Bogue, 2020), vegetable seedling transplanting (Sharma & Khar, 2022), pollination (Oliveira et al., 2021), pruning (Zahid et al., 2021), and general tasks related to transport and facilitation and seat support for farm worker (Lytridis et al., 2021).

There are a large number of academic papers on the functioning and construction of innovative field robots and the number of these publications is growing daily. However, they are mostly conceptual studies that have either been tried out only on a limited scale or only under laboratory conditions. Although field robots are currently being researched and tested in field conditions, the dynamic development in the past 10 years and especially currently suggests that in the next 10 years, field robots will probably be seen working in fields more often. In this study, we identified 31 commercial field robots (Appendix Table 20 and Appendix Table 21). The majority are applicable for crop production. Despite the current field robots available on the market, 93% of surveyed farmers stated that they are not planning to purchase a field robot (Gabriel and Gandorfer, (2022).

Below, we provide a few examples of the most well-known field robots and their mode of operation are. A full list is available in Appendix Table 20 and Appendix Table 21.

The FD20 robot, from the Danish company FarmDroid, operates with four photovoltaic modules that generate the electricity to move and work. It performs sowing and weeding in different crops such as sugar beets (*Beta vulgaris* L.), onion, spinach, kale, flowers, and rapeseed (*Brassica napus* L.). During sowing, the FD20 robot registers the coordinates of each plant, using high-precision GPS, and knows where it must regulate weeds. Therefore, it does not work with cameras and sensors to distinguish plants from weeds. It stops itself and sends a Short Message System (SMS) to the farmer in case of errors, stops, or deviations. Bručienė et al. (2022) achieved 48% effectiveness by using FD20 compared with 81% effectiveness with a traditional tractor hoeing.

The BoniRob field robot was developed in Germany by AMAZONEN-Werke H. Dreyer GmbH & Co. KG, Robert Bosch GmbH, and the University of Applied Sciences Osnabrück. It is an example of successful cooperation between research and industry in Germany (Ruckelshausen et al., 2009). The BoniRob weighs around 1 t and moves across the field on four individually driven wheels. It is a multipurpose robot with different application modules (BoniRob-Apps) (Goettinger et al., 2014; Schwich et al., 2018). Sensors, electronics, and software ensure that it recognises its position and manoeuvres over the field with centimetre precision without damaging the crop plants. With the help of sensors, BoniRob recognises and measures individual plants and can check their health status (Langsenkamp et al., 2014). Under specific soil conditions, BoniRob can achieve a control rate of 96.86% in the intra-row area (Langsenkamp et al., 2014).

The *K.U.L.T Robovator* from *KRESS* is a vision-based robot for mechanical weeding. It uses hoeing blades that move in and out of the crop row as a crop plant passes, to remove weeds (Lati et al., 2016). Similarly, the *Robocrop InRow Weeder* from *Garford* relies on video-image-analysis (machine vision) to determine the positions of individual crop plants in order to then remove the weeds mechanically from between and within the crop rows (Fontanelli et al., 2015; Hemming et al., 2018; Muscalu et al., 2019).

The French company Naïo Technologies has developed the OZ weeding robot, which was launched mainly for asparagus producers, small-scale farms, and greenhouses. It is a small (150 kg) 100% electric

robot equipped with a vision system, GPS/RTK, and LiDAR²² sensor. The accuracy of the images can be up to 2 cm with autonomy that depends on the attached tool, among which can be plough shares, comb harrow, brush, and a trailer (Epée Missé et al., 2020; Robert et al., 2020). A full list is available under Appendix Table 20 and Appendix Table 21.

5.4.3 Unmanned aerial vehicles (UAV) and unmanned aerial systems (UAS)

Unmanned aerial vehicles (UAV) or also known as unmanned aerial systems and drones are digital technologies, that are controlled remotely by humans or semi-autonomously by an integrated computer (Clarke, 2014). According to (EU) 2019/947, 2019 (2019) an unmanned aircraft system means an unmanned aircraft and the equipment to control it remotely. The size of a drone can vary a lot and their reaction time is very short (Kardasz & Doskocz, 2016). The basic element of a drone is a frame, which should be very light. The number of arms and the motors of a drone can be divided into different categories, e.g., bi-copters = two engines, octocopters = eight engines (ibid.).

UAVs are becoming increasingly handy and are often more cost-effective than other technologies (Perz & Wronowski, 2019) e.g., for monitoring crop cultivation and assisting decision support on farms (Abdullahi et al., 2015). UAVs offer aerial transport operation of materials and high-definition image-processing in combination with object and pattern recognition, which can be enhanced, restored and analysed (Da Silva & Mendonça; Patrício & Rieder, 2018). Drones' most important usage is in weed detection, mapping and management (Boursianis et al., 2022; Tsouros et al., 2019). Other applications include monitoring of crop development, yield and plant health (Tsouros et al., 2019). Therefore, their use in agriculture has become multidisciplinary and multipurpose in the past decade, but currently, there are a few reviews that discuss drone applications in the agricultural sector, as the review of (Rejeb et al., 2022) found out. A full list is available under Appendix Table 22.

²² LiDAR – Light Detection and Ranging. Remote sensing method primarily used to examine the surface of the Earth and to create 3D models and maps of environments.

6 Survey about digital technologies in agriculture and barriers

6.1 Results

6.1.1 Demographics

In the first question, we asked the participants in which area they are full-time employees. Figure 47 shows that the majority (38.3%) of the participants come from research, followed by farmers and employees from politics/administrations (each at 18.3%). These areas are followed by participants from other companies (industries; 13.3%). The smallest number of stakeholders originate from the categories associations/nongovernmental organisations and “others”.

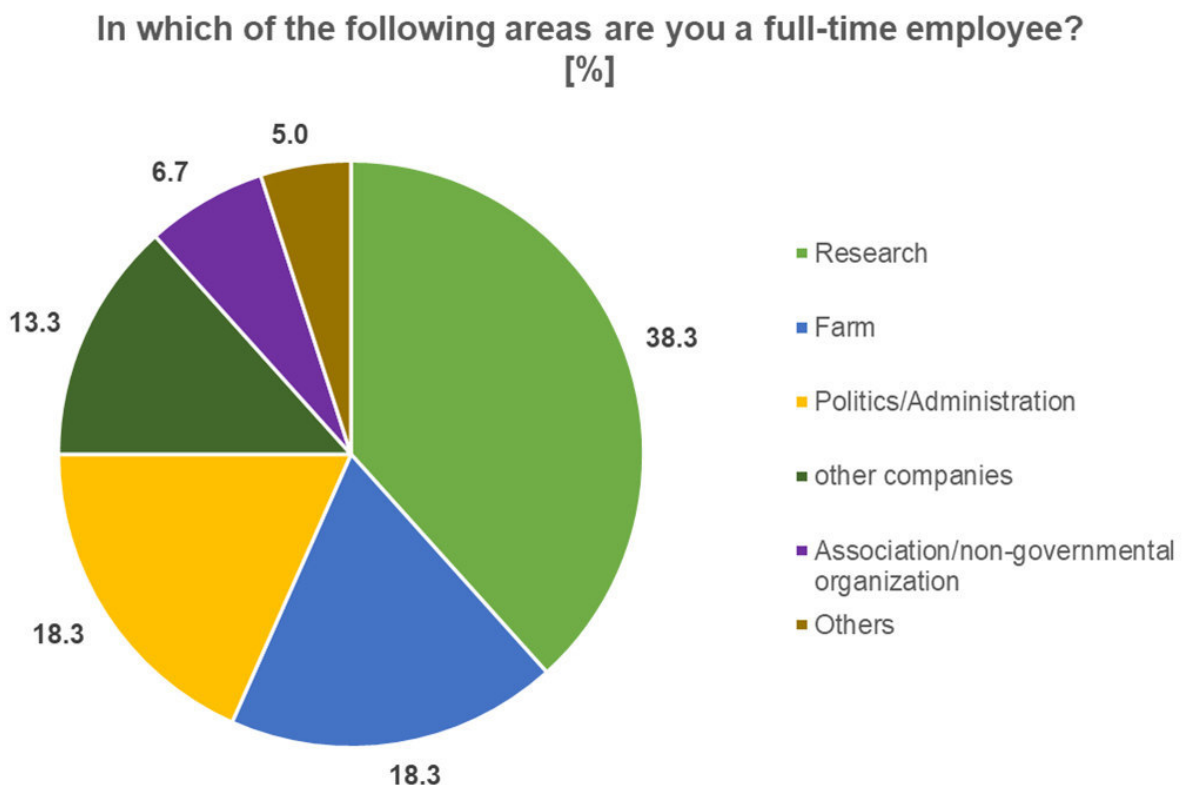


Figure 47. Distribution [%] of the participants among the working areas. Our illustration.

We asked the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category in which agricultural sector they are active. Multiple answers were allowed (Appendix Figure 1). Arable farming is the most represented agricultural sector (35.1%), followed by grassland management (27%) and livestock farming (24.3%) (Figure 48). Only a small number of the participants in these stakeholder groups report that they are active in horticulture and others (Figure 48).

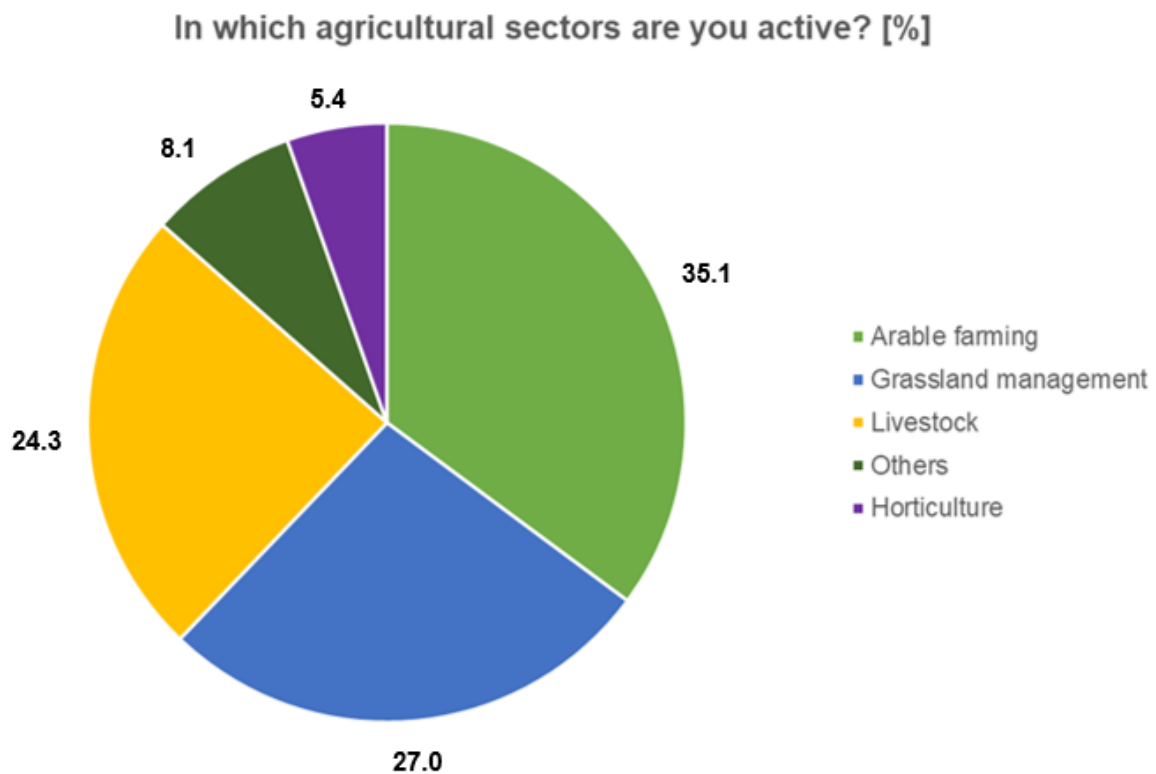


Figure 48. Distribution [%] of farm types among the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category (60 total participants). Our illustration.

With the next question, we aimed to get an overview of the operation models among the participating farmers. Again, multiple answers were allowed. As Figure 49 shows, organic farming (42.9%) is the predominant operation model, followed closely by conventional farming with reduced use of fertilisers and pesticides (35.7%). The least indicated operation model is the classic conventional model (21.4%).

**What is the underlying operating model for your operation?
[%]**

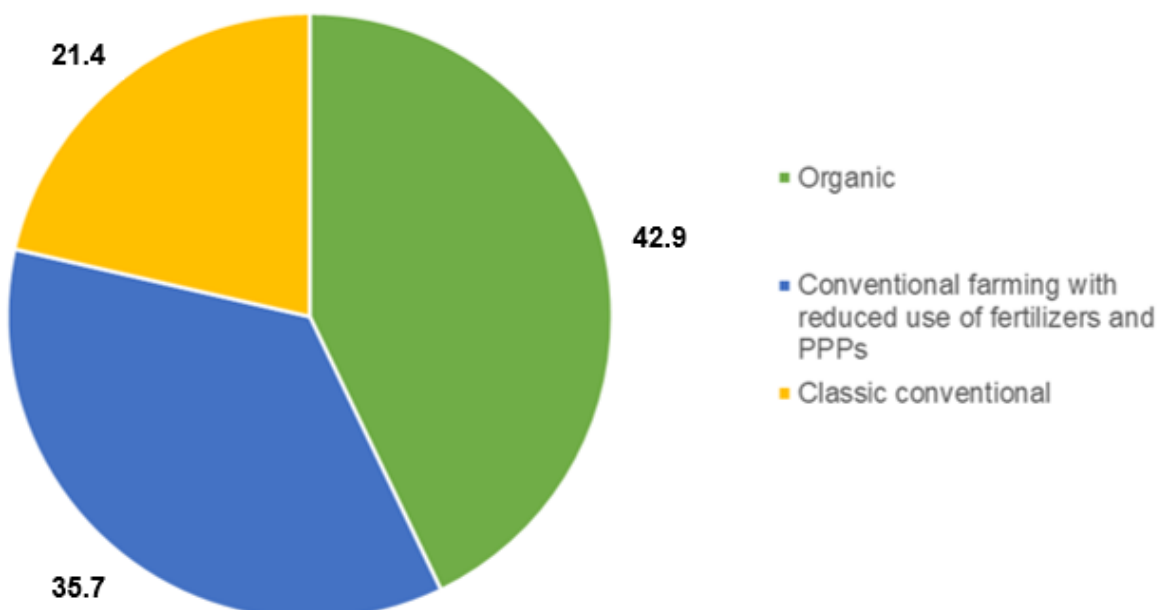


Figure 49. Distribution [%] of farm operating models among the participating farmers. Our illustration.

For further categorisation of the participating farmers and the structure of their farms, we asked them to state the total hectares of farmland they are currently managing. Figure 50 displays an almost equal distribution between small-scale (≤ 100 hectares) and large-scale (> 100 hectares) farms. The most common sizes are 201–500 ha and $> 1,000$ ha (21.5% each), followed by 101–200 ha, 501–1,000 ha, and < 5 ha (14% each). The least common sizes were 51–100 ha and 21–50 ha.

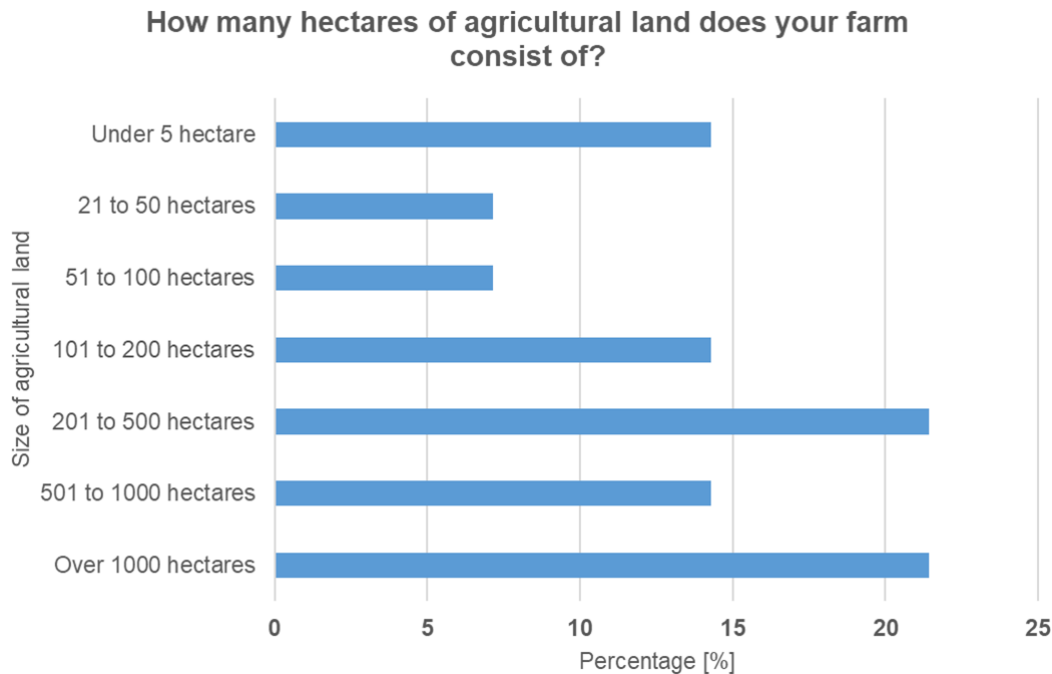


Figure 50. Distribution [%] of the farm sizes among the participating farmers. Our illustration.

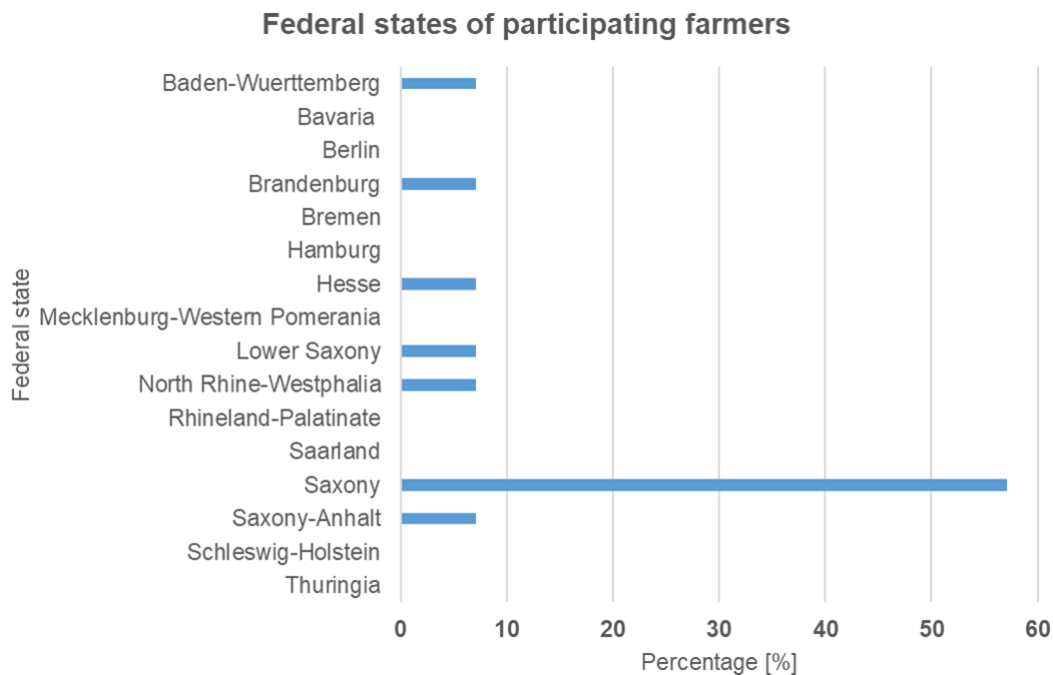


Figure 51. Distribution [%] of the farms across Germany among the participating farmers. Our illustration.

We also wanted to know the distribution of the farms in the federal states of Germany. Further included in this question were participants of the categories agricultural service supply agencies and other. As Figure

51 shows, the majority (58%) of the farms are in Saxony. The other represented federal states - Baden-Wuerttemberg, Brandenburg, Hesse, Lower Saxony, North Rhine-Westphalia, and Saxony-Anhalt – each contain 8% of the farms (Figure 51).

6.1.2 Additional classification of participating researchers and employees of politics/administration, associations, nongovernmental organisations, and industry

For a closer classification of the participating researchers and employees of politics/administrations, associations, nongovernmental organisations, and industry, we asked them to specify their employer or the institution for which they work. As Figure 52 shows, most participants of this group work for a state institute of agriculture (24%), followed by universities of applied sciences (18%), regular universities (16%), supra-regional associations (10.5%), and chamber of agriculture and state ministry (2.5% each). Regarding the participating employees of industry (the “other companies” category), we asked for the size of the company for which they are currently working. There is an equal distribution between employees of smaller and larger companies: 37% each for large and small companies, and 12% each for micro-companies and medium-sized companies (Figure 53).

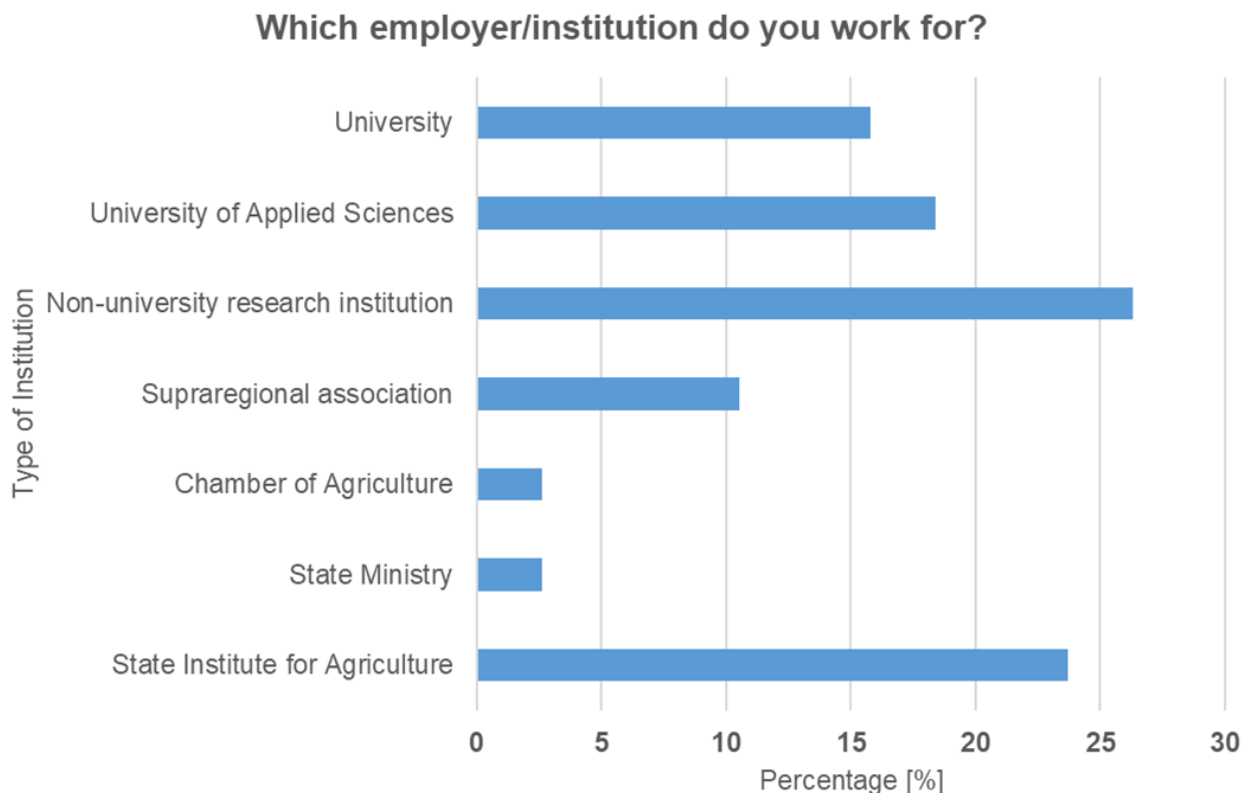


Figure 52. Distribution of workplaces among the participating researchers and employees of politics/administrations, associations, nongovernmental organisations, and industry. Our illustration.

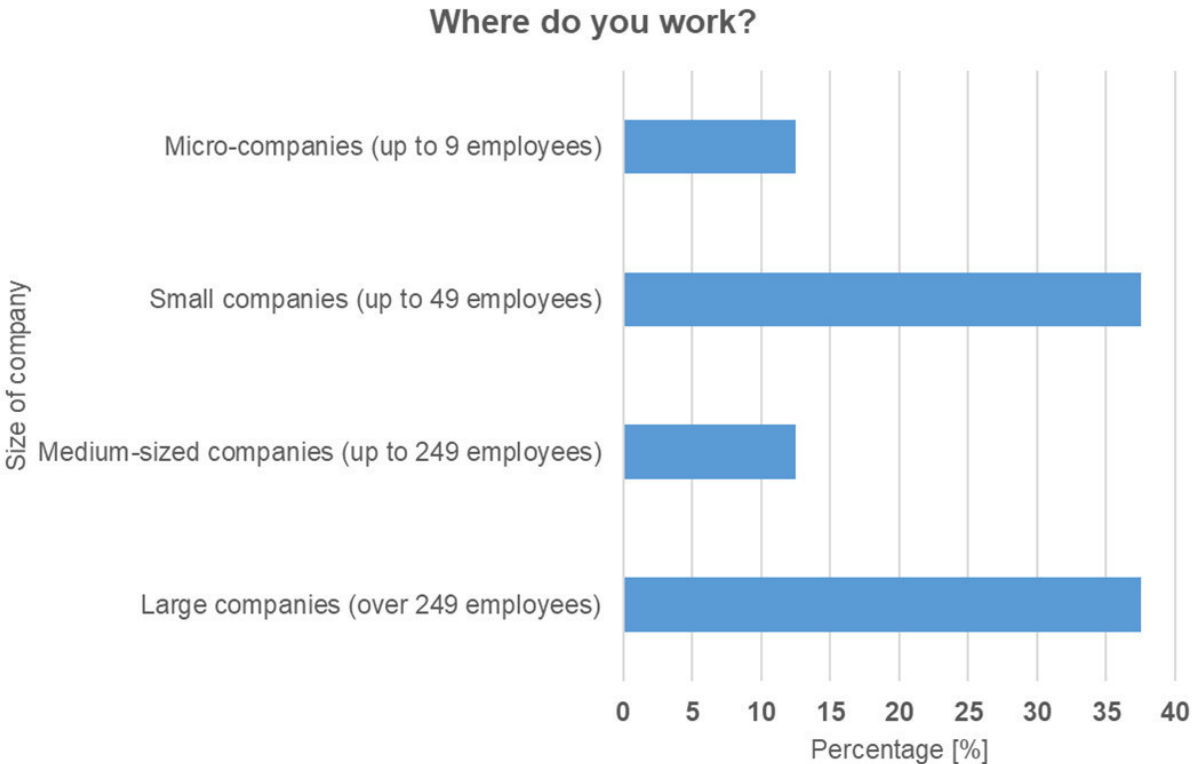


Figure 53. Distribution of workplaces among the participating employees of industry. Our illustration.

To classify the working and expert knowledge of the participating researchers and employees of politics/administrations, associations, nongovernmental organisations, and industry, we asked them how long they had worked in their indicated focus area. Most of the stakeholders of these groups (59%) had worked for more than 10 years in their respective focus area, followed by 2–5 years (18%), 6–10 years (18%), and up to 1 year (6%) (Figure 54).

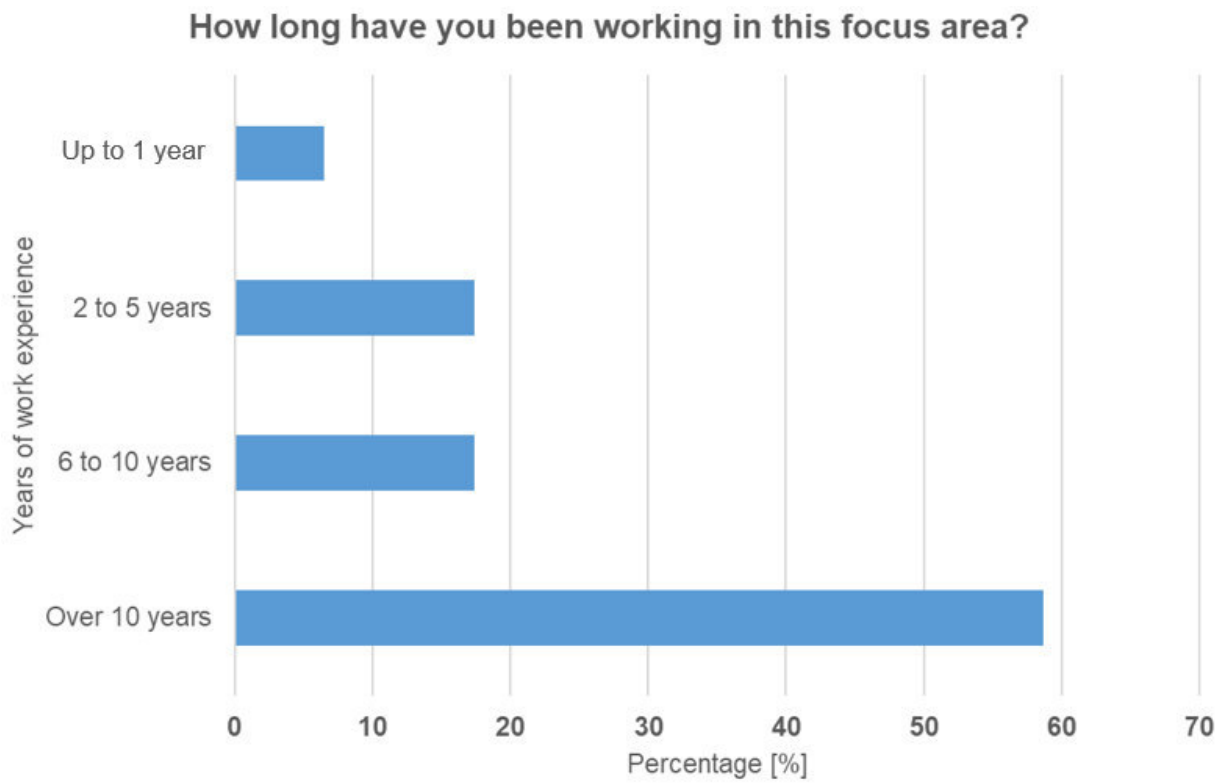


Figure 54. Indicated work experience in their focus area of the participating researchers and employees of politics/administrations, associations, nongovernmental organisations, and industry. Our illustration.

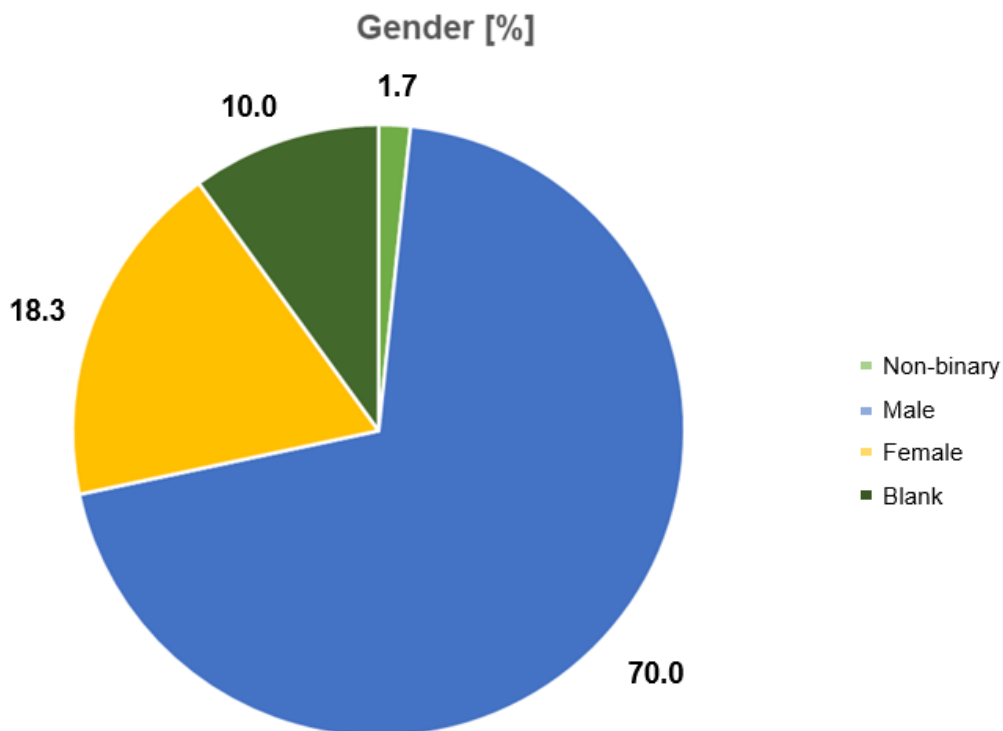


Figure 55. Gender distribution of the 60 surveyed stakeholders. Our illustration.

Regarding the personal demographic characteristic of the 60 participants, we first asked for their gender. As Figure 55 shows, 70% of the participants identify as male, 18.3% identify as female, 1.7% identify as non-binary, and 10% gave no answer.

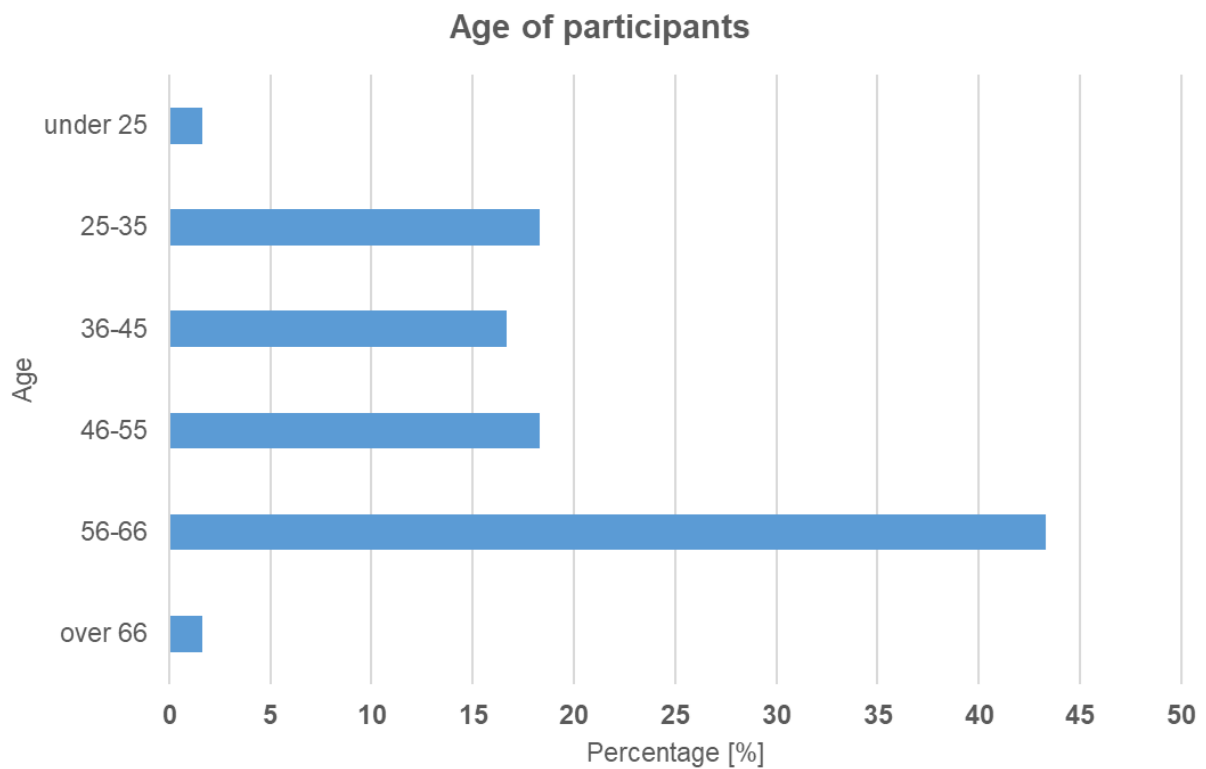


Figure 56. Age distribution of the 60 surveyed stakeholders. Our illustration.

As illustrated in Figure 56, the largest group of the participants (43%) are 56–66 years, followed by 25–35 years (18%), 46–55 years (18%), 36–45 years (16.5%), and over 66 years old (1.5%).

For the final last personal demographic question, we asked for the highest degree our participants hold at the time of the survey. At 45%, most of the participants hold a PhD, followed by a diploma (20%), a master's degree (20%), a professional school degree (5%), vocational training (3%), a bachelor's degree (3%), or another degree (3%) (Figure 57).

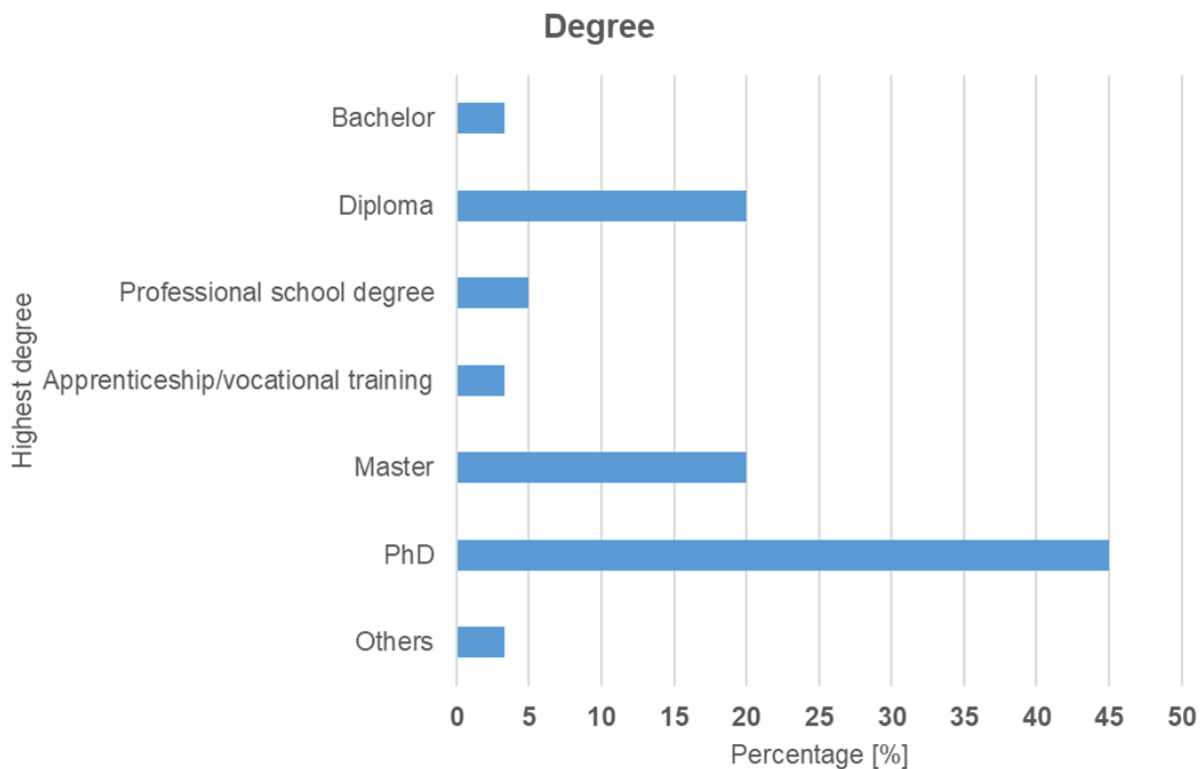


Figure 57. Educational background of the 60 surveyed stakeholders. Our illustration.

Previous experience with digital and smart technologies

The first content category we asked the participants was their previous experience with digital and smart farming technologies. Therefore, we designed divergent survey pathways for the three different stakeholder groups defined for our survey.

The first survey path was for the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. We asked which respective digital and smart technology they already use and how often. As Figure 58 shows, the most prevalent and frequently used technologies among this stakeholder group are digital technologies for agricultural machinery – actuator technology, which are used daily or regularly (weekly) by 36% of the participants in this group. The second most used technology group is detection and sensor technologies – sensor technology (daily: 21%; regularly: 0%; occasionally [monthly]: 7%). This is followed by FMIS/DSS (daily: 7%; regularly: 29%; occasionally: 7%), and DIP (daily: 0%; regularly: 21%; occasionally: 14%). Among the least used digital and smart technologies are CS platforms (79% neither used nor planned to use them at all), unmanned aerial vehicles and systems (64% neither used nor planned to use them at all), and field robots (64% neither used nor planned to use them at all). However, unmanned aerial vehicles and air systems seem to be a bit more popular compared with field robots: 7% indicate regular use and 14% indicate occasional use.

Which digital and smart technologies do you use for your activities and how often?

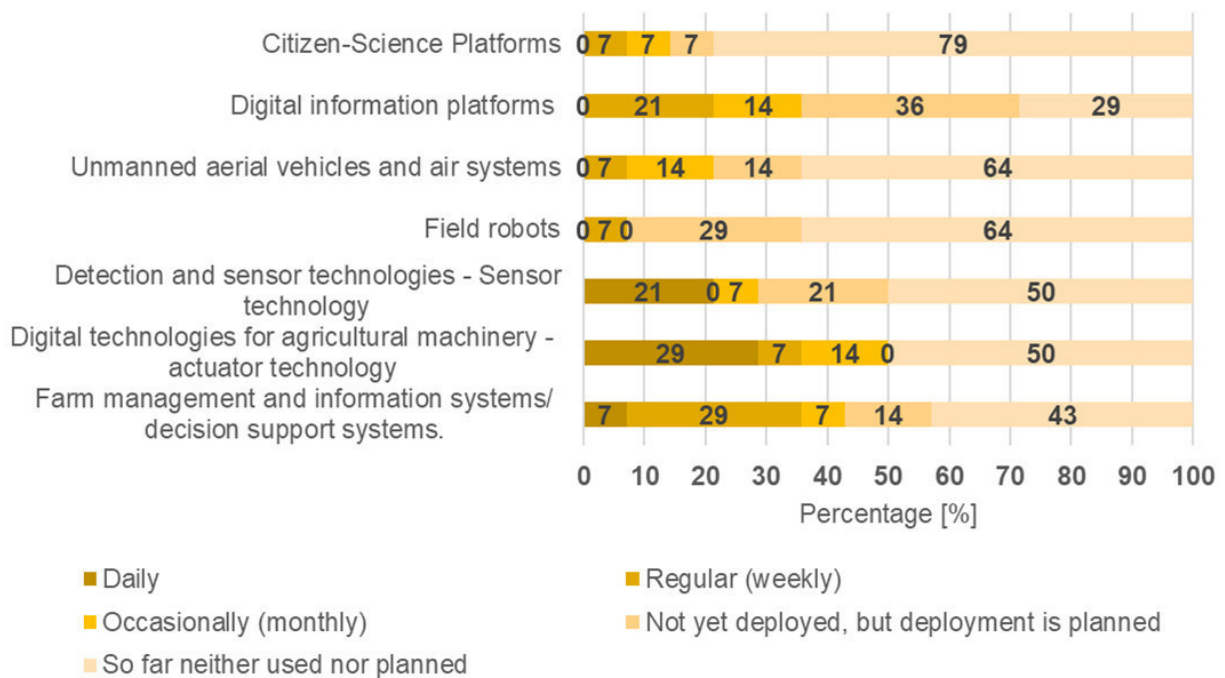


Figure 58. Frequency of use of different digital and smart technologies by the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. Our illustration.

We asked the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category who indicated that they already use digital and smart technologies the purposes for which they use the specified digital and smart technologies. Multiple answers were allowed. As Figure 59 shows, the most common field of application is monitoring of fields and improved operational management (92%). The second most prevalent application area is for the implementation of regulations on environmental protection (83%). Other areas in which the indicated technologies are already frequently used is the reduction of spreading environmentally harmful substances (75%), the transfer of data and knowledge (67%), and support of decisions through data-driven analytics (67%). Digital and smart technologies are used the least for the improvement of soil structure as well as the promotion and protection of biodiversity (58% indicated no for each category).

For what purposes do you use the specified digital and smart technologies?

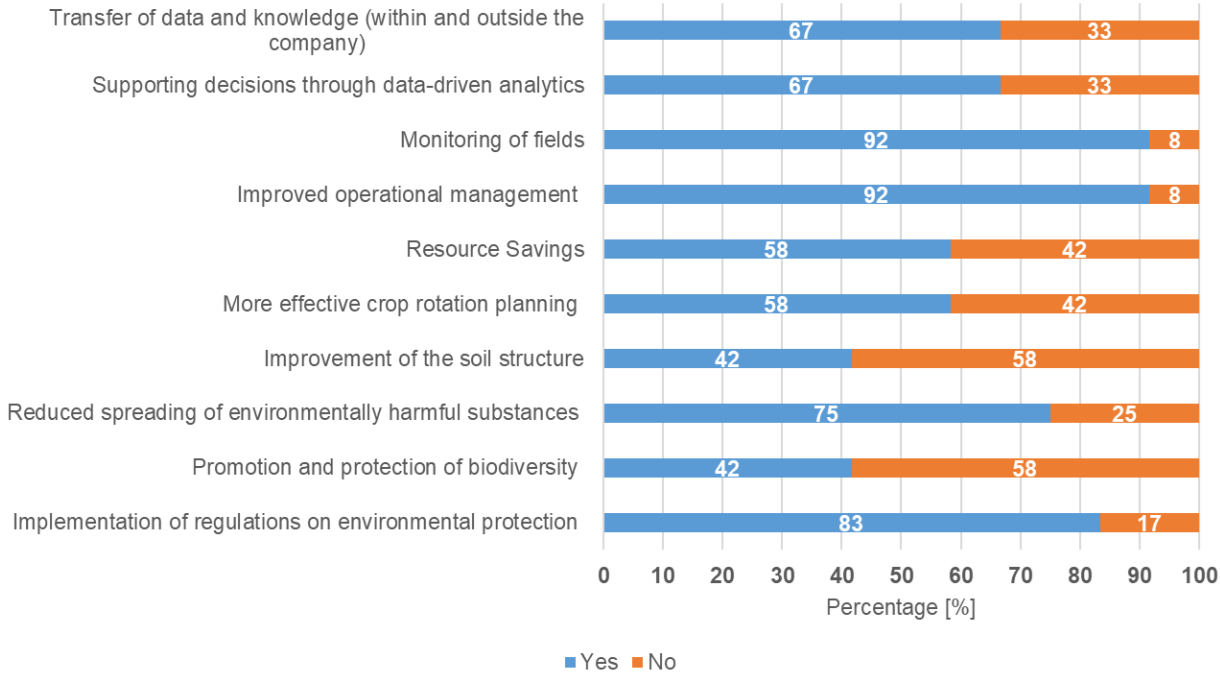


Figure 59. Indicated purpose for using digital and smart technologies by the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. Our illustration.

The second path was for the participating employees of politics/administrations, associations, and nongovernmental organisations. We asked this stakeholder group to what extent they think the use of digital and smart technologies in agriculture could contribute to achieve different goals. The two greatest contributions of digital and smart technologies are seen for resource savings and the reduced application of environmentally harmful substances (60% each) (Figure 60). These are followed by support of decisions through data-driven analytics (53%), monitoring of fields (40%), and transfer of data knowledge and improved farm management (27%). The smallest contribution of digital and smart technologies is seen for the improvement of soil structure (no contribution at all: 7%; for small contribution: 67%). Similarly, only small contribution is seen for a more effective crop rotation planning (no contribution at all: 7%; a small contribution: 47%) (Figure 60).

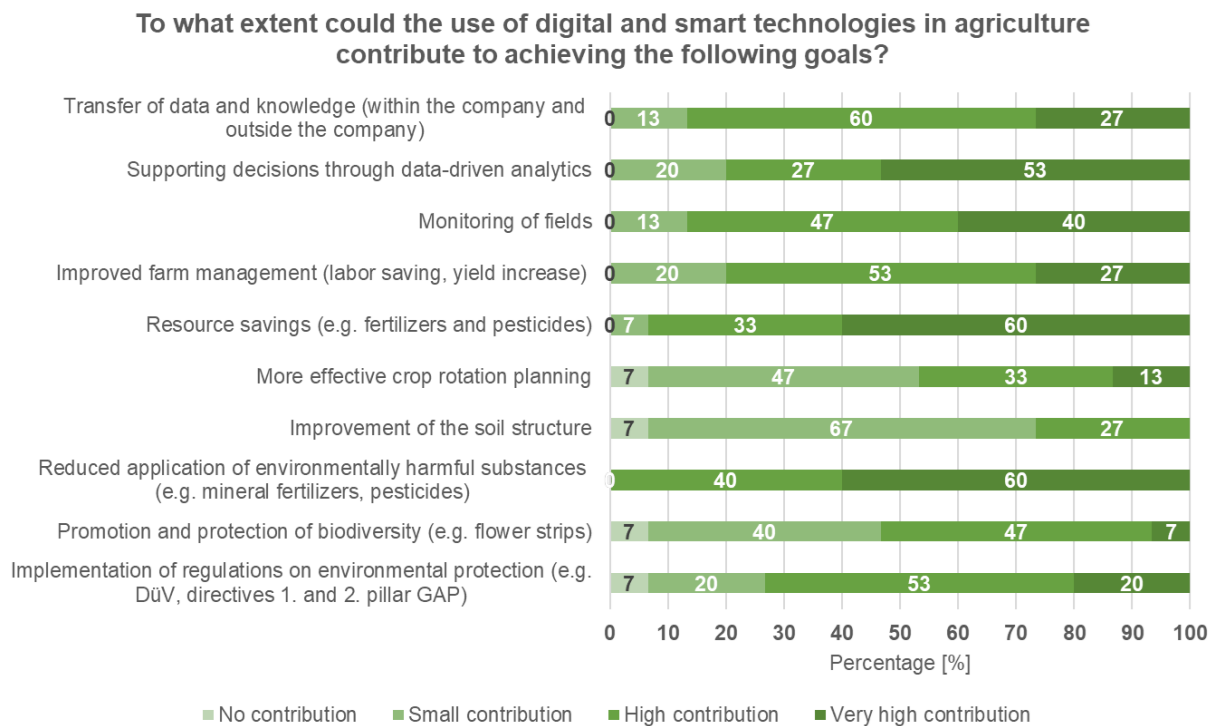


Figure 60. Assigned contribution of digital and smart technologies to achieve selective goals by the participating employees of politics/administration, associations, and non-governmental organisation. Our illustration.

The third path of this survey question was dedicated to the participating researchers and employees of other companies. We asked how they classify the state of development (technology readiness level) of the respective digital and smart technologies. As Figure 61 shows, the most developed (technology readiness level 7–9: deployment) digital and smart technology is agricultural machinery – actuator technology (77%), followed by FMIS/DSS (65%) and recording and sensor technologies – sensor technology (61%).

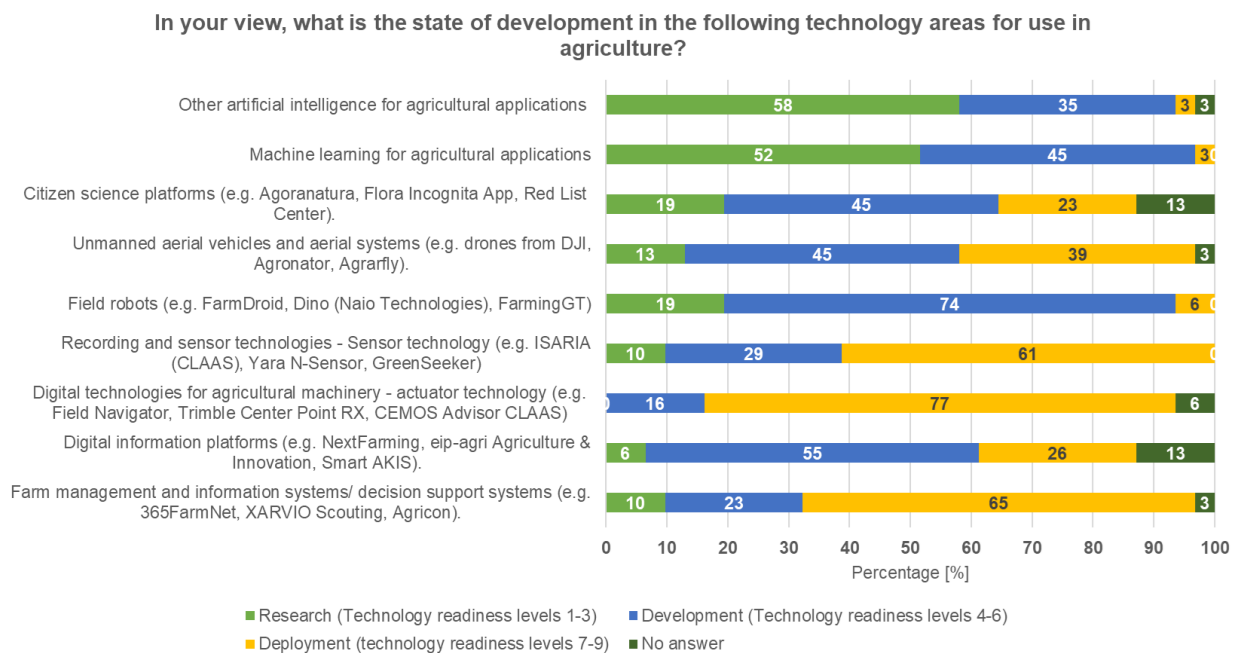


Figure 61. Assigned state of development of digital and smart technologies by the stakeholders (research and other industries).

6.1.3 Barriers to the regular use of digital and smart technologies

In the next part of the survey, we wanted to get an overview of the current difficulties regarding and barriers to regular use of digital and smart technologies. Here we designed two different survey paths for the participants.

The first path was again dedicated to the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. We asked them which factors impede or prevent the use of digital and smart technologies for their activities. Each participant could provide one answer per option. The biggest impeding factor is the lack of compatibility between technologies from different vendors (very-big obstacle: 29%; big obstacle: 64%) (Figure 62). This is followed by the high acquisition costs of digital and smart technologies as well as an unstable internet connection (very-big obstacle: 14%; big obstacle: 36%).

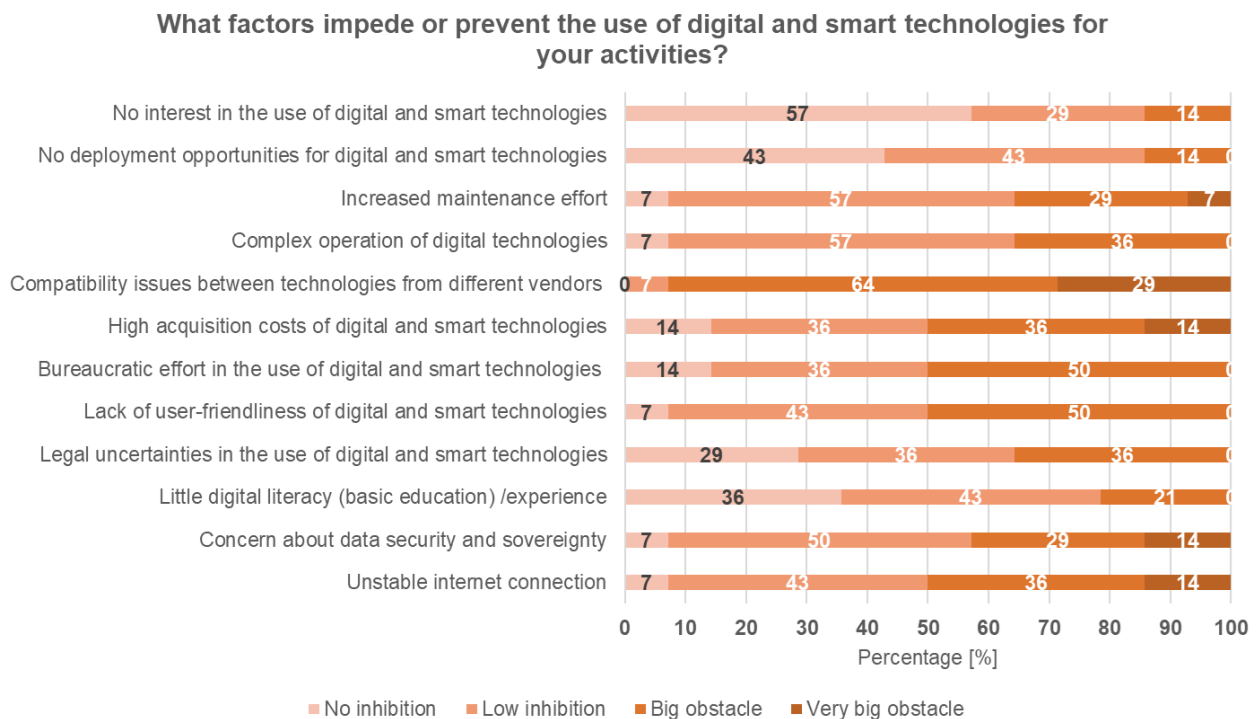


Figure 62. Barriers impeding or preventing the use of digital and smart technologies by the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. Our illustration.

The second path was dedicated to all participating researchers and employees of politics/administrations, associations, nongovernmental organisations, and industry. We asked them which factors, from their perspective, impede or prevent the use of digital and smart technologies in agriculture. Although the question differed a bit from the question we asked for path 1, the answer options were the same. Again, each participant could provide one answer per option. As Figure 63 illustrates, similarly to the answers given by the first stakeholder group, the second stakeholder group indicate the lack of compatibility as the most important (very-big obstacle: 50%). The second most important factor is an unstable internet connection (very-big obstacle: 41%), followed by the concern about data security and sovereignty (very-

big obstacle: 22%; big obstacle: 54%), a perceived lack of user-friendliness of digital and smart technologies (very-big obstacle: 41%), high acquisition costs of digital and smart technologies (very-big obstacle: 15%) and bureaucratic efforts (very-big obstacle: 15%) (Figure 63).

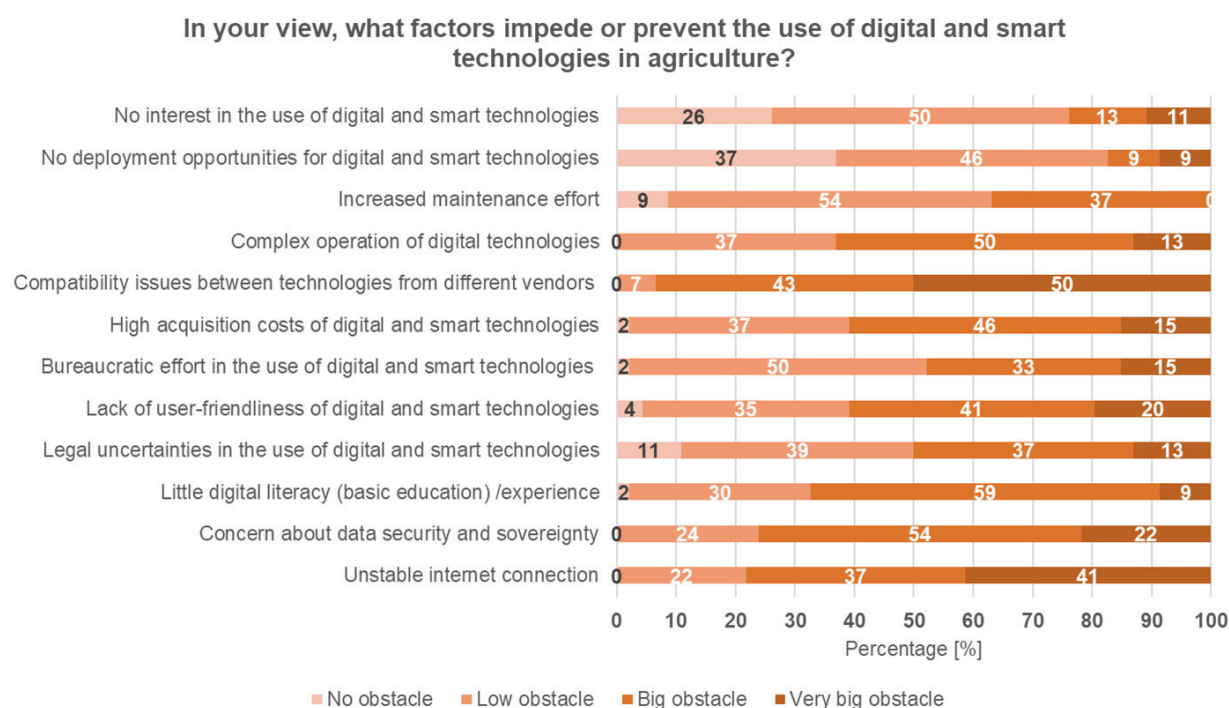


Figure 63. Barriers impeding or preventing the use of digital and smart technologies according to the participating researchers and employees of politics/administrations, associations, nongovernmental organisations, and industry. Our illustration.

6.1.4 Potentials of digital and smart technologies

We also wanted to know how important the participants consider the indicated measures to enable an increased use of digital and smart technologies for their activities in agriculture. Again, we considered two stakeholder groups.

Figure 64 shows the answers given by the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. The most important measure is the introduction of standards for data and technologies to increase compatibility (very-important measure: 64%). This measure is followed by clear legal regulations for data sovereignty (very-important measure: 50%; rather important measure: 36%); provision of specific support programmes for small and medium-sized farms (very-important measure: 43%; rather important measure: 29%); and consulting, education, and training services (very-important measure: 36%; rather important measure: 57%). According to this stakeholder group, subsidies for the acquisition of digital and smart technologies have less influence on the application of digital and smart technologies (very-important measure: 21%; rather important measure: 50%) (Figure 64).

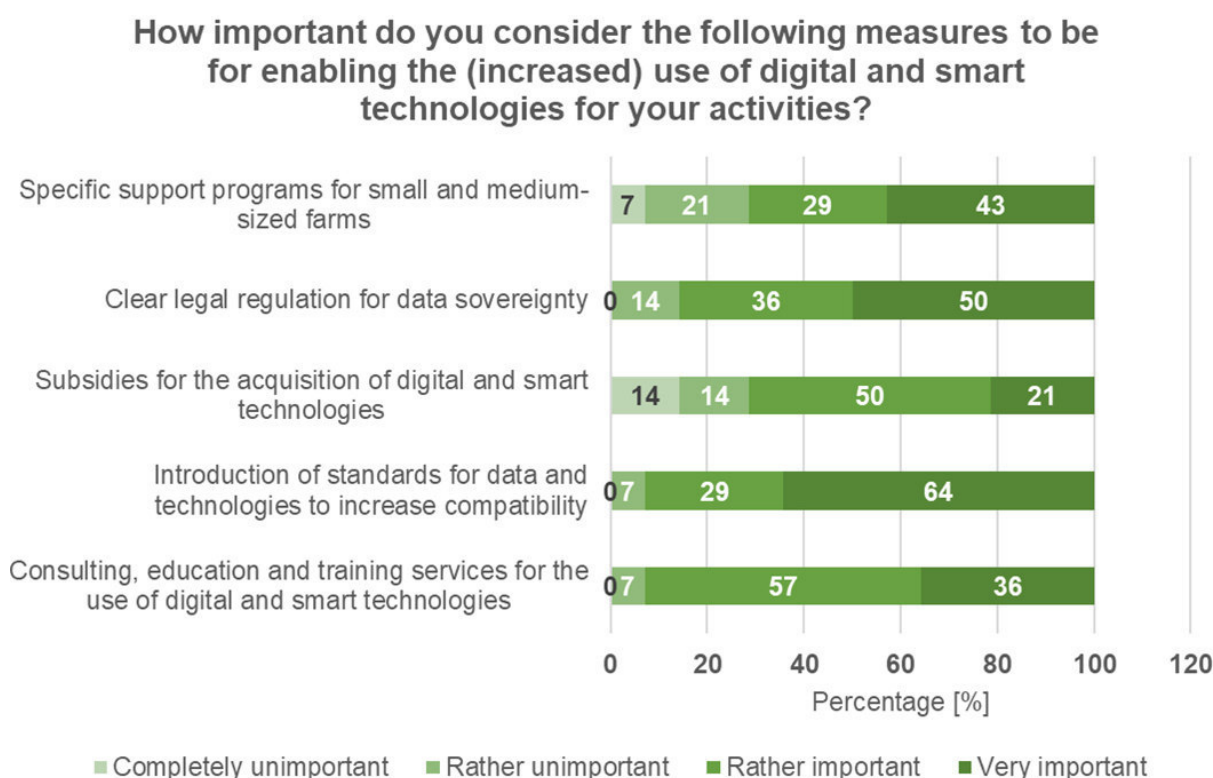


Figure 64. Necessary measures to enable or increase the use of digital and smart technologies according to the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. Our illustration.

The second stakeholder group – including researchers and employees of politics/administrations, associations, nongovernmental organisations, and industry – indicated that the most important measure for increased use of digital and smart technologies in agriculture is the introduction of standards for data and technologies to increase compatibility (very-important measure: 32%; rather important measure: 12%) (Figure 65). This measure is followed by the introduction of clear legal regulation for data sovereignty (very-important measure: 18%; rather important measure: 22%) and the provision of consulting, education, and training services for the use of digital and smart technologies (very-important measure: 18%; rather important measure: 25%) (Figure 65). Unlike the first stakeholder group, specific support programmes for small and medium-sized farms are not in the third but rather the fourth position (very-important measure: 14%; rather important measure: 21%). Similarly to the first stakeholder group, the second stakeholder group regards subsidies for the acquisition of digital and smart technologies as the least important measure to foster the application of digital and smart technologies in agriculture (very-important measure: 6%; rather important measure: 18%; rather unimportant measure: 17%) (Figure 65).

How important do you consider the following measures to be for enabling the (increased) use of digital and smart technologies on farms?

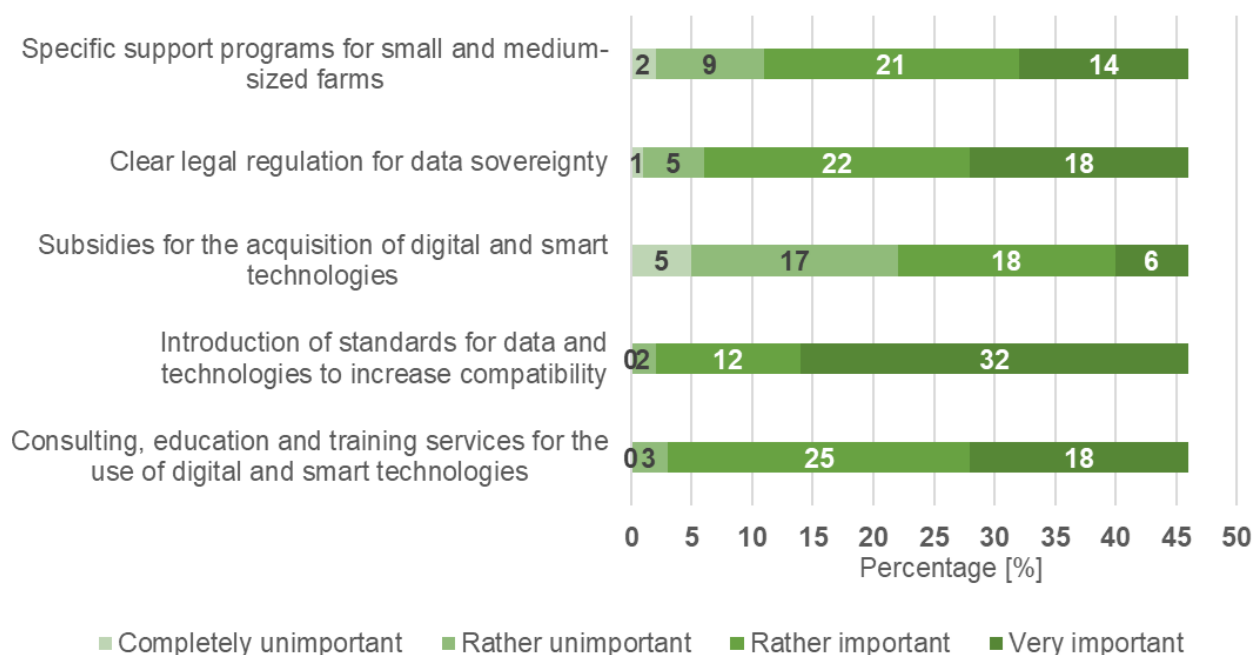


Figure 65. Necessary measures to enable or increase the use of digital and smart technologies according to the participating researchers and employees of politics/administrations, associations, nongovernmental organisations, and industry. Our illustration.

In the next question, we wanted the participants to estimate the contribution of digital and smart technologies to efficiency improvements in different farming systems within the next 10 years. Figure 66 shows that the greatest potential of digital and smart technologies for efficiency improvement is seen for conventional farming with reduced use of fertilisers and pesticides and a strong focus on “good agricultural practice” (very-high potential: 43%; high potential: 42%). This is followed by efficiency improvement in vegetable cultivation (very-high potential: 42%; high potential: 42%), arable farming (very-high potential: 38%; high potential: 42%), classic conventional farming (very-high potential: 25%; high potential: 48%; moderate potential: 25%), and finally, far behind, grassland cultivation (very-high potential: 10%; high potential: 23%; moderate potential: 28%).

Regarding efficiency improvements: How high do you estimate the potential of digital and smart technologies in the following areas of agriculture in the next 10 years?

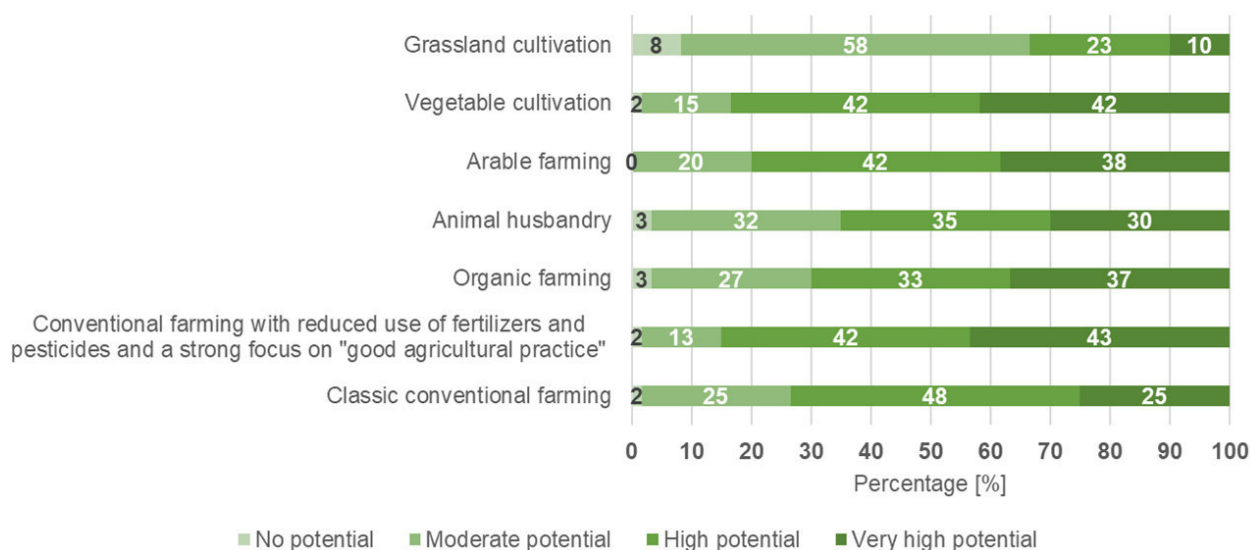


Figure 66. Classification of the potential contribution of digital and smart technologies to efficiency improvements for different farming systems within the next 10 years (all participants). Our illustration.

Regarding environmental protection: How high do you estimate the potential of digital and smart technologies in the following areas of agriculture to achieve positive effects in the next 10 years?

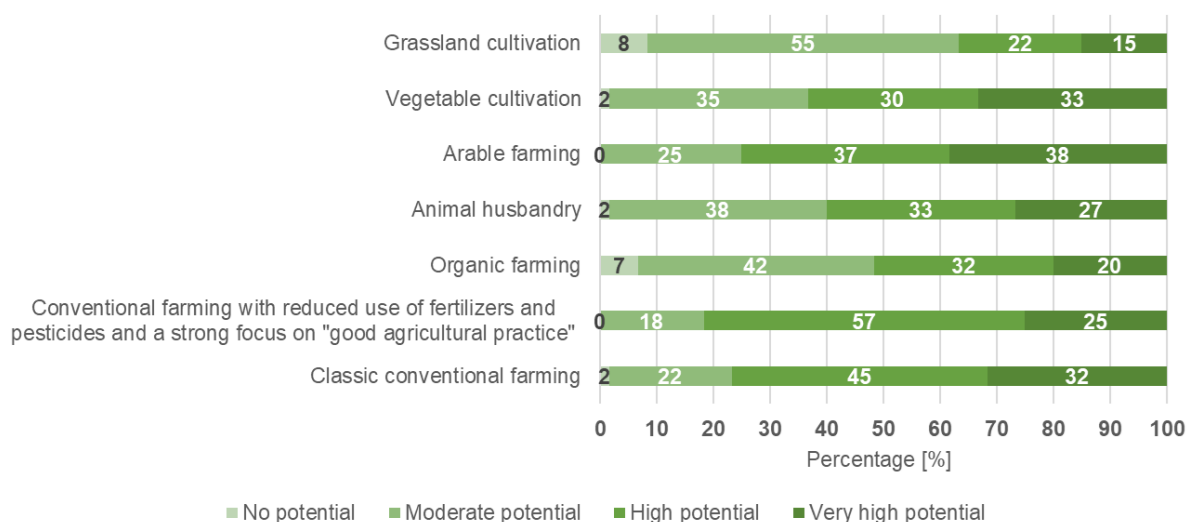


Figure 67. Classification of the potential contribution of digital and smart technologies to environmental protection for different farming systems within the next 10 years (all participants). Our illustration.

We asked the participants to estimate the contribution of digital and smart technologies to efficiency improvements in different farming systems within the next 10 years regarding environmental protection (multiple answers were allowed). We noted a slight shift in the expectations of the participants. For environmental protection, they see the greatest potential of digital and smart technologies for arable farming (very-high potential: 38%; high potential: 37%) (Figure 67). This is followed by vegetable farming (very-high potential: 33%; high potential: 30%), classic conventional farming (very-high potential: 32%; high potential: 45%), organic farming (very-high potential: 20%; high potential: 32%;

moderate potential: 42%), and, again in the last position, grassland farming (very-high potential: 15%; high potential: 22%; moderate potential: 55%).

To get more detailed estimates from all of the participants regarding the potential of digital and smart technologies for sustainability and environmental protection in the next 10 years, we asked them to assess specific sustainability parameters. Figure 68 shows the greatest potential of digital and smart technologies is ascribed to increased sub-area specific measures (very-high potential: 50%; high potential: 37%), followed by the promotion of small-scale farming systems to protect biodiversity (very-high potential: 22%; high potential: 33%), and the expansion of organic farming (very-high potential: 18%; high potential: 20%). The least potential of digital and smart technologies for sustainability and environmental protection in the next 10 years is seen for the diversification of crop rotations (very-high potential: 10%; high potential: 33%; moderate potential: 47%). The participants also see relatively little potential of digital and smart technologies for the improvement of soil structure (very-high potential: 13%; high potential: 32%; moderate potential: 48%) and the reduction of soil pollution (very-high potential: 13%; high potential: 47%; moderate potential: 40%).

How high do you estimate the potential of digital and smart technologies in agriculture for sustainability and environmental protection in the next 10 years?

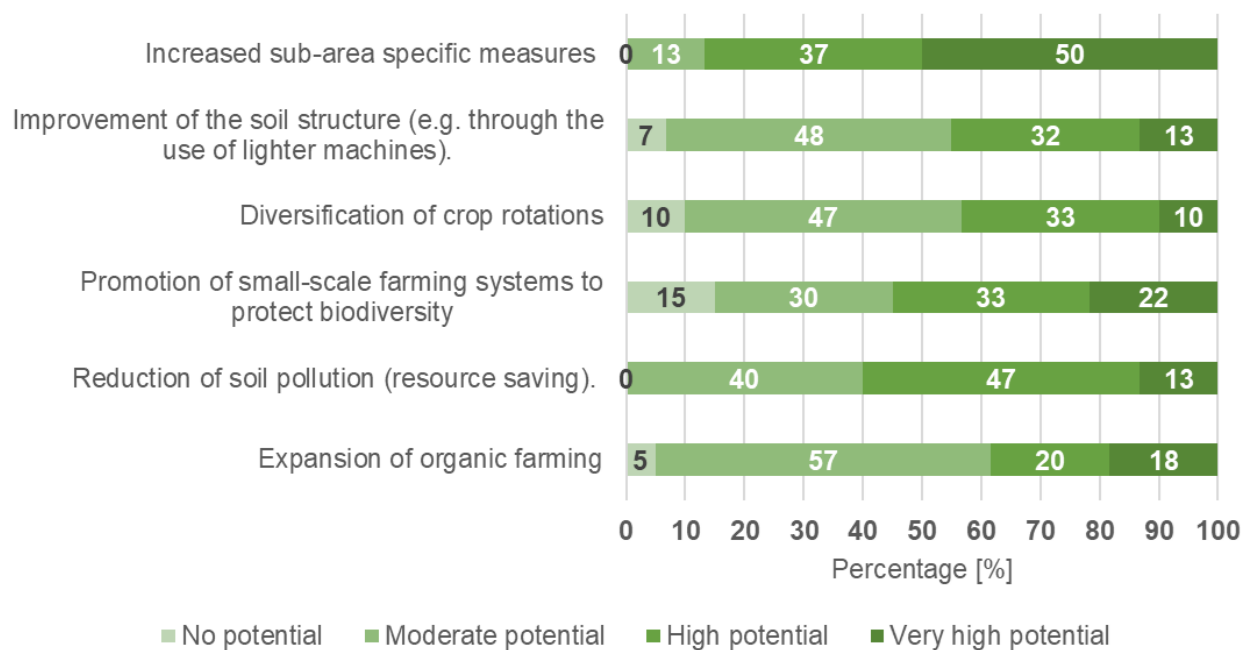


Figure 68. Classification of the potential contribution of digital and smart technologies to foster sustainability and environmental protection in agriculture within the next 10 years (all participants). Our illustration.

We also asked all of the participants which digital and smart technologies could contribute to achieve several climate targets: climate protection, biodiversity, and food-related issues. For this question we also offered the possibility of “no answer”, and multiple answers were allowed. As Figure 69 displays, CS platforms are by far the most difficult technology category to assess (no answer: 41%), followed by DIP

(no answer: 24%), other AI for agricultural application (no answer: 18%), and ML for agricultural applications (no answer: 17%). For climate protection, detection and sensor technologies – sensor technology has the highest potential contribution (33%), followed by FMIS (32%), digital technologies for agricultural machinery – actuators (32%), and field robots (30%). The participants ascribe the least potential to CS platforms (17%, considering their difficult assessment), unmanned aerial vehicles and systems (24%), and DIP (22%). With regard to biodiversity, unmanned aerial vehicles are classified as the most beneficial digital and smart technologies (38%), followed by field robots (32%), detection and sensor technologies – sensor technology (31%), ML for agricultural application (30%), other AI for agricultural applications (29%), digital technologies for agricultural machinery (29%), DIP (25%), and CS platforms (23%). For food-related issues, the participants consider that DIP could contribute most to a solution of the global food problem caused by a growing world population (29%), followed by other AI for agricultural applications (28%), FMIS (28%), detection and sensor technologies – sensor technology (27%), ML for agricultural applications (26%), FR (26%), DIP (26%), UAV and UAS (21%), and CS platforms (20%) (Figure 69).

Which digital and smart technologies can contribute to achieving the climate targets in Germany, to preserving biodiversity and to solving the global food problem caused by a growing world population?

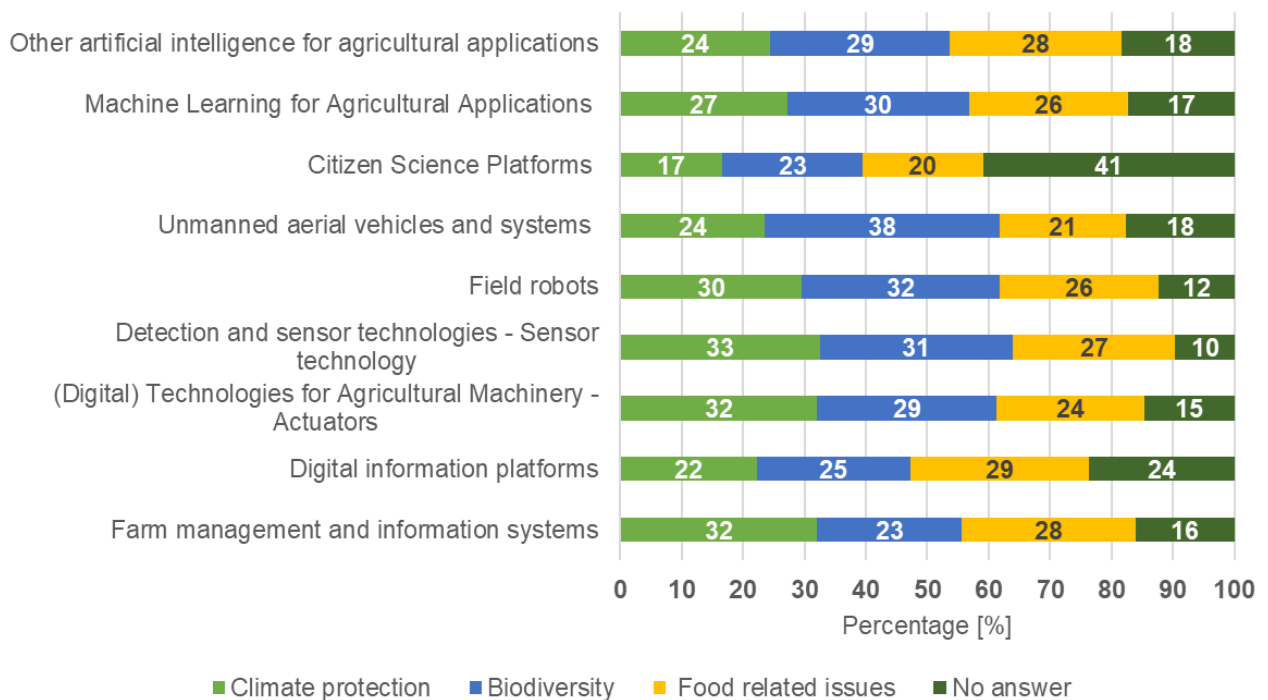


Figure 69. Classification of the potential of digital and smart technologies to preserve biodiversity and to solve the global food problem caused by a growing world population (all participants). Our illustration.

6.1.5 Digital and smart technologies in the context of biodiversity preservation

For the next part of the survey, we considered the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. We wanted to concretely focus on the

contribution and the participants' acceptance of digital and smart technologies on the preservation of biodiversity in agricultural landscapes.

We began by asking these participants about their experience implementing environmental and conservation measures. As shown in Figure 70, the majority of the participants had already implemented environmental and climate measures every year (69.2%). Moreover, 7.7% had already implemented environmental and climate measures twice, and 7.7% had implemented them once. Finally, 15.4% of the participants had not yet implemented environmental and climate measures.

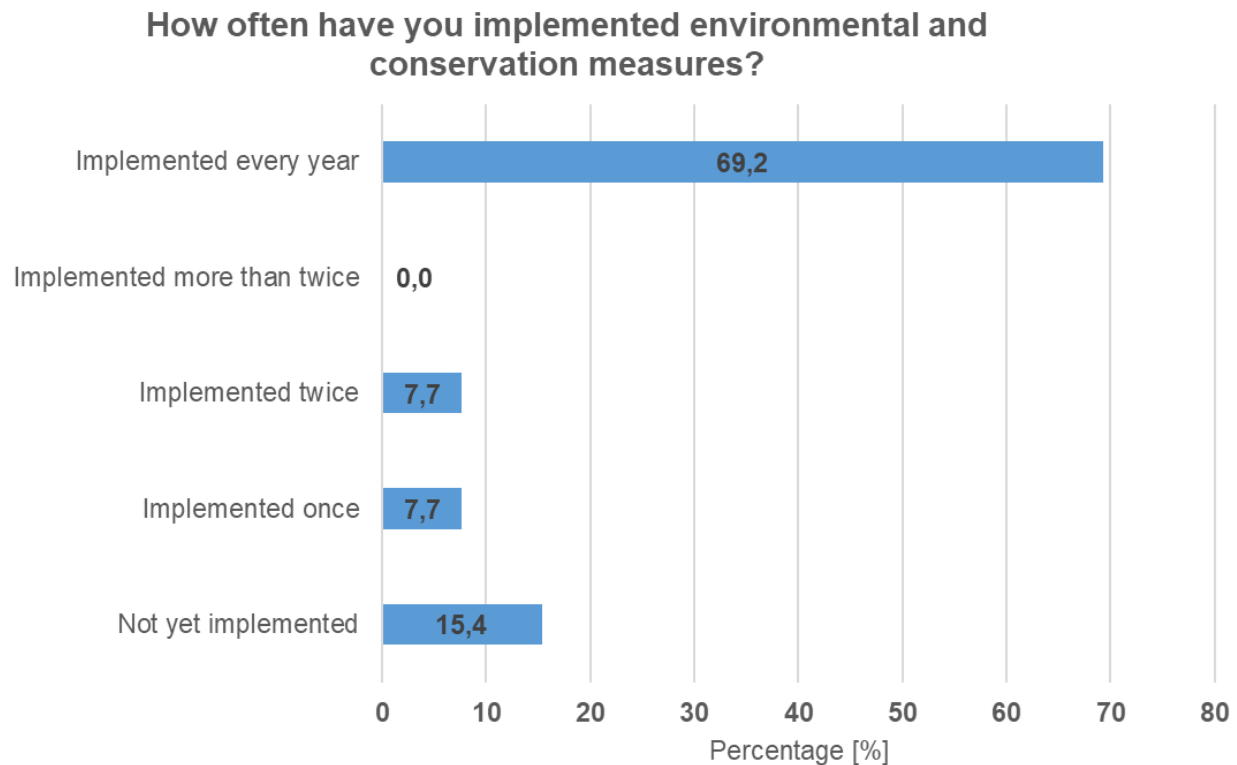


Figure 70. Indicated frequency of the implementation of environmental and conservation measures by the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. Our illustration.

Next, we asked for the biggest remaining challenges for continuous and regular use of digital and smart technologies for the protection of biodiversity in agricultural landscapes. As Figure 71 shows, the biggest remaining challenges are a lack of compatibility of digital devices with established technologies (very-big challenge: 36%; big challenge: 43%), followed by a lack of digital communication processes at local authorities/ministries (very-big challenge: 36%; big challenge: 50%), insufficient digital structures within the CAP (very-big challenge: 14%; big challenge: 50%), and nature conservation and environmental protection (very-big challenge: 7%; big challenge: 64%).

**With regard to the protection of biodiversity in agricultural areas:
Where do you see the biggest remaining challenges for a
continuous, regular use of digital and smart technologies?**

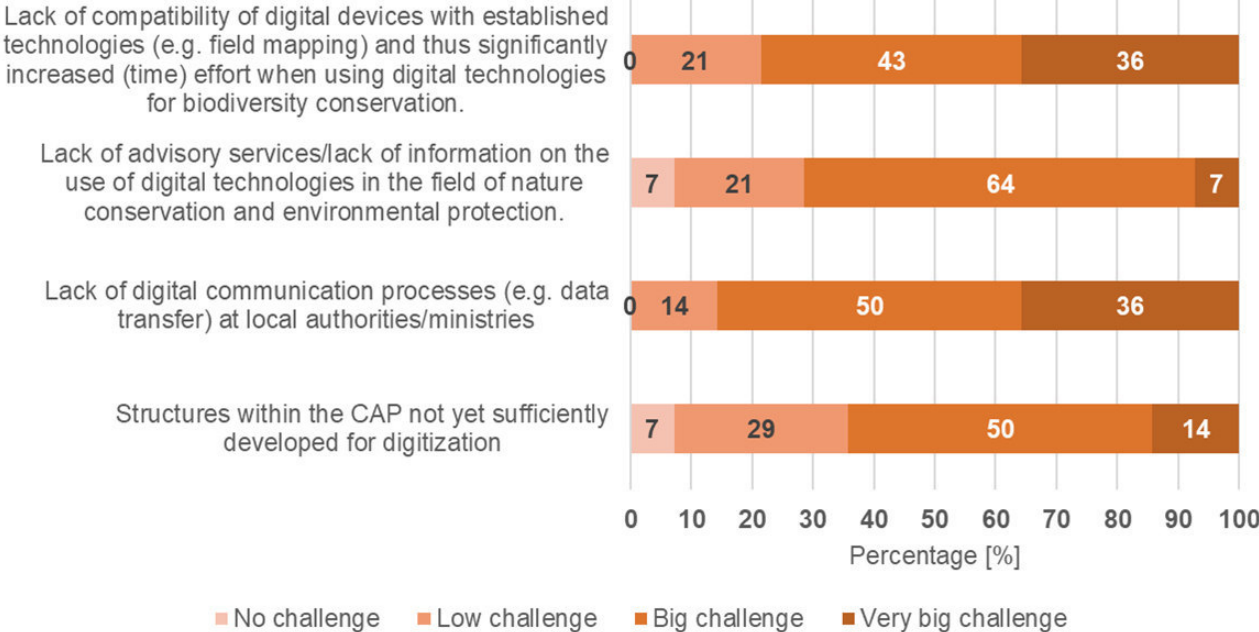


Figure 71. The remaining challenges regarding continuous, regular use of digital and smart technologies according to the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. Our illustration.

Finally, we asked the participants about the potentials of digital and smart technologies for the implementation of measures to protect biodiversity. The greatest is for the simplified transmission of documented proof of implemented measures (very-high potential: 21%; high potential: 50%), followed by better prepared information options (very-high potential: 7%; high potential: 64%), more effective (site-specific) biodiversity conservation options (very-high potential: 7%; high potential: 50%), and the implementation of conservation measures (very-high potential: 21%; moderate potential: 71%) (Figure 72).

In terms of implementing measures to protect biodiversity, where do you see the greatest potential for digital and smart technologies?

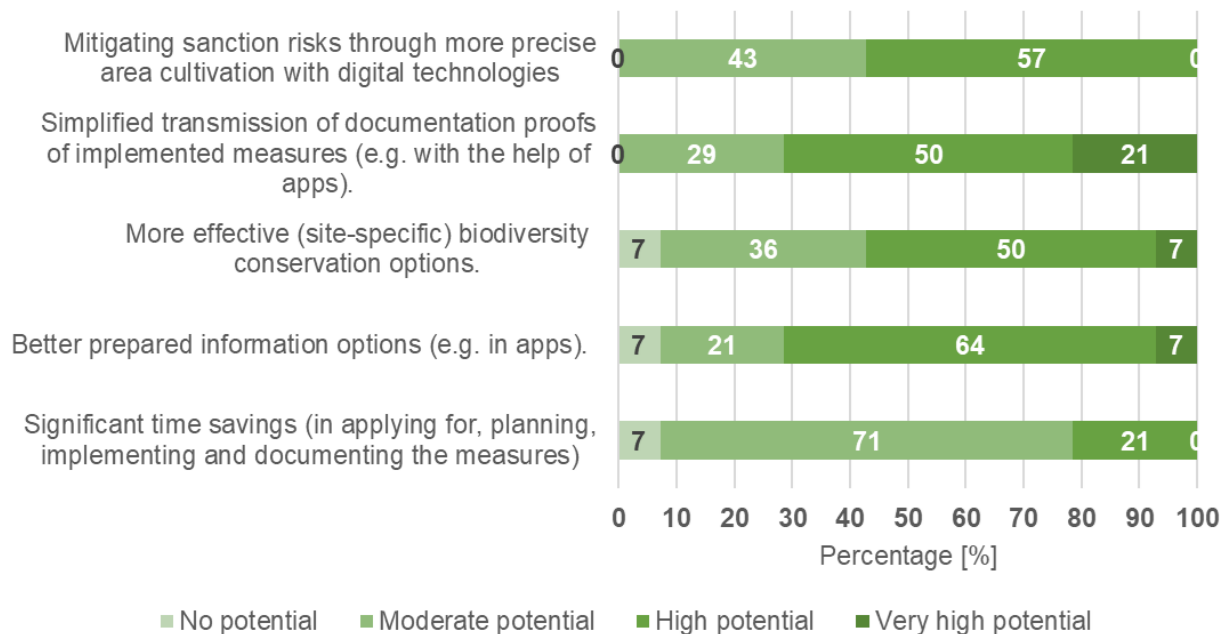


Figure 72. The assumed potential of digital and smart technologies to contribute to the protection of biodiversity in agricultural landscapes according to the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category. Our illustration.

6.2 Conclusions

The largest category of the participants in the survey are researchers (38.3%), followed by farmers (18.3%) and employees of politics/administrations (18.3%). This distribution of stakeholders in Germany provides validity to the results of our research.

Regarding the demographic parameters, most participants identify as male (70%), are 56–66 years old (43%), and have an academic degree (45% PhD, 20% diploma, 20% master’s degree, and 3% bachelor’s degree). The fact that most of the participants have a degree could be explained by the high share of researchers who participated in our survey. In addition, most of the participants had more than 10 years of working experience in their focus area (59%).

Of the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category, most are active in arable farming (35.1%), followed by grassland management (27%) and livestock (24.3%). We achieved a relatively balanced distribution of the farmers. Concerning farm size, more than half (58%) work on big farms and more than half (58%) of the farms are in Saxony.

With reference to the content statements of the participants, the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category already have experience with digital and smart technologies, especially digital technologies for agricultural machinery – actuator technology (29% daily used) and detection and sensor technologies – sensor technology (21% daily used). The participating researchers and employees of politics/administrations, associations, nongovernmental

organisations, and industry see the greatest contribution of digital and smart technologies for support of decisions through data-driven analytics, the monitoring of fields and resource savings (fertilisers, pesticides), reduced application of substances harmful to the environment, an improvement in farm management, and the implementation of environmental protection regulations. These statements are in line with the indications of the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category: they see advantages for monitoring fields, improved operational management, and implementation of regulations on environmental protection. However, the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category see fewer advantages in decision support and reduced spread of substances harmful to the environment compared with the participating researchers and employees of politics/administrations, associations, nongovernmental organisations. The view of the participating researchers and employees of other companies regarding the technology readiness level (7–9) of the technologies matches very well with the technologies the farmers state they already regularly use on their farms: agricultural machinery – actuator technology, FMIS/DSS, and detection and sensor technologies – sensor technology.

According to the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category, the most prevalent obstacle when using digital and smart farming technologies in agriculture is compatibility issues between technologies from different vendors, followed by a lack of digital infrastructure (unstable internet connection), high acquisition costs of digital and smart technologies, and concern about data sovereignty. These results again coincide well with the answers given by the participating researchers and employees of politics/administrations, associations, nongovernmental organisations, who also indicate compatibility issues as the biggest obstacle for the use of digital and smart technologies, followed by an unstable internet connection and concern about data sovereignty. These findings highlight areas where action is required.

The participating farmers, employees of agricultural service supply agencies, and participants in the “others” category indicate that an introduction of standards for data and technologies to increase compatibility (64%) and clear regulations for data sovereignty (50%) are definitely required for a broader use of digital and smart technologies in agriculture. Specific support programmes for small- and medium-sized farms are also desirable. These statements again align the answers given by the participating researchers and employees of politics/administrations, associations, nongovernmental organisations: they see the introduction of standards for data and technologies to increase compatibility as the most necessary measure for an increased use of digital and smart technologies in agriculture (32%). However, compared with the other stakeholder group, they see a greater requirement for consulting, education, and training services for the use of digital and smart technologies (18%), and a little less need for clear legal regulation of data sovereignty (18%).

Regarding the potentials of digital and smart technologies considering efficiency improvements in the distinct agricultural areas in the next 10 years, the greatest potential is seen for conventional farming with reduced use of fertilisers and pesticides and a strong focus on “good agricultural practice” (43%), followed by vegetable cultivation (42%) and arable farming (38%). The same question regarding

environmental protection provides a slightly different emphasis in the results. In this context, arable farming is indicated as the area where digital and smart technologies will have the greatest potential in the next 10 years (38%), followed by vegetable cultivation (33%) and classic conventional farming (32%). Regarding the potentials of digital and smart technologies considering environmental protection and sustainability in the next 10 years, the participants see the greatest potential in the implementation of increased sub-area specific measures (50%), followed by the promotion of small-scale farming systems to protect biodiversity (22%) and the expansion of organic farming (18%). These results show that the biggest potential and added value of digital and smart technologies is mainly attributed to the optimised implementation of tailored, site-specific management measures, rather than in the improvement of more production-oriented measures such as crop rotation or soil structure.

Regarding the contribution of the digital and smart technologies to achieve the climate targets, to preserve biodiversity, and to provide a solution for the global food problem, the participants classify all technologies, except CS platforms and DIP, rather similarly, with no clear emphasis of one technology for one particular category. We observed a slight tendency for the positive contribution of digital and smart technologies for the preservation of biodiversity. Digital and smart technologies such as CS and DIP cannot be classified well by the relevant stakeholders, probably due to a lack of experience. Nevertheless, the other results of this question show that the participants of this survey generally see the potential positive contribution of digital and smart technologies to the most urgent and severe challenges in agriculture.

Considering the opinion of participating farmers, employees of agricultural service supply agencies, and participants in the “others” category regarding the contribution of digital and smart technologies particularly to the conservation of biodiversity, the challenges and barriers for their broader use are almost equal to the challenges of their overall use in agriculture. Compatibility between digital and smart technologies and established agricultural technologies as well as compatibility among digital and smart technologies themselves are vital for their broader and more practical use (36% indicated it as a very-big challenge). The same applies to the lack of digital infrastructure at local agricultural administrations for fluent data and information exchange between farmers and local authorities (36% indicated it as a very-big challenge). Moreover, 64% of these participants see missing information and education about the opportunities regarding the use of digital and smart technologies for nature conservation and the revitalisation of biodiversity in agricultural landscapes as big challenges hindering the broader use of digital and smart technologies.

In summary, the results of the survey show a clear need for three main aspects to foster a broader use of digital and smart technologies in agriculture: the creation of compatibility between digital and smart technologies and already established technologies in agriculture, as well as among themselves; the creation of clear regulations on data sovereignty and access to data; and the provision of tailored education and support programmes for farmers to gain knowledge and information on the appropriate and potential use of digital and smart farming technologies in their daily practices.

7 Discussion with relevant experts

Q1 A: How do you assess the potential of digital and smart technologies to contribute to sustainable agriculture?

All experts were unanimous on this question – the potential that lies in digitalisation in agriculture is great. On the one hand, the potential of digital and smart technologies to contribute to sustainable agriculture is strongly dependent on the framework conditions and the intended use (FUA). On the other hand, they have a very high potential and “are partly already established e.g., for sub-area specific N application by precision farming. Desirable are farm-specific digital twins for optimisation of application (4R), which consider plant requirements, soil N_{\min} , and abiotic conditions (soil water content, weather conditions)” (RS1).

According to PM, the extent of the actual contribution depends on the consideration of the expense of reporting and documentation. Especially for farmers, “digital technologies can play a significant role in improving agriculture, e.g., documentation, fertiliser application, information flow both on the farm itself and with authorities” (FRM1). Although the potential can be seen as very high, “digitisation” is a tool. For this, the legal and funding programme framework conditions must be designed accordingly. The creation of uniform “socio-*technical*” standards also enables a lower “entry barrier” for the use of digital solutions. According to CSO, for a broader benefit of digital and smart technologies, overall agricultural value chains would have to be digitalised across the board – against the backdrop of economic and ecological added value. This statement is underlined by the argument of RS2 that “the potential high contribution of digital and smart technologies only works and helps if everything else is right. But the benefit and security for agriculture must be increased”.

IE emphasised that digital technologies offer a large contribution to secure yields while also reducing emissions and improving biodiversity. This is followed by the opinion of FRM2, who also considered that digital and smart technologies could have a very large contribution to sustainable agriculture as long as “the solution of these issues is accompanied by process optimisation (increase in working time efficiency)”. Another expert from research (RS3) also indicated a very high potential of contribution of digital and smart technologies: FMIS can be used for site-specific applications. The use of robotics and sensors can support diversity and site-specific applications” as well as an “optimal irrigation”. “Through this, fungal infestation or disease can be detected in time and measures can be taken” and “demand-based irrigation with the help of drip irrigation” realised. “I also see very high potential in digital twins. Through the digital twin, scenarios can be tested and played through and thus the optimal real use can be determined. Savings in process flow, time, and costs” (RS3).

Q1 B: Where do you see the greatest potential in relation to Q1 A?

One potential lies in the “site-specific N application by precision farming. It “should be carried out nationwide. This requires high-resolution data (temporal + spatial) on the current state/concentration of N_{\min} in the soil (RS1). In the view of PM, one of the greatest potentials is “resource conservation: time,

resources, soil, water”. On the other hand, FRM1 indicated that “digital technologies have the greatest potential in decision-making processes. However, there is often no secure data basis for this, e.g., should more or less be applied in site-specific applications?” For farmers it is often not clear “which data is needed for which decision” (FRM1). CSO located the greatest potential of digital and smart technologies also in the planning support for “partial surface-specific application” and the creation of “interfaces and standardisation by “facilitating the recording of activities to increase efficiency”; in this way, digital and smart technologies can significantly contribute to sustainable agriculture (RS2). IE emphasised the great potential of partial area application. However, “consideration of optimising the timing of applications is lacking where further savings are possible”. The “provision of accurate digital field boundaries by authorities is an important prerequisite for subplot application” (IE). “Digital decision support and AI agricultural helper bots” (FRM 2) as well as “uniform communication protocols and interfaces” (RS3) are further considered by the experts as concrete benefits of digital and smart technologies for sustainable agriculture.

Q2: Where do you see the greatest difficulties/barriers in establishing the application of digital and smart technologies in agriculture (in crop production)?

For RS1, the greatest difficulties/barriers for the establishment of digital and smart technologies in agriculture lie in the “access to software (which tools and software for which question and which target group)”. Because there are too many single players, there are too many single solutions (“island solutions”); the same applies to data availability. Currently, no nationwide information on where and which data can be used is available (RS1). PM also discussed the issue of data provision: “no uniform data formats are given”, public data are not free to use, and so far, there has been no consultation on digital options including their data protection and data sovereignty. Uniformity is an important issue regarding data. FRM1 also stated that “data interfaces must be created and made easy to use”. Although good applications are already available, they are often isolated solutions. For a broader use, “applications must have a clear added value for the farmer”. Thereby, the advantages do not necessarily have to be monetary, such as savings in operating resources. Likewise, more homogeneous crop or labour savings are an incentive to use digital and smart technologies. An important point is that the operation of the applications is usable for all farmers “even for the 60-year-old farmer”; otherwise, structural change will be fuelled even further or evoke digital frustration (FRM1). An additional barrier is German federalism. Each of the 16 federal states releases different data and has a different application portal: “Why does the wheel have to be invented 16 times? Wouldn’t a centralised provision of data for all federal states simplify many things?” (FRM2).

CSO remarked that “the greatest challenges probably lie both in the creation of socio-technical interoperability between technical solutions and in “bringing along” the farmers. Digital solutions, whether sensors, drones, apps, software platforms, or others, must be designed to be extremely user-friendly for the various users (CSO). RS2 affirmed the lack of compatibility and uncertainty of data security.

IE mentioned the federalism challenge in Germany. Due to the federal system, there are different and incompatible systems among the federal states. Geospatial data (e.g., field boundaries) are not provided on a nationwide basis. Furthermore, education and advice on the use of digital systems must be provided and the implementation of biodiversity measures for farmers must be economically attractive (IE). Again, as FRM2 remarked, data and system fragmentation and too many isolated solutions on the market are some of the biggest barriers and challenges for a broader use of digital and smart tools in agricultural practice. From a science perspective, “financial support through the expansion of the machine park for robotics (acquisition, maintenance, and implementation costs) or commissioning of a contracting company” constitute another barrier (see 8.3). Moreover, opportunity costs compared with productive use or cultures with higher contribution margin are a considerable barrier on the farmers’ side (RS3).

Q3 A: What specific measures need to be taken to overcome the barriers?

RS1 indicated the overcoming federalism is required to overcome the existing barriers: all decision support tools should be listed and data and software/programs should be centralised. Further bureaucracy must be reduced “to overcome digitisation fatigue of agriculture” (too many programs and tools, hardly any time and capacities to try them out, partly no information at all about which tools are available at all) (RS1). This statement is supported by CSO, who claimed the need for a uniform digital strategy among the federal states.

PM mentioned much more concretely that hopefully the results of the 14 digital experimentation fields will be used. FRM1 added a clear demand for simplification and cost reduction of digital tools. In addition, data interfaces must be improved and made easy to use. Many providers of digital technologies promise a lot, but they often cannot offer everything “yet”. However, digital and smart technologies must be tested thoroughly by independent bodies so “that farmers are not the first guinea pig” (FRM1). IE demanded financial support of emission reduction measures (e.g., spot application) in the CAP to create incentives for sustainable agriculture. To establish digital tools in the daily farming work, digital solution should be anchored in regulation – for example, in plant protection regulation (IE). RS2 and RS3 endorsed the standardisation of interfaces and systems, their widespread availability, increased attractiveness, and adequate advice and training for farmers. Moreover, FRM2 postulated the creation of a common agricultural data space that “is efficient, dynamic, and easy for farmers to manage”.

Q3 B: In your opinion, what political framework conditions would have to occur, to overcome the greatest obstacles?

With this last question, we sought clear recommendations for action from the experts. RS1 stated the need for “a central institution/federal office for digitisation in agriculture for the establishment of an ‘agricultural data room’ in Germany, which retrieves tools and data from all offices/chambers of agriculture/industry/research projects and disseminates this information to agriculture”. Moreover, research data should be published consistently 1 year after project ends (RS1). PM remarked that IACS (InVeKoS) “is only a means to an end, now it is a central, agricultural instrument of action; the narrative

would have to become climate and biodiversity protection”. The farmers stated that adequate advice is essential. Official advice and training should be provided for farmers. Regarding the access to data, only one portal for all federal states with all relevant data should be established. Open data must be available across all federal states (FRM1). CSO mentioned the need for digital education and training in the agricultural sector. Potential added value must be identified and communicated to industry. In addition, different actors should be brought together: “in an example of ‘biotope networking’ in a region, not only different farmers, are required to create flower strips/lark windows, for example. Municipal actors also run corresponding programmes on ‘Eh-Da’ areas/roadside strips, which are perceived to run in parallel” (COS). IE called for greater state dedication to digitalisation in the form of a commitment to the digital transformation in agriculture by the BMEL. Another incentive could be area funding for the application of digital technologies (IE). FM2 and RS3 demanded consistent implementation of open data and FM2 stated that it should be available in a high-quality technical form.

Conclusion

Summing up the expert discussion and the statements of the different stakeholders, it is obvious that all of the experts see a potential contribution of digital and smart technologies to sustainable agriculture. These potentials have already been established and used in agricultural practice or they are expected for the future. Several experts mentioned support for precise management operations accompanied by resource savings, site-specific area management and implementation of measures, as well as yield savings and emission reductions. The limitations each of the experts gave to this first question are all in a similar direction: digitalisation is a tool that needs a clear and working framework to have real advantages. The experts expect digital and smart technologies to support decision-making processes, partial surface-specific application, facilitation of recording, and uniform communication protocols.

Asking more specifically about the potential of digital and smart technologies to contribute to the promotion and protection of biodiversity in agricultural land, the experts indicated that with the help of such technologies, unproductive/uneconomic or high erosion-prone sub-areas could be taken out of the field information and the implementation of measures at the landscape level could be facilitated. In addition, digital and smart technologies could provide better monitoring, action-planning, and documentation (automatic proof) of field areas and conservation measures. There would also be easier and uniform communication with the authorities. Considering specific technologies, field robots are capable of managing fields with less environmental impact than big farm machines and can better adapt to the conditions of species protection in the fields.

Regarding the barriers and challenges as well as required actions, five main subjects emerged during the discussion. These subjects include: (1) the lack of compatibility among data and the available systems; (2) issues regarding access to and the sovereignty of data; (3) acquisition costs for digital and smart technologies that are still too high, especially considering the lack of monetary support of their use; (4) the massively bloated and complex federalist structure in Germany, leading to incompatibility among the

German federal states; and (5) the need for advice and adequate training for farmers to provide information and knowledge regarding the use of digital and smart technologies in agriculture.

To overcome these barriers and challenges, standardisation, interoperability, adequate incentives, and financial support for the use of digital and smart technologies and specific education and training programmes are highly desirable and required. Furthermore, the designed tools must be easy to use and thoroughly tested, and the acquisition costs must be reduced. Germany needs one uniform digital strategy, which might also incorporate a common agricultural data space and anchor the use of digital technologies for certain measurements (e.g., emission reductions) in the CAP. In terms of concrete recommendations for action, the experts advocated for example, a central institution/federal office for digitalisation in agriculture, which pools and provides all relevant data and information all over Germany. This is followed by the demand for open and high-quality data. In the experts' view, this also requires a commitment from BMEL to facilitate digital transformation in agriculture. Other crucial recommendations for action are funding for the application of digital technologies and promotion of official advice and training for farmers.

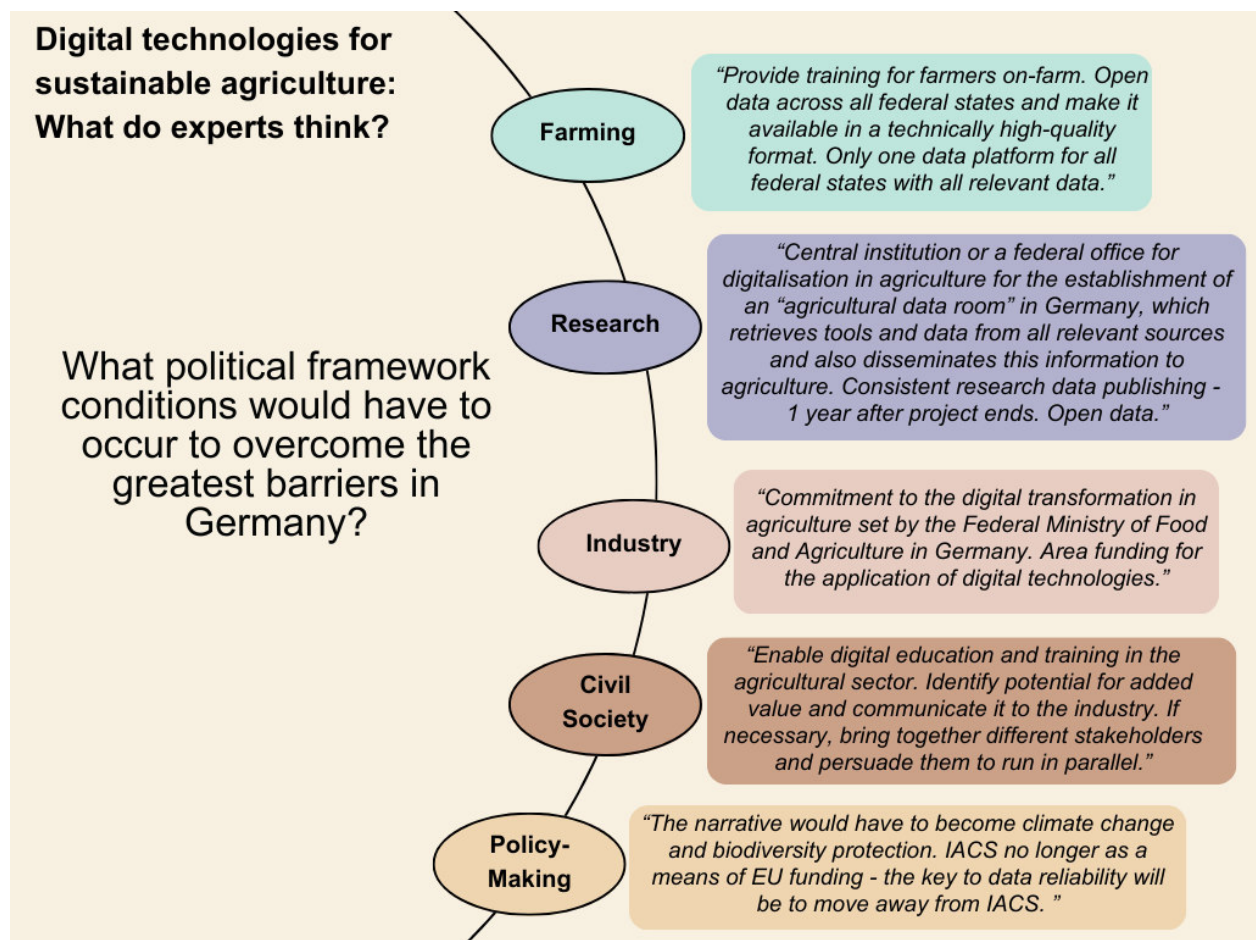


Figure 73. Core statements to the question "What political framework conditions would have to occur to overcome the greatest barriers in Germany". Our illustration.

8 Assessment of digital technologies and barriers for sustainable agriculture

8.1 Literature review and our insights

Germany is one of the world's leading nations in the production and use of modern technologies. With the help of digitalisation, the competitiveness of German agriculture can be advanced (BMEL, 2022d). However, the ambitious goals set regarding digitalisation as a solution for ecological problems have not yet been fulfilled, and future success depends heavily on agriculture as well as social acceptance and economic and political conditions. Digital technologies can enable an ecological utopia for sustainability or trigger an ecological dystopia and support unsustainable intensification of agriculture (Daum, 2021). Therefore, the industry alone should set the guiding goals, nor should policy makers only look at food security when discussing digital technologies. Farmers and society must also be included in the design of sustainable agriculture supported by digital technologies (Kliem et al., 2023). As Daum (2021) concluded, responsible innovation in agriculture is possible only when a wide range of stakeholders is included in the entire design and development process of a technology. There are multiple possible transformation pathways for digitalisation towards sustainable agriculture that do not get enough attention because, as we found, the current digital transformation is strongly focused on global food security, sustainable intensification, and climate-smart agriculture measures. However, digitalisation in organic farming, permaculture, or regenerative agriculture is not of interest due to a lower yield potential (Figure 74).

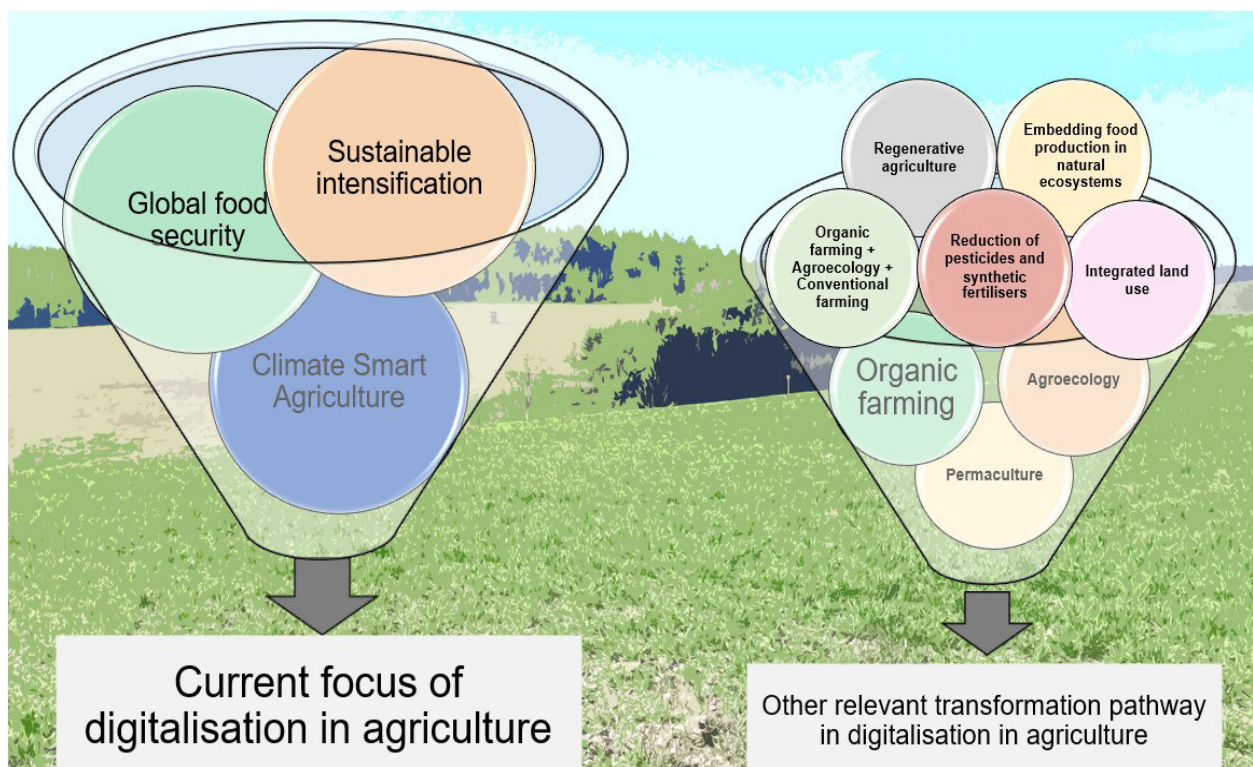


Figure 74. Possible transformation pathways towards a sustainable agriculture versus current focus of the digitalisation in agriculture. Our illustration.

The available research does not provide sufficient information on the potentials and risks of how the use of digital technologies affects biodiversity conservation. This research gap is an obstacle to the

implementation of more biodiversity-enhancing measures in agriculture. On the other hand, the difficulty analysing the rapidly developing digitalisation based on publications could be behind the development of digital technologies in practice. However, without a well-founded knowledge base, it is difficult to formulate regulatory measures or policy recommendations (Kliem et al., 2023). Whether and which potentials and risks for sustainability will result from the use of digital technologies will have to be shown via research and practice. The opinions of the experts from the competence areas of research and farms differ greatly regarding digitalisation and sustainability. While the researchers see a broader spectrum of obstacles and preconditions for the future development and use of digital technologies, as well as many research gaps, it is important for farmers to address the aspects that currently characterise everyday life on a farm (Kliem et al., 2023). There is a great deal of potential in the use of digital technologies. However, the potentials need to be recognised, developed, and combined for practical ecosystem service conservation so that sustainable methods can be widely implemented in agriculture in the near future. Therefore, we present various potentials, barriers, and risks.

8.2 Potentials

The currently available digital technologies are commonly developed and used to optimise farming processes to increase crop yield in the context of economics (Hennes et al., 2022). For digital technologies to be effective, a main function is production monitoring, which generally provides yield, biomass, and soil- and water-related data. Besides field monitoring data, some technologies such as FMIS provide options to collect data, to plan field operations, and to implement management activities (Fountas et al., 2015; Mouratiadou et al., 2023). Digital technologies might also be used for a wider purpose, including data collection for a sustainable design of agriculture in Germany; hence, wider system monitoring could also be considered. Digitalisation is a concept within the agricultural sector that is already being used to optimise procedures and processes (Hennes et al., 2022) Digital technologies offer new opportunities that can facilitate coordination among different stakeholders (WEF, 2020). Due to rapid technological progress, technological innovations can contribute to significantly increase resource use efficiency and reduce GHG emissions (Basso & Antle, 2020; Finger et al., 2019). As our survey and expert discussion showed, when digital technologies are implemented, researchers often hope for a significant improvement in terms of nature conservation.

Drones and field robots are among the newest digital technologies that show great potential for sustainable agriculture (Kliem et al., 2023). We use these two examples to illustrate the motivation originally drove technological progress and the positive effects that can be observed. Figure 75 and Figure 76 are also intended to illustrate that the drivers for digital technologies remain on the “red” side. The fact that technology development alone still rules the direction of technology use in practice is not a contemporary way of thinking in the time of climate change and a strong reduction in biodiversity. Therefore, we appeal to policy makers for the development of sustainable rather than business models for digitalisation of agriculture in Germany.

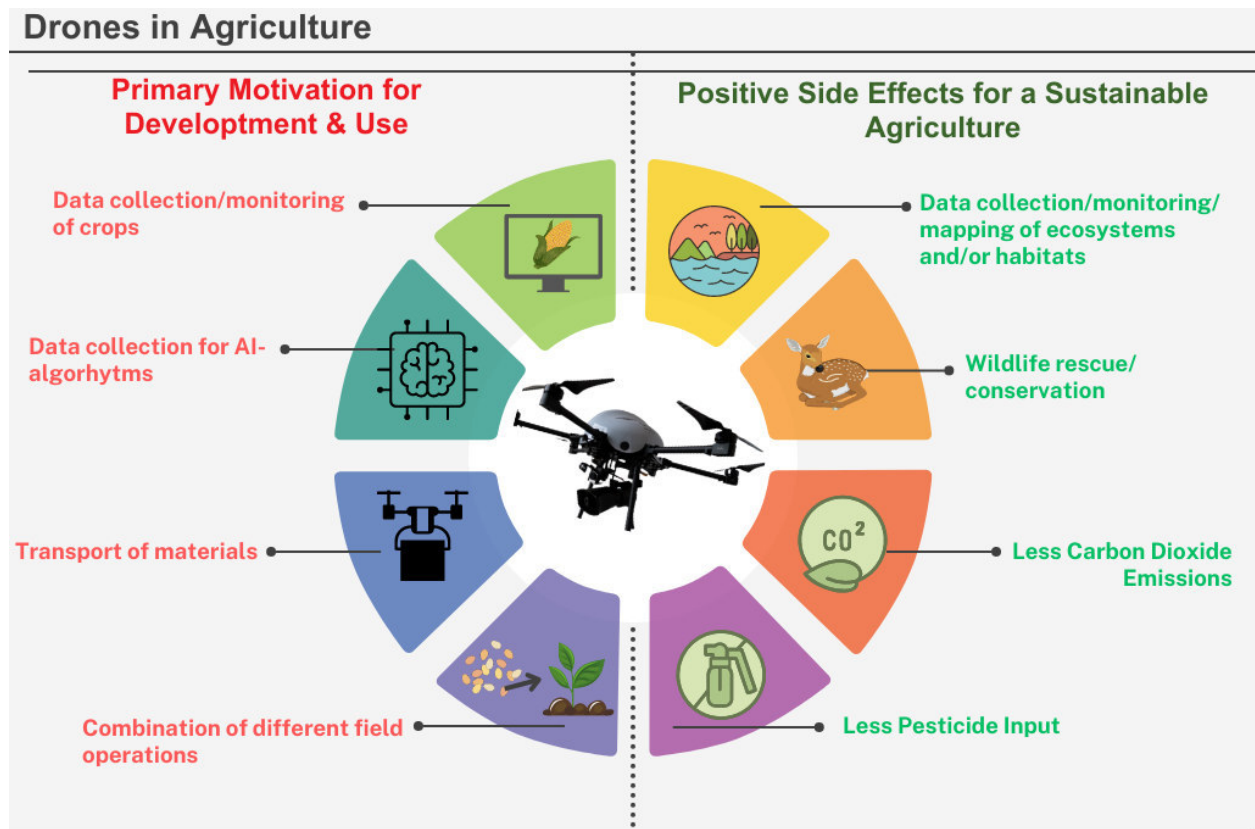


Figure 75. Illustration of primary motivation for development and use of UAV/UAS in agriculture and the positive side effects of their usage for a sustainable agriculture. Our illustration.

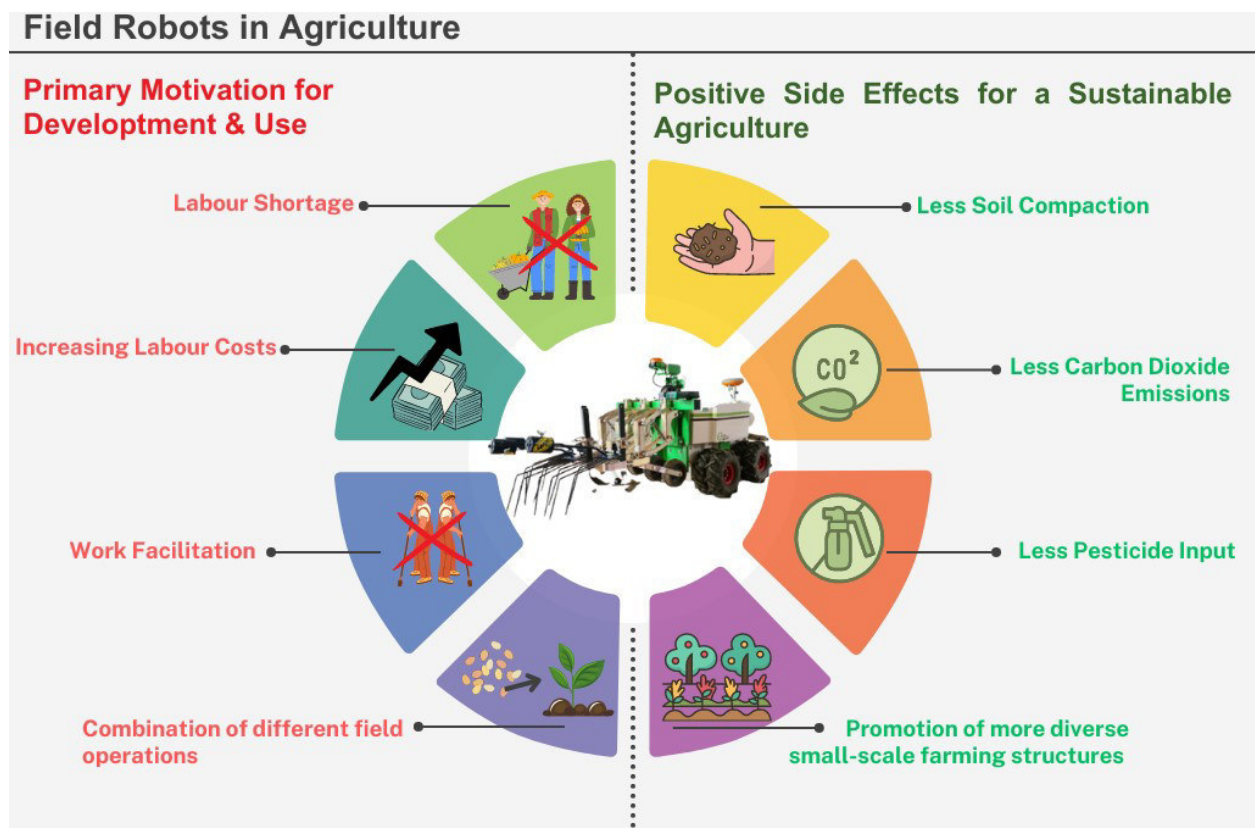


Figure 76. Illustration of primary motivation for development and use of field robots in agriculture and the positive side effects of their usage for a sustainable agriculture. Our illustration.

Reduction of GHG emissions and N and P pollution in agriculture

According to DüV, 2017 (2017), farmers are obliged to determine fertilisation requirements before the first fertilisation measure is carried out in the field. There are multiple factors that must be considered when determining the fertilisation requirements, including the land type, crop species, yield level, harvest residues, previous crops, intercrop, soil type, and humus content. When using a DSS, the more data a farm has entered in to the system, the more information the system automatically includes in the fertiliser calculation, which can contribute to achieve the NO₃- goals set in the Nitrate Report (BMEL, 2020c).

Agricultural production relies on fertiliser applications, mostly N fertilisers, to produce a large quantity of food (Coskun et al., 2017). Many of the sensor technologies available on the market in Central Europe offer site-adapted N-fertiliser application based on chlorophyll measurements (Kendall et al., 2017). Satellite imagery offers yield potential maps and precise navigation during N fertiliser application in field. With the aid of site-adapted N-fertilisation, the risk of over-fertilisation is significantly reduced. If crops are fertilised according to their nutrient requirements, then less surplus N is released into the environment to cause negative impacts, such as gas emissions (especially during soil cultivation after harvest). This view also applies to other fertilisers: agriculture contributes half of the P pollution (mainly P loads to water bodies) in Germany (Chapter 4.3). P water loads are the result of excessive and inappropriate P use on crop fields. Here, sensor technologies and satellite imagery could provide valuable assistance to reduce undesirable fertiliser losses into the environment.

Reduction of pesticide pollution

Currently, the most efficient and common ways to control disease and weed and pest populations is by using digital technologies for precise pesticide application. The main aim of site-adapted pesticide application, especially for large-scale farmers, is to reduce the cost, time, and resource use – hence, it is also cost-efficient (Niggli et al., 2020). Site-adapted or reduced application of chemicals can also represent a sustainable approach. Sensors, field robots, and unmanned aerial vehicle work at the plant level: they use a data source (e.g., satellite imagery and AI) that can differentiate crop plants from weeds or healthy from pest-infested crop plants. Site-adapted pesticide application for site-adapted fertiliser application relies mainly on navigation, detection, and actuation systems. Digital technologies support farmers in the implementation of PflSchG, 2012/20.12.2022 (2012) in Germany. A digital technology programme established by BMEL, Horticulture 4.0, promotes the use of a “digital insect trap” as well as a digital assistance system for pest management. The application has favourable ecological effects due to reduced pesticide use (Ludwig-Ohm et al., 2023). Additional studies have demonstrated how a script-programmed pesticide application model (mixture toxicity of application spray series [MITAS]) can be used to determine the exposure risk to soil organisms (Sybertz et al., 2020) and how pesticide application technology (greenRelease) can reduce the environmental impact of pesticides (Kuhn et al., 2022).

Diversification of crop species and crop rotations

Simple crop rotations are typical for Central Europe, in particular Germany; they consist mainly of cereals for grain production (eurostat, 2022b). Apart from cereals (species from Poaceae, maize for silage winter rapeseed, potatoes (*Solanum tuberosum* L.), and sugar beet are also grown on a large scale (Destatis, 2021a). Maize, potatoes, and sugar beet are very humus-consuming crops, which has a negative effect on soil fertility. Planning a crop rotation is a time-consuming process in which many different aspects have to be considered: previous crops, the plant-available mineral content of N in the soil, the soil characteristics of the site, weather conditions, pests, and disease, among others (Diepenbrock et al., 2005). As planning must take place separately for each field, digital technologies can facilitate the process by collecting and partially analysing the necessary data to decide which crops to plant.

Precise navigation in DTDS, lighter field robots, sensors, and drones can help farmers to adapt soil management strategies (Gabriel & Gandorfer, 2020b; Kliem et al., 2023). Improved soil management is closely linked to the diversification of crop stands and rotations. AI solutions and hardware-based technologies (sensors) can make it possible to process large datasets that include numerous variables, such as soil temperature, soil humidity, weather, and crop plants, and to structure the results as recommendations to reduce soil defects (Javaid et al., 2023).

Nature conservation and biodiversity protection

Robotic weed control can significantly increase soil bulk density in the topsoil layer compared with conventional heavy agricultural machinery (Bručienė et al., 2022). Compaction of arable soils leads first and foremost to the destruction of pores and thus worsens water and oxygen availability in these areas (Johnson et al., 2017; Li et al., 2017). Deep tillage disturbs many soil animals: some of the animals are injured or killed, while the habitat for others is destroyed. Prolonged fallow, species-poor crop rotations and overly large arable fields without connections to other semi-natural biotopes also contribute to the impoverishment of soil fauna (Baeumer, 1992). Soil organisms are primary actors in nutrient cycling: they regulate the dynamics of organic matter and are thus indispensable for ecosystem services within agriculture (Chude et al., 2020; Geisen et al., 2019). Robotic AI-based technologies to detect and/or eliminate yield-reducing weed species in the field improve crop quality and quantity, preserve soil nutrients and health, and reduce herbicide application (Sohail et al., 2021). Field robots can work 24 hours a day, 7 days a week, allowing farmers to adopt diverse small-scale agroecological-friendly approaches (Daum, 2021).

CS and DIP are particularly relevant for biodiversity conservation, as biodiversity indicators and the diversity of flora and fauna must be first recorded and assessed before nature conservation and biodiversity protection can begin. Profound decision-making regarding implementation of biodiversity-promoting measures can proceed (Fischer et al., 2020; Ingram & Maye, 2020; Jones, 2020). The assessment of biodiversity-relevant data is a very intense process (Bowker, 2000), which is why CS apps and DIP platforms are useful.

Although weeds are reluctantly tolerated among crops, they should be considered a direct measure for biodiversity conservation (Steinmann, 2020). In this sense, a direct contribution to biodiversity and conservation is possible with the help of field robots: they can distinguish between crop plants and other plants when a certain degree of machine intelligence is reached (Mathanker et al., 2010; Steward et al., 2019). In the near future, if a sufficient database associated with biodiversity becomes available, field robots will be able to contribute to direct biodiversity conservation by targeting endemic and protected plants and sparing weeds for insect feeding during mechanical weed control.

Unmanned aerial vehicles can be successfully used in wildlife ecology, especially to observe bird species and their nests (Ogawa et al., 2021; Santangeli et al., 2020) and to detect mammals (Kock et al., 2022; Psiroukis et al., 2021; Sarwar et al., 2021) and indicator plant species when DL algorithms are applied to high-resolution unmanned aerial vehicle imagery (Basavegowda et al., 2022). Monitoring insects has not yet been sufficiently developed or researched and is oriented towards pest detection and control (Chu et al., 2018; Garcia Furuya et al., 2021).

By combining FMIS with other technologies, farm management and system planning can be used to contribute to nature conservation (Mouratiadou et al., 2023). As mentioned above, planning a crop rotation is a time-consuming process in which many different aspects have to be considered (Diepenbrock et al., 2005); this process could be facilitated by appropriate AI algorithms.

Enabling adaption to climate change management and innovative cropping systems

Digital technologies cannot stop climate change, but they can help farmers implement new field management and crop systems more quickly and easily. An example is the adoption of agroforestry, which offers an increase in the soil carbon stocks and promotes biodiversity, as agroforestry systems contain a variety of crop plants and tree species. A good example is the data and value-based decision-making for a sustainable land use (DaVaSus) project, which is aimed to help agriculture through digitalisation, at the Gut&Bösel farm (www.gutundboesel.org). The farm has created a complex agroforestry system, which should be supported by digital solutions, such as field robots, that aid their small-scale cropping model to ensure there is a high degree of diversification. Another example is the platform AgoraNatura (see Appendix Table 14). Since October 2020, AgoraNatura has enabled anyone who manages land and wants to implement a nature conservation project to finance it via crowdfunding or through partnerships with companies. Private investors and companies can specifically promote biodiversity and nature services by purchasing nature conservation certificates. The price of a single certificate (as a donation for a certain project) is between 3 and 20 euros. For example, a project²³ about the protection of meadow nesting birds in grassland landscapes has already received 894 certificates (each for 5,40 euros). The donations will be used for the development of an herb- and species-rich grassland and for the selective introduction of important plant species in areas with open patches of soil until 2027. NatApp is another example of a digital technology that aims to support farmers in their climate change measurement adaption. It focuses on the support of farmers with administration processes so that they can

²³ Source: <https://agora-natura.de/produkt/wiesenbrueterschutz-im-bachinger-moos/>

apply and comply with the relevant authorities (Geppert et al., 2023), as administrative burdens are a big obstacle for the implementation of climate change adaption and nature conservation measures (see Chapter 0). The Uckerbot field robot has been developed in a cooperation between industry and research. It is a system that promotes ecological sugar beet cultivation under unfavourable soil conditions while simultaneously supporting weed biodiversity. The weed diversity on the field is examined from the beginning of the field robot development as an adaption measure to poor soil conditions (Steinherr et al., 2023).

Enabling communication and knowledge-sharing among farmers and different stakeholders

Coordination and communication among different stakeholders are important for the development of new digital tools and the collection and analysis of data to design sustainable agricultural systems (BMEL, 2022c). New learning opportunities emerge in the context of agricultural knowledge and innovation systems (AKIS), (Ingram & Maye, 2020), where communication and interaction between different actors is a crucial component to push innovation processes (Knierim et al., 2015; van de Gevel et al., 2020). These actors can be individual farmers, whole farms, and extension services for farmers. Knowledge sharing is necessary in the same environment (e.g., in same the geographical region) as well as at the national and EU levels. A survey from Germany showed that 89% of the participating farmers use smartphone in their daily life and work, with 79% of them agreeing that mobile and digital communication will make it easier to check farm workflows (Fecke et al., 2018). Farmers want to show society that they are improving their skills and are willing to profit from all new digital technologies and information in order to improve their production and sustainability (Schnebelin et al., 2021).

8.3 Barriers and risks

There is an urgent need for research on the practical implementation of digital technologies that promote biodiversity protection and conservation. Digitalisation of agricultural management gives rise to new, different challenges and risks, such as rebound effects assessing the energy efficiency of digital tools (Ahlefeld, 2019; Golde, 2016; Madlener & Alcott, 2011). Digital technologies often focus primarily on marginal efficiency improvements along existing technology paths and might promote further intensification of agriculture. For an ecologically sustainable transformation of agriculture, however, more far-reaching changes are needed along agricultural and ecological concepts that promote the diversification and long-term resilience of agricultural systems (Kliem et al., 2022).

Legal barriers, data limitations, and data protection

Autonomous technologies such as robots are still in a grey area according to EU law (Basu et al., 2020). In Germany, the European Machinery Directive (Directive 95/16/EC, 2006) applies to manufacturing and marketing: autonomous robots must be operated by a person. According to Basu et al. (2020), the applicable laws for autonomous field robots are not so clear and the introduction of the term field robot (such as an agribot) is necessary, as the working conditions in the field are not equivalent to other areas of

operation, such as road traffic. In December 2022, the European Commission announced that a new proposal for a Regulation of the European Parliament and of the Council on machinery products had been filed (European Commission, 2022b). From the current point of view, the liability regime is challenged by technical legal arguments (Basu et al., 2020).

EU-wide regulations for the operation of unmanned aerial vehicles have been in force since the beginning of 2021, following a decision by the European Commission on 24 May 2019 ((EU) 2019/947, 2019). For the operation of drones ≥ 250 g, proof of competence and registration of the drone is mandatory; this can be done online. This rule applies for most of the DJI drone models, which are used with cameras and sensors. For the operation of a drone < 4 kg, in addition to the proof of competence, a practical self-study must be completed by the remote pilot and a further theory test must be passed. Furthermore, drone liability insurance is mandatory, and risk assessment is necessary ((EU) 2019/947, 2019). Based on our request to the competent authority, a processing time of 6 weeks is estimated for the approval of a drone flight for monitoring purposes over an agricultural area.

Public agricultural data are collected for administrative purposes only and there is currently no intention to collect and/or use it for decision-making regarding digital technologies (Luyckx & Reins, 2022). Furthermore, it is not yet clear whether large datasets will be able to capture and assess the complexity of agricultural systems, ecosystems as a whole, or biodiversity because the data analysis might not be mature enough (Delgado et al., 2019).

The data management of digital technologies is characterised by a difficult legal situation and controversial discussions about data protection (Lutz, 2017; Vogel, 2020). The problem mainly lies in the fact that the General Data Protection Regulation ((EU) 2016/679, 2016) currently in force within the EU does not guarantee data sovereignty for non-personal data. As the application of digital technologies involves the collection and storage of very sensitive data (e.g., location, engine operating hours, and fuel consumption), there is still scepticism among farmers regarding data protection (Schleichler & Gandorfer, 2018). There is also a danger in handling digital data, which is a valuable commodity for data traders (Clasen, 2021). Large-scale data collections and analyses are often not directly accessible to farms, but rather to global and financially strong actors (Zscheischler et al., 2021). In this respect, there is currently a need for more transparency for farmers regarding how and whether their data are handled securely (Härtel, 2019; Horstmann, 2020). One example of this is the joint project OdiL, which promises secure data handling (Hertzberg et al., 2020). For example, data collected from John Deere sensors is compared with both legacy and real-time data and made available exclusively to agricultural users within the John Deere platform (Ge & Bogaardt, 2015). Systems that can be used on local computers are considered to inspire confidence in farms in Bavaria (Gabriel & Gandorfer, 2020a).

Economic aspects in the foreground: an unclear sustainability effect, socio-cultural issues

The currently available digital technologies are commonly developed and used to optimise farming processes, especially to increase crop yield (Hennes et al., 2022). For digital technologies to be effective, one main function is generally providing yield, biomass, and soil- and water-related data. It is important

to clarify that the current transformation of the agricultural sector depends on the digital technologies and their functions as well as stakeholders on multiple levels, including farmers, technology manufacturers and developers, scientists, consumers, and policy makers. Currently, there are two development paths for the further transformation of the agricultural sector: digitalisation of existing management methods and administrative processes, where existing large-scale farm machines and technologies are supplemented with digital and automated applications; and cultivation of fundamentally new small-scale technologies (e.g., robots and drones) that deviate from previously used agricultural machinery and cultivation methods (Gaus et al., 2017; Kliem et al., 2023).

According to a survey of 500 farmers in Germany by Rohleder and Meinel (2022), some of the biggest obstacles for farmers:

- the prices for agricultural products are too low (79%);
- the implementation of sustainability measures is a challenge (67%);
- digitalisation is a challenge for the farmers' business (51%).

The authors concluded that farms are first and foremost businesses that need to secure their income. As long as producer prices are low and the acquisition of digital technologies is very expensive, no significant progress towards sustainable digitalisation will be possible.

Hackfort (2023) concluded that the companies dictating the agricultural digital technology market in Germany, as well as in the rest of the world, are allied with powerful national and international policy actors. The author added that digitalisation pushes low-tech approaches into the background and argued for a structural transformation on policy and funding. Whole systems could be marginalised by claiming primacy of “sustainable” digitalisation in agriculture, while in practice more time will be needed to achieve the declared sustainability goals. Beyond that, however, the public perception of digitalisation in agriculture has hardly occurred. The main participants in the digitalisation discussion are researchers and the smallest cohort of participants are farmers (Martens & Zscheischler, 2022). Ferrari et al. (2022) surveyed participants from rural areas and asked them to describe socio-cultural impacts and found that there are concerns about an exclusion of those subjects who cannot keep up with digitalisation.

High costs for acquisition and services

Farms with a field area under 100 ha have an average yearly income of 25,000 euros, which makes it difficult to access new smart technologies. This results in a low adoption of digital and smart technologies in agriculture in the EU: less than 25% of EU farmers access digital tools (Dryancour, 2017).

According to Dryancour (2017), farms that are less than 50 ha do not have access to digital technologies such as guidance systems or nutrient-sensing tools because they cannot afford to invest in expensive technologies. When farmers use digital technologies in practice, they could be more eligible to receive CAP payments if a certain technology is certified as for certain sustainable management options (e.g., widening of crop rotations with legumes). In this case, however, small-sized farms will lag in the development of digital technologies. Researchers are warning that this issue can lead to a “digital divide” (Kliem et al., 2023; Ryan, 2020). This phenomenon could be particularly troubling for Germany:

currently, 180,200 of 263,500 farms in Germany are classified as small-sized farms (≤ 50 hectares) (Destatis, 2021d).

Because many technology manufacturers do not provide prices online, we wrote to four companies that offer drone services for agriculture. We have kept the names and locations of the companies anonymous. A 1-day drone survey with an RGB, multispectral, and thermal camera for a maximum of 300 ha costs between 6,000 and 9,000 euros. The evaluation of the raw data is an additional service, which can cost 1,500–3,000 euros. In this case, a farmer will not have a direct income source for providing biodiversity protection or nature conservation measures.

Another big obstacle is the financing of field robots. Policy makers are not ready to finance the acquisition cost for field robots for farmers. Contractors do not yet offer robots for hire, as the demand would be very low. With a single field robot unit that costs 70,000 euros and has a low working speed, a contractor would need more robots. We did not find typical agricultural machine contractors that offer field robots for hire online. Such a business model is offered by some of the field robot manufacturers (e.g., Naio). Furthermore, the application of FMIS is partly cost-intensive and often complex, which is why their use is still limited (Munz et al., 2020).

Further intensification versus sustainability

In the case of biodiversity, smart agricultural machinery could push the further intensification to cultivate the agricultural residual areas that are important for nature conservation as ecological stepping stone biotopes, insofar as they are not under protection or ecological priority areas within the framework of the CAP. This phenomenon could lead to the loss of valuable areas. At the same time, there are concerns that an increase in the number of large-scale farms alongside digital technologies would have a negative impact on biodiversity. There is fundamental scepticism regarding the use of algorithms that are being developed for yield enhancement (Reichel et al., 2021). BD structures could support particular agricultural crop systems (Bronson & Knezevic, 2016), especially when the main focus is a yield increase. The authorities in Germany have already developed strategies regarding AI and BD (see Chapter 5.2) that also include the keyword “sustainability”, but it is important that the planned competence centres work closely with farmers, agricultural researchers, and nature conservation specialists to provide the right input at the right time. If nature conservation as a sustainable approach and especially biodiversity conservation are not considered from the beginning, it will be more difficult to add new drivers into such a complex system at a later time.

Limitations of digital technologies in practice

Challenges for practice arise from data quality. For example, the GreenSeeker optical sensor should only be used for large-scale measurements, as smaller measurement units and not canopies that are not completely closed can lead to measurement errors (Ali et al., 2020). Therefore, farmers are concerned that the adoption of digital technologies requires a larger field (Ferrari et al., 2022). Limitations also emerge from the calibration of sensors, which are primarily intended to detect the genetic diversity of common

crops, such as wheat (Khadka et al., 2021b; Pratap, 2019b). Currently, the genetic diversity of other crops and/or weeds in the stand remains unaddressed for cost reasons.

Agriculture is becoming more digital and new ideas and services are pushing the ISO-XML format to its limits. For example, it can only send completed jobs as a file and cannot send data in real time. However, it would be necessary to display telemetry data such as the position of the machine in the farm management software. To make this possible, the new EFDI file format is being developed. Nevertheless, ISO-XML and Shape will remain the standard formats for the exchange of application maps in the coming years (Göggerle, 2020).

AI-based technologies are currently facing difficulties with classification models where crop and weed recognition is needed. Juwono et al. (2023) listed a few key challenges that AI-based digital technologies are facing. The first one is the fact that vegetation images obtained for the ML process are often taken at different growth stages of the plants, where not only the size of the plant but also the heterogeneity of the species varies. Second, under field conditions, the growth of different plant species overlaps; this overlap is hard to segment during the ML process (Juwono et al., 2023).

Unmanned aerial vehicles have some disadvantages for species protection: they can cause noise pollution and disturb bird species (Schrader, 2017). Additional research is needed regarding the extent to which unmanned aerial vehicles pose a threat to biodiversity protection. For example, the Federal Nature Conservation Act (BNatSchG) clearly states that wild animals and protected species of European bird species are not to be disturbed wantonly (BNatSchG, 2020).

Plant disease are often caused by more than one pathogen and can show different symptoms, including different colours and patterns, which is a challenge for digital technologies, since they rely on image material (Zhang et al., 2020).

Maturity level of digital technologies for practice

The development and analysis of data related to nature conservation indicators is still in its initial phase (Adão et al., 2017). Despite the rapid development of technology, data collection and recording of biodiversity in CS platforms is still in a very initial phase. (Ball-Damerow et al., 2019). Seamless functioning of FMIS requires a robust communication infrastructure, especially when submitting documentation for regulation. Nevertheless, FMIS should be able to be connected to each other via standardised interfaces and offer a use guidance, following the example of Windows and Android (LfULG, 2020).

While sensors generate a great amount of data, only a very small fraction of these data are used in agricultural DSS or data-driven technology. The main reasons are compatibility problems when processing data from different sensors, excessive time and cost expenditures, and a lack of multicausal DSS. Therefore, sensor systems have so far been offered as isolated solutions (Kehl et al., 2021).

Another barrier for a broader application of digital and smart technologies in arable farming is the current working speed and working area of robotic technologies (Fountas et al., 2020). The working speed of robots is 1–4 km/h (Gil et al., 2023). Furthermore, the effectiveness of weeding can vary greatly among

field robots depending on the site, soil type, weed infestation, weed composition, and the weeding time (Ahmad et al., 2014; Bručienė et al., 2022; Fountas et al., 2020). Especially on loamy soils, robotic technologies must have enough power and weight to successfully plough and further cultivate the soil. Currently, robotic technologies cannot cope with the heterogeneous and changing conditions in the field and are still niche products (Kehl et al., 2021). The comprehensive use of drones is retarded by the necessity of complex and expensive image processing and analysis software for application in agriculture. In addition, real-time recordings and analyses with drones are still not possible. The delayed provision of the results of drone pictures limits their implementation in agriculture (Kehl et al., 2021).

Non-sustainable targets and further intensification

Biodiversity is the key component of nature: risks to biodiversity conservation arise from the fact that biodiversity is far from the primary goal of digitisation in agriculture, but merely an afterthought. A striking example can be found in the catalogue of habitats from the (Directive 92/43/EEC, 1992) (1992) (Fauna-Flora-Habitatrichtlinie [FFH]) under Annex II (Richtlinie 92/43/EWG, 1992), where arable land is not found as a habitat in agricultural areas (Hampicke, 2018).

While technologies such as field robots are aimed at reducing the workload of farms (Chapter 5.4.2), the use of drones in practice is severely limited due to strict regulations. Drones are generally used in monitoring and to map habitats; hence, their use on farms is relatively limited. Thus, we conclude that digital and smart technologies are either agriculture centric (DTGS, sensors, field robots, and FMIS) or biodiversity-centric (unmanned aerial vehicles and CS).

On the other hand, Tschardt et al. (2021) stated that organic agriculture is becoming more intensive and specialised, which can lead to loss of biodiversity. The precise and intensive use of all land areas can lead to a reduction in habitat niches in the marginal areas (Reichel et al., 2021). Furthermore, the selection of weeds that remain on the field depends on the robot's calibration or on the farmer. Hence, there is a risk that certain weed species are arbitrarily selected or omitted if there is not enough knowledge on their ecosystem service provisioning. Risks arise from the calibration of sensors, which are primarily intended to detect the genetic diversity of cultivated crops, such as wheat varieties that have been described in the literature (Khadka et al., 2021a; G. Kumar et al., 2017; Pratap, 2019a). Thus, the genetic diversity of other plants in the stand or weeds in the field can remain unnoticed.

Increased administrative workload through digitalisation

The administrative burden on farms is increasing in Germany. Hundreds of documents in the paper or digital format must be processed regularly and filed systematically with the authorities. This burden realistically results in little time for the implementation of measures towards sustainability, especially when the practical implementation of sustainability measures is associated with additional administrative workload (Brown et al., 2021) and there is a threat of strict sanctions in case of administrative gaps (Joormann & Schmidt, 2019). The provision of digital administration platforms does not necessarily facilitate farms if the regulations remain very complicated, the sanctions are strict, and the controls are

time-consuming (Reissig et al., 2022). Based on out browsing of the relevant websites, users often must click through various other pages of an authority to get to the right portal. Next, users have to read long regulations before they can apply for funding. The requirements for applying for subsidies are equally as complicated in the digital format and could overwhelm a farmer. Heilmann (2018) described the requirements for applying for support under the agri-environmental and climate measures as “uninteresting” due to the small print and complex requirements. Furthermore, payments for *specific* nature conservation objectives are currently quite low. Lakner (2020) evaluated data from the rural development programmes and concluded that only 0.7% of expenditures under Pillar II (EUR 17 million euros per year.) relate directly to Natura 2000 objectives. The lack of financial resources as well as the high administrative burden contribute to the fact that, overall, too few targeted measures seem to be programmed within the agri-environmental and climate measures in the Regulation (EU) No 1305/2013, 2013 (2013). According to Council Regulation (EC) No 834/2007, 2007 (2007), farmers voluntarily agree to comply with the management requirements set out in the funding guidelines of the federal states in Germany within the framework of the agri-environmental and climate measures or environmentally and animal-friendly husbandry practices on their farm, usually for a period of 5 years. Payments for organic farming and animal welfare measures may only compensate for the additional costs and lost income beyond the requirements for management and husbandry practices prescribed elsewhere by law (for example, if lower yields are achieved as a result of a reduction in fertilisation or a reduction in the use of plant-protection products).

Additional control procedures and special permits are necessary to promote nature conservation, whereby the ratio of administrative effort to the premium amount is disputed. For example, farmers in Saxony can participate in additional control measures, where the additional financial support increases by 40 euros per hectare, but does not exceed 550 euros per farm per year in total (FRL ÖBL, 2015/4. Oktober 2022). In this case, the use of digital technologies for nature conservation measures has no influence on the amount of financial support. Furthermore, from 1 January 2023, the changes to the CAP (European Commission, 2022a) for the EU funding period 202–2027 will come into force. The premium level, premium scales, and degression will remain at the same level as in 2022 despite the numerous economic challenges farmers are facing (see Chapter 2).

Weather dependence

Agriculture is a sector that completely depends on environmental and weather conditions. Digital technologies can track weather conditions and go beyond what the naked human eye can see (Javaid et al., 2022), but they reach their limits when it comes to climate forecasting. Although weather forecasting apps and models are most commonly used by farmers (Gabriel & Gandorfer, 2022), it is not possible to influence extreme weather events such as heavy rain or hailstorms. Weather risks cannot be reduced through digital technologies (Weltzien, 2016). Climate models have been developed by a large number of research groups throughout the world. The individual model components are described differently, which in turn can lead to different results. However, one thing is certain: it is practically impossible to precisely

predict the influence of humans, or in particular agriculture, on the climate in the coming years and decades (DWD, 2022a).

Cyber-related issues

Cyber-related issues, such as cyberattacks and data fraud or theft, are among the top 10 long-term risks. Cyber war in particular must be looked at more closely as all digital technologies are connected by a computer network, making them a potential target for attacks (Watson, 2014). Other technological risks are information infrastructure breakdown (WEF, 2020). Such incidents have a massive impact on the ordinary daily farming procedures and can cause severe damage – for example, crop damage due to incorrect fertiliser application or the breakdown of farming machines. They often cause chain reactions and lead to complex troubles along the whole agricultural value chain (Hanuschik & Moritz, 2023). Cloud solutions for data storage are one option for farmers to better protect themselves against cyberattacks and complete data loss. Besides technical solutions, soft skills like special training to impart knowledge about the characteristic of cyberattacks are essential. Further, a multidisciplinary approach is required for a comprehensive reduction of cyberattacks. This also includes preventive measures on behalf of the industry and policy makers (Hanuschik & Moritz, 2023; Strauß & Bettin, 2023).

Trade-offs

Digital technologies also require energy resources. An increased use of digital tools can lead to a higher demand of energy and certain raw materials. Gold, iron ores, or rare earths are indispensable for the production process and the functionality of digital devices and can contaminate soils, rivers, and ground water. Rare earth metals, iron, cadmium, and mercury are used to produce mobile phones, tablets, and other digital devices. The mining and installation of these components can cause massive damage to the environment and wastes are costly and difficult to dispose. Mining often occurs under conditions that are not congruent with human rights (Hoiß, 2023). Furthermore, the occurrence of rare earth metals in only a small number of countries leads to dependence on states, such as China and Russia that are not considered desirable under the current geopolitical situation.

The huge amount of data, often stored on multiple cloud accounts is increasing drastically every year, while it is not known with certainty whether data centres have access to or use renewable energy sources (van der Velden, 2018). Moreover, data centres produce high amounts of heat loss, which negatively contributes to global warming. Likewise, the production and use of digital and smart technologies demands a lot of energy (Gensch et al., 2019).

9 Key recommendations

For the advancing of digitalisation in agriculture regarding sustainability and nature conservation in Germany the study's authors suggest following key recommendations.

9.1 General recommendations

Governmental authorities should see themselves as a service and advice provider for digitalisation and sustainable agricultural practices. A smooth exchange between farmers and authorities combined with financial support for the implementation of sustainable management measures using digital technologies will accelerate the adaption process of farmers and help the technological step forward in practice in the next 10 years. Taxes on unsustainable regulations would be demotivating for farmers: farmers are afraid of authorities and need some positive motivation for the implementation of digital technologies for sustainable practices. This view was clearly communicated during the dialogue with the experts and it is also based on our expertise. A smooth exchange and possibilities for financial support, when using digital tools, will lead to more applications from farmers to receive this particular financial support and to use the tools in their fields.

9.2 Biotope networking

All relevant stakeholders in one region should be connected physically and digitally to create a “biotope network”. Farmers are required to establish valuable areas for nature protection, and municipal actors run similar programmes on existing areas that have not yet been used commercially to promote biodiversity. Knowledge sharing about possible nature conservation measures, possibilities to restore ecosystem services (or which ecosystem services in a particular area are severely damaged and must be addressed as soon as possible), as well as biodiversity protection are necessary in the same environment (e.g., in the same geographical region) and at the national and EU levels. Data sharing as well as the possibility for uncomplicated knowledge sharing over a platform (e.g., a farmer can ask an expert or authority representative for advice, anonymously or not, or get networked with farmers and other stakeholders with similar problems and ideas). Best practice examples specifically for agriculture are not yet available in this context. There are CS platforms throughout the world where maps of species, indicators, richness patterns, etc., are being collected and shared (Map of Life). However, their scientific expertise and network are at a low level due to a lack of political and scientific support. SMART AKIS is a platform for the entire EU and is not regularly updated. During our literature review, we found that many of the technologies presented as “available on the market” no longer exist or have not received updates and are not commonly used. Moreover, the database is very outdated: for example, a technology that was already presented as commercial in 2016 still has the status “soon available on the market”. The search for digital technologies on AKIS is also presented as a mixture of German and English. A lot of information is only available in English, which can be a barrier for farmers.

9.3 Compatibility and reliability of technologies and data

For a broader common use of digital and smart technologies for sustainable agriculture, farmers require better compatibility between technologies, especially from different vendors. Furthermore, digital and smart technologies must be designed to be more user friendly and easier to use. Likewise, stakeholders from politics, research, and industry underline the need for standardization of technology interfaces. Additional preconditions that will improve and facilitate the use of digital and smart technologies for sustainable agriculture are widespread availability for all federal states as well as increased attractiveness regarding price and usability. A technology manufacturer must provide information in advance on where the specific technology can be used – which field sizes, crop plants, weather conditions, and federal states the technology covers. For farmers as users, such information is barely available when they look for digital technologies. This lack of information makes many digital technologies unattractive for farmers according to experts.

Interfaces are essential to work unimpededly with digital and smart technologies for sustainable agriculture; this applies to the technologies as well as the data. Stakeholders from research as well as farmers indicate that data must be easy and transparent to use, to foster a willingness and trust to deploy them. The crucial point of data reliability could be strengthened by the implementation of a central institution/federal office for digitalisation. Researchers and policy makers even endorse the establishment of an “agricultural data room” in Germany. Agri-Gaia is aimed at AI developers and users; farmers are not a direct target group. The website also specifically states the aim of knowledge transfer from developers to developers. Something else is meant by an agri-data room. For example, the German Weather Service (Deutscher Wetterdienst) offers a wide range of data sets in raw form, but also processed for users. These data are not sold and are scientifically processed. At the same time, users can download a table with raw data and analyse the data themselves. There is no such platform for agricultural data in Germany. If we want to know, for example, which crops were grown in Brandenburg for the period of 2009–2020 (the exact location, crop rotation, and yields from specific soils), such data are not available to researchers or farmers.

Bureaucracy and federalism must be significantly reduced: there is too much fragmentation of data and information due to different regulations in the different federal states. Legal changes and possibilities for financial support for the acquisition costs of digital technologies on-farm must be made easily available via a federal platform. Researchers and farmers demand a single data portal for all federal states with all relevant data. Further, data must be available across all federal states and of high quality. Researchers criticise the existence of too many single players on the commercial digital technology market in agriculture (230 as of March 2023) in Germany and call for nationwide information accessibility. The digital facilitation of administrative procedures is currently controversial – even with digitalisation the procedures for applying for nature conservation subsidies are complicated – and farmers are overwhelmed and their interest even in the digital format is quite low.

9.4 Clear legal regulations and data safety

The establishment of clear legal regulations of data sovereignty are inevitable from the point of view of all stakeholders for the broader use of digital and smart technologies in agriculture in Germany. The use of drones is subject to lengthy approval hurdles and deadlines (EU regulation 2019/947 on the rules and procedures for the operation of unmanned aircraft; Federal Ministry for Digital and Transport). In addition, when a farmer hires an external company for drone services, the farmer bears the costs for administrative tasks. This approach is not attractive for the implementation of sustainable agriculture, in particular, biodiversity protection (based on our expertise). Autonomous technologies such as field robots are still in a grey area according to EU law (Directive 2006/42/EC on machinery, and amending Directive 95/16/EC).

9.5 Education programmes and offers

Currently, studies provide very heterogeneous results on the use of digital technologies, and very often they are prototypes that are far from having reached the maturity level required for practice. Therefore, it is difficult to make concrete recommendations. Instead of researching and working on individual technologies, a multitude of technologies are currently emerging that have no practical relevance, especially in terms of sustainability. It is important that policy specifically promotes the development of digital technologies that are promising for practice and sustainability.

9.6 Cost reductions

Acquisition and general costs for the use of digital and smart technologies for sustainable management in agriculture must be markedly reduced for farmers. For example, software-based technologies such as FMIS are expensive and often too complex, which is why their use is still limited, especially for nature conservation purposes. If farmers were to use digital technologies for nature conservation and environmental protection, they would not make a profit – they would actually lose income. With field robots, sharing is likely to be difficult. Field robots that hoe weeds are currently relatively slow. The time windows for weed control are very narrow, so there is no total yield loss. Therefore, sharing robot hardware would be practically impossible.

A 1-day operation of a drone with a thermal imaging camera for a fawn rescue before mowing costs around 5,000 euros for an average field. At this rate, the farmer would not make any profit.

Digital and smart technologies do not yet make financial sense for smaller farms. They continue to do without new and smart technologies in everyday life to increase yields, so nature conservation with digital technologies is not even a topical issue.

Digital and smart technologies have great potential to contribute to sustainable agriculture, if they allow process optimization (e.g., increase in working time efficiency or reduction of operating resources) on the farms, specifically when used for sustainable practices. Therefore, they must be sufficiently tested at government-funded independent locations, so that “farmers are not the first guinea pig”. The focus is

currently not on the impact of digital and smart technologies on nature conservation and biodiversity protection during the development and test phases. However, very specific statements are needed – for example, an answer to the question “Which technologies help us to protect and/or promote ground beetles (*Carabidae*) on agricultural land?” So far, there are only theories without scientific evidence. Digital technologies need to be continuously moderated as a system by giving the right input – and that is not solely increasing crop yields.

The stakeholders from industry postulate a greater appreciation for the application of digital and smart technologies by area funding and financial support for sustainable farming practices via the use of digital and smart technologies, such as emission reduction measures (e.g., pesticide spot application) in the CAP to strongly promote the immediate use of digital and smart technologies for sustainable farming in practice.

9.7 Infrastructure

Basic internet infrastructure such as broadband network coverage and GPS signal, which are crucial for the functioning of digital and smart technologies, must be significantly improved according to the farmers, policy-makers, researchers, and industry stakeholders. Accordingly, agricultural value chains and legal and funding programme framework conditions must be digitalised and designed across the board. The greatest challenge lies in the creation of socio-technical interoperability between technical solutions and in actively involving farmers.

From the industry’s perspective, commitment from BMEL, including taking on a coordinating role for the digital transformation, would be a helpful next step to push digitalisation for sustainable agriculture. Concrete subjects of central coordination include a standardised open data platform or the pooling of information on nature conservation programmes included in the CAP in a digital, open access information desk. In general, there should be greater transparency between farmers, policy makers, administration, industry, and society.

10 Best-practice examples from other European countries

In this chapter, best practice examples of technologies that can be applied in practice in Germany are listed with a short description in Table 3 to Table 5.

Table 3. Best-practice examples of digital and smart farming technologies available and applied other European countries (EU and Austria).

Country	Technology	Short description
Europe-wide	FaST https://fastplatform.eu/	FaST digital service platform will make available capabilities for agriculture, environment and sustainability to EU farmers, Member State Paying Agencies, farm advisors and developers of digital solutions. The vision is for the FaST to become a world-leading platform for the generation and re-use of solutions for sustainable and competitive agriculture based on space data (Copernicus and Galileo) and other data public and private datasets. The modular platform will support EU agriculture and the Common Agricultural policy by also enabling the use of solutions based on machine learning applied to image recognition, as well as the use and reuse of IoT data, various public sector data, and user generated data.
	Agri-food data portal https://agridata.ec.europa.eu/extensions/iacs/iacs.html	The data portal hold by the European Commission provides a set of different data for and about agriculture in the EU. In the Agri-food data portal, data on national and European agriculture and common agricultural policy (CAP), are provided by the European Commission's agricultural and rural development department. The available data range from geodata, available in the Member States Geoportal. This portal delivers geodata of and for all regions of the member states, including some IACS data. Further portals provide farm economic data (FADN public data base); data about the agri-food market, CAP indicators, EU financing, country fact sheets as well as data about food supply and security.
	DigitAF https://digitaf.eu/	Founded by the EU, a consortium of 26 European and international partners committed to provide digital tools to boost Agroforestry in Europe. The key actions are 1) to collect data and evidences to support policy and decision makers for the implementation of agroforestry systems: 2) to improve communication and boost networking to reach different targets; 3) to implement a tailored multi-actor approach directly engaging with stakeholders whose decisions impact the spread of agroforestry practices.
Austria	Aws KI-Marktplatz www.ki-marktplatz.at	In 2021, a marketplace for AI was launched to provide an overview of the supplier landscape and their services in the field of artificial intelligence. Its goal is to establish contacts between AI suppliers and potential customers, and to introduce Austrian companies to AI applications. This enables market participants to find suitable partners more quickly and thus contributes to increased market dynamics (with more growth and employment).
	CORDULUS Cordulus Farm https://www.cordulus.com/de/	Technology company that delivers hyper-local weather data and AI solutions to their customers, that helps them in making proactive decisions and managing risks. With Cordulus Farm, Cordulus delivers weather station solutions to farmers. The technology enables localised forecasts to be made for fields, giving an advantage in planning agricultural activities, and making farm management easier. The actionable weather data can increase agricultural efficiency, reduce costs, and save time.
	Telesense https://www.telesense.ag/	TeleSense develops, produces, and sells wireless sensors which measure temperature and relative humidity. The products are used to monitor and ensure the security of biological products. TeleSense has a simple interface which makes it easy for users to monitor their stores. It can easily be accessed from PC, tablet or mobile.

Table 4. Best-practice examples of digital and smart farming technologies available and applied other European countries (Finland, Latvia, Netherlands, Norway).

Country	Technology	Short description
Finland	Mtech Digital Solutions Oy https://www.mtech.fi/en/	Mtech is a Finnish pioneer in smart food supply chains. They provide information systems and process integrations, data storage solutions, analysing and reporting solutions, mobile solutions, and cloud services. The company is also a trusted digital partner of advisory organisations, breeding associations and public authorities in the agricultural sector.
	EFI https://efi.int/projects/digitaf-digital-tools-help-agroforestry-meet-climate-biodiversity-and-farming	The European Forest Institute is a Finnish research institution with the aim of enhancing international forest research and providing decision makers with unbiased forest-related information at a pan-European level. EFI is one of the main stakeholders in the DigitAF project (<i>see DigitAF above</i>).
Latvia	Rural Support Service https://karte.lad.gov.lv/	Free of charge rural support service, which provides publicly accessible information about agricultural fields. The data receives daily updates.
Netherlands	VanderSat https://docs.vandersat.com/VanderSat_Data_Products.html	VanderSat is a leading provider of global satellite-observed data, products, and services over land with a special emphasis on water and crops. VanderSat offers a unique and patented technology that makes observations possible without any cloud and darkness interference. VanderSat gives its customers essential insights into soil and crop conditions by applying mathematical expertise to raw data from a constellation of satellites. For farmers, delivers valuable soil moisture, biomass proxy and inundation data.
	AgroExact weather stations https://www.agroexact.com/ 1) Soil Exact 2) Crop Exact	1) The soil moisture sensors of AgroExact provide watering instructions by measuring soil moisture at root depth. The most up to date irrigation advice is included in AgroExact app. 2) Sensor to monitor the harvest: monitoring of precipitation, temperature, soil temperature, air moisture, field capacity
Norway	DigiFarm https://digifarm.io/ 1) Delineated Field Boundaries 2) Deep Resolution Imagery 3) Sustainability Index 4) S2 Time-Series 5) Productivity Zones 6) Weed Detection (soon) 7) Automatic Yield Mapping (soon)	ag-tech startup developing technology for automatically detecting the highest accuracy field boundaries and seed acres using deep neural network models and super resolved EO data 1) Automatic detection of field boundaries and seeded acres 2) Sentinel-2 images up to 1-meter-deep resolution 3) Multi-year analysis of vegetation indices, such as EVI/ NDVI 4) Long-term and in-season cloud filtered vegetation indices on the same chart. 5) Historical biomass accumulation in low, medium, and high zones 6) Based on digital image processing and computer vision. 7) A simple system to generate yield maps in a reliable, low-cost manner
	Kilter AX-1 https://businessnorway.com/solutions/kilter-robotic-weeder-radically-reduces-herbicide-use-and-increases-yields	Kilter's autonomous weeding robot for precision farming, the AX-1, aims herbicide droplets directly at weeds without hitting the crop or soil. A machine vision system maps its way by identifying the shape and position of every weed and crop. Simultaneously the patented nozzle matrix aims individual droplets of herbicide at the weed leaves without touching the crop or soil. The nozzle even hits weeds entangled in the crop, enabling the use of novel weeding agents for herbicide-sensitive vegetable crops.
	Thorvald https://sagarobotics.com/thorvald-platform/	Thorvald has been designed to work across all farming environments and terrains. Its modular construction means there are almost limitless possibilities for adaption, tools, and applications. While Thorvald performs autonomous farming tasks, you and your team can focus on managing the farm as a whole. Thorvald is a number of different robots rolled into one, all built using the same basic modules, and rebuilt using only basic hand tools. The modules are designed to enable high quality robots that can quickly be customised for a given application in a given environment, such as a greenhouse, tunnel, open field and vineyard.

Table 5. Best-practice examples of digital and smart farming technologies available and applied other European countries (Switzerland).

Country	Technology	Short description
Switzerland	<p>xFarm https://xfarm.ag/iot-sensors/?lang=en</p> <p>1) xSense devices 2) Digital platform</p> <p><i>Also: for Italy and Spain</i></p>	<p>1) Smartly connected sensors to each other and to the xFarm platform. xSense stations are equipped with a sim card that allows to send data via GSM to the platform, while all xNode modules use the LoRa wireless system, which allows very low battery consumption, up to ten kilometers radius (depending on environmental conditions) and connect up to 100 devices on the same network. Internet of Things (IoT) is the characteristic that distinguishes xFarm sensors and means that the devices are interconnected and that they can communicate via internet directly with the account.</p> <p>2) xFarm is a singular platform, accessible from any device and equipped with dozens of different modules. A simple and intuitive interface allows to control fields and activities:</p> <ul style="list-style-type: none"> - via a map all land of a farm can be visualized from satellite and land registry - all details of the fields can be read - simple activity: registration and rapid programming of field activities - notes: registration of memo on an activity or in a specific location <p>Data can be used to improve efficiency. Collected data via sensors and interfaces to develop decision-making tools, maps and forecasting models are capable of giving personalized advice for plots. Irrigation advice can be received based on sensors, watering program and activate the systems. For fertilization prescription maps for variable rate fertilizer application can be obtained that evaluate the diversity of plots. For plant protection the app delivers information on how to use phytosanitary products through the databases and when to take action through the forecasting models based on sensors measurements. Telemetry to control the performance of vehicles, send prescription maps and allocate fuel costs.</p>
	<p>Barto https://www.barto.ch/de/fuer-bauern-und-baeuerinnen/das-ist-smart-farming</p>	<p>Barto is a web-based platform for managing the entire farm and fulfilling documentation obligations. Web-based means the platform is accessible from anywhere with internet access. Log in works with familiar Agate access data. This eliminates the need for a tedious registration process. In addition, other modules can be added to the basic function. Thereto account for example: storage module; crop rotation and crop planning module or a meadow and outdoor journal.</p>
	<p>1) Global FieldID 2) SoilHive</p> <p>https://www.vara.ag</p>	<p>To tackle the challenge of data fragmentation in the agricultural industry and address the lack of standards of data produced on farms every day. After ingesting and validating field boundaries, Global FieldID™ assigns a unique alphanumeric code to each field, enabling field identification of agricultural land plots, globally. Global FieldID is like a ‘QR code for fields’ that allows the identification of agricultural land plots in a standard way across digital farming tools, agricultural service providers and the food value chain, making the flow of information easier and cheaper.</p> <p>2) SoilHive is a web-based platform that consolidates and harmonizes soil data from public and private data sources based on voluntary contributions. The platform gives access to fragmented and invisible soil data for public and commercial purposes, acting as a catalyser for global collaboration for soil health.</p>

11 Summary and Conclusions

The negative environmental impacts of agriculture are noticeable in Germany

The results presented in Chapters 2 and 4 show that the environmental impact of agriculture in Germany is still high. Agriculture accounts for 8.35% of all German GHG emissions; moreover, it is the biggest driver of Germany's overall CH₄ emissions and the most important contributor to Germany's overall N₂O emissions. Furthermore, several critical thresholds of environmentally harmful substances are still being exceeded, such as N and NO₃⁻ concentrations > 50 mg/l in water bodies.

As a consequence, the impact on biodiversity and the ecological condition of the German landscape is quite high. As illustrated in Chapter 4.5, agricultural as well as adjacent areas, which are often nature conservation areas, are negatively affected by intensive agricultural management practices. Plant and animal species diversity shows a much greater decline in these areas compared with natural open spaces that do not neighbour agricultural fields. For example, insect biomass has been reduced by 75% in nature conservation areas surrounded by agricultural land within the last three decades.

The aforementioned figures support the need for a sustainable transformation in German agriculture. With its strong dependence on natural resources and conditions, agriculture is a great contributor to the negative environmental consequences of its course of action and one of the main victims of the impacts. Thereby, the effects are particularly complex, involving a great number of aspects, such as plant and soil health, and climate change, which directly affect yield generation and nature conservation.

Although several concepts for transformation already exist – for example, the IPCC, the SDGs, the Kyoto Protocol, the Green Deal, and the Biodiversity Strategy of BMEL – the concrete path to reach all these defined goals is still not clear and ready to go. There is a consensus on what needs to be changed and transformed, but not on how these targets can be reached together and consistently. All available means and resources should be used to achieve the set targets as quickly and efficiently as possible. Regarding agriculture, digital and smart farming technologies have increased expectations for a more sustainable and environmentally friendly agriculture (while simultaneously securing sufficient yields) within the last two decades. Therefore, we concentrated on the availability and potential of digital and smart tools for sustainable agriculture.

The technology market in Germany offers many digital technologies

Digitisation in agriculture is not a new concept: work on robots and sensors for agriculture has been ongoing since the end of the 20th century. The connection to satellite data and other databases that make agricultural work more precise gave rise to the term precision farming in the late 1980s. Precision farming refers only to economic aspects, such as increasing yields. With the increase in environmentally related problems, such as GHG emissions, the trend of smart farming grew in the 1990s. Smart farming aims to reduce negative impacts on the environment through smart digital technologies. Due to the increase in data-generating tools and the possibilities connections that can be derived from them, the Agriculture 4.0

trend in agriculture has developed over the last 13 years. Agriculture 4.0 aims to address and solve food security as well as climate change issues through digitalisation.

Many of the methods and technologies on the market that are currently being described as “new and innovative” have already come a long way. In Chapter 5, we listed and categorised the commercially available digital technologies in Germany. Due to the many possibilities for combined functions in the development of a technology, it was difficult to identify only a few categories. We considered the main use of the technologies for the categorisation. This resulted in three categories of a total of 201 digital technologies: complex systems for data processing, software-based digital technologies, and hardware-based digital technologies.

Complex systems for data processing involving ML have been developed since the 1950s. ML describes the systematisation and categorisation of datasets according to mathematical algorithms. ML gave rise to AI – the digital-based ability of a mechanical being to perform very specific tasks related to intelligent beings in the field of computer science. As the volume of data grew, BD emerged: a very complex data processing system that can process very large amounts (volume) of a wide variety of data with high quality (veracity) and very quickly (velocity).

We sorted the software-based technologies into four sub-categories. FMIS and DSS are IoT-based digital technologies that use plausible relationships between data from all other technologies (such as sensors) to optimise agricultural processes. DTGS refer to GNSS-based digital technologies for precise steering and driving; they usually enable semi-automatic machine guidance and precision of the actuators. DIP are digital platforms for digital collaboration, networking, and knowledge-sharing. CS applications and platforms collect and can provide large amounts of data, which can be used to develop and enhance ML algorithms.

Hardware is the touchable part and includes everything from simple capacitors to fully assembled circuit boards, devices, and their accessories. The three subcategories of hardware-based technologies in this study include sensors, field robots, and drones. Sensors are physical devices that collect information from their surroundings through observation. Sensors can be stationary and help agriculture with mapping and data collection. As mobile tools, sensors can measure various physical parameters such as soil and air temperature, humidity, rainfall, evaporation, the chlorophyll content, and light intensity. Field robots are semi-autonomous or autonomous machines that are built and programmed to perform specific tasks in agricultural production.

Farmers struggle with many challenges – digitalisation for sustainability has not yet arrived convincingly in practice – the barriers outweigh the potentials and cause scepticism

The stakeholder survey results (Chapter 6 and 7) show clear demands and recommendations for action to facilitate and establish the use of digital and smart technologies in German agriculture. Based on the survey and expert discussion, the participating farmers, employees of agricultural service supply agencies, and participants in the “others” category see compatibility, data access and sovereignty, significant reduction of federalism, cost reductions, and adequate training programmes as the key aspects. The

participating researchers and employees of politics/administrations, associations, nongovernmental organisations, and industry see the potential contribution of digital and smart technologies to sustainable agriculture. These potentials are either already established and used in agricultural practices or are expected to be useful in the future. Support for precise management processes while saving resources is mentioned several times, as well as site-specific regional management and implementation of measures. Moreover, there is a potential to increase production and reduce emissions. The limitations provided by the participants emphasise that digitalisation is a tool that requires a clear and effective framework to be truly useful.

At this point, policy plays an important role to create the significant and indispensable framework conditions, to set the right incentives, and to guide the necessary transformation into the direction of sustainability. Policy should not dictate standards and laws, which might inhibit innovations; rather, it should provide the backbone to foster standardisation and interoperability. This also includes the prevention of market monopolies and the guarantee of data security and sovereignty.

Policymakers must advocate for and promote the development of sustainable digital systems

Digital technologies can enable sustainable ecotopias, or they can trigger ecological dystopias and support further unsustainable agricultural intensification. Therefore, industry should set key targets, policy makers should prioritise sustainability when discussing digital technologies, and farmers and society must also be involved in designing sustainable agriculture supported by digital technologies. In the era of climate change and steep declines in biodiversity, it is not appropriate to rely solely on technological developments to determine the direction of technology use. Therefore, we call on politicians to develop sustainable and non-commercially oriented models for the digitalisation of German agriculture.

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Appendix

Inventory of environmental impacts

Appendix Table 1. Inventory of environmental impacts (Literature research, part I)

Search Key	Keyword(s)	Retrieval	Date	Hits	Relevant hits
GEI 1	General Environmental Impacts	TITLE-ABS-KEY (Umweltbelastungen UND Stickstoff UND Landwirtschaft Deutschland); PUBYEAR> 2019; <i>Google</i>	05.01.2023	250	9
GEI 2	General Environmental Impacts	TITLE-ABS-KEY (Umweltbelastungen UND Stickstoff UND Landwirtschaft Deutschland); PUBYEAR> 2019; <i>Google Scholar</i>	05.01.2023	35	1
N1	Nitrate pollution agriculture	TITLE-ABS-KEY (Umweltbelastungen UND Stickstoff UND Landwirtschaft Deutschland); PUBYEAR> 2019; <i>Google Scholar</i>	05.01.2023	13	5
N2	Nitrate pollution agriculture	TITLE-ABS-KEY (agriculture, pollution, nitrogen, Germany), PUBYEAR> 2019; <i>LIVIVO</i>	09.01.2023	40	8
N3	Nitrate pollution agriculture	TITLE-ABS-KEY (nitrate, impact, agriculture, Germany), PUBYEAR> 2020; <i>Web of Science</i>	18.01.2023	35	7
C1	Carbon dioxide pollution agriculture	TITLE-ABS-KEY (CO2, pollution, agriculture, Germany), AND PUBYEAR> 2020; <i>Web of Science</i>	18.01.2023	27	9
INV/GE	ntories/Gaseous emiss	TITLE-ABS-KEY (GHG Emissions, agriculture, Germany (NIR Report)) PUBYEAR> 2019; <i>Google</i>	18.01.2023	167	9
M1	Methane pollution agriculture	TITLE-ABS-KEY (methane, pollution, agriculture, Germany), AND PUBYEAR>2020; <i>Web of Science</i>	23.01.2023	21	2
M2	Methane pollution agriculture	TITLE-ABS-KEY (Methane, pollution, agriculture, Germany AND digital AND livestock OR grazing) AND TITLE-ABS-KEY (precision AND livestock AND farming)) AND PUBYEAR >2020; <i>Google Scholar</i>	23.01.2023	38	3

Appendix Table 2. Inventory of environmental impacts (Literature research, part II)

Search Key	Keyword(s)	Retrieval	Date	Hits	Relevant hits
N2O 1	Nitrous oxide pollution agriculture	TITLE-ABS-KEY (nitrous oxide AND environmental impact AND German agriculture); Article type: Research articles; Subject area: Agriculture and biological sciences PUBYEAR > 2019; <i>Elsevier</i>	07.03.2023	62	3
N2O 2	Nitrous oxide pollution agriculture	TITLE-ABS-KEY (nitrous oxide AND environmental impact AND German agriculture); Content type: articles; Subdiscipline: Agriculture PUBYEAR > 2019; <i>Springer</i>	07.03.2023	36	4
N2O 3	Nitrous oxide pollution agriculture	TITLE-ABS-KEY (nitrous oxide), PUBYEAR > 2019; <i>UBA</i>	17.03.2023	30	1
P1	Phosphorus pollution agriculture	TITLE-ABS-KEY (Phosphorus, environmental impact, German agriculture) AND PUBYEAR > 2019; <i>Perplexity</i>	02.02.2023	5	1
P2	Phosphorus pollution agriculture	TITLE-ABS-KEY (Phosphorus, environmental impact, German agriculture) AND PUBYEAR > 2019; <i>elicit</i>	02.02.2023	52	5
P3	Phosphorus pollution agriculture	TITLE-ABS-KEY (Phosphorus AND Germany AND Agriculture), PUBYEAR > 2019; <i>Scopus</i>	03.03.2023	49	8
A1	Ammonium pollution agriculture	TITLE-ABS-KEY (ammonia pollution, agriculture, Germany) AND PUBYEAR > 2020; <i>Web of Science</i>	09.03.2023	44	1
A2	Ammonium pollution agriculture	TITLE-ABS-KEY (Ammonia AND Germany AND Agriculture), PUBYEAR> 2019; <i>Scopus</i>	21.03.2023	27	3
AM1	Ammonia pollution agriculture	TITLE-ABS-KEY (Ammoniak Landwirtschaft), PUBYEAR> 2019; <i>UBA</i>	24.03.2023	2	1
AM2	Ammonia pollution agriculture	TITLE-ABS-KEY (Ammoniakemissionen, Landwirtschaft Deutschland), PBYEAR > 2019; <i>Google</i>	24.03.2023	56	1
AM3	Ammonia pollution agriculture	TITLE-ABS-KEY (Ammoniak Emissionen Landwirtschaft Deutschland), PUBYEAR >2019; <i>Google Scholar</i>	24.03.2023	86	1

Appendix Table 3. Inventory of environmental impacts (Literature research, part III)

Search Key	Keyword(s)	Retrieval	Date	Hits	Relevant hits
PE1	Pesticide pollution agriculture	Datenbanken <i>FAO, BMEL, UBA</i>	05.01.2023	3	3
PE2	Pesticide pollution agriculture	TITLE-ABS-KEY (pesticide pollution, agricultural areas, Germany) PUBYEAR > 2019; <i>Google Scholar</i>	24.03.2023	150	6
PE3	Pesticide pollution agriculture	TITLE-ABS-KEY (pesticide load, agriculture, Germany) AND PUBYEAR > 2019; <i>Web of Science</i>	24.03.2023	20	2
PE4	Pesticide pollution agriculture	TITLE-ABS-KEY (Pestizidbelastungen Landwirtschaft) PUBYEAR > 2019; <i>UBA</i>	24.03.2023	6	2
PE5	Pesticide pollution agriculture	TITLE-ABS-KEY (pesticide AND loads, AND agriculture, AND Germany) AND PUBYEAR > 2019; <i>Scopus</i>	24.03.2023	6	2
BI 1	Biodiversity Indicators in agricultural landscapes	TITLE-ABS-KEY (indicators), PUBYEAR > 2019; <i>BMJV</i>	15.03.2023	34	9
BI 2	Biodiversity Indicators in agricultural landscapes	TITLE-ABS-KEY (indicators), PUBYEAR > 2019; <i>BfN</i>	15.03.2023	5	2
I_Bio1	Insect Biodiversity in agricultural landscapes	TITLE-ABS-KEY (Germany AND agriculture AND insect biodiversity); Content type: article; Discipline: environment; Sub-discipline: environment general PUBYEAR > 2022; <i>Springer</i>	12.03.2023	84	1
I_Bio2	Insect Biodiversity in agricultural landscapes	TITLE-ABS-KEY (Germany AND agriculture AND insect biodiversity); Article type: research articles; Publication title: Ecological Indicators PUBYEAR > 2019; <i>Science Direct</i>	13.03.2023	42	2
IOF 1	Condition of agricultural land	TITLE-ABS-KEY (condition AND Germany AND agricultural land); PUBYEAR > 2019; <i>Scopus</i>	22.03.2023	39	5
PL1	Peatlands	TITLE-ABS-KEY (peatlands AND GHG emissions AND Germany); PUBYEAR > 2019; <i>Google</i>	22.06.2023	40	7

Appendix Table 4. GHG emissions from German agriculture in Tg CO₂eq (Submission2022) (GWPC_{H4} = 25, GWPC_{N2O} = 298), source: Vos et al. (2022)

year	Total GHG from German agriculture	CH ₄ enteric fermentation	CH ₄ manure management	N ₂ O manure management ^a	CH ₄ + N ₂ O energy crops ^b	N ₂ O soils ^c	CO ₂ liming	CO ₂ urea application
1990	70.581	33.162	7.802	3.656	0.000	22.769	2.711	0.481
1991	63.953	29.546	6.961	3.221	0.001	21.326	2.460	0.437
1992	62.532	28.790	6.939	3.184	0.001	20.922	2.198	0.497
1993	61.558	28.812	6.903	3.179	0.002	20.323	1.881	0.458
1994	61.253	29.018	7.209	3.231	0.002	19.616	1.728	0.449
1995	61.252	29.061	7.130	3.210	0.005	19.718	1.670	0.459
1996	61.798	29.081	7.202	3.226	0.008	20.023	1.772	0.485
1997	60.910	28.246	7.116	3.162	0.011	20.019	1.858	0.499
1998	61.373	28.081	7.343	3.179	0.024	20.262	1.959	0.525
1999	61.589	27.879	7.289	3.158	0.027	20.592	2.093	0.552
2000	60.997	27.410	7.235	3.152	0.042	20.501	2.062	0.593
2001	61.673	27.833	7.322	3.207	0.060	20.584	2.045	0.622
2002	59.542	26.729	7.142	3.133	0.086	19.900	1.913	0.640
2003	58.961	26.394	7.175	3.172	0.102	19.588	1.882	0.650
2004	58.233	25.660	6.936	3.095	0.131	19.981	1.795	0.634
2005	58.081	25.491	6.828	3.136	0.346	19.902	1.736	0.641
2006	56.994	24.969	6.640	3.098	0.472	19.459	1.725	0.631
2007	57.549	25.061	6.628	3.137	0.625	19.690	1.760	0.648
2008	57.877	25.288	6.567	3.137	0.706	19.678	1.806	0.695
2009	58.243	25.319	6.536	3.143	0.877	19.902	1.789	0.677
2010	57.761	25.181	6.173	3.090	1.067	19.733	1.806	0.711
2011	57.844	24.836	6.146	3.056	1.285	20.010	1.857	0.654
2012	58.511	24.839	6.282	3.045	1.294	20.416	1.946	0.690
2013	59.271	25.148	6.292	3.051	1.535	20.507	2.065	0.673
2014	60.547	25.366	6.413	3.071	1.582	21.212	2.153	0.750
2015	60.388	25.353	6.418	3.057	1.635	20.997	2.136	0.791
2016	59.993	25.102	6.458	3.037	1.623	20.850	2.107	0.815
2017	59.311	24.906	6.505	3.021	1.600	20.409	2.151	0.720
2018	57.634	24.520	6.444	2.967	1.573	19.274	2.250	0.605
2019	56.912	24.238	6.446	2.937	1.566	18.994	2.233	0.498
2020	56.095	23.867	6.471	2.908	1.566	18.673	2.153	0.457

^a N₂O from manure management includes indirect N₂O emissions due to deposition of NH₃-N and NO-N emitted from housing and storage

^b emissions from digester and storage of digestate from anaerobic digestion of energy crops

^c including N₂O due to field application of digestate from anaerobic digestion of energy crops

Appendix Table 5. Commercial fertiliser consumption in agriculture Europe in Europe - Nitrogen, source: BMEL (2022k)

**Handelsdüngerverbrauch in der Landwirtschaft
Europa**

Tabellennummer: 8031000

a. Reinnährstoff von Stickstoff (N)

Mitgliedstaat	Einheit	Fußnote	1999/00	2009/10	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Belgien	1000 Tonnen		171	151	181	189	177	172	172	175	175	175
Bulgarien	1000 Tonnen		.	199	292	297	330	334	351	339	352	364
Tschechische Republik	1000 Tonnen		210	270	332	329	397	404	366	352	332	285
Dänemark	1000 Tonnen		248	190	179	178	225	228	236	224	225	233
Deutschland	1000 Tonnen		2 014	1 569	1 675	1 823	1 711	1 659	1 497	1 342	1 372	1 265
Estland	1000 Tonnen		20	29	34	36	36	36	37	39	41	41
Irland	1000 Tonnen		429	338	332	331	322	302	344	396	367	380
Griechenland	1000 Tonnen		291	213	189	180	164	173	182	179	190	203
Spanien	1000 Tonnen		1 181	941	962	1 102	1 068	982	1 079	1 033	1 011	1 059
Frankreich	1000 Tonnen		2 571	2 080	2 168	2 159	2 240	2 192	2 234	2 248	2 025	2 078
Kroatien	1000 Tonnen		.	109	78	74	87	72	98	99	97	99
Italien	1000 Tonnen		468	497	601	574	605	603	599	595	599	575
Zypern	1000 Tonnen		11	9	7	6	8	8	8	8	8	8
Lettland	1000 Tonnen		34	59	70	73	76	78	77	75	81	84
Litauen	1000 Tonnen		94	143	157	163	163	160	167	159	179	186
Luxemburg	1000 Tonnen		.	14	13	13	13	14	14	13	14	13
Ungarn	1000 Tonnen		321	281	343	327	358	366	424	424	416	445
Malta	1000 Tonnen		0	1	3	4	4	2	1	1	1	1
Niederlande	1000 Tonnen		345	205	202	222	241	261	224	209	209	214
Österreich	1000 Tonnen		122	105	109	116	120	118	118	113	98	106
Polen	1000 Tonnen		861	1 027	1 098	1 004	1 043	1 151	1 179	994	1 034	912
Portugal	1000 Tonnen		120	100	111	123	118	105	103	101	105	105
Rumänien	1000 Tonnen		.	296	344	304	357	344	381	469	456	469
Slowenien	1000 Tonnen		34	27	27	29	28	27	27	27	28	28
Slowakei	1000 Tonnen		65	107	114	119	115	126	123	129	129	128
Finnland	1000 Tonnen		176	157	138	147	143	138	139	138	147	139
Schweden	1000 Tonnen		197	168	161	181	190	186	198	184	183	215
Vereinigtes Königreich	1000 Tonnen		1 268	1 016	1 060	1 049	1 026	1 040	1 041	1 033	1 038	.
EU-28	1000 Tonnen		.	.	10 980	11 149	11 368	11 283	11 421	11 100	10 911	.
EU-27	1000 Tonnen		1	9 984	10 194	.	.	.	.	.	.	9 812

b. Stickstoff (N) in Kilogramm je Hektar Landfläche

Mitgliedstaat	Einheit	Fußnote	1999/00	2009/10	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Belgien	kg je ha Landfläche		112	.	135	141	133	127	130	129	129	128
Bulgarien	kg je ha Landfläche		.	60	59	60	66	66	70	67	70	72
Tschechische Republik	kg je ha Landfläche		49	68	94	93	114	116	104	100	94	81
Dänemark	kg je ha Landfläche		83	68	69	67	85	87	90	85	86	89
Deutschland	kg je ha Landfläche		117	107	100	109	102	100	90	81	82	76
Estland	kg je ha Landfläche		20	30	35	37	37	36	37	39	42	42
Irland	kg je ha Landfläche		97	63	74	66	73	68	77	88	64	84
Griechenland	kg je ha Landfläche		74	59	67	53	32	33	35	34	37	39
Spanien	kg je ha Landfläche		46	40	41	47	45	41	45	43	41	43
Frankreich	kg je ha Landfläche		86	73	69	76	77	75	77	77	73	72
Kroatien	kg je ha Landfläche		.	50	60	59	57	47	66	67	65	66
Italien	kg je ha Landfläche		30	39	44	47	48	47	.	46	46	44
Zypern	kg je ha Landfläche		74	71	88	67	63	71	65	59	65	60
Lettland	kg je ha Landfläche		14	33	38	39	40	41	40	38	41	43
Litauen	kg je ha Landfläche		27	39	54	55	54	54	57	54	60	63
Luxemburg	kg je ha Landfläche		.	102	102	108	99	105	103	99	105	99
Ungarn	kg je ha Landfläche		52	56	64	61	67	68	79	79	78	89
Malta	kg je ha Landfläche		46	29	290	331	350	183	54	112	65	55
Niederlande	kg je ha Landfläche		174	116	109	121	131	145	125	115	109	118
Österreich	kg je ha Landfläche		36	30	38	43	44	44	44	43	37	40
Polen	kg je ha Landfläche		47	76	76	70	72	80	81	68	72	63
Portugal	kg je ha Landfläche		31	27	30	33	32	29	28	28	.	27
Rumänien	kg je ha Landfläche		.	23	25	22	26	25	29	35	33	36
Slowenien	kg je ha Landfläche		69	56	57	59	59	57	26	57	58	58
Slowakei	kg je ha Landfläche		27	49	59	62	60	66	64	67	67	67
Finnland	kg je ha Landfläche		80	92	61	65	63	61	61	61	65	61
Schweden	kg je ha Landfläche		64	55	53	60	63	62	66	61	61	72
Vereinigtes Königreich	kg je ha Landfläche		79	66	61	61	60	60	60	60	59	.
EU-28	kg je ha Landfläche		.	.	62	63	63	63	64	62	62	.
EU-27	kg je ha Landfläche		1	61	60	.	.	.	.	.	.	61

Anmerkung: Ab 2013 EU 28 mit Kroatien.

Quelle: EUROSTAT [apro_cpsh1] (Stand: Juli 2022), FAO (Juli 2022), BLE (414).

Veröffentlicht unter: bmel.statistik.de

1) Ab 2020: EU-27 ohne Vereinigtes Königreich.

Appendix Table 6. Commercial fertiliser consumption in agriculture Europe in Europe – Phosphate, source: BMEL (2022k)

Handelsdüngerverbrauch in der Landwirtschaft Europa

Tabellennummer: 8031000

c. Reinnährstoff von Phosphat (P₂O₅)

Mitgliedstaat	Einheit	Fußnote	1999/00	2009/10	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Belgien	1000 Tonnen		45	.	22	18	18	19	19	19	19	19
Bulgarien	1000 Tonnen		.	158	70	54	66	66	68	76	77	79
Tschechische Republik	1000 Tonnen		35	35	41	42	49	47	55	51	58	47
Dänemark	1000 Tonnen		41	21	35	39	33	34	48	34	34	37
Deutschland	1000 Tonnen		420	235	284	301	288	231	209	201	248	192
Estland	1000 Tonnen		4	6	7	9	8	8	9	9	9	11
Irland	1000 Tonnen		115	67	82	84	121	113	118	129	127	143
Griechenland	1000 Tonnen		119	47	111	52	50	52	51	59	60	65
Spanien	1000 Tonnen		643	264	433	399	412	415	437	426	480	487
Frankreich	1000 Tonnen		969	399	259	445	440	410	451	430	400	453
Kroatien	1000 Tonnen		.	.	29	39	30	13	34	34	34	35
Italien	1000 Tonnen		514	166	171	169	169	162	165	164	176	225
Zypern	1000 Tonnen		7	5	5	4	5	5	5	5	5	5
Lettland	1000 Tonnen		11	11	24	23	24	25	26	26	27	31
Litauen	1000 Tonnen		20	47	65	44	46	51	54	51	53	55
Luxemburg	1000 Tonnen		.	1	1	1	1	1	1	1	1	1
Ungarn	1000 Tonnen		321	44	72	82	81	92	118	117	114	112
Malta	1000 Tonnen		0	0	0	0	0	0	0	1	0	0
Niederlande	1000 Tonnen		58	10	14	9	9	9	13	13	12	14
Österreich	1000 Tonnen		48	18	23	42	40	32	32	28	26	27
Polen	1000 Tonnen		296	353	341	304	326	343	339	344	359	322
Portugal	1000 Tonnen		69	48	42	42	46	49	41	37	38	40
Rumänien	1000 Tonnen		.	306	114	119	133	126	145	188	201	188
Slow enien	1000 Tonnen		20	7	9	9	9	9	9	9	8	8
Slow akei	1000 Tonnen		13	13	23	23	22	24	23	26	26	27
Finnland	1000 Tonnen		52	63	12	12	25	23	28	25	26	26
Schw eden	1000 Tonnen		43	19	27	28	29	30	33	33	29	38
Vereinigtes Königreich	1000 Tonnen		317	184	201	196	197	198	195	188	186	.
EU-28	1000 Tonnen		.	.	2 516	2 617	2 620	2 588	2 724	2 727	2 834	.
EU-27	1000 Tonnen		1	4 180	2 526	.	.	.	.	.	.	2 669

d. Phosphat(P₂O₅) in Kilogramm je Hektar Landfläche

Mitgliedstaat	Einheit	Fußnote	1999/00	2009/10	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Belgien	kg je ha Landfläche		30	.	17	13	13	14	14	14	14	14
Bulgarien	kg je ha Landfläche		.	32	10	11	13	13	13	15	15	16
Tschechische Republik	kg je ha Landfläche		8	8	12	12	14	14	16	15	16	13
Dänemark	kg je ha Landfläche		14	8	13	15	13	13	18	13	13	14
Deutschland	kg je ha Landfläche		24	14	17	18	14	14	12	12	15	12
Estland	kg je ha Landfläche		4	6	7	9	8	8	9	9	9	11
Irland	kg je ha Landfläche		26	16	18	19	27	25	26	29	28	32
Griechenland	kg je ha Landfläche		30	6	16	10	10	10	10	11	12	12
Spanien	kg je ha Landfläche		25	10	18	17	17	17	18	18	20	20
Frankreich	kg je ha Landfläche		33	14	17	15	15	14	15	15	14	16
Kroatien	kg je ha Landfläche		.	.	22	49	19	9	23	23	24	23
Italien	kg je ha Landfläche		33	12	13	13	13	13	.	13	13	17
Zypern	kg je ha Landfläche		50	41	50	37	38	48	41	39	42	37
Lettland	kg je ha Landfläche		4	6	13	12	13	13	13	14	14	16
Litauen	kg je ha Landfläche		6	17	14	15	15	17	18	17	18	19
Luxemburg	kg je ha Landfläche		.	5	9	9	9	9	9	7	6	7
Ungarn	kg je ha Landfläche		52	8	14	15	15	17	22	22	22	22
Malta	kg je ha Landfläche		46	11	6	6	7	11	11	8	9	38
Niederlande	kg je ha Landfläche		29	5	5	5	5	5	7	7	7	8
Österreich	kg je ha Landfläche		14	6	14	15	15	12	12	11	10	10
Polen	kg je ha Landfläche		16	22	24	21	23	24	23	24	24	22
Portugal	kg je ha Landfläche		18	13	11	11	13	14	11	10	.	10
Rumänien	kg je ha Landfläche		.	7	8	9	10	9	11	14	15	14
Slow enien	kg je ha Landfläche		40	15	19	19	20	19	19	19	17	17
Slow akei	kg je ha Landfläche		5	7	11	12	11	13	12	13	14	14
Finnland	kg je ha Landfläche		24	27	5	12	11	10	12	11	11	12
Schw eden	kg je ha Landfläche		14	6	9	9	9	10	11	11	10	13
Vereinigtes Königreich	kg je ha Landfläche		20	11	12	11	11	11	11	11	11	.
EU-28	kg je ha Landfläche		.	.	15	15	15	15	15	15	16	.
EU-27	kg je ha Landfläche		1	.	13	.	.	.	.	.	.	17

Anmerkung:

Quelle: EUROSTAT [apro_cpsh1] (Stand: Juli 2022), FAO (Juli 2022), BLE (414).

Veröffentlicht unter: BMEL-Statistik.de

1) Ab 2020: EU-27 ohne Vereinigtes Königreich.

Appendix Table 7. Commercial fertiliser consumption in agriculture Europe in Europe – Potassium, source: BMEL (2022k)

Handelsdüngerverbrauch in der Landwirtschaft

Europa

Tabellennummer: 8031000

e. Reinnährstoff von Kali (K₂O)

Mitgliedstaat	Einheit	Fußnote	1999/00	2009/10	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Belgien	1 000 t		88	.	71	57	58	60	60	60	61	61
Bulgarien	1 000 t		.	4	35	28	33	34	37	43	43	43
Tschechische Republik	1 000 t		24	20	30	34	33	38	34	30	22	25
Dänemark	1 000 t		86	43	67	76	64	64	102	64	67	73
Deutschland	1 000 t		599	363	457	460	398	430	392	410	420	446
Estland	1 000 t		4	8	12	11	11	11	13	12	12	13
Irland	1 000 t		148	90	113	114	133	141	159	172	167	171
Griechenland	1 000 t		59	30	47	42	42	44	46	50	52	52
Spanien	1 000 t		496	166	355	358	380	379	390	415	369	399
Frankreich	1 000 t		1 216	414	449	484	469	393	463	451	406	503
Kroatien	1 000 t		.	.	32	44	36	18	42	43	43	43
Italien	1 000 t		402	153	111	109	111	116	115	114	111	131
Zypern	1 000 t		2	4	3	2	3	3	3	3	5	4
Lettland	1 000 t		10	11	27	26	29	30	30	30	32	36
Litauen	1 000 t		40	10	52	55	57	71	76	72	72	75
Luxemburg	1 000 t		.	1	1	1	1	1	1	1	1	1
Ungarn	1 000 t		63	48	71	78	80	97	116	111	100	97
Malta	1 000 t		0	0	0	0	0	0	0	0	0	0
Niederlande	1 000 t		68	17	29	28	28	27	64	58	56	51
Österreich	1 000 t		55	16	32	38	35	38	38	35	32	37
Polen	1 000 t		369	397	497	485	527	556	559	568	559	495
Portugal	1 000 t		48	41	46	38	35	33	33	33	38	35
Rumänien	1 000 t		.	30	34	30	43	44	55	66	92	82
Slowenien	1 000 t		24	7	11	11	12	11	11	11	10	10
Slowakei	1 000 t		11	8	15	17	16	19	18	20	20	20
Finnland	1 000 t		82	8	31	32	31	33	34	42	41	43
Schweden	1 000 t		50	22	31	31	31	32	37	39	36	44
Vereinigtes Königreich	1 000 t		411	251	284	272	270	286	276	262	267	.
EU-28	1 000 t		.	.	2 941	2 961	2 965	3 010	3 204	3 213	3 131	.
EU-27	1 000 t		1	1 911	.	.	.	.	.	.	.	2 991

f. Kali (K₂O) in Kilogramm je Hektar Landfläche

Mitgliedstaat	Einheit	Fußnote	1999/00	2009/10	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Belgien	kg je ha Landfläche		58	.	53	43	44	44	45	44	45	45
Bulgarien	kg je ha Landfläche		.	1	7	6	7	7	7	9	9	9
Tschechische Republik	kg je ha Landfläche		6	5	9	10	9	11	10	8	6	7
Dänemark	kg je ha Landfläche		29	16	26	29	24	24	39	24	26	28
Deutschland	kg je ha Landfläche		35	21	27	27	24	26	23	25	25	27
Estland	kg je ha Landfläche		4	9	12	12	12	11	13	12	12	13
Irland	kg je ha Landfläche		33	22	25	25	30	32	36	38	37	38
Griechenland	kg je ha Landfläche		15	4	13	8	8	8	9	9	10	10
Spanien	kg je ha Landfläche		19	6	15	15	16	16	16	17	15	16
Frankreich	kg je ha Landfläche		41	14	16	17	16	14	16	16	16	17
Kroatien	kg je ha Landfläche		.	.	24	35	24	12	28	29	28	29
Italien	kg je ha Landfläche		25	11	8	9	9	9	.	9	8	10
Zypern	kg je ha Landfläche		13	29	36	23	22	29	28	26	37	26
Lettland	kg je ha Landfläche		4	6	15	14	15	16	16	16	16	18
Litauen	kg je ha Landfläche		11	4	18	19	19	24	26	24	24	25
Luxemburg	kg je ha Landfläche		.	10	7	9	8	10	7	5	4	6
Ungarn	kg je ha Landfläche		10	8	13	15	15	18	22	21	19	19
Malta	kg je ha Landfläche		13	13	8	6	10	13	12	11	16	15
Niederlande	kg je ha Landfläche		34	9	16	15	15	15	36	32	30	28
Österreich	kg je ha Landfläche		16	5	12	14	13	14	14	13	12	14
Polen	kg je ha Landfläche		20	25	34	34	37	39	39	39	39	34
Portugal	kg je ha Landfläche		12	11	11	10	9	9	9	9	.	9
Rumänien	kg je ha Landfläche		.	2	2	2	3	3	4	5	7	6
Slowenien	kg je ha Landfläche		49	15	23	22	24	24	23	23	21	20
Slowakei	kg je ha Landfläche		4	4	8	9	8	10	9	10	10	10
Finnland	kg je ha Landfläche		37	4	14	14	14	14	15	18	18	19
Schweden	kg je ha Landfläche		16	7	10	10	10	11	12	13	12	15
Vereinigtes Königreich	kg je ha Landfläche		26	14	16	16	16	16	16	.	15	.
EU-28	kg je ha Landfläche		.	.	17	17	17	17	19	18	18	.
EU-27	kg je ha Landfläche		1	14	.	.	.	.	.	.	.	18

Anmerkung:

Quelle: EUROSTAT [apro_cpsh1] (Stand: Juli 2022), FAO (Juli 2022), BLE (414).

Veröffentlicht unter: BMEL-Statistik.de

1) Ab 2020: EU-27 ohne Vereinigtes Königreich.

Appendix Table 8. Overview and short description of AI-based technologies, commercially available in Germany (A–W)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application area	Source link
AgriGaia	Agrotech Valley Forum e. V.	Open AI ecosystem for the agri-food industry based on GAIA-X, the European sovereign data infrastructure.	Free of charge	Crop cultivation/ livestock/nature conservation	https://bit.ly/3twpYTi
agriGPT	LV digital GmbH	Virtual assistant for agriculture.	Free of charge	Crop cultivation	https://bit.ly/45CamuY
ANA App	Spacenus GmbH	Agricultural nutrient assistant for fertiliser recommendations based on satellite imagery	Subject to charge	Crop cultivation	https://bit.ly/45tpGtF
API Field Boundary	Spacenus GmbH	Field Boundaries by request: the system provides a polygon of the field geometry. Based on field geometry classification of zones is possible.	Subject to charge	Crop cultivation	https://bit.ly/3SeVIH1
API Field Map	Spacenus GmbH	Platform for illumination of different field maps: nitrogen shortage, disease risk, soil productivity, nitrogen uptake, vegetation index and dry matter maps.	Subject to charge	Crop cultivation	https://bit.ly/3FfSFXe
heliopas.ai	heliopas.ai GmbH	Platform for a wide variety of analytics with highly accurate data daily based on parameters such as soil homogeneity, soil moisture, crop type, land usage, floor bearing capacity and plant health.	Subject to charge	Crop cultivation	https://bit.ly/3LYmdMB
John Deere Command Cab	John Deere Walldorf GmbH & Co. KG	Operating concept containing joystick control, touchscreen screen and networking of all machine components. Through the integration of real-time weather data, individual presets and order management, the cabin becomes a command centre for the farm.	Subject to charge	Crop cultivation/ administration	https://bit.ly/45wz9Ae
KPI map	Spacenus GmbH	Automated process of estimation of the carbon sequestration potentials. The user provides field boundaries and crop history data and the app gives recommendation for sampling. After sampling the data is being utilised and given back to the user.	Subject to charge	Crop cultivation	https://bit.ly/3rRpGGc
Mantis (Augmenta field analyzer)	Augmenta (Raven, CNH industrial brand)	AI-based visual analyser – automatically calibrates rates according to the in-field variability according to the initial input. Pre-calibration possible through agronomical algorithms.	Subject to charge	Crop cultivation	https://bit.ly/45o42Ha
NutriLabApp	MMM Tech Support©	App for interpreting and archiving measured values from the press juice analysis of fresh plant organs. The app can be used with a computer, tablet, or smartphone.	Subject to charge	Crop cultivation	https://bit.ly/48UfoWf
See & Spray (John Deere)	John Deere Walldorf GmbH & Co. KG	With See & Spray technology, high-resolution cameras capture 20 images per second. Based on the images and artificial intelligence, the system recognises the difference between cultivated plants and weeds so that individual plants can be specifically treated.	Subject to charge	Crop cultivation	https://bit.ly/3RVrFDO
Waterfox	heliopas.ai GmbH	AI-based sensorless and yield-optimised irrigation scheduling tool	Subject to charge	Crop cultivation	https://bit.ly/46JFA47

Appendix Table 9. Overview and short description of farm management information systems (FMIS), commercially available in Germany (3–A–V)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application area	Source link
365FarmNet Platform	365FarmNet GmbH	Agricultural software program that administers data coming from the crops or livestock. The software allows automation of data, cross-compliance, nutrient reporting, and document administrative tasks.	Free of charge	Crop cultivation/administration	https://bit.ly/3NpBR8J
AGRAVIS NetFarming	AGRAVIS Raiffeisen AG	Big data-based software for agriculture. The software works with data from various networked web tools in cooperation with geo-konzept GmbH.	Subject to charge	Crop cultivation/administration	https://bit.ly/3r1KBFr
Amazone 4.0	Amazonen-Werke H. Dreyer SE & Co. KG	Optimises operational processes and helps farmers to work more precisely and efficiently, conserve resources with the help of software, electronics, service, and networking.	Subject to charge	Crop cultivation/administration	https://bit.ly/3Js6eFt
DELOS	OVIS IT GmbH	Arable land use index in the browser and as an app for your mobile phone for federal state-specific fertiliser requirement planning and material flow balances in accordance with the latest legal requirements.	Subject to charge	Crop cultivation/administration	https://bit.ly/3rAtBHm
Greenspin mofato (Croptify)	Green spin GmbH	A decision-making support that provides global, satellite-based monitoring of growing conditions on agricultural land – updated daily.	Subject to charge	Crop cultivation/administration	https://bit.ly/3rO0KiH
MyFarm24 HELM Software (shareMyFarm)	HELM-Software	shareMyFarm manages the complete documentation on a farm and allows communication with partners.	Subject to charge	Crop cultivation/administration	https://bit.ly/48JU0mF
NEXT Farming Pro	FarmFacts GmbH	The software networks data islands and extracts the maximum amount of information from the daily flood of data in a structured way.	Subject to charge	Crop cultivation/administration	https://bit.ly/3tqrBBX
NEXT Farming Live	FarmFacts GmbH	Intelligent networking of mixed fleets and cross-manufacturer integration of important machine data.	Subject to charge	Crop cultivation/administration	https://bit.ly/45pqy2j
ProFlura	ASSW GmbH & Co KG	Documentation software for market fruit, fodder, vegetable, fruit, wine, hops and biogas farms for all federal states and neighbouring EU countries.	Subject to charge	Crop cultivation/administration	https://bit.ly/45kP2tv
sigAgroasesor	ITAP, NEIKER, IFAPA, AEMET, INTIA, S.A.	It integrates public information, databases and cartography using GIS-WEB services. The platform enables the operation of several Decision Support Tools with geo-localised information of each agricultural plot, and accessing data from remote sensors or different databases.	Subject to charge	Crop cultivation/administration	https://bit.ly/3rKs4yl
TAP Topcon Agriculture Platform	Topcon Deutschland Positioning GmbH	Software with three modules – Fields, Fleet and Pro, for documentation management, machinery tracking, data networking and decision-making.	Subject to charge	Crop cultivation/administration	https://bit.ly/3LPWB4r
VarioDoc Pro/Fendt Task Doc	Fendt/ AGCO GmbH	Software for management documentation. Processing of files in ISO-XML format as well as application maps in Shape format possible.	Subject to charge	Crop cultivation/administration	https://bit.ly/48KcoM9

Appendix Table 10. Overview and short description of decision support systems (DSS), commercially available in Germany (A–X)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application area	Source link
agriDOC	Agricon GmbH	Fully automatic documentation for field management and provides access to advisory services. Various modules available.	Subject to charge	Crop cultivation/administration	https://bit.ly/3NGKKqQ
AGROCOM NET	CLAAS KGaA	Digital farmland register.	Subject to charge	Crop cultivation/administration	https://bit.ly/44cYpLW
CLAAS connect	CLAAS KGaA	Digital field diary with telemetry data of agricultural machinery based on a remote service contract.	Subject to charge	Crop cultivation/administration	https://bit.ly/44bnxCF
CLAAS TELEMATICS	CLAAS KGaA	Continuous digital documentation and retrieving of work data, tracks, yield data, combine harvesters, forage harvesters, tractors.	Subject to charge	Crop cultivation/administration	https://bit.ly/3JqLrCl
Climate FieldView™	The Climate Corporation International SA	Digital platform for farmland management with integration of digital maps.	Subject to charge	Crop cultivation/administration	https://bit.ly/3PIK5wb
CropSAT	Dataväxt AB	Visualisation of crop biomass variation for decision support of fertiliser and pesticide applications.	Free of charge	Crop cultivation	https://bit.ly/3Xi1Dv4
EcoPay	UFZ, Freie Universität Berlin, BTU	Ecological-economic modelling to compare organic and conventional farming on endangered grassland bird and butterfly species.	Subject to charge	Nature conservation	https://bit.ly/3CE3X6n
EOS Data Analytics	EOS Data Analytics, Inc.	Satellite-based crop monitoring solutions for monitoring, scouting, management, weather, and zoning.	Subject to charge	Crop cultivation/administration	https://bit.ly/3NHno4q
FAIRshare - Digital Tools for Farm Advisors	Gato de Bigode/EU	Digital assessment tool helping farm advisors to compare different digital tools, address their needs and evaluate it.	Subject to charge	Crop cultivation	https://bit.ly/43PNOxp
Isaria Connect	Fritzmeier Umwelttechnik GmbH & Co. KG	Software solution for data and task management.	Subject to charge	Crop cultivation/administration	https://bit.ly/3XglOtz
Magic Scout	Bayer AG	Digital tool for plant pests' and disease recognition, weather analysis and field diary.	Subject to charge	Crop cultivation	https://bit.ly/3NiWLRR
MyDataPlant	Kleffmann Digital RS GmbH	Software for site-adapted decision making based on satellite imagery.	Subject to charge	Crop cultivation	https://bit.ly/3thXZ9F
MyEasyFarm	MyEasyFarm	Software solution to support the management and optimisation of arable farms.	Subject to charge	Crop cultivation	https://bit.ly/3Q7LzKu
NEXT Farming Office App	FarmFacts GmbH	App for work documentation, information collection and data analysis on site	Subject to charge	Crop cultivation/administration	https://bit.ly/3ZM5NwF
SatAgro	SatAgro Sp. zo.o.	Digital, personable maps compatible with a wide range of agricultural machinery with Cloud Computing.	Subject to charge	Crop cultivation	https://bit.ly/3CD9pq6
Talking FieldsMaps	Vista GmbH – Remote Sensing in Geosciences	Digital map based on geostatistical analysis of satellite data for making site-specific crop cultivation decisions.	Subject to charge	Crop cultivation	https://bit.ly/3RS2jqk
Xarvio® FIELD MANAGER	BASF Digital Farming GmbH	Software solution for optimising field and field zone specific crop production based on more than 30 crop optimisation models.	Subject to charge	Crop cultivation	https://bit.ly/3PQYUFD
Xarvio® HEALTHY FIELDS	BASF Digital Farming GmbH	Software optimises field and season-specific application timing, product, and dosage for crop protection. Can be used with own machines or with a contractor.	Subject to charge	Crop cultivation	https://bit.ly/46nYIKI
Xarvio® SCOUTING	BASF Digital Farming GmbH	Application for instant pheromone trap analysis function to support growers of grapes and fruit in Europe.	Subject to charge	Crop cultivation	https://bit.ly/3LQPj0z

Appendix Table 11. Overview and short description of digital technologies for guidance and steering (DTGS), commercially available in Germany (A–E)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
AES-35	geo-konzept GmbH	For vehicles without a steering system pre-installation. It combines the performance of a hydraulic system with the convenience of an electric solution. Accurate electric steering with RTK accuracy of up to 2.5 cm - even in reverse.	Subject to charge	Crop cultivation	https://bit.ly/3OXumU4
AFS AccuGuide™ komplett von Case IH	<u>CNH Industrial Österreich GmbH</u>	Automatic track guidance in the field with an accuracy of up to 2 cm, with up to 6 active screens with field maps, track guidance system settings and tractor and implement functions.	Subject to charge	Crop cultivation	https://bit.ly/3OVqIPM
AFS AccuTurn Pro and HMC II	CNH Industrial America LLC	Next-generation auto guidance technology for automated headland-turning, using the same software logic found on Autonomous Concept Vehicles. The system reduces operator fatigue and increases productivity by automatic repeatable turns.	Subject to charge	Crop cultivation	https://bit.ly/3MPqVMt
AFS Connect™ - Advanced Farming Systems	<u>CNH Industrial Österreich GmbH</u>	The system enables real-time remote monitoring and management of operational and fleet data activities of all tractors in fields.	Subject to charge	Crop cultivation	https://bit.ly/3OVsFX0
(agri) EASE Tool	European Union Agency for the Space Program	Provide farmers with cost-benefit analyses on the use of EGNOS for machinery guidance in some of their typical agricultural labours: sowing, spreading, spraying, and harvesting.	Free of charge	Crop cultivation/ administration	https://bit.ly/3trYcqR
Autopilot™	CNH Industrial Österreich GmbH	A steering system that can be retrofitted to machines and models from many manufacturers. With the help of this retrofit, efficient agricultural work is possible, because a driver can work more precisely and over longer steering periods.	Subject to charge	Crop cultivation	https://bit.ly/3ITPkiP
CEMOS Advisor von CLAAS	CLAAS KGaA mbH	App as an optimisation aid on the smartphone when driving combine harvesters. The app enables error corrections and improves settings for less crop loss.	Free of charge	Crop cultivation	https://bit.ly/3Cg5csi
CLOUD farmunited	ETO DYNAMIC Digital GmbH und farmunited GmbH	Simple, geodata-based documentation of operating machines in the field. Device management, capture and management of programmes, jobs, and machine data. Access via mobile devices with web browser.	Subject to charge	Crop cultivation	https://bit.ly/3qx9QiI
CoGIS	geo-konzept GmbH	CoGIS offers a range of surveying, soil sampling and remote sensing functions for various service providers. It consists of the modules Basic, Mapping, Advanced Mapping and UAV. In the mapping area, the user can use simple GIS functions, such as the recording of points and areas, as well as more complex tasks, such as georeferenced soil sampling with automatic barcode generation.	Subject to charge	Crop cultivation	https://bit.ly/3CeCRSY
Easy on board von CLAAS	CLAAS KGaA mbH	The app provides for documentation with any AEF-certified field cards. The exchange of job data is done via email per ISO-XML file. The machine can be controlled via iPad using ISOBUS.	Subject to charge	Crop cultivation	https://bit.ly/3OXR4LU
EZ-Pilot™	CNH Industrial Österreich GmbH	The steering system turns the steering wheel using an integrated electric motor to keep your hands free. It still allows unrestricted manual steering when the power steering is not engaged, and manual intervention is possible at any time.	Subject to charge	Crop cultivation	https://bit.ly/3oShLH1

Appendix Table 12. Overview and short description of digital technologies for guidance and steering (DTGS), commercially available in Germany (F–T)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
Fahrspurplanung geoTRAX	geo-konzept GmbH	Practically developed software module for planning lanes for any impact shapes. Free choice of headland and working direction, planning for partial areas of the field is also possible.	Subject to charge	Crop cultivation	https://bit.ly/3WR02w8
farmpilot-App	Arvato Systems GmbH	Once the data has been transferred to the app, position data and status information is sent while the work is being carried out. This gives an overview of fleet and the progress of job processing in real time.	Free of charge	Crop cultivation/ administration	https://bit.ly/3MUUsnS
Field Navigator app	Farmis Inc.	App for accurate, parallel driving in Precision Farming. Measures the size of the farm, arable land, or grassland, without the necessary additional and expensive equipment.	Free of charge	Crop cultivation	https://bit.ly/43w2Kde
FieldBee app	eFarmer B.V., Incorporated	Tractor navigation system or automatic steering system based on RTK with high accuracy of 2.5 cm and easy installation.	Free of charge	Crop cultivation	https://bit.ly/43HjwWn
IntelliSteer™	New Holland Agriculture (a brand of CNH Industrial©)	A fully integrated automatic steering system developed by New Holland. One monitor can be used for machine functions, automatic steering, mapping and implement control. Grade compensation is achieved by sensing the machine's roll, pitch and yaw movements and correcting them to avoid misses and overlaps on uneven ground.	Subject to charge	Crop cultivation	https://bit.ly/45VnHzC
Reichhardt PSR SLIDE – Shifting frame	geo-konzept GmbH	Active implement steering for special crops, row crops, vegetable crops. Track guidance can be provided by a high-precision RTK steering system or optionally by ultrasonic sensors from Reichhardt. The shifting frame can be used universally and independently of vehicle and implement.	Subject to charge	Crop cultivation	https://bit.ly/3oSzeza
RTK-Netzwerk AgCelNet	geo-konzept GmbH	The RTK network AgCelNet enables the reception of correction data throughout Germany. The central computer can provide correction data in different formats - for different receiver makes - and for GPS and GLONASS simultaneously. The correction data from RTK networks are accessible via the internet.	Subject to charge	Crop cultivation	https://bit.ly/3MZJc9Z
SMARTPILOT farmunited	farmunited GmbH ETO DYNAMIC Digital GmbH	Modular ultrasonic steering system for tractors, work platforms and harvesters. Precise navigation in plantation rows and tramlines. Precise navigation in plantation rows and tramlines. Orientation on parallel or single rows.	Subject to charge	Crop cultivation	https://bit.ly/3WXHI4p
Sprayer calibrator	Farmis Inc.	An GPS-based app that helps farmers choose and adjust the spray nozzle and keep track of the real-time flow rate of pesticides.	Free of charge	Crop cultivation	https://bit.ly/3qvFz44
TopNET Global	TOPCON Corporation	Satellite-based correction service with 4-10 cm accuracy and RTK service.	Subject to charge	Crop cultivation	https://bit.ly/3WZGd66
Trimble Center Point RX, Trimble RangePoint ® RTX	Trimble Inc.	The system provides high-accuracy GPS survey correction up to 2 cm via satellite or cellular delivery worldwide.	Subject to charge	Crop cultivation/ grassland	https://bit.ly/3NizyAp
TrueGuide	Trimble Inc.	A passive device steering system that monitors and corrects the position of the equipment by acting on the steering of the tractor.	Subject to charge	Crop cultivation	https://bit.ly/3J2QwR8

Appendix Table 13. Overview and short description of digital information platforms (DIP), commercially available in Germany (A–S)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
Agricultural Industry Electronics Foundation (AEF)	Agricultural Industry Electronics Foundation e.V.	Platform to establish and maintain transparency regarding the functionalities supported by specific products and their compatibility with others.	Subject to charge	Crop cultivation/livestock/nature conservation	https://bit.ly/3twHC9o
Einfache Feldgefügeansprache für den Praktiker (FGA)	Landwirtschaftsverlag GmbH	This guide to a simple field structure analysis is intended to help you to draw conclusions from the current state of the structure for gentle soil cultivation and driving.	Free of charge	Crop cultivation	https://apple.co/46vDNjs
Eip-agri Agriculture&Innovation	European Commission	The EIP-AGRI brings together innovation actors (farmers, advisers, researchers, businesses, NGOs, and others) in agriculture and forestry, at EU level. Together they form an EU-wide EIP network. On the digital platform knowledge transfer within the EU is possible.	Free of charge	Crop cultivation/livestock/Nature conservation	https://bit.ly/48TQeqQ https://bit.ly/3QhioEP
Farm21 Plattform	Farm21	Platform with multiple data sources from sensors (FS21), satellite images, public weather data. Exchange with other users possible.	Subject to charge	Crop cultivation/livestock/Nature conservation	https://bit.ly/3ZVvKda
GODAN (Global Open Data for Agriculture and Nutrition)	GODAN	Platform for agricultural and nutritional data to be available, accessible, usable, and unrestricted.	Free of charge	Crop cultivation/livestock/Nature conservation	https://bit.ly/40cqLFn
NatApp	ZALF e.V. / flynet	A software-based tool that enables the legally compliant, ordinance-compliant establishment, documentation, and control of environmental and climate actions.	Free of charge	Nature Conservation	https://bit.ly/48U39Jd
SAI Platform - Spotlight	SAI Platform	Supporting farmers with an online platform that helps align their work with local, regional, national, and international sustainability goals. The platform enables members to connect to other members while supporting their value and supply chains in a sustainable way.	Subject to charge	Crop cultivation/livestock/nature conservation	https://bit.ly/3LZEt8k
Smart Farming Platform (Smart AKIS)	European Union	A free digital information platform providing several tools for disseminating and making easier the use of Smart Farming technologies. The platform is open to farmers, advisory services, agriculture consultants, and farming equipment providers, setting up an open community where these groups can interact.	Free of charge	Crop cultivation/livestock/nature conservation	https://bit.ly/45zOFeG

Appendix Table 14. Overview and short description of citizen science applications and platforms, commercially available in Germany (A–F)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
3000 Pflanzen bestimmen	Coogni GmbH	Database for the identification of more than 3100 plants, including trees, shrubs, perennials, annuals, biennials, ferns.	Subject to charge	Nature conservation	https://bit.ly/3Qe9Kak
Agoranatura	ZALF e.V./Universität Greifswald/Deutsche Umwelthilfe/DVL	The first online marketplace for certified nature conservation projects. It enables people who manage land and want to implement a nature conservation project to finance it through crowdfunding or partnerships with companies. Private investors and companies can specifically promote biodiversity and nature services through the purchase of nature conservation certificates.	Free of charge	Nature conservation	https://bit.ly/48Pflv1
ArtenFinder	Ministry for Climate Protection, Environment, Energy and Mobility Rhineland	The data transmitted on the portal will initially be kept available on the internet in a protected form exclusively for the user. The release of reports for quality assurance by the Species Data Coordination Unit requires your explicit consent. External experts then check the plausibility of the data before they are transferred to the official databases.	Free of charge	Nature conservation	https://bit.ly/3ZT5bWa
Bäume und Sträucher bestimmen	Palatinate/ Nature and Environment Foundation Rhineland Palatinate"	More than 330 trees and shrubs of the world recognise and name: native and immigrant trees and shrubs as well as garden trees.	Subject to charge	Nature conservation	https://bit.ly/3rZvs8u
Baumführer 2 PRO and Lite	Coogni GmbH	With the Tree Guide 2 PRO you get a practical identification and reference work of the most common tree species in Europe and North America.	Subject to charge	Nature conservation	https://apple.co/3ZXDxYc
BirdNET: Vogelstimmen einfach erkennen	NATURE MOBILE G.m.b.H.	BirdNET is an artificial neural network that has been trained to recognize the 500 most common bird species from North America and Germany. With this app you can analyse pictures of bird voices with your smartphone from BirdNET.	Free of charge	Nature conservation	https://bit.ly/3LZrtQn
Deutschlandflora App	Federal Ministry of Education and Research (BMBF)/ TU Chemnitz	The app makes it possible to enter plant observations directly in the field with GPS-accurate finding points. The observations can be supplemented with photos taken on site. The data are fed into the Deutschlandflora portal and made publicly available in summarised forms as distribution data by BfN on the website www.floraweb.de	Free of charge	Nature conservation	https://bit.ly/3QheEn2
Eh-da-Flächen	pocket.science	Initiators and responsible persons of an Eh-da project are citizens of a municipality, farmers, beekeepers, gardeners, Nature conservationists, everyone who has an interest in the ecological enhancement of the landscape. The experts of the Eh-da initiative support committed project initiators with corresponding digital maps and geodata material.	Subject to charge	Nature conservation	https://bit.ly/45qKnGt
Feldbotanik	Haupt Verlag AG	The field botanical app and the associated book <i>Fundamentals of field botanicals</i> are intended to be useful tools for anyone who wants to build up their botanical knowledge and train their knowledge of species.	Subject to charge	Nature conservation	https://apple.co/45t6Oeo

Appendix Table 15. Overview and short description of citizen science applications and platforms, commercially available in Germany (F–M)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
Flora Capture: digitale Pflanzensammlung		Plant observations are digitally uploaded and identified by botanists. Photographs of flowering wild plants from specified angles are used to train the image recognition algorithms that are used in the app.	Free of charge	Nature conservation	https://bit.ly/3S5qSQG
Flora Incognita: automatische Pflanzenbestimmung	Technische Universität Ilmenau/ Max-Planck-Institut für Biogeochemie	Identification app for 4,851 wild plant species found in Germany. With automatic image recognition and by answering a few questions, the user is guided to the plant species they are looking for. The core of the app is an intelligent image recognition technique for identifying plants using smartphones and tablets.	Free of charge	Nature conservation	https://bit.ly/3FcWA7f
Frösche, Kröten, Unke bestimmen	Coogni GmbH	Frogs, toads, salamanders, newts determine in Germany, Austria, and Switzerland. An animal guide from Naturetouch.	Subject to charge	Nature conservation	https://bit.ly/3ZW0vNq
Früchte sammeln & bestimmen 2 PRO and Lite	NATURE MOBILE GmbH	Reference work for fruits and berries of the most common species of wild plants and crops.	Subject to charge	Nature conservation	https://bit.ly/3RYwOLk
Gartenvögel	Franckh-Kosmos Verlags-GmbH & Co. KG	Portray of the 37 most popular native garden birds. Own observations can be created in a list directly in the app.	Subject to charge	Nature conservation	https://apple.co/3rL9ne2
Heuschrecken bestimmen	Coogni GmbH	An animal guide from Naturetouch. Recognition and determination of all the important locusts of Germany.	Subject to charge	Nature conservation	https://bit.ly/3S28WXu
iFlora	Dr. Oliver Tackenberg	iFlora-Germany contains more than 2500 illustrations. Information on taxonomy, systematics, ecology, and distribution in Germany is also integrated into the app.	Free of charge	Nature conservation	https://bit.ly/3LYoUhp
Igel, Hase, Fuchs bestimmen	Coogni GmbH	Naturetouch determination of 74 mammals in Central Europe.	Subject to charge	Nature conservation	https://bit.ly/48TTnXG
iNaturalist – Mit anderen Usern Insekten bestimmen	California Academy of Sciences/ National Geographic	Naturalist is one of the most popular nature apps in the world for identifying the plants and animals. A community of over 800,000 scientists and naturalists with reporting and sharing own observations, research-quality data to scientists is being provided.	Free of charge	Nature conservation	https://bit.ly/3LYICti
Map of Life (MOL)	NASA, National Science Foundation (NSF), MacArthur Foundation	It is not only a reference work, but also a tool for "citizen science": you can use it to directly document animal observations and thus supplement and expand the Map of Life.	Free of charge	Nature conservation	https://bit.ly/3rVbonV
Mollusken Deutschlands - Datenportal	Deutsche Malakozoologischen Gesellschaft, BfN, Rote-Liste-Zentrum (RLZ)	Recording of snails and mussels for nature Nature conservation/ red lists The database offers an overview of current projects and scientific data providers as well as expert support.	Free of charge	Nature conservation	https://bit.ly/3QhyeiJ
Moose Deutschlands - Datenportal	BfN, DLR, RLZ, BLAM - Bryologisch-Lichenologische Arbeitsgemeinschaft für Mitteleuropa e.V.	Recording of moose for nature Nature conservation/ red lists The database offers an overview of current projects and scientific data providers as well as expert support.	Free of charge	Nature conservation	https://bit.ly/45zQdW2

Appendix Table 16. Overview and short description of citizen science applications and platforms, commercially available in Germany (F–M)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
NABU - Zeit der Schmetterlinge	NABU e.V.	Used to identify the most common butterflies in North Rhine Westphalia to report observations.	Free of charge	Nature conservation	https://bit.ly/3Q0jBiN
NABU Insektensommer	NABU e.V.	With the free app the user can identify, map and report the most common domestic insects.	Free of charge	Nature conservation	https://bit.ly/3PT9U5D
NABU Vogelwelt	NABU e.V.	Identification and reporting of 308 bird species through the app.	Free of charge	Nature conservation	https://bit.ly/3ZTJViz
Naturblick	Museum für Naturkunde Berlin	The user takes photos of plants and determines them with the automatic image recognition. The observations are recorded with location.	Free of charge	Nature conservation	https://bit.ly/3PYeu2p
Naturgucker.de-meldeapp	Naturgucker	Reporting app for observations, information can be recorded in the terrain and uploaded with images to the observations.	Free of charge	Nature conservation	https://bit.ly/45rWH9H
Neuropteren Deutschlands	BfN, DLR, RLZ, DGgaaE	Recording of Neuroptera species for nature Nature conservation/ red lists The database offers an overview of current projects and scientific data providers as well as expert support.	Free of charge	Nature conservation	https://bit.ly/3FCj5CR
Nützlinge im Garten	Bundesinformationzentrum Landwirtschaft (BZL)	The app helps to identify the most important beneficial insects and shows how to promote them.	Free of charge	Nature conservation	https://bit.ly/3tzJFJW
Pilzfürer 2 PRO and Lite	NATURE MOBILE GmbH	Practical determination and reference work of the most common mushroom species.	Subject to charge	Nature conservation	https://bit.ly/3LZIkSQ
Pl@ntNet Pflanzenbestimmung	several French institutions	With the app, users can identify one plant from a picture, and be part of a citizen science project on plant biodiversity.	Free of charge	Nature conservation	https://bit.ly/3SibhOb
Praxisapp Naturgucker	Naturgucker	The app is aimed at nature-loving people who want to record their observations outside and report them.	Free of charge	Nature conservation	https://bit.ly/3tzNwqx
Reptilien bestimmen	Coogni GmbH	Naturetouch determination of lizards, snakes, turtles etc.	Subject to charge	Nature conservation	https://bit.ly/45rYADj
Rote Liste Zentrum	BfN, DLR, RLZ	Scientific reports on the endangerment situation of species.	Free of charge	Nature conservation	https://bit.ly/45xZCNO
Schmetterlinge Deutschlands	KBS GmbH	For sharing observations about butterflies. Discoveries are displayed on the map of Germany.	Free of charge	Nature conservation	https://bit.ly/3QjuOfJ
Spinnen bestimmen	Coogni GmbH	Naturetouch determination of spiders in Central Europe.	Subject to charge	Nature conservation	https://bit.ly/46NqZVi
Tagaktive Schmetterlinge	Haupt Verlag AG	The Day-Active Butterflies app portrays 160 butterfly species that can often be found in Germany and neighbouring Central Europe.	Subject to charge	Nature conservation	https://apple.co/46to4Bt
Schädlinge (DLG)	Landwirtschaftsverlag GmbH	Digital image database for the recognition of pests on crop plants.	Free of charge	Nature conservation	https://bit.ly/3M39Yyi
Vogelführer 2 PRO and Lite	NATURE MOBILE GmbH	Identification and reference work for the most common birds in Europe.	Subject to charge	Nature conservation	https://apple.co/45Ak4Oh
Wilde Beeren und Kräuter 2 Pro and Lite	NATURE MOBILE GmbH	Determination and reference of the most common types of wild berries, fruits, herbs, and selected nuts.	Subject to charge	Nature conservation	https://bit.ly/3QecEvD
Unkräuter (DLG)	Landwirtschaftsverlag GmbH	Digital image database for the recognition of weeds in crop plants.	Free of charge	Nature conservation	https://bit.ly/46sDc1S
Wilde Tiere und Spuren 2 PRO and Lite	NATURE MOBILE GmbH	Determination and reference for the most common mammals in Central Europe and the Alps.	Subject to charge	Nature conservation	https://bit.ly/3tG0QcD

Appendix Table 17. Overview and short description of sensors (S) for agricultural work, commercially available in Germany (A–F)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
3D-Smart-Sensor O3M151 – Line Tracking	ifm electronic GmbH	Sensors based on algorithmics with e generic recognition of line-like contours and their tracking. Data interpolation available, when the contours are interrupted.	Subject to charge	Crop cultivation	https://bit.ly/3Pk3QUX
3D/2D-sensor for mobile apps (O3M251,O3M261)	ifm electronic GmbH	3D detection of scenes and objects, suited for use in mobile machines. Distance measurement and 2D camera with overlay function included. Indication of warnings and obstacles (live view).	Subject to charge	Crop cultivation	https://bit.ly/43VB9ly
Accupar LP-80 (apogee instruments)	METER Environment ®	Measures leaf area index (LAI), fractional interception and canopy growth (canopy PAR) in order to determine if water loss is from evaporation or transpiration.	Subject to charge	Crop cultivation	https://bit.ly/3JhryNS
AudioMoth (v1.0)	Open Acoustic Devices ©	Full-spectrum acoustic logger, based on the Gecko processor range from Silicon Labs. Just like its namesake the moth, AudioMoth can listen at audible frequencies, well into ultrasonic frequencies.	Subject to charge	Nature conservation	https://bit.ly/43MadVu
Baumer © sensors for agricultural equipment	Baumer Holding AG	Sensors for agricultural machines for the application areas sprayer boom height, combine header height control and implement ground clearance.	Subject to charge	Crop cultivation	https://bit.ly/469yeri
CLAAS©-Fertiliser System Isaria	CLAAS KGaA mbH	A sensor-based system for the optimised application of N-fertilisers, growth regulators or pesticides in different crops	Subject to charge	Crop cultivation	https://bit.ly/447LNFP
CROP SENSOR von CLAAS©	CLAAS KGaA mbH	Sensor with free calibration for optimal application of N-fertilisers, growth regulators/pesticides, liming.	Subject to charge	Crop cultivation	https://bit.ly/42J7pag
ecomatController CR721S	ifm electronic GmbH	Sensor signals are picked up by a central control (SPS) via decentralised sensor signals are received via decentralised modules and transmitted to the SPS via CAN-Bus - for a targeted fertilisation, e.g., when spreading slurry	Subject to charge	Crop cultivation	https://bit.ly/44mIQCD
e-obs digital tags and collars	e-obs GmbH	Lightweight GPS-tag and collars with several sensors combining high data rates for birds, mammals, and exotic species (e.g., coconut crabs). Battery and solar powered options available.	Subject to charge	Livestock	https://bit.ly/3CATCII
FS21 Sensor	Farm 21	Sensor measures air temperature, air humidity, soil moisture and soil temperature. It supports other modules of third-party sensors and global connectivity with NB-IoT, LTE-M and 2G.	Subject to charge	Crop cultivation	https://bit.ly/445zDNu
GEM-2	Geophex Ltd.	Hand-held, multi-frequency electromagnetic sensor for investigation of soil contamination from chemicals, investigation of groundwater occurrence, helping tool for precision agriculture.	Subject to charge	Crop cultivation	https://bit.ly/3NeYJmx
GPR – Ground Penetrating Radar	Sensors & Software Inc.	Control of soil water content, Application in the localisation of buried infrastructures as well as the localisation and detection of contaminant pathways	Subject to charge	Crop cultivation	https://bit.ly/42LKsDw
Grasshopper ®	True North Technologies Ltd.	Grass-cover measurement system, based on a sensor for sward height measurement.	Subject to charge	Grassland cultivation	https://bit.ly/3NAOJp3

Appendix Table 18. Overview and short description of sensors (S) for agricultural work, commercially available in Germany (S–Y)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
SC-1 Leaf Porometer (apogee instruments)	METER Environment ®	Measurement of stomatal conductance, which tells the difference between transpiring leaves and ones that have shut down.	Subject to charge	Crop cultivation	https://bit.ly/3Pbd8Tg
SN-500 Net Radiation Sensor	METER Environment ®	Sensor measures net radiation in real time (net radiation influences evapotranspiration).	Subject to charge	Crop cultivation	https://bit.ly/3CwrbLp
SU-221 Ultraviolet (UV) Sensor	METER Environment ®	Sensor measures total radiation from 300-400 nm in- and outdoors.	Subject to charge	Crop cultivation	https://bit.ly/3NISXuV
Terahertz-Systems	TOPTICA Photonics AG	Water-contrast imaging of plant leaves - in-situ measurements of the water content of plant leaves for optimisation of irrigation strategies.	Subject to charge	Crop cultivation	https://bit.ly/3qP5ofH
TEROS-sensors	METER Environment ®	Sensors for environmental measurements: soil water content, soil temperature. Different sensor models available.	Subject to charge	Crop cultivation	https://bit.ly/3qLDkd5
Topsoilmapper (TSM)	Geoprospectors GmbH	TSM is an integrated geophysical measurement system for the determination of different soil parameters. Using geophysical measurement technology and automated analysis methodology, the uppermost soil layers (up to 1 m depth) are measured precisely and with high resolution	Subject to charge	Crop cultivation	https://bit.ly/3JhLuA1
Ultraschall-sensor RU100U	Hans Turck GmbH & Co. KG	The sensor detects the distance of the spray bars from the ground. It is acid-resistant and reliably withstands temperatures from -25 to +50 degrees Celsius and is therefore suitable for use in all climate zones.	Subject to charge	Crop cultivation	https://bit.ly/3NuDjmx
Vence®	Merck & Co. Inc.	Virtual Fencing for cattle and livestock management, which controls cattle movement, manages grazing, and creates virtual fences to dictate grazing behaviour.	Subject to charge	Livestock	https://bit.ly/3CxI2xx
Weedseeker 2	Trimble Inc.	System for pinpoint injection. Developed for impeccable weed killer, it detects resistant weeds. In the case of weeds under the sensor, it signals to the connected spray nozzle that the herbicide is precisely delivered and the weeds are destroyed.	Subject to charge	Crop cultivation	https://bit.ly/3Xbe5wF
WILDRETTTER	ISA Industrieelektronik GmbH	A machine-bound tracking system (assembly of various sensors on a boom arm at the mower), detects fawns due to their higher heat radiation of the animals compared to the meadow.	Subject to charge	Nature conservation	https://bit.ly/3JhcZtE
Winkelsensor QR20	Hans Turck GmbH & Co. KG	Sensor for site-adapted guidance of the spray boom. It measures the position of the spray arms inductively and withstands temperatures from -40 to +85 degrees Celsius.	Subject to charge	Crop cultivation	https://bit.ly/3NuDjmx
Yara N-Sensor	Yara GmbH & Co. KG	The Yara N-sensor detects with high spatial resolution how much nitrogen is supplied to the stock. From this, the required amount of fertiliser is calculated.	Subject to charge	Crop cultivation	https://bit.ly/3p8Sx7q

Appendix Table 19. Overview and short description of sensors (S) for agricultural work, commercially available in Germany (G–R)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
IRT Infrared Thermometer	METER Environment ®	Sensor for surface temperature measurements. It measures the thermal energy radiated from any surface within its field of view.	Subject to charge	Crop cultivation	https://bit.ly/3qL1W8j
Isaria Pro Active Spray	Fritzmeier Umwelttechnik GmbH & Co. KG	The sensor is an active measuring system with four high power LEDs. It can be used 24 hours a day as the system operates regardless of environmental influences such as ambient light or dew. Can also be used for pest management.	Subject to charge	Crop cultivation	https://bit.ly/43J8hx0
Isaria Pro Compact	Fritzmeier Umwelttechnik GmbH & Co. KG	Crop sensor for N fertilisation, crop appraisal and N intake scan, application of organic substance, pest management and grassland reseeding.	Subject to charge	Crop cultivation	https://bit.ly/42KxjdC
K.U.L.T. iVision PV	K.U.L.T. Kress Umweltschonende Landtechnik GmbH	Camera-controlled precision weeding instrument with sensors, the parallelogram displacement allows the rear mounting of a 3 m hoe in the lightweight ARGUS frame construction for conditions in which the use of heavy solutions is not possible.	Subject to charge	Crop cultivation	https://bit.ly/3qIH3rD
ME-Blockage	Müller® Elektronik	Sensor for monitoring of fertiliser flow in precision planters and to monitor seeding in pneumatic seeders.	Subject to charge	Crop cultivation	https://bit.ly/442sdKT
Moenit Sensor Network	Moenit GmbH	Sensor network for measurements of temperature (air, soil), humidity, soil moisture, irrigation monitoring, light measurements, pH, and EC-measurements.	Subject to charge	Crop cultivation/livestock	https://bit.ly/43L5vHs
NEXT Weather Station Basic, Eco and Pro	FarmFacts GmbH	NEXT Weather Station is the right tool for the job: an integrated system for recording, documenting, and analysing weather data, and forecasting the weather.	Subject to charge	Crop cultivation/administration	https://bit.ly/3CywOJ6
OEM-Sensors (Original Equipment-Manufacturer)	Hottinger Brüel & Kjaer GmbH	Development and production of customised sensor solutions for contact pressure, load, torque in tractors, planting and harvesting machines; sensors for seeds and fertilisers.	Subject to charge	Crop cultivation	https://bit.ly/3p5rF8p
Opto-sensor	Müller® Elektronik	Sensor for precise seed detection during seeding procedures with a sending and a receiving signal unit.	Subject to charge	Crop cultivation	https://bit.ly/3qRndL6
OptRX Plant sensor	PH.RODEN NACHF. KG	CAN-BUS based sensor for measuring of the vegetation index and enables recommendations for a needs-based fertilisation.	Subject to charge	Crop cultivation	https://bit.ly/3JjYlIm
PAR-Sensor (apogee instruments)	METER Environment ®	Full-spectrum quantum sensor that measures the Photosynthetic. Photon Flux Density (PPFD) from a field of view of 180 degrees. Outdoor and indoor sensor.	Subject to charge	Crop cultivation	https://bit.ly/3Ph7mj2
Phytos 31 (apogee instruments)	METER Environment ®	Sensor uses capacitance technology: it senses submilligram levels of water condensing on the surface, including frost and ice formation.	Subject to charge	Crop cultivation	https://bit.ly/3PhdF6f
PLANTiriumCsensor	Müller® Elektronik	Sensor for automatic seed pattern detection with status messages.	Subject to charge	Crop cultivation	https://bit.ly/3qHzFwB
PYR Sensor (Pyranometer)	METER Environment ®	Sensor measures the solar radiation flux density from a field of view of 180 degrees.	Subject to charge	Crop cultivation	https://bit.ly/3Njtc2S
Qstarz GPS Sensors	QStarz International Co. Ltd.	GPS Travel Recorder suitable for livestock pattern recognition and position monitoring.	Subject to charge	Livestock	https://bit.ly/3NaJhYo
Robocrop Side Shift System	Garford Farm Machinery Ltd.	Equipped with two cylinders, a potentiometer and a control valve, these units can be retrofitted to any hoe or mounted machine requiring precise guidance.	Subject to charge	Crop cultivation	https://bit.ly/43JizNE
RumiWatchSystem	ITIN+HOCH GmbH	Automatic system for activity and behaviour monitoring of ruminants for research.	Subject to charge	Livestock	https://bit.ly/445MtlG

Appendix Table 20. Overview and short description of field robots (FR), commercially available in Germany (A–N)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
AgBot T2, W3 and W4	AgXeed B.V.	Autonomous vehicles for soil preparation, seedbed preparation, crop management, fertiliser application. Managed via the many platforms, software, and apps.	Subject to charge	Crop cultivation	https://bit.ly/440LvQY
Autonome Feldspritze John Deere	John Deere Walldorf GmbH & Co. KG	Light autonomous sprayer, which can drive on fields after rain without causing soil compaction. High ground clearance and all-wheel steering, which enables manoeuvrability.	Subject to charge	Crop cultivation	https://bit.ly/3CAviGm
AVO – Weed robot	Ecorobotix	Autonomous field robot with solar traction and ultra-ecological spraying. It can treat up to 10 hectares per day.	Subject to charge	Crop cultivation	https://bit.ly/3qM5y7x
BoniRob	University of Applied Sciences Osnabrück/Amazone/Bosch	Field robot for stamping weeds. Imaging sensor data is transmitted from the field via internet to a telework station, where a human marks the weeds and then the weed positions are sent to the field for automated regulatory action.	Subject to charge	Crop cultivation/ administration	https://bit.ly/3Pg4V00
Carrè ANATIS Field robot	<u>Pool Agri Import & Export</u>	Fully electrically driven field robot for weeding. Completely autonomous and all-wheel steered, it works through the rows of plants based on GPS data entered in advance supported by two cameras that recognise the row of the plants.	Subject to charge	Crop cultivation	https://bit.ly/3Cy9mM7
CLAWS	Earth Rover Ltd.	A lightweight, autonomous field robot able to perform a variety of tasks such as scouting, weeding and real-time data analysis.	Subject to charge	Crop cultivation	https://bit.ly/42LCKck
Dahlia 4.3	Dahlia Robotics GmbH	Guided by artificial intelligence the robot controls an in-house build removal system towards weed plants whilst avoiding accidental damage to the crop plants. A mechanical end-effector removes the weed plants.	Subject to charge	Crop cultivation	https://bit.ly/43IZ9Zn
ETAROB	University of Applied Sciences Aachen	Autonomous agricultural robot for automating monotonous and physically demanding field work. In real time, while driving, the position of each plant relative to the tool is determined,	Subject to charge	Crop cultivation	https://bit.ly/4613DHk
FarmDroid FD20	Farmdroid ApS	Solar-powered, fully automatic, and light weight seeding and weeding robot, usable for many crops. Sows and weeds via GPS in and between the rows, range of 20ha.	Subject to charge	Crop cultivation	https://bit.ly/3p8D8Ec
Farming GT	Farming revolution GmbH	Autonomous field robot with precise plant detection and remote monitoring via internet. Up to 30 h autonomy. Detects green already in the cotyledon stage, by day and by night.	Subject to charge	Crop cultivation	https://bit.ly/3CyamWZ
Greenbot CR12/CR18	Precision Makers B.V.	A self-driving machine that has been specially developed to work for fruit farming, horticulture, and arable farming. It can sow, mow, plough or fertilise.	Subject to charge	Crop cultivation	https://bit.ly/3JGd1M3
JoWeeding/Multipurpose Robot	Naio Technologies	Autonomous vehicle that provides mechanical weeding, can carry tools, and has a power adapter to plug in electrical tools.	Subject to charge	Crop cultivation	https://bit.ly/3Pgn2ms
KRIBL	Universität zu Lübeck	Small robot with automated image and sensor data evaluation for autonomous navigation, detection of plant types in pasture land for small-scale farms.	Subject to charge	Grassland/ livestock	https://bit.ly/43N7QSu
MARS	AGCO GmbH, Fendt Marketing	MARS's approach is to plan, monitor and accurately document the precise sowing of maize with small, swarm-based robotic units and a cloud-based solution.	Subject to charge	Crop cultivation	https://bit.ly/448LISI
Naio Dino	Naio Technologies	Weeding robots for large-scale vegetable crops. It detects crop rows and adjusts the tools to weed as close to the plants as possible. Based on RTK GPS and other sensors.	Subject to charge	Crop cultivation	https://bit.ly/3ph9gW2
NEXT GreenSeeker	FarmFacts GmbH	Sensor and robotic equipment that can record, monitor, document and analyse data regarding weather, watering needs, biomass, distribution, pests, as well as fertilizer application and plant protection.	Subject to charge	Crop cultivation	https://bit.ly/3NxmmuH

Appendix Table 21. Overview and short description of field robots (FR), commercially available in Germany (A–N).

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
OMNiDRIVE™	Raven Industries, Inc.	Autonomous grain cart technology with safety cameras. Camera images run with artificial intelligence that recognises humans, animals, equipment, and other dangerous obstacles.	Subject to charge	Crop cultivation	https://bit.ly/46187h8
OMNiPOWER™ 3200	Raven Industries, Inc.	Multipurpose power platform for autonomous seeding, spreading, and spraying. Remote command, supervision and monitoring in the field or another cab.	Subject to charge	Crop cultivation	https://bit.ly/43YNx3S
Orio Robot	Naio Technologies	A field robot with guidance system based on RTK GPS signal. This robot offers the possibility to add options for greater autonomy and precision.	Subject to charge	Crop cultivation	https://bit.ly/3PhYERr
Oz Multipurpose Robot	Naio Technologies	A field robot with guidance system based on RTK GPS signal. The robot can seed, hoe, weed, transport, assist and make furrows.	Subject to charge	Crop cultivation	https://bit.ly/3XeBwoM
Robocrop Guided Hoes	Garford Farm Machinery Ltd.	Crop imaging system which achieves row following by viewing multiple crop rows over a large area.	Subject to charge	Crop cultivation	https://bit.ly/4454ZnC
Robocrop InRow Weeder & Spot Sprayer	Garford Farm Machinery Ltd.	The system uses video image analysis techniques to locate individual plants to mechanically remove weeds from the inter row and between the plants. Developed for use on transplanted crops such as lettuce, cabbage, celery	Subject to charge	Crop cultivation	https://bit.ly/3XaAom6
Robotti (Long Range)	Agro Intelligence A/S	Field robot for high-precision, site-specific agricultural work, e.g., for vegetable growers, seed growers and trial growers: seedbed preparation, hoeing, weeding, harrowing, soil sampling, precise planting, and land management.	Subject to charge	Crop cultivation	https://bit.ly/3JigYGo
Robotti 150D	Agro Intelligence A/S	A powerful field robot for power intensive operations, with 2 engines, a PTO and traditional diesel-hydraulic setup. It can provide seeding, weeding, spraying, ridging, mowing and rotovating operations.	Subject to charge	Crop cultivation	https://bit.ly/3PhV4qH
Robotti LR	Agro Intelligence A/S	Digital infrastructure enabling automatic data collection in the field, crop as well as technical data, that can support decision support and management systems.	Subject to charge	Crop cultivation	https://bit.ly/42Fod20
Robovator Mechanical	F. Poulsen Engineering ApS.	Equipped with a camera plant detection above every row, which enables automatic hoeing in the row. It can work in darkness and can be operated by smartphone.	Subject to charge	Crop cultivation	https://bit.ly/3qJvj8h
See & Spray™ Blue River Technology	John Deere Walldorf GmbH & Co. KG/ Blue River Technology	A high-resolution camera captures 20 frames per second. Using the images and artificial intelligence, the system recognises the difference between crops and weeds. Subsequently, the individual plants are treated in a targeted manner.	Subject to charge	Crop cultivation	https://bit.ly/43KdRiI
Ted Weeding Robot	Naio Technologies	Dedicated to vineyards, the robot removes weeds mechanically.	Subject to charge	Crop cultivation	https://bit.ly/3N59ffW
Uckerbot	Zauberzeug GmbH	Robots for weed management, harvesting, inspection in the field. Additional functions are possible through additional modules	Subject to charge	Crop cultivation/ livestock	https://bit.ly/3JetzKL
Vitirover SAS	Vitirover©	Autonomous robot that detects obstacles to get as close as possible to a crop plant and cut grass around. Suitable for viticulture.	Subject to charge	Crop cultivation/ grassland	https://bit.ly/43N60ko
Warthog/Husky/Jackal	Clearpath™ Robotics	Unmanned all-terrain ground vehicles customised with sensors, manipulators, cameras.	Subject to charge	Crop cultivation/ grassland	https://bit.ly/3qDGPlx

Appendix Table 22. Overview and short description of unmanned aerial vehicles and systems (UAV/UAS), commercially available in Germany (A–V)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application area	Source link
Agronator® e-Duster, e-Seeder®	Agronator AG	Drone for heavy-duty transport of seeds, fertilisers. Suitable for pesticide application.	Subject to charge	Crop cultivation	https://bit.ly/3Pi0dPn
Autonome Feldspritz-Drohne JD	John Deere Walldorf GmbH & Co. KG	Equipped with a weed scanner and a field syringe. This allows weeds to be scanned from the air and then specifically combated. The 10.6-litre tank is filled fully automatically in a field edge station.	Subject to charge	Crop cultivation	https://bit.ly/3p8knAO
DJI Agras T30/T10	SZ DJI Technology Co., Ltd.	Data-driven agricultural drone with a maximum payload of 40 kg. Suitable for efficient spraying and fertilising.	Subject to charge	Crop cultivation	https://bit.ly/3PA3KsH
DJI Cameras and Drones (Company)	SZ DJI Technology Co., Ltd.	Various camera drones that can capture data with high resolution.	Subject to charge	Crop cultivation	https://bit.ly/3qQ0eA5
DJI Matrice 30 Series	SZ DJI Technology Co., Ltd.	High-resolution data acquisition with dual vision and TOF sensors on all six sides. The integrated ADS-B receiver warns in good time of manned aircraft in the vicinity.	Subject to charge	Nature conservation	https://bit.ly/4637ybD
DJI Matrice 200 Series V2	SZ DJI Technology Co., Ltd.	Drone platform for air workflows – high resolution data acquisition at night possible.	Subject to charge	Crop cultivation/grassland/livestock	https://bit.ly/3Phsohe
DJI P4P V2.0	SZ DJI Technology Co., Ltd.	Drone for high quality photos at 20 MP and videos in 4K at 60 fps with stable HD transmission and obstacle detection in five directions.	Subject to charge	Crop cultivation/grassland/livestock	https://bit.ly/444bLKh
eBee X, Ag and Geo drones	AgEagle Aerial Systems Inc.	Drones for mapping with 3D, RGB, multispectral and thermal cameras.	Subject to charge	Crop cultivation/grassland/livestock	https://bit.ly/3N5yqis
High-End MultiKopter Drohne MK-U25	MultiKopter	Drone with a modular design for long flights with camera systems, LiDAR systems, sensors, or transport of good up to 10 kg.	Subject to charge	Crop cultivation	https://bit.ly/3Pdark5
MC8-Octocopter	AiDrones GmbH	Electrical coaxial octocopter drone with autonomous operation, designed for various applications requiring automatic operation with electro-optical payloads.	Subject to charge	Crop cultivation/nature conservation	https://bit.ly/3JiaF5E
Quanfeng Agricultural Spraying Drones	Hangzhou Qifei Intelligent Technology Co., Ltd.	Small and compact drone for spraying operations in different crop species, equipped with FPV camera, support AB Point Flight and a fully autonomous mode.	Subject to charge	Crop cultivation	https://bit.ly/3NC3cRD
Scout System	American Robotics	Fully-autonomous, AI-powered drone including data analysis with high resolution and real time data.	Subject to charge	Crop cultivation/grassland/livestock	https://bit.ly/42PSHhM
VoloDrone	Volocopter GmbH	Fully-electric utility drone suitable for heavy-lift-services up to 200 kg.	Subject to charge	Crop cultivation	https://bit.ly/3XeWUKX

Filled out questionnaires (exemplary, anonymised) to show the different subject areas and the design of the survey.



Sehr geehrte Teilnehmer/innen,

willkommen bei der gemeinsamen Umfrage des Leibniz-Zentrums für Agrarlandschaftsforschung (ZALF) und der Expertenkommission Forschung und Innovation (EFI). Gemeinsam möchten wir gerne von Ihnen erfahren, wie digitale und smarte Technologien in der Landwirtschaft genutzt werden und ob sie zu mehr Nachhaltigkeit beitragen können. Unter digitalen und smarten Technologien verstehen wir sowohl Systeme zur Entscheidungsunterstützung bzw. Betriebsmanagement als auch Technologien aus dem Bereich Precision Farming. Ihre Antworten fließen anonym in eine wissenschaftliche Studie des ZALF ein. Auf Basis dieser Studie erarbeitet die EFI in ihrer Funktion als wissenschaftliches Beratungsgremium Handlungsempfehlungen für die Bundesregierung. Dazu ist es wichtig, dass Sie den nachfolgenden Fragebogen vollständig beantworten. Dies wird circa 15 Minuten in Anspruch nehmen.

Die Auswertung der Daten erfolgt anonym und unter Einhaltung aller Datenschutzbestimmungen. Ergebnisse werden nur zusammengefasst mit den Antworten anderer Befragten veröffentlicht und eine Rückführung auf die Identität der befragten Personen ist ausgeschlossen. Detaillierte Informationen zu den Datenschutzbestimmungen erhalten Sie auf der folgenden Seite.

Bei weiteren Fragen schreiben Sie uns gerne eine E-Mail an: frauke.geppert@zalf.de

Vielen Dank für Ihre Unterstützung!

Ihr Umfrage-Team von EFI und ZALF



A2. Ich kann meine Einwilligung jederzeit kostenfrei widerrufen, ohne dass mir dadurch Nachteile entstehen. Die Rechtmäßigkeit, der bis zum Widerruf erfolgten Verarbeitung meiner personenbezogenen Angaben bleibt davon unberührt. Meinen Widerruf kann ich an die oben angegebenen Kontaktmöglichkeiten richten.

Ja, ich akzeptiere und gehe weiter zum Fragebogen.

Nein, ich akzeptiere nicht und beende den Fragebogen.

A3.

2

B1. In welchem der folgenden Bereiche sind Sie hauptamtlich tätig?

Landwirtschaftsbetrieb

Lohnunternehmen

andere Unternehmen

Politik/Verwaltung

Verband/Nichtregierungsorganisation

Forschung

Sonstiges

Sonstiges

C1. In welchen landwirtschaftlichen Bereichen sind Sie aktiv?

(Mehrfachauswahl möglich)

Viehzucht

Ackerbau

Gartenbau

Grünlandbewirtschaftung



Sonstiges



Sonstiges

D1. Bei welchem Arbeitgeber/Institution sind Sie beschäftigt?

Bundesministerium

Landesministerium

Landesanstalt für Landwirtschaft

Landwirtschaftskammer

Bundestag

Landtag

Kreistag

Sonstiges

Sonstiges

D2. Bei welcher Art von Verband sind Sie tätig?

Überregionaler Verband

Regionaler Verband

Sonstiges

Sonstiges



D3. Wo sind Sie tätig?

Kleinstunternehmen (bis 9 Beschäftigte)

Kleinunternehmen (bis 49 Beschäftigte)

Mittelunternehmen (bis 249 Beschäftigte)

Großunternehmen (über 249 Beschäftigte)

Sonstiges

Sonstiges

D4. Wo sind Sie tätig?

Universität

Fachhochschule und Hochschule für Angewandte Wissenschaft (HAW)

Außeruniversitäre Forschungseinrichtung

Sonstiges

Sonstiges

E1. In welchem Bereich liegt Ihr Arbeitsschwerpunkt bzw. Ihre persönliche Expertise?

(Bitte geben Sie maximal 1-2 Stichworte an.)



F1. Seit wann arbeiten Sie in diesem Arbeitsschwerpunkt?

Bis 1 Jahr

2 bis 5 Jahre

6 bis 10 Jahre

Über 10 Jahre

G1. Welche digitalen und smarten Technologien nutzen Sie für Ihre Tätigkeiten und wie häufig?

	Täglich	Regelmäßig (wöchentlich)	Gelegentlich (monatlich)	Bisher noch nicht eingesetzt, aber Einsatz ist geplant	Bisher weder genutzt, noch geplant
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365 FarmNet, Xarvio Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B.: Field Navigator, Trimble Center Point RX; CEMOS Adviser CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

G2. Nutzen Sie sonstige digitale und smarte Technologien?

Ja

Nein

H1. Inwieweit könnte der Einsatz digitaler und smarterer Technologien in der Landwirtschaft zum Erreichen der folgenden Ziele beitragen?

	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeits erleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transfer von Daten und Wissen (innerhalb des Betriebs und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

H2. Nennen Sie ggf. weitere mögliche Ziele.

I1. Was ist aus Ihrer Sicht der Entwicklungsstand in den folgenden Technologiebereichen für den Einsatz in der Landwirtschaft?

	Forschung (Technology readiness levels 1-3)	Entwicklung (Technology readiness levels 4-6)	Einsatz (Technology readiness levels 7-9)	Keine Antwort
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365FarmNet, XARVIO Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B. Field Navigator, Trimble Center Point RX, CEMOS Advisor CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Machine Learning für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Andere künstliche Intelligenz für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



J1. Für welche Zwecke nutzen Sie die angegebenen digitalen und smarten Technologien?

	Ja	Nein
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeitserleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Monitoring von Flächen	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Transfer von Daten und Wissen (innerhalb und außerhalb des Betriebs)	<input type="checkbox"/>	<input checked="" type="checkbox"/>

J2. Ergänzen Sie ggf. weitere Zwecke.

K1. Welche Faktoren erschweren oder verhindern den Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Grundbildung/Erfahrung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarter Technologien	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarter Technologien	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarter Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Komplexe Bedienung digitaler Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

K2. Nennen Sie ggf. weitere Hemmnisse.

L1. Welche Faktoren erschweren oder verhindern aus Ihrer Sicht den Einsatz digitaler und smarterer Technologien in der Landwirtschaft?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Kenntnisse	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Komplexe Bedienung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



L2. Nennen Sie ggf. weitere Hemmnisse.

M1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

M2. Nennen Sie ggf. weitere Maßnahmen.

N1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien in Landwirtschaftsbetrieben zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



N2. Nennen Sie ggf. weitere Maßnahmen.

O1. Bezüglich Effizienzsteigerungen: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

O2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Gemüsebau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Grünlandbewirtschaftung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P1. Bezüglich Umweltschutz: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein, um positive Effekte zu erreichen?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

P2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>



Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Gemüsebau

Grünlandbewirtschaftung

Q1. Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in der Landwirtschaft für Nachhaltigkeit und Umweltschutz ein?

Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Ausdehnung von ökologischem Landbau

Verringerung der Bodenbelastung (Ressourceneinsparung)

Förderung von kleinflächigen Anbausystemen zum Schutz der Biodiversität

Diversifizierung von Fruchtfolgen

Verbesserung der Bodenstruktur (z.B. durch den Einsatz leichterer Maschinen)

Vermehrte teilflächenspezifische Maßnahmen

Q2. Nennen Sie ggf. weitere Punkte.

R1.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

**Farm-Management- und Informationssysteme/
Entscheidungsunterstützungssysteme**

Klimaschutz

Biodiversität

Ernährungsproblematik

Keine Antwort



R2.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Digitale Informationsplattformen

- Klimaschutz
- Biodiversität
- Ernährungsproblematik
- Keine Antwort

R3.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

(Digitale) Technologien für Landmaschinen – Aktorik

- Klimaschutz
- Biodiversität
- Ernährungsproblematik
- Keine Antwort

R4.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Erfassungs- und Sensortechnologien – Sensorik

- Klimaschutz
- Biodiversität
- Ernährungsproblematik

Keine Antwort **R5.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Feldroboter

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R6.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Unbemannte Luftfahrzeuge und -systeme

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R7.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Citizen-Science-Plattformen

Klimaschutz Biodiversität

Ernährungsproblematik Keine Antwort **R8.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Machine Learning für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R9.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Andere künstliche Intelligenz für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort



S1. Wie oft haben Sie bereits Umwelt- und Naturschutzmaßnahmen umgesetzt?

- Einmal durchgeführt
- Zweimal durchgeführt
- Jedes Jahr durchgeführt
- Noch nicht durchgeführt
- Mehr als zweimal durchgeführt und zwar

Mehr als zweimal durchgeführt und zwar

T1. Im Hinblick auf den Schutz der Biodiversität in Agrarflächen: Wo sehen Sie die größten verbleibenden Herausforderungen für einen kontinuierlichen, regelmäßigen Einsatz digitaler und smarter Technologien?

	Keine Herausforderung	Geringe Herausforderung	Große Herausforderung	Sehr große Herausforderung
Strukturen innerhalb der GAP noch nicht ausreichend für Digitalisierung ausgebaut	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Mangelnde digitale Kommunikationsvorgänge (z.B. Datenübermittlung) bei örtlichen Behörden/Ministerien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Fehlende Beratungsangebote/mangelnde Informationsmöglichkeiten über die Nutzung digitaler Technologien im Bereich des Natur- und Umweltschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Fehlende Kompatibilität digitaler Geräte mit etablierten Technologien (z.B. Ackerschlagkartei) und dadurch erheblich erhöhter (Zeit-) Aufwand bei Nutzung digitaler Technologien für den Biodiversitätsschutz	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

T2. Nennen Sie ggf. weitere Herausforderungen.



U1. Im Hinblick auf die Umsetzung von Maßnahmen zum Schutz der Biodiversität: Wo sehen Sie das größte Potential digitaler und smarterer Technologien?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Signifikante Zeiteinsparungen (bei Beantragung, Planung, Durchführung und Dokumentation der Maßnahmen)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Besser aufbereitete Informationsmöglichkeiten (z.B. in Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Effektivere (standortspezifischere) Möglichkeiten des Biodiversitätsschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Vereinfachte Übermittlung der Dokumentationsnachweise von implementierten Maßnahmen (z.B. mit Hilfe von Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Minderung von Sanktionsrisiken durch präzisere Flächenbearbeitung mit digitalen Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

U2. Nennen Sie ggf. weitere Potentiale.

V1. Welches Betriebsmodell liegt ihrem Betrieb zugrunde?

- Klassisch konventionell
- Konventionell wirtschaftend mit reduziertem Dünge- und PSM- Einsatz
- Ökologisch

V2. Wie viele Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

- Bis 9 Beschäftigte
- 10 bis 49 Beschäftigte
- 50 bis 249 Beschäftigte
- Mehr als 249 Beschäftigte



V3. Wie viel Hektar landwirtschaftlich genutzter Fläche umfasst Ihr Betrieb?

- Unter 5 Hektar
- 5 bis 10 Hektar
- 11 bis 20 Hektar
- 21 bis 50 Hektar
- 51 bis 100 Hektar
- 101 bis 200 Hektar
- 201 bis 500 Hektar
- 501 bis 1000 Hektar
- Über 1000 Hektar

W1. In welchen Betriebsmodellen sind Sie aktiv?

(Mehrfachauswahl möglich)

- Klassisch konventionell
- Konventionell wirtschaftend mit reduziertem Dünge- und PSM Einsatz
- Ökologisch

W2. Wie viel Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

- Bis 9 Beschäftigte
- 10 bis 49 Beschäftigte
- 50 bis 249 Beschäftigte
- Mehr als 249 Beschäftigte



W3. Wie viel Hektar landwirtschaftlich genutzter Fläche bewirtschaften Sie?

- Unter 5 Hektar
- 5 bis 10 Hektar
- 11 bis 20 Hektar
- 21 bis 50 Hektar
- 51 bis 100 Hektar
- 101 bis 200 Hektar
- 201 bis 500 Hektar
- 501 bis 1000 Hektar
- Über 1000 Hektar

X1. In welchem Bundesland bzw. in welchen Bundesländern befindet/befinden sich Ihre bewirtschaftete(n) Fläche(n)?

(Mehrfachauswahl möglich)

- Baden-Württemberg
- Bayern
- Berlin
- Brandenburg
- Bremen
- Hamburg
- Hessen
- Mecklenburg-Vorpommern
- Niedersachsen
- Nordrhein-Westfalen
- Rheinland-Pfalz
- Saarland
- Sachsen
- Sachsen-Anhalt
- Schleswig-Holstein
- Thüringen



Y1. Welchem Geschlecht ordnen Sie sich zu?

- Männlich
- Weiblich
- Divers

Z1. Wie alt sind Sie?

- Unter 25 Jahre
- 25 bis 35 Jahre
- 36 bis 45 Jahre
- 46 bis 55 Jahre
- 56 bis 66 Jahre
- Über 66 Jahre

AA1. Was ist Ihr höchster beruflicher Abschluss?

- Promotion
- Diplom
- Master
- Bachelor
- Fachschulabschluss
- Lehre/Berufsausbildung
- Kein beruflicher Abschluss
- Sonstiges

Sonstiges



A2. Ich kann meine Einwilligung jederzeit kostenfrei widerrufen, ohne dass mir dadurch Nachteile entstehen. Die Rechtmäßigkeit, der bis zum Widerruf erfolgten Verarbeitung meiner personenbezogenen Angaben bleibt davon unberührt. Meinen Widerruf kann ich an die oben angegebenen Kontaktmöglichkeiten richten.

Ja, ich akzeptiere und gehe weiter zum Fragebogen.

Nein, ich akzeptiere nicht und beende den Fragebogen.

A3.

2

B1. In welchem der folgenden Bereiche sind Sie hauptamtlich tätig?

Landwirtschaftsbetrieb

Lohnunternehmen

andere Unternehmen

Politik/Verwaltung

Verband/Nichtregierungsorganisation

Forschung

Sonstiges

Sonstiges

C1. In welchen landwirtschaftlichen Bereichen sind Sie aktiv?

(Mehrfachauswahl möglich)

Viehzucht

Ackerbau

Gartenbau

Grünlandbewirtschaftung



Sonstiges



Sonstiges

D1. Bei welchem Arbeitgeber/Institution sind Sie beschäftigt?

Bundesministerium

Landesministerium

Landesanstalt für Landwirtschaft

Landwirtschaftskammer

Bundestag

Landtag

Kreistag

Sonstiges

Sonstiges

D2. Bei welcher Art von Verband sind Sie tätig?

Überregionaler Verband

Regionaler Verband

Sonstiges

Sonstiges



D3. Wo sind Sie tätig?

Kleinstunternehmen (bis 9 Beschäftigte)

Kleinunternehmen (bis 49 Beschäftigte)

Mittelunternehmen (bis 249 Beschäftigte)

Großunternehmen (über 249 Beschäftigte)

Sonstiges

Sonstiges

D4. Wo sind Sie tätig?

Universität

Fachhochschule und Hochschule für Angewandte Wissenschaft (HAW)

Außeruniversitäre Forschungseinrichtung

Sonstiges

Sonstiges

E1. In welchem Bereich liegt Ihr Arbeitsschwerpunkt bzw. Ihre persönliche Expertise?

(Bitte geben Sie maximal 1-2 Stichworte an.)



F1. Seit wann arbeiten Sie in diesem Arbeitsschwerpunkt?

Bis 1 Jahr

2 bis 5 Jahre

6 bis 10 Jahre

Über 10 Jahre

G1. Welche digitalen und smarten Technologien nutzen Sie für Ihre Tätigkeiten und wie häufig?

	Täglich	Regelmäßig (wöchentlich)	Gelegentlich (monatlich)	Bisher noch nicht eingesetzt, aber Einsatz ist geplant	Bisher weder genutzt, noch geplant
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365 FarmNet, Xarvio Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B.: Field Navigator, Trimble Center Point RX; CEMOS Adviser CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

G2. Nutzen Sie sonstige digitale und smarte Technologien?

Ja

Nein

H1. Inwieweit könnte der Einsatz digitaler und smarterer Technologien in der Landwirtschaft zum Erreichen der folgenden Ziele beitragen?

	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeiterleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transfer von Daten und Wissen (innerhalb des Betriebs und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

H2. Nennen Sie ggf. weitere mögliche Ziele.

I1. Was ist aus Ihrer Sicht der Entwicklungsstand in den folgenden Technologiebereichen für den Einsatz in der Landwirtschaft?

	Forschung (Technology readiness levels 1-3)	Entwicklung (Technology readiness levels 4-6)	Einsatz (Technology readiness levels 7-9)	Keine Antwort
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365FarmNet, XARVIO Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B. Field Navigator, Trimble Center Point RX, CEMOS Advisor CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Machine Learning für landwirtschaftliche Anwendungen	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Andere künstliche Intelligenz für landwirtschaftliche Anwendungen	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



J1. Für welche Zwecke nutzen Sie die angegebenen digitalen und smarten Technologien?

	Ja	Nein
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeitserleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>
Transfer von Daten und Wissen (innerhalb und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>

J2. Ergänzen Sie ggf. weitere Zwecke.

K1. Welche Faktoren erschweren oder verhindern den Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Grundbildung/Erfahrung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Komplexe Bedienung digitaler Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

K2. Nennen Sie ggf. weitere Hemmnisse.

L1. Welche Faktoren erschweren oder verhindern aus Ihrer Sicht den Einsatz digitaler und smarterer Technologien in der Landwirtschaft?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Kenntnisse	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Komplexe Bedienung digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



L2. Nennen Sie ggf. weitere Hemmnisse.

M1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

M2. Nennen Sie ggf. weitere Maßnahmen.

N1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien in Landwirtschaftsbetrieben zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



N2. Nennen Sie ggf. weitere Maßnahmen.

O1. Bezüglich Effizienzsteigerungen: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

O2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Gemüsebau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Grünlandbewirtschaftung	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

P1. Bezüglich Umweltschutz: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein, um positive Effekte zu erreichen?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

P2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>



Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Gemüsebau

Grünlandbewirtschaftung

Q1. Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in der Landwirtschaft für Nachhaltigkeit und Umweltschutz ein?

Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Ausdehnung von ökologischem Landbau

Verringerung der Bodenbelastung (Ressourceneinsparung)

Förderung von kleinflächigen Anbausystemen zum Schutz der Biodiversität

Diversifizierung von Fruchtfolgen

Verbesserung der Bodenstruktur (z.B. durch den Einsatz leichterer Maschinen)

Vermehrte teilflächenspezifische Maßnahmen

Q2. Nennen Sie ggf. weitere Punkte.

R1.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

**Farm-Management- und Informationssysteme/
Entscheidungsunterstützungssysteme**

Klimaschutz

Biodiversität

Ernährungsproblematik

Keine Antwort

**R2.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Digitale Informationsplattformen

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input type="checkbox"/> |
| Biodiversität | <input checked="" type="checkbox"/> |
| Ernährungsproblematik | <input type="checkbox"/> |
| Keine Antwort | <input type="checkbox"/> |

R3.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

(Digitale) Technologien für Landmaschinen – Aktorik

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input type="checkbox"/> |
| Biodiversität | <input type="checkbox"/> |
| Ernährungsproblematik | <input checked="" type="checkbox"/> |
| Keine Antwort | <input type="checkbox"/> |

R4.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Erfassungs- und Sensortechnologien – Sensorik

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input type="checkbox"/> |
| Biodiversität | <input type="checkbox"/> |
| Ernährungsproblematik | <input checked="" type="checkbox"/> |

Keine Antwort **R5.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Feldroboter

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R6.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Unbemannte Luftfahrzeuge und -systeme

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R7.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Citizen-Science-Plattformen

Klimaschutz Biodiversität

Ernährungsproblematik Keine Antwort **R8.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Machine Learning für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R9.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Andere künstliche Intelligenz für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort



S1. Wie oft haben Sie bereits Umwelt- und Naturschutzmaßnahmen umgesetzt?

- Einmal durchgeführt
- Zweimal durchgeführt
- Jedes Jahr durchgeführt
- Noch nicht durchgeführt
- Mehr als zweimal durchgeführt und zwar

Mehr als zweimal durchgeführt und zwar

T1. Im Hinblick auf den Schutz der Biodiversität in Agrarflächen: Wo sehen Sie die größten verbleibenden Herausforderungen für einen kontinuierlichen, regelmäßigen Einsatz digitaler und smarter Technologien?

	Keine Herausforderung	Geringe Herausforderung	Große Herausforderung	Sehr große Herausforderung
Strukturen innerhalb der GAP noch nicht ausreichend für Digitalisierung ausgebaut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde digitale Kommunikationsvorgänge (z.B. Datenübermittlung) bei örtlichen Behörden/Ministerien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende Beratungsangebote/mangelnde Informationsmöglichkeiten über die Nutzung digitaler Technologien im Bereich des Natur- und Umweltschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende Kompatibilität digitaler Geräte mit etablierten Technologien (z.B. Ackerschlagkartei) und dadurch erheblich erhöhter (Zeit-) Aufwand bei Nutzung digitaler Technologien für den Biodiversitätsschutz	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

T2. Nennen Sie ggf. weitere Herausforderungen.



U1. Im Hinblick auf die Umsetzung von Maßnahmen zum Schutz der Biodiversität: Wo sehen Sie das größte Potential digitaler und smarterer Technologien?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Signifikante Zeiteinsparungen (bei Beantragung, Planung, Durchführung und Dokumentation der Maßnahmen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Besser aufbereitete Informationsmöglichkeiten (z.B. in Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere (standortspezifischere) Möglichkeiten des Biodiversitätsschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vereinfachte Übermittlung der Dokumentationsnachweise von implementierten Maßnahmen (z.B. mit Hilfe von Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Minderung von Sanktionsrisiken durch präzisere Flächenbearbeitung mit digitalen Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

U2. Nennen Sie ggf. weitere Potentiale.

V1. Welches Betriebsmodell liegt ihrem Betrieb zugrunde?

- Klassisch konventionell
- Konventionell wirtschaftend mit reduziertem Dünge- und PSM- Einsatz
- Ökologisch

V2. Wie viele Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

- Bis 9 Beschäftigte
- 10 bis 49 Beschäftigte
- 50 bis 249 Beschäftigte
- Mehr als 249 Beschäftigte



V3. Wie viel Hektar landwirtschaftlich genutzter Fläche umfasst Ihr Betrieb?

Unter 5 Hektar

5 bis 10 Hektar

11 bis 20 Hektar

21 bis 50 Hektar

51 bis 100 Hektar

101 bis 200 Hektar

201 bis 500 Hektar

501 bis 1000 Hektar

Über 1000 Hektar

W1. In welchen Betriebsmodellen sind Sie aktiv?

(Mehrfachauswahl möglich)

Klassisch konventionell

Konventionell wirtschaftend mit reduziertem Dünge- und PSM Einsatz

Ökologisch

W2. Wie viel Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

Bis 9 Beschäftigte

10 bis 49 Beschäftigte

50 bis 249 Beschäftigte

Mehr als 249 Beschäftigte



W3. Wie viel Hektar landwirtschaftlich genutzter Fläche bewirtschaften Sie?

- Unter 5 Hektar
- 5 bis 10 Hektar
- 11 bis 20 Hektar
- 21 bis 50 Hektar
- 51 bis 100 Hektar
- 101 bis 200 Hektar
- 201 bis 500 Hektar
- 501 bis 1000 Hektar
- Über 1000 Hektar

X1. In welchem Bundesland bzw. in welchen Bundesländern befindet/befinden sich Ihre bewirtschaftete(n) Fläche(n)?

(Mehrfachauswahl möglich)

- Baden-Württemberg
- Bayern
- Berlin
- Brandenburg
- Bremen
- Hamburg
- Hessen
- Mecklenburg-Vorpommern
- Niedersachsen
- Nordrhein-Westfalen
- Rheinland-Pfalz
- Saarland
- Sachsen
- Sachsen-Anhalt
- Schleswig-Holstein
- Thüringen



Y1. Welchem Geschlecht ordnen Sie sich zu?

- Männlich
- Weiblich
- Divers

Z1. Wie alt sind Sie?

- Unter 25 Jahre
- 25 bis 35 Jahre
- 36 bis 45 Jahre
- 46 bis 55 Jahre
- 56 bis 66 Jahre
- Über 66 Jahre

AA1. Was ist Ihr höchster beruflicher Abschluss?

- Promotion
- Diplom
- Master
- Bachelor
- Fachschulabschluss
- Lehre/Berufsausbildung
- Kein beruflicher Abschluss
- Sonstiges

Sonstiges



A2. Ich kann meine Einwilligung jederzeit kostenfrei widerrufen, ohne dass mir dadurch Nachteile entstehen. Die Rechtmäßigkeit, der bis zum Widerruf erfolgten Verarbeitung meiner personenbezogenen Angaben bleibt davon unberührt. Meinen Widerruf kann ich an die oben angegebenen Kontaktmöglichkeiten richten.

Ja, ich akzeptiere und gehe weiter zum Fragebogen.

Nein, ich akzeptiere nicht und beende den Fragebogen.

A3.

2

B1. In welchem der folgenden Bereiche sind Sie hauptamtlich tätig?

Landwirtschaftsbetrieb

Lohnunternehmen

andere Unternehmen

Politik/Verwaltung

Verband/Nichtregierungsorganisation

Forschung

Sonstiges

Sonstiges

C1. In welchen landwirtschaftlichen Bereichen sind Sie aktiv?

(Mehrfachauswahl möglich)

Viehzucht

Ackerbau

Gartenbau

Grünlandbewirtschaftung



Sonstiges

Sonstiges

D1. Bei welchem Arbeitgeber/Institution sind Sie beschäftigt?

Bundesministerium

Landesministerium

Landesanstalt für Landwirtschaft

Landwirtschaftskammer

Bundestag

Landtag

Kreistag

Sonstiges

Sonstiges

D2. Bei welcher Art von Verband sind Sie tätig?

Überregionaler Verband

Regionaler Verband

Sonstiges

Sonstiges



D3. Wo sind Sie tätig?

- Kleinstunternehmen (bis 9 Beschäftigte)
- Kleinunternehmen (bis 49 Beschäftigte)
- Mittelunternehmen (bis 249 Beschäftigte)
- Großunternehmen (über 249 Beschäftigte)
- Sonstiges

Sonstiges

D4. Wo sind Sie tätig?

- Universität
- Fachhochschule und Hochschule für Angewandte Wissenschaft (HAW)
- Außeruniversitäre Forschungseinrichtung
- Sonstiges

Sonstiges

E1. In welchem Bereich liegt Ihr Arbeitsschwerpunkt bzw. Ihre persönliche Expertise?

(Bitte geben Sie maximal 1-2 Stichworte an.)

Business Development Landtechnik
 Dipl.Ing. (FH) agar - Nebenerwerbsbetrieb Ackerbau



F1. Seit wann arbeiten Sie in diesem Arbeitsschwerpunkt?

Bis 1 Jahr

2 bis 5 Jahre

6 bis 10 Jahre

Über 10 Jahre

G1. Welche digitalen und smarten Technologien nutzen Sie für Ihre Tätigkeiten und wie häufig?

	Täglich	Regelmäßig (wöchentlich)	Gelegentlich (monatlich)	Bisher noch nicht eingesetzt, aber Einsatz ist geplant	Bisher weder genutzt, noch geplant
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365 FarmNet, Xarvio Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B.: Field Navigator, Trimble Center Point RX; CEMOS Adviser CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

G2. Nutzen Sie sonstige digitale und smarte Technologien?

Ja

Nein

H1. Inwieweit könnte der Einsatz digitaler und smarterer Technologien in der Landwirtschaft zum Erreichen der folgenden Ziele beitragen?

	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeiterleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transfer von Daten und Wissen (innerhalb des Betriebs und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

H2. Nennen Sie ggf. weitere mögliche Ziele.

I1. Was ist aus Ihrer Sicht der Entwicklungsstand in den folgenden Technologiebereichen für den Einsatz in der Landwirtschaft?

	Forschung (Technology readiness levels 1-3)	Entwicklung (Technology readiness levels 4-6)	Einsatz (Technology readiness levels 7-9)	Keine Antwort
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365FarmNet, XARVIO Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B. Field Navigator, Trimble Center Point RX, CEMOS Advisor CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Machine Learning für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Andere künstliche Intelligenz für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



J1. Für welche Zwecke nutzen Sie die angegebenen digitalen und smarten Technologien?

	Ja	Nein
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeitserleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>
Transfer von Daten und Wissen (innerhalb und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>

J2. Ergänzen Sie ggf. weitere Zwecke.

K1. Welche Faktoren erschweren oder verhindern den Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Grundbildung/Erfahrung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Komplexe Bedienung digitaler Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

K2. Nennen Sie ggf. weitere Hemmnisse.

L1. Welche Faktoren erschweren oder verhindern aus Ihrer Sicht den Einsatz digitaler und smarterer Technologien in der Landwirtschaft?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Kenntnisse	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Komplexe Bedienung digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



L2. Nennen Sie ggf. weitere Hemmnisse.

Implementierungsaufwand
 Kosten Nutzen Darstellung oft schwierig - wie viel €/ha mehr liefert mir es am Ende des Tages wirklich?

M1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarterer Technologien für Ihre Tätigkeiten zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

M2. Nennen Sie ggf. weitere Maßnahmen.

N1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarterer Technologien in Landwirtschaftsbetrieben zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>



N2. Nennen Sie ggf. weitere Maßnahmen.

O1. Bezüglich Effizienzsteigerungen: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

O2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Gemüsebau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Grünlandbewirtschaftung	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

P1. Bezüglich Umweltschutz: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein, um positive Effekte zu erreichen?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Gemüsebau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Grünlandbewirtschaftung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q1. Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in der Landwirtschaft für Nachhaltigkeit und Umweltschutz ein?

Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Ausdehnung von ökologischem Landbau	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verringerung der Bodenbelastung (Ressourceneinsparung)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Förderung von kleinflächigen Anbausystemen zum Schutz der Biodiversität	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Diversifizierung von Fruchtfolgen	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur (z.B. durch den Einsatz leichterer Maschinen)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vermehrte teilflächenspezifische Maßnahmen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

Q2. Nennen Sie ggf. weitere Punkte.

R1.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

**Farm-Management- und Informationssysteme/
Entscheidungsunterstützungssysteme**

Klimaschutz	<input type="checkbox"/>
Biodiversität	<input type="checkbox"/>
Ernährungsproblematik	<input checked="" type="checkbox"/>
Keine Antwort	<input type="checkbox"/>

**R2.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Digitale Informationsplattformen

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input type="checkbox"/> |
| Biodiversität | <input type="checkbox"/> |
| Ernährungsproblematik | <input type="checkbox"/> |
| Keine Antwort | <input checked="" type="checkbox"/> |

R3.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

(Digitale) Technologien für Landmaschinen – Aktorik

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input checked="" type="checkbox"/> |
| Biodiversität | <input checked="" type="checkbox"/> |
| Ernährungsproblematik | <input checked="" type="checkbox"/> |
| Keine Antwort | <input type="checkbox"/> |

R4.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Erfassungs- und Sensortechnologien – Sensorik

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input checked="" type="checkbox"/> |
| Biodiversität | <input checked="" type="checkbox"/> |
| Ernährungsproblematik | <input type="checkbox"/> |

Keine Antwort **R5.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Feldroboter

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R6.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Unbemannte Luftfahrzeuge und -systeme

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R7.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Citizen-Science-Plattformen

Klimaschutz Biodiversität

Ernährungsproblematik Keine Antwort **R8.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Machine Learning für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R9.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Andere künstliche Intelligenz für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort



S1. Wie oft haben Sie bereits Umwelt- und Naturschutzmaßnahmen umgesetzt?

- Einmal durchgeführt
- Zweimal durchgeführt
- Jedes Jahr durchgeführt
- Noch nicht durchgeführt
- Mehr als zweimal durchgeführt und zwar

Mehr als zweimal durchgeführt und zwar

T1. Im Hinblick auf den Schutz der Biodiversität in Agrarflächen: Wo sehen Sie die größten verbleibenden Herausforderungen für einen kontinuierlichen, regelmäßigen Einsatz digitaler und smarter Technologien?

	Keine Herausforderung	Geringe Herausforderung	Große Herausforderung	Sehr große Herausforderung
Strukturen innerhalb der GAP noch nicht ausreichend für Digitalisierung ausgebaut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde digitale Kommunikationsvorgänge (z.B. Datenübermittlung) bei örtlichen Behörden/Ministerien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende Beratungsangebote/mangelnde Informationsmöglichkeiten über die Nutzung digitaler Technologien im Bereich des Natur- und Umweltschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende Kompatibilität digitaler Geräte mit etablierten Technologien (z.B. Ackerschlagkartei) und dadurch erheblich erhöhter (Zeit-) Aufwand bei Nutzung digitaler Technologien für den Biodiversitätsschutz	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

T2. Nennen Sie ggf. weitere Herausforderungen.



U1. Im Hinblick auf die Umsetzung von Maßnahmen zum Schutz der Biodiversität: Wo sehen Sie das größte Potential digitaler und smarterer Technologien?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Signifikante Zeiteinsparungen (bei Beantragung, Planung, Durchführung und Dokumentation der Maßnahmen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Besser aufbereitete Informationsmöglichkeiten (z.B. in Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere (standortspezifischere) Möglichkeiten des Biodiversitätsschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vereinfachte Übermittlung der Dokumentationsnachweise von implementierten Maßnahmen (z.B. mit Hilfe von Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Minderung von Sanktionsrisiken durch präzisere Flächenbearbeitung mit digitalen Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

U2. Nennen Sie ggf. weitere Potentiale.

V1. Welches Betriebsmodell liegt ihrem Betrieb zugrunde?

- Klassisch konventionell
- Konventionell wirtschaftend mit reduziertem Dünge- und PSM- Einsatz
- Ökologisch

V2. Wie viele Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

- Bis 9 Beschäftigte
- 10 bis 49 Beschäftigte
- 50 bis 249 Beschäftigte
- Mehr als 249 Beschäftigte



V3. Wie viel Hektar landwirtschaftlich genutzter Fläche umfasst Ihr Betrieb?

Unter 5 Hektar

5 bis 10 Hektar

11 bis 20 Hektar

21 bis 50 Hektar

51 bis 100 Hektar

101 bis 200 Hektar

201 bis 500 Hektar

501 bis 1000 Hektar

Über 1000 Hektar

W1. In welchen Betriebsmodellen sind Sie aktiv?

(Mehrfachauswahl möglich)

Klassisch konventionell

Konventionell wirtschaftend mit reduziertem Dünge- und PSM Einsatz

Ökologisch

W2. Wie viel Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

Bis 9 Beschäftigte

10 bis 49 Beschäftigte

50 bis 249 Beschäftigte

Mehr als 249 Beschäftigte



W3. Wie viel Hektar landwirtschaftlich genutzter Fläche bewirtschaften Sie?

- Unter 5 Hektar
- 5 bis 10 Hektar
- 11 bis 20 Hektar
- 21 bis 50 Hektar
- 51 bis 100 Hektar
- 101 bis 200 Hektar
- 201 bis 500 Hektar
- 501 bis 1000 Hektar
- Über 1000 Hektar

X1. In welchem Bundesland bzw. in welchen Bundesländern befindet/befinden sich Ihre bewirtschaftete(n) Fläche(n)?

(Mehrfachauswahl möglich)

- Baden-Württemberg
- Bayern
- Berlin
- Brandenburg
- Bremen
- Hamburg
- Hessen
- Mecklenburg-Vorpommern
- Niedersachsen
- Nordrhein-Westfalen
- Rheinland-Pfalz
- Saarland
- Sachsen
- Sachsen-Anhalt
- Schleswig-Holstein
- Thüringen



Y1. Welchem Geschlecht ordnen Sie sich zu?

- Männlich
- Weiblich
- Divers

Z1. Wie alt sind Sie?

- Unter 25 Jahre
- 25 bis 35 Jahre
- 36 bis 45 Jahre
- 46 bis 55 Jahre
- 56 bis 66 Jahre
- Über 66 Jahre

AA1. Was ist Ihr höchster beruflicher Abschluss?

- Promotion
- Diplom
- Master
- Bachelor
- Fachschulabschluss
- Lehre/Berufsausbildung
- Kein beruflicher Abschluss
- Sonstiges

Sonstiges



A2. Ich kann meine Einwilligung jederzeit kostenfrei widerrufen, ohne dass mir dadurch Nachteile entstehen. Die Rechtmäßigkeit, der bis zum Widerruf erfolgten Verarbeitung meiner personenbezogenen Angaben bleibt davon unberührt. Meinen Widerruf kann ich an die oben angegebenen Kontaktmöglichkeiten richten.

Ja, ich akzeptiere und gehe weiter zum Fragebogen.

Nein, ich akzeptiere nicht und beende den Fragebogen.

A3.

2

B1. In welchem der folgenden Bereiche sind Sie hauptamtlich tätig?

Landwirtschaftsbetrieb

Lohnunternehmen

andere Unternehmen

Politik/Verwaltung

Verband/Nichtregierungsorganisation

Forschung

Sonstiges

Sonstiges

C1. In welchen landwirtschaftlichen Bereichen sind Sie aktiv?

(Mehrfachauswahl möglich)

Viehzucht

Ackerbau

Gartenbau

Grünlandbewirtschaftung



Sonstiges



Sonstiges

D1. Bei welchem Arbeitgeber/Institution sind Sie beschäftigt?

Bundesministerium

Landesministerium

Landesanstalt für Landwirtschaft

Landwirtschaftskammer

Bundestag

Landtag

Kreistag

Sonstiges

Sonstiges

D2. Bei welcher Art von Verband sind Sie tätig?

Überregionaler Verband

Regionaler Verband

Sonstiges

Sonstiges



D3. Wo sind Sie tätig?

Kleinstunternehmen (bis 9 Beschäftigte)

Kleinunternehmen (bis 49 Beschäftigte)

Mittelunternehmen (bis 249 Beschäftigte)

Großunternehmen (über 249 Beschäftigte)

Sonstiges

Sonstiges

D4. Wo sind Sie tätig?

Universität

Fachhochschule und Hochschule für Angewandte Wissenschaft (HAW)

Außeruniversitäre Forschungseinrichtung

Sonstiges

Sonstiges

E1. In welchem Bereich liegt Ihr Arbeitsschwerpunkt bzw. Ihre persönliche Expertise?

(Bitte geben Sie maximal 1-2 Stichworte an.)

Lohnunternehmen
Landhandel

Lohnunternehmen
Landhandel



F1. Seit wann arbeiten Sie in diesem Arbeitsschwerpunkt?

Bis 1 Jahr

2 bis 5 Jahre

6 bis 10 Jahre

Über 10 Jahre

G1. Welche digitalen und smarten Technologien nutzen Sie für Ihre Tätigkeiten und wie häufig?

	Täglich	Regelmäßig (wöchentlich)	Gelegentlich (monatlich)	Bisher noch nicht eingesetzt, aber Einsatz ist geplant	Bisher weder genutzt, noch geplant
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365 FarmNet, Xarvio Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B.: Field Navigator, Trimble Center Point RX; CEMOS Adviser CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

G2. Nutzen Sie sonstige digitale und smarte Technologien?

Ja

Nein

H1. Inwieweit könnte der Einsatz digitaler und smarterer Technologien in der Landwirtschaft zum Erreichen der folgenden Ziele beitragen?

	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>



	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeits erleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Transfer von Daten und Wissen (innerhalb des Betriebs und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

H2. Nennen Sie ggf. weitere mögliche Ziele.

I1. Was ist aus Ihrer Sicht der Entwicklungsstand in den folgenden Technologiebereichen für den Einsatz in der Landwirtschaft?

	Forschung (Technology readiness levels 1-3)	Entwicklung (Technology readiness levels 4-6)	Einsatz (Technology readiness levels 7-9)	Keine Antwort
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365FarmNet, XARVIO Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B. Field Navigator, Trimble Center Point RX, CEMOS Advisor CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Machine Learning für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Andere künstliche Intelligenz für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



J1. Für welche Zwecke nutzen Sie die angegebenen digitalen und smarten Technologien?

	Ja	Nein
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeitserleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>
Transfer von Daten und Wissen (innerhalb und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>

J2. Ergänzen Sie ggf. weitere Zwecke.

K1. Welche Faktoren erschweren oder verhindern den Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Grundbildung/Erfahrung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Komplexe Bedienung digitaler Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

K2. Nennen Sie ggf. weitere Hemmnisse.

L1. Welche Faktoren erschweren oder verhindern aus Ihrer Sicht den Einsatz digitaler und smarterer Technologien in der Landwirtschaft?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Kenntnisse	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Komplexe Bedienung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



L2. Nennen Sie ggf. weitere Hemmnisse.

M1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

M2. Nennen Sie ggf. weitere Maßnahmen.

N1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien in Landwirtschaftsbetrieben zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>



N2. Nennen Sie ggf. weitere Maßnahmen.

O1. Bezüglich Effizienzsteigerungen: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

O2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Gemüsebau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Grünlandbewirtschaftung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P1. Bezüglich Umweltschutz: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein, um positive Effekte zu erreichen?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>



Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Gemüsebau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Grünlandbewirtschaftung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q1. Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in der Landwirtschaft für Nachhaltigkeit und Umweltschutz ein?

Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Ausdehnung von ökologischem Landbau	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verringerung der Bodenbelastung (Ressourceneinsparung)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Förderung von kleinflächigen Anbausystemen zum Schutz der Biodiversität	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Diversifizierung von Fruchtfolgen	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur (z.B. durch den Einsatz leichterer Maschinen)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vermehrte teilflächenspezifische Maßnahmen	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

Q2. Nennen Sie ggf. weitere Punkte.

R1.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

**Farm-Management- und Informationssysteme/
Entscheidungsunterstützungssysteme**

Klimaschutz	<input type="checkbox"/>
Biodiversität	<input type="checkbox"/>
Ernährungsproblematik	<input checked="" type="checkbox"/>
Keine Antwort	<input type="checkbox"/>

**R2.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Digitale Informationsplattformen

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input type="checkbox"/> |
| Biodiversität | <input type="checkbox"/> |
| Ernährungsproblematik | <input checked="" type="checkbox"/> |
| Keine Antwort | <input type="checkbox"/> |

R3.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

(Digitale) Technologien für Landmaschinen – Aktorik

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input checked="" type="checkbox"/> |
| Biodiversität | <input type="checkbox"/> |
| Ernährungsproblematik | <input type="checkbox"/> |
| Keine Antwort | <input type="checkbox"/> |

R4.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Erfassungs- und Sensortechnologien – Sensorik

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input type="checkbox"/> |
| Biodiversität | <input type="checkbox"/> |
| Ernährungsproblematik | <input checked="" type="checkbox"/> |

Keine Antwort

R5.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Feldroboter

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort

R6.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Unbemannte Luftfahrzeuge und -systeme

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort

R7.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Citizen-Science-Plattformen

Klimaschutz Biodiversität

Ernährungsproblematik Keine Antwort **R8.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Machine Learning für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R9.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Andere künstliche Intelligenz für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort



S1. Wie oft haben Sie bereits Umwelt- und Naturschutzmaßnahmen umgesetzt?

- Einmal durchgeführt
- Zweimal durchgeführt
- Jedes Jahr durchgeführt
- Noch nicht durchgeführt
- Mehr als zweimal durchgeführt und zwar

Mehr als zweimal durchgeführt und zwar

T1. Im Hinblick auf den Schutz der Biodiversität in Agrarflächen: Wo sehen Sie die größten verbleibenden Herausforderungen für einen kontinuierlichen, regelmäßigen Einsatz digitaler und smarter Technologien?

	Keine Herausforderung	Geringe Herausforderung	Große Herausforderung	Sehr große Herausforderung
Strukturen innerhalb der GAP noch nicht ausreichend für Digitalisierung ausgebaut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde digitale Kommunikationsvorgänge (z.B. Datenübermittlung) bei örtlichen Behörden/Ministerien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende Beratungsangebote/mangelnde Informationsmöglichkeiten über die Nutzung digitaler Technologien im Bereich des Natur- und Umweltschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende Kompatibilität digitaler Geräte mit etablierten Technologien (z.B. Ackerschlagkartei) und dadurch erheblich erhöhter (Zeit-) Aufwand bei Nutzung digitaler Technologien für den Biodiversitätsschutz	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

T2. Nennen Sie ggf. weitere Herausforderungen.



U1. Im Hinblick auf die Umsetzung von Maßnahmen zum Schutz der Biodiversität: Wo sehen Sie das größte Potential digitaler und smarterer Technologien?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Signifikante Zeiteinsparungen (bei Beantragung, Planung, Durchführung und Dokumentation der Maßnahmen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Besser aufbereitete Informationsmöglichkeiten (z.B. in Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere (standortspezifischere) Möglichkeiten des Biodiversitätsschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vereinfachte Übermittlung der Dokumentationsnachweise von implementierten Maßnahmen (z.B. mit Hilfe von Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Minderung von Sanktionsrisiken durch präzisere Flächenbearbeitung mit digitalen Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

U2. Nennen Sie ggf. weitere Potentiale.

V1. Welches Betriebsmodell liegt ihrem Betrieb zugrunde?

- Klassisch konventionell
- Konventionell wirtschaftend mit reduziertem Dünge- und PSM- Einsatz
- Ökologisch

V2. Wie viele Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

- Bis 9 Beschäftigte
- 10 bis 49 Beschäftigte
- 50 bis 249 Beschäftigte
- Mehr als 249 Beschäftigte



V3. Wie viel Hektar landwirtschaftlich genutzter Fläche umfasst Ihr Betrieb?

Unter 5 Hektar

5 bis 10 Hektar

11 bis 20 Hektar

21 bis 50 Hektar

51 bis 100 Hektar

101 bis 200 Hektar

201 bis 500 Hektar

501 bis 1000 Hektar

Über 1000 Hektar

W1. In welchen Betriebsmodellen sind Sie aktiv?

(Mehrfachauswahl möglich)

Klassisch konventionell

Konventionell wirtschaftend mit reduziertem Dünge- und PSM Einsatz

Ökologisch

W2. Wie viel Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

Bis 9 Beschäftigte

10 bis 49 Beschäftigte

50 bis 249 Beschäftigte

Mehr als 249 Beschäftigte



W3. Wie viel Hektar landwirtschaftlich genutzter Fläche bewirtschaften Sie?

- Unter 5 Hektar
- 5 bis 10 Hektar
- 11 bis 20 Hektar
- 21 bis 50 Hektar
- 51 bis 100 Hektar
- 101 bis 200 Hektar
- 201 bis 500 Hektar
- 501 bis 1000 Hektar
- Über 1000 Hektar

X1. In welchem Bundesland bzw. in welchen Bundesländern befindet/befinden sich Ihre bewirtschaftete(n) Fläche(n)?

(Mehrfachauswahl möglich)

- Baden-Württemberg
- Bayern
- Berlin
- Brandenburg
- Bremen
- Hamburg
- Hessen
- Mecklenburg-Vorpommern
- Niedersachsen
- Nordrhein-Westfalen
- Rheinland-Pfalz
- Saarland
- Sachsen
- Sachsen-Anhalt
- Schleswig-Holstein
- Thüringen



Y1. Welchem Geschlecht ordnen Sie sich zu?

- Männlich
- Weiblich
- Divers

Z1. Wie alt sind Sie?

- Unter 25 Jahre
- 25 bis 35 Jahre
- 36 bis 45 Jahre
- 46 bis 55 Jahre
- 56 bis 66 Jahre
- Über 66 Jahre

AA1. Was ist Ihr höchster beruflicher Abschluss?

- Promotion
- Diplom
- Master
- Bachelor
- Fachschulabschluss
- Lehre/Berufsausbildung
- Kein beruflicher Abschluss
- Sonstiges

Sonstiges



A2. Ich kann meine Einwilligung jederzeit kostenfrei widerrufen, ohne dass mir dadurch Nachteile entstehen. Die Rechtmäßigkeit, der bis zum Widerruf erfolgten Verarbeitung meiner personenbezogenen Angaben bleibt davon unberührt. Meinen Widerruf kann ich an die oben angegebenen Kontaktmöglichkeiten richten.

Ja, ich akzeptiere und gehe weiter zum Fragebogen.

Nein, ich akzeptiere nicht und beende den Fragebogen.

A3.

2

B1. In welchem der folgenden Bereiche sind Sie hauptamtlich tätig?

Landwirtschaftsbetrieb

Lohnunternehmen

andere Unternehmen

Politik/Verwaltung

Verband/Nichtregierungsorganisation

Forschung

Sonstiges

Sonstiges

C1. In welchen landwirtschaftlichen Bereichen sind Sie aktiv?

(Mehrfachauswahl möglich)

Viehzucht

Ackerbau

Gartenbau

Grünlandbewirtschaftung



Sonstiges



Sonstiges

D1. Bei welchem Arbeitgeber/Institution sind Sie beschäftigt?

Bundesministerium

Landesministerium

Landesanstalt für Landwirtschaft

Landwirtschaftskammer

Bundestag

Landtag

Kreistag

Sonstiges

Sonstiges

D2. Bei welcher Art von Verband sind Sie tätig?

Überregionaler Verband

Regionaler Verband

Sonstiges

Sonstiges



D3. Wo sind Sie tätig?

Kleinstunternehmen (bis 9 Beschäftigte)

Kleinunternehmen (bis 49 Beschäftigte)

Mittelunternehmen (bis 249 Beschäftigte)

Großunternehmen (über 249 Beschäftigte)

Sonstiges

Sonstiges

D4. Wo sind Sie tätig?

Universität

Fachhochschule und Hochschule für Angewandte Wissenschaft (HAW)

Außeruniversitäre Forschungseinrichtung

Sonstiges

Sonstiges

E1. In welchem Bereich liegt Ihr Arbeitsschwerpunkt bzw. Ihre persönliche Expertise?

(Bitte geben Sie maximal 1-2 Stichworte an.)

Verfahrenstechnik



F1. Seit wann arbeiten Sie in diesem Arbeitsschwerpunkt?

Bis 1 Jahr

2 bis 5 Jahre

6 bis 10 Jahre

Über 10 Jahre

G1. Welche digitalen und smarten Technologien nutzen Sie für Ihre Tätigkeiten und wie häufig?

	Täglich	Regelmäßig (wöchentlich)	Gelegentlich (monatlich)	Bisher noch nicht eingesetzt, aber Einsatz ist geplant	Bisher weder genutzt, noch geplant
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365 FarmNet, Xarvio Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B.: Field Navigator, Trimble Center Point RX; CEMOS Adviser CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

G2. Nutzen Sie sonstige digitale und smarte Technologien?

Ja

Nein

H1. Inwieweit könnte der Einsatz digitaler und smarterer Technologien in der Landwirtschaft zum Erreichen der folgenden Ziele beitragen?

	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>



	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeiterleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Transfer von Daten und Wissen (innerhalb des Betriebs und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

H2. Nennen Sie ggf. weitere mögliche Ziele.

I1. Was ist aus Ihrer Sicht der Entwicklungsstand in den folgenden Technologiebereichen für den Einsatz in der Landwirtschaft?

	Forschung (Technology readiness levels 1-3)	Entwicklung (Technology readiness levels 4-6)	Einsatz (Technology readiness levels 7-9)	Keine Antwort
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365FarmNet, XARVIO Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B. Field Navigator, Trimble Center Point RX, CEMOS Advisor CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Machine Learning für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Andere künstliche Intelligenz für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



J1. Für welche Zwecke nutzen Sie die angegebenen digitalen und smarten Technologien?

	Ja	Nein
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeitserleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>
Transfer von Daten und Wissen (innerhalb und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>

J2. Ergänzen Sie ggf. weitere Zwecke.

K1. Welche Faktoren erschweren oder verhindern den Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Grundbildung/Erfahrung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Komplexe Bedienung digitaler Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

K2. Nennen Sie ggf. weitere Hemmnisse.

L1. Welche Faktoren erschweren oder verhindern aus Ihrer Sicht den Einsatz digitaler und smarterer Technologien in der Landwirtschaft?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Kenntnisse	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Komplexe Bedienung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



L2. Nennen Sie ggf. weitere Hemmnisse.

M1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

M2. Nennen Sie ggf. weitere Maßnahmen.

N1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien in Landwirtschaftsbetrieben zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>



N2. Nennen Sie ggf. weitere Maßnahmen.

O1. Bezüglich Effizienzsteigerungen: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

O2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Gemüsebau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Grünlandbewirtschaftung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P1. Bezüglich Umweltschutz: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein, um positive Effekte zu erreichen?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

P2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>



Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Gemüsebau

Grünlandbewirtschaftung

Q1. Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in der Landwirtschaft für Nachhaltigkeit und Umweltschutz ein?

Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Ausdehnung von ökologischem Landbau

Verringerung der Bodenbelastung (Ressourceneinsparung)

Förderung von kleinflächigen Anbausystemen zum Schutz der Biodiversität

Diversifizierung von Fruchtfolgen

Verbesserung der Bodenstruktur (z.B. durch den Einsatz leichterer Maschinen)

Vermehrte teilflächenspezifische Maßnahmen

Q2. Nennen Sie ggf. weitere Punkte.

R1.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

**Farm-Management- und Informationssysteme/
Entscheidungsunterstützungssysteme**

Klimaschutz

Biodiversität

Ernährungsproblematik

Keine Antwort

**R2.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Digitale Informationsplattformen

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input type="checkbox"/> |
| Biodiversität | <input type="checkbox"/> |
| Ernährungsproblematik | <input type="checkbox"/> |
| Keine Antwort | <input checked="" type="checkbox"/> |

R3.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

(Digitale) Technologien für Landmaschinen – Aktorik

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input checked="" type="checkbox"/> |
| Biodiversität | <input type="checkbox"/> |
| Ernährungsproblematik | <input checked="" type="checkbox"/> |
| Keine Antwort | <input type="checkbox"/> |

R4.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Erfassungs- und Sensortechnologien – Sensorik

- | | |
|-----------------------|-------------------------------------|
| Klimaschutz | <input checked="" type="checkbox"/> |
| Biodiversität | <input type="checkbox"/> |
| Ernährungsproblematik | <input checked="" type="checkbox"/> |

Keine Antwort

R5.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Feldroboter

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort

R6.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Unbemannte Luftfahrzeuge und -systeme

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort

R7.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Citizen-Science-Plattformen

Klimaschutz Biodiversität

Ernährungsproblematik Keine Antwort **R8.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Machine Learning für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R9.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Andere künstliche Intelligenz für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort



S1. Wie oft haben Sie bereits Umwelt- und Naturschutzmaßnahmen umgesetzt?

- Einmal durchgeführt
- Zweimal durchgeführt
- Jedes Jahr durchgeführt
- Noch nicht durchgeführt
- Mehr als zweimal durchgeführt und zwar

Mehr als zweimal durchgeführt und zwar

T1. Im Hinblick auf den Schutz der Biodiversität in Agrarflächen: Wo sehen Sie die größten verbleibenden Herausforderungen für einen kontinuierlichen, regelmäßigen Einsatz digitaler und smarter Technologien?

	Keine Herausforderung	Geringe Herausforderung	Große Herausforderung	Sehr große Herausforderung
Strukturen innerhalb der GAP noch nicht ausreichend für Digitalisierung ausgebaut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde digitale Kommunikationsvorgänge (z.B. Datenübermittlung) bei örtlichen Behörden/Ministerien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende Beratungsangebote/mangelnde Informationsmöglichkeiten über die Nutzung digitaler Technologien im Bereich des Natur- und Umweltschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende Kompatibilität digitaler Geräte mit etablierten Technologien (z.B. Ackerschlagkartei) und dadurch erheblich erhöhter (Zeit-) Aufwand bei Nutzung digitaler Technologien für den Biodiversitätsschutz	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

T2. Nennen Sie ggf. weitere Herausforderungen.



U1. Im Hinblick auf die Umsetzung von Maßnahmen zum Schutz der Biodiversität: Wo sehen Sie das größte Potential digitaler und smarterer Technologien?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Signifikante Zeiteinsparungen (bei Beantragung, Planung, Durchführung und Dokumentation der Maßnahmen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Besser aufbereitete Informationsmöglichkeiten (z.B. in Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere (standortspezifischere) Möglichkeiten des Biodiversitätsschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vereinfachte Übermittlung der Dokumentationsnachweise von implementierten Maßnahmen (z.B. mit Hilfe von Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Minderung von Sanktionsrisiken durch präzisere Flächenbearbeitung mit digitalen Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

U2. Nennen Sie ggf. weitere Potentiale.

V1. Welches Betriebsmodell liegt ihrem Betrieb zugrunde?

- Klassisch konventionell
- Konventionell wirtschaftend mit reduziertem Dünge- und PSM- Einsatz
- Ökologisch

V2. Wie viele Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

- Bis 9 Beschäftigte
- 10 bis 49 Beschäftigte
- 50 bis 249 Beschäftigte
- Mehr als 249 Beschäftigte



V3. Wie viel Hektar landwirtschaftlich genutzter Fläche umfasst Ihr Betrieb?

Unter 5 Hektar

5 bis 10 Hektar

11 bis 20 Hektar

21 bis 50 Hektar

51 bis 100 Hektar

101 bis 200 Hektar

201 bis 500 Hektar

501 bis 1000 Hektar

Über 1000 Hektar

W1. In welchen Betriebsmodellen sind Sie aktiv?

(Mehrfachauswahl möglich)

Klassisch konventionell

Konventionell wirtschaftend mit reduziertem Dünge- und PSM Einsatz

Ökologisch

W2. Wie viel Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

Bis 9 Beschäftigte

10 bis 49 Beschäftigte

50 bis 249 Beschäftigte

Mehr als 249 Beschäftigte



W3. Wie viel Hektar landwirtschaftlich genutzter Fläche bewirtschaften Sie?

- Unter 5 Hektar
- 5 bis 10 Hektar
- 11 bis 20 Hektar
- 21 bis 50 Hektar
- 51 bis 100 Hektar
- 101 bis 200 Hektar
- 201 bis 500 Hektar
- 501 bis 1000 Hektar
- Über 1000 Hektar

X1. In welchem Bundesland bzw. in welchen Bundesländern befindet/befinden sich Ihre bewirtschaftete(n) Fläche(n)?

(Mehrfachauswahl möglich)

- Baden-Württemberg
- Bayern
- Berlin
- Brandenburg
- Bremen
- Hamburg
- Hessen
- Mecklenburg-Vorpommern
- Niedersachsen
- Nordrhein-Westfalen
- Rheinland-Pfalz
- Saarland
- Sachsen
- Sachsen-Anhalt
- Schleswig-Holstein
- Thüringen



Y1. Welchem Geschlecht ordnen Sie sich zu?

- Männlich
- Weiblich
- Divers

Z1. Wie alt sind Sie?

- Unter 25 Jahre
- 25 bis 35 Jahre
- 36 bis 45 Jahre
- 46 bis 55 Jahre
- 56 bis 66 Jahre
- Über 66 Jahre

AA1. Was ist Ihr höchster beruflicher Abschluss?

- Promotion
- Diplom
- Master
- Bachelor
- Fachschulabschluss
- Lehre/Berufsausbildung
- Kein beruflicher Abschluss
- Sonstiges

Sonstiges



A2. Ich kann meine Einwilligung jederzeit kostenfrei widerrufen, ohne dass mir dadurch Nachteile entstehen. Die Rechtmäßigkeit, der bis zum Widerruf erfolgten Verarbeitung meiner personenbezogenen Angaben bleibt davon unberührt. Meinen Widerruf kann ich an die oben angegebenen Kontaktmöglichkeiten richten.

Ja, ich akzeptiere und gehe weiter zum Fragebogen.

Nein, ich akzeptiere nicht und beende den Fragebogen.

A3.

2

B1. In welchem der folgenden Bereiche sind Sie hauptamtlich tätig?

Landwirtschaftsbetrieb

Lohnunternehmen

andere Unternehmen

Politik/Verwaltung

Verband/Nichtregierungsorganisation

Forschung

Sonstiges

Sonstiges

Landmaschinenindustrie

C1. In welchen landwirtschaftlichen Bereichen sind Sie aktiv?

(Mehrfachauswahl möglich)

Viehzucht

Ackerbau

Gartenbau

Grünlandbewirtschaftung



Sonstiges

Sonstiges

D1. Bei welchem Arbeitgeber/Institution sind Sie beschäftigt?

Bundesministerium

Landesministerium

Landesanstalt für Landwirtschaft

Landwirtschaftskammer

Bundestag

Landtag

Kreistag

Sonstiges

Sonstiges

D2. Bei welcher Art von Verband sind Sie tätig?

Überregionaler Verband

Regionaler Verband

Sonstiges

Sonstiges



D3. Wo sind Sie tätig?

Kleinstunternehmen (bis 9 Beschäftigte)

Kleinunternehmen (bis 49 Beschäftigte)

Mittelunternehmen (bis 249 Beschäftigte)

Großunternehmen (über 249 Beschäftigte)

Sonstiges

Sonstiges

D4. Wo sind Sie tätig?

Universität

Fachhochschule und Hochschule für Angewandte Wissenschaft (HAW)

Außeruniversitäre Forschungseinrichtung

Sonstiges

Sonstiges

E1. In welchem Bereich liegt Ihr Arbeitsschwerpunkt bzw. Ihre persönliche Expertise?

(Bitte geben Sie maximal 1-2 Stichworte an.)



F1. Seit wann arbeiten Sie in diesem Arbeitsschwerpunkt?

Bis 1 Jahr

2 bis 5 Jahre

6 bis 10 Jahre

Über 10 Jahre

G1. Welche digitalen und smarten Technologien nutzen Sie für Ihre Tätigkeiten und wie häufig?

	Täglich	Regelmäßig (wöchentlich)	Gelegentlich (monatlich)	Bisher noch nicht eingesetzt, aber Einsatz ist geplant	Bisher weder genutzt, noch geplant
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365 FarmNet, Xarvio Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B.: Field Navigator, Trimble Center Point RX; CEMOS Adviser CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

G2. Nutzen Sie sonstige digitale und smarte Technologien?

Ja

Nein

Spüführungssystem., automatische Teilbreitenschaltung, Variable Ausbringmengensteuerung,
Kameragesteuerte Hacktechnik

H1. Inwieweit könnte der Einsatz digitaler und smarterer Technologien in der Landwirtschaft zum Erreichen der folgenden Ziele beitragen?

	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



	Kein Beitrag	Geringer Beitrag	Hoher Beitrag	Sehr hoher Beitrag
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeits erleichterung, Ertragssteigerung)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transfer von Daten und Wissen (innerhalb des Betriebs und außerhalb des Betriebs)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

H2. Nennen Sie ggf. weitere mögliche Ziele.

I1. Was ist aus Ihrer Sicht der Entwicklungsstand in den folgenden Technologiebereichen für den Einsatz in der Landwirtschaft?

	Forschung (Technology readiness levels 1-3)	Entwicklung (Technology readiness levels 4-6)	Einsatz (Technology readiness levels 7-9)	Keine Antwort
Farm-Management- und Informationssysteme/ Entscheidungsunterstützungssysteme (z.B. 365FarmNet, XARVIO Scouting, Agricon)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Informationsplattformen (z.B. NextFarming, eip-agri Agriculture & Innovation, Smart AKIS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Digitale Technologien für Landmaschinen – Aktorik (z.B. Field Navigator, Trimble Center Point RX, CEMOS Advisor CLAAS)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erfassungs- und Sensortechnologien – Sensorik (z.B. ISARIA (CLAAS), Yara N-Sensor, GreenSeeker)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feldroboter (z.B. FarmDroid, Dino (Naio Technologies), FarmingGT)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unbemannte Luftfahrzeuge und Luftsysteme (z.B. Drohnen von DJI, Agronator, Agrarfly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citizen-Science-Plattformen (z.B. Agoranatura, Flora Incognita App, Rote Liste Zentrum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Machine Learning für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Andere künstliche Intelligenz für landwirtschaftliche Anwendungen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



J1. Für welche Zwecke nutzen Sie die angegebenen digitalen und smarten Technologien?

	Ja	Nein
Umsetzung von Regelungen zum Umweltschutz (z.B. DüV, Richtlinien 1. und 2. Säule GAP)	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Förderung und Schutz von Biodiversität (z.B. Blühstreifen)	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Reduzierte Ausbringung umweltbelastender Stoffe (z.B. Mineraldünger, Pflanzenschutzmittel)	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Verbesserung der Bodenstruktur	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Effektivere Fruchtfolgeplanung	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ressourceneinsparung (z.B. Düngemittel und Pflanzenschutzmittel)	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Verbessertes Betriebsmanagement (Arbeitserleichterung, Ertragssteigerung)	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Monitoring von Flächen	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Unterstützung von Entscheidungen durch datengetriebene Analysen	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Transfer von Daten und Wissen (innerhalb und außerhalb des Betriebs)	<input type="checkbox"/>	<input checked="" type="checkbox"/>

J2. Ergänzen Sie ggf. weitere Zwecke.

K1. Welche Faktoren erschweren oder verhindern den Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Grundbildung/Erfahrung	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarter Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>



	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Komplexe Bedienung digitaler Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

K2. Nennen Sie ggf. weitere Hemmnisse.

L1. Welche Faktoren erschweren oder verhindern aus Ihrer Sicht den Einsatz digitaler und smarterer Technologien in der Landwirtschaft?

	Kein Hemmnis	Geringes Hemmnis	Großes Hemmnis	Sehr großes Hemmnis
Instabile Internetverbindung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sorge um Datensicherheit und -hoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wenig digitale Kenntnisse	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rechtliche Unsicherheiten bei der Nutzung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Nutzerfreundlichkeit von digitalen und smarten Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bürokratischer Aufwand beim Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kompatibilitätsprobleme zwischen Technologien von verschiedenen Anbietern	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Komplexe Bedienung digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Erhöhter Wartungsaufwand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Keine Einsatzmöglichkeiten für digitale und smarte Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kein Interesse am Einsatz digitaler und smarterer Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



L2. Nennen Sie ggf. weitere Hemmnisse.

M1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien für Ihre Tätigkeiten zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

M2. Nennen Sie ggf. weitere Maßnahmen.

N1. Für wie wichtig erachten Sie die folgenden Maßnahmen, um den (vermehrten) Einsatz digitaler und smarter Technologien in Landwirtschaftsbetrieben zu ermöglichen?

	Völlig unwichtig	Eher unwichtig	Eher wichtig	Sehr wichtig
Beratungs-, Aus- und Weiterbildungsangebote zur Nutzung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Einführung von Standards für Daten und Technologien zur Steigerung der Kompatibilität	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Subventionen für die Anschaffung digitaler und smarter Technologien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Klare gesetzliche Regelung zur Datenhoheit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spezifische Förderprogramme für kleine und mittelständische Landwirtschaftsbetriebe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



N2. Nennen Sie ggf. weitere Maßnahmen.

O1. Bezüglich Effizienzsteigerungen: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

O2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Gemüsebau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Grünlandbewirtschaftung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

P1. Bezüglich Umweltschutz: Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in den folgenden Bereichen der Landwirtschaft ein, um positive Effekte zu erreichen?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Klassisch konventioneller Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Konventioneller Landbau mit reduzierten Dünge- und Pestizideinsätzen und starker Ausrichtung entlang „guter landwirtschaftlicher Praxis“	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ökologischer Landbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

P2.

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Tierhaltung	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Ackerbau	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>



Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Gemüsebau

Grünlandbewirtschaftung

Q1. Wie hoch schätzen Sie die Potentiale digitaler und smarter Technologien in den kommenden 10 Jahren in der Landwirtschaft für Nachhaltigkeit und Umweltschutz ein?

Kein Potential Mäßiges Potential Hohes Potential Sehr hohes Potential

Ausdehnung von ökologischem Landbau

Verringerung der Bodenbelastung (Ressourceneinsparung)

Förderung von kleinflächigen Anbausystemen zum Schutz der Biodiversität

Diversifizierung von Fruchtfolgen

Verbesserung der Bodenstruktur (z.B. durch den Einsatz leichterer Maschinen)

Vermehrte teilflächenspezifische Maßnahmen

Q2. Nennen Sie ggf. weitere Punkte.

R1.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

**Farm-Management- und Informationssysteme/
Entscheidungsunterstützungssysteme**

Klimaschutz

Biodiversität

Ernährungsproblematik

Keine Antwort

**R2.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Digitale Informationsplattformen

- Klimaschutz
- Biodiversität
- Ernährungsproblematik
- Keine Antwort

R3.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

(Digitale) Technologien für Landmaschinen – Aktorik

- Klimaschutz
- Biodiversität
- Ernährungsproblematik
- Keine Antwort

R4.

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Erfassungs- und Sensortechnologien – Sensorik

- Klimaschutz
- Biodiversität
- Ernährungsproblematik

Keine Antwort **R5.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Feldroboter

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R6.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Unbemannte Luftfahrzeuge und -systeme

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R7.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Citizen-Science-Plattformen

Klimaschutz Biodiversität

Ernährungsproblematik Keine Antwort **R8.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Machine Learning für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort **R9.**

Welche digitalen und smarten Technologien können einen Beitrag zur Erreichung der Klimaziele in Deutschland, zur Erhaltung der Biodiversität und zur Lösung der globalen Ernährungsproblematik durch eine wachsende Weltbevölkerung leisten?

(Mehrfachauswahl auch pro Zeile möglich)

Andere künstliche Intelligenz für landwirtschaftliche Anwendungen

Klimaschutz Biodiversität Ernährungsproblematik Keine Antwort



S1. Wie oft haben Sie bereits Umwelt- und Naturschutzmaßnahmen umgesetzt?

- Einmal durchgeführt
- Zweimal durchgeführt
- Jedes Jahr durchgeführt
- Noch nicht durchgeführt
- Mehr als zweimal durchgeführt und zwar

Mehr als zweimal durchgeführt und zwar

T1. Im Hinblick auf den Schutz der Biodiversität in Agrarflächen: Wo sehen Sie die größten verbleibenden Herausforderungen für einen kontinuierlichen, regelmäßigen Einsatz digitaler und smarter Technologien?

	Keine Herausforderung	Geringe Herausforderung	Große Herausforderung	Sehr große Herausforderung
Strukturen innerhalb der GAP noch nicht ausreichend für Digitalisierung ausgebaut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Mangelnde digitale Kommunikationsvorgänge (z.B. Datenübermittlung) bei örtlichen Behörden/Ministerien	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Fehlende Beratungsangebote/mangelnde Informationsmöglichkeiten über die Nutzung digitaler Technologien im Bereich des Natur- und Umweltschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Fehlende Kompatibilität digitaler Geräte mit etablierten Technologien (z.B. Ackerschlagkartei) und dadurch erheblich erhöhter (Zeit-) Aufwand bei Nutzung digitaler Technologien für den Biodiversitätsschutz	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

T2. Nennen Sie ggf. weitere Herausforderungen.



U1. Im Hinblick auf die Umsetzung von Maßnahmen zum Schutz der Biodiversität: Wo sehen Sie das größte Potential digitaler und smarterer Technologien?

	Kein Potential	Mäßiges Potential	Hohes Potential	Sehr hohes Potential
Signifikante Zeiteinsparungen (bei Beantragung, Planung, Durchführung und Dokumentation der Maßnahmen)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Besser aufbereitete Informationsmöglichkeiten (z.B. in Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Effektivere (standortspezifischere) Möglichkeiten des Biodiversitätsschutzes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Vereinfachte Übermittlung der Dokumentationsnachweise von implementierten Maßnahmen (z.B. mit Hilfe von Apps)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Minderung von Sanktionsrisiken durch präzisere Flächenbearbeitung mit digitalen Technologien	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

U2. Nennen Sie ggf. weitere Potentiale.

V1. Welches Betriebsmodell liegt ihrem Betrieb zugrunde?

- Klassisch konventionell
- Konventionell wirtschaftend mit reduziertem Dünge- und PSM- Einsatz
- Ökologisch

V2. Wie viele Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

- Bis 9 Beschäftigte
- 10 bis 49 Beschäftigte
- 50 bis 249 Beschäftigte
- Mehr als 249 Beschäftigte



V3. Wie viel Hektar landwirtschaftlich genutzter Fläche umfasst Ihr Betrieb?

- Unter 5 Hektar
- 5 bis 10 Hektar
- 11 bis 20 Hektar
- 21 bis 50 Hektar
- 51 bis 100 Hektar
- 101 bis 200 Hektar
- 201 bis 500 Hektar
- 501 bis 1000 Hektar
- Über 1000 Hektar

W1. In welchen Betriebsmodellen sind Sie aktiv?

(Mehrfachauswahl möglich)

- Klassisch konventionell
- Konventionell wirtschaftend mit reduziertem Dünge- und PSM Einsatz
- Ökologisch

W2. Wie viel Mitarbeiter und Mitarbeiterinnen sind in Ihrem Betrieb beschäftigt?

- Bis 9 Beschäftigte
- 10 bis 49 Beschäftigte
- 50 bis 249 Beschäftigte
- Mehr als 249 Beschäftigte



W3. Wie viel Hektar landwirtschaftlich genutzter Fläche bewirtschaften Sie?

- Unter 5 Hektar
- 5 bis 10 Hektar
- 11 bis 20 Hektar
- 21 bis 50 Hektar
- 51 bis 100 Hektar
- 101 bis 200 Hektar
- 201 bis 500 Hektar
- 501 bis 1000 Hektar
- Über 1000 Hektar

X1. In welchem Bundesland bzw. in welchen Bundesländern befindet/befinden sich Ihre bewirtschaftete(n) Fläche(n)?

(Mehrfachauswahl möglich)

- Baden-Württemberg
- Bayern
- Berlin
- Brandenburg
- Bremen
- Hamburg
- Hessen
- Mecklenburg-Vorpommern
- Niedersachsen
- Nordrhein-Westfalen
- Rheinland-Pfalz
- Saarland
- Sachsen
- Sachsen-Anhalt
- Schleswig-Holstein
- Thüringen



Y1. Welchem Geschlecht ordnen Sie sich zu?

- Männlich
- Weiblich
- Divers

Z1. Wie alt sind Sie?

- Unter 25 Jahre
- 25 bis 35 Jahre
- 36 bis 45 Jahre
- 46 bis 55 Jahre
- 56 bis 66 Jahre
- Über 66 Jahre

AA1. Was ist Ihr höchster beruflicher Abschluss?

- Promotion
- Diplom
- Master
- Bachelor
- Fachschulabschluss
- Lehre/Berufsausbildung
- Kein beruflicher Abschluss
- Sonstiges

Sonstiges