Development of future scenarios for sustainable pesticide use and achievement of pesticide-use and risk-reduction targets announced in the Farm to Fork and Biodiversity Strategies by 2030

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Executive Summary

Pesticide use plays an important role in managing food production by driving increases in agricultural yield through prevention and eradication of harmful organisms from plants. However, pesticides have the potential to cause significant detrimental effects on human and environmental health. It is therefore vital to consider how to manage future pesticide use and encourage the development of sustainable practices as part of the discussion on supporting agricultural production and food security in the future.

The sustainable use of pesticides has been of growing concern within the European Union (EU) policy since the 1980s, with multiple directives and policies developed and implemented to tackle the associated challenges. However, the multiplicity of interests and diverse stakeholder views (e.g. the agrochemical industry, policymakers, farmers, citizens) challenge the achievement of EU targets to reduce the use of pesticides and their risk to the environment and human health.

This foresight study has been commissioned by the European Commission Directorate-General for Health and Food Safety (DG SANTE) to systematically consider future scenarios on the use of pesticides to 2030 and beyond, linked to specific pesticide-use and risk-reduction targets to be achieved by 2030. Scenarios are tools used to explore uncertainty and represent plausible futures across a spectrum of possibilities. Scenarios are not intended as forecasts but are designed to represent a wide range of possible future states to explore policy implications. This approach aims to explore different possible futures for 2030 and beyond. This approach also recognises the possibility of limited change by 2030, given the complex nature of the policy area and the different factors influencing policy development and implementation.

Pesticide use in the EU is influenced by a broad spectrum of factors, ranging from driving forces within the political, economic, and societal spheres to issues related to technology and environmental impacts. To understand how the future could unfold by 2030 and beyond, we must assess the trends underpinning such factors and their interdependency and uncertainty.

We conducted an evidence review of academic and grey literature and legal and regulatory documents to identify the key factors driving pesticide use in the EU. A PESTLE framework was used to structure the approach and identify potential factors across different influence areas.[i]

In collaboration with our study team's subject experts, we drew up a longlist of factors based on the trends identified in the evidence review, prioritising those considered of high importance for future food provision and pesticide use and uncertain in terms of their future development.

These factors were validated through a survey of stakeholder groups representing academia, industry, civil society and the civil service. Factors were scored according to their perceived importance and likely future development to 2030 and beyond.

In parallel, we conducted a small-scale citizen-engagement activity to explore the general public's views on pesticide use and broader sustainability issues around the agricultural and food sectors. This activity consisted of an online discussion facilitated and moderated using Qualboard, an online dashboard provided by a market research partner, Schlesinger Group. Participants were recruited from France, Germany, Greece, Netherlands, Romania and Spain to obtain a snapshot of views from a selection of

[i] PESTLE stands for Political, Economic, Social, Technological, Legal and Environmental. The PESTLE framework facilitates structured exploration of factors that may operate within each of these influence areas.

different European countries. Their specific demographics are unknown, and it is worth bearing in mind that views may vary between different socio-economic groups and between rural and urban backgrounds (e.g. willingness to pay more for food). While not representative of the entire population, these results provide a useful starting point for engaging with citizens and understanding some of the perspectives relating to this complex topic. The citizen group was consulted before and after the scenario development to explore whether their views of pesticide use would change in light of the different scenarios.

Drawing on the findings from these stakeholder-engagement activities, we developed four future scenarios situated in 2030 and beyond: (1) Mixed Sustainable Approaches, (2) Commercial Sustainability, (3) Unsustainable Inertia, and (4) Widespread Sustainability. Each scenario is composed of a set of projections that differentiate it from other scenarios in ways that aim to inform policymaking. A summary description of each scenario is presented in Box 1 below.

Box 1. Summary description of the future scenarios developed in this study

<u>Scenario 1: Mixed Sustainable Approaches</u>

Against a backdrop of geopolitical instabilities and the rapidly worsening effects of climate change, the EU has begun adopting a more inward-looking economic approach to build resilience in its agricultural sector. The agri-food sector has seen a shift towards more sustainable practices; however, this has been slow-moving. Despite some reductions in chemical-pesticide use, this trend has not been homogeneous across the agricultural sector. Financial and other policy support measures are needed to encourage innovation and alternative approaches to reduce pesticide use further.

<u>Scenario 2: Commercial Sustainability</u>

The EU has experienced moderate economic growth, with agricultural prices remaining relatively stable. Although consumers have gradually shifted towards diets with lower environmental impact, change is slower than predicted by market forecasts. In the absence of stronger regulatory and legal incentives from the EU, sustainability and innovation in the agricultural sector have become increasingly driven by large enterprises. Overall, the EU's chemical-pesticide consumption has continued to decrease. However, it continues to play a role, with differential willingness amongst farmers to engage with new practices to reduce or eliminate pesticide use (e.g. Integrated Pest Management - IPM).

<u>Scenario 3: Unsustainable Inertia</u>

A global recession has shifted political priorities away from innovation and sustainable practices. This has translated into limited resources for farmers to adopt new approaches and continued reliance on chemical pesticides, as well as a lack of alternatives for pest management. Consumers prioritise affordability over environmental sustainability. Large companies across the food supply chain continue to dominate the global agri-food system, leading to the displacement of small-scale producers. Climate change has yet to significantly impact agricultural production, which has remained stable in terms of yield, prices and competitiveness.

<u>Scenario 4: Widespread Sustainability</u>

EU policies reflect a stronger ambition to foster sustainable economic growth and address environmental issues. Technologies and alternative agricultural practices enabling pesticide reduction are considered important enablers of these objectives, leading to their widespread deployment across all domains of the food supply chain. EU consumers also show increasingly green attitudes. These trends have allowed for a rapid shift towards environmentally sustainable practices, including reductions in pesticide use. Consumer willingness to pay more for products with higher health and environmental standards and improved production processes have buffered the impact of increased food prices, underpinned by costly advanced technologies and sustainable approaches.

The scenarios were presented at a workshop of representatives from several stakeholder groups, including National Competent Authorities from the EU Member States, industry, professional organisations, non-profit organisations, scientific experts, representatives from non-EU countries and the European Commission. The workshop's purpose was to validate the scenarios' plausibility and explore the policy implications associated with each potential future. Although the scenarios were high-level and showcased a broad context for the agricultural and food sector, they enabled identification of several insights to aid policy formulation regarding the sustainable use of pesticides.

This study highlighted the complex landscape surrounding pesticide use and explored the implications for each scenario presented. One important insight is that policy strategies need to be equipped with adequate incentives and response measures, as well as implementation and monitoring strategies. Challenges in food production and pesticide use need to be addressed holistically across all contexts, including political, legal, economic, societal, technological and environmental. The inherent variation across regions must also be considered, in an increasingly globalised context.

Insights from this study have been condensed into five main points to help shape future policy development, as outlined below.

1. **Pesticide use needs to be managed in the longer term**

A suite of alternatives can potentially reduce pesticide use in some crops, ranging from biologicals/plant-biostimulants, IPM, organic and agroecological practices to technology-driven approaches such as precision agriculture. The outcomes of these research efforts must translate effectively into practice and address 'on the ground' challenges. Policy strategies need to provide a robust framework for farmers to take risks in implementing new practices that accounts for the time needed to implement change.

2. **Innovation should consider public understanding and consumer demands**

Engaging with the public is an important activity alongside implementing innovative approaches to farming and developing policies to support their rollout. With increasing population growth and changing demands, particularly from emerging economies, there is a need to consider how farmers can further adapt to meet consumer demand whilst maintaining their competitiveness in the global market.

3. **Regulation must support a level playing field for farmers across the EU**

The EU is recognised for its leadership on sustainability issues, including pesticide use, through its regulatory framework and policy actions. However, significant consideration must be given to how regulatory burden may impact the level playing field and competitiveness of different Member States, particularly in the global agricultural market.

4. A future strategy needs to accommodate both large multinational companies as key players, alongside smallholder farmers

Large multinational companies along the food chain can play an important role in ensuring more sustainability in future food provision. However, if the future agricultural landscape is driven mostly by a business-led agenda, there is a risk that the social dimension underpinning the agricultural sector will not receive due consideration and support. This could have major implications for smallholder farmers, exacerbating a downward trend in employment.

5. Further research is required to reach a consensus on how pesticide use should be reduced

Policy strategies require a built-in capacity and flexibility to respond to short-term and long-term stressors to be future-proof. There needs to be consensus across stakeholder groups regarding the priorities that should feature in the policy agenda at a national and EU level. To this end, further research is necessary to identify a clear stepwise action plan towards reducing pesticide use and risk.

Contents

Preface

DG SANTE commissioned RAND Europe to conduct a foresight study on future use of pesticides in the EU to 2030 and beyond. The study identifies the main drivers and emerging trends for pesticide use. These are used to create a set of future scenarios for the sustainable use of pesticides in keeping with the risk-reduction targets announced in the EU's Farm to Fork and Biodiversity Strategies. This report sets out the main study findings to inform further discussions on how stakeholders could manage pesticide use in the future. It is accompanied by a set of annexes that provide detailed information on this study's methods and findings.

This study was conducted by RAND Europe, a not-for-profit research organisation that helps to improve policy and decision-making through research and analysis, with expert advice from Dr Elta Smith and Daniel Traon (Arcadia International).

We are grateful for the support and contributions of Mr Rex Horgan (Directorate-General for Health and Food Safety), as well as the stakeholders involved in the engagement exercises (survey, citizen engagement and stakeholder workshop). We are also grateful for the contributions of our Quality Assurance Reviewers at RAND Europe, Dr Daniella Rodriguez-Rincon and Dr Salil Gunashekar.

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Abbreviations

AI	Artificial Intelligence
AKIS	Agricultural Knowledge and Innovation Systems
CAP	Common Agricultural Policy
DG AGRI	Directorate-General for Agriculture and Rural Development
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
DG INTPA	Directorate-General for International Partnerships
DG SANTE	Directorate-General for Health and Food Safety
EAP	Environmental Action Programme
EC	European Commission
EFSA	European Food Safety Authority
EIP-AGRI	European Innovation Partnership for Agricultural Productivity and Sustainability
EEA	European Economic Area
EMPL	European Parliament's Committee on Employment and Social Affairs
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GM	Genetically Modified
GMOs	Genetically Modified Organisms
IoT	Internet of Things
IPM	Integrated Pest Management
JRC	Joint Research Centre
ML	Machine Learning
MRL	Maximum Residues Limits
NAPs	National Action Plans
POPs	Persistent Organic Pollutants
PPP	Plant Protection Product
R&D	Research and Development
REFIT	Regulatory Fitness and Performance
RDP	Rural Development Programme
SCAR	Standing Committee on Agricultural Research
SDG	Sustainable Development Goal
SUD	Sustainable Use of pesticides Directive
UN	United Nations
WHO	World Health Organization

1 Introduction

1.1 Context and purpose

The European Commission Directorate-General for Health and Food Safety (DG SANTE) commissioned RAND Europe and expert advisors to conduct a foresight study to develop appropriate future scenarios on the use of pesticides to 2030 and beyond, aligning with the 2030 pesticide-use and risk-reduction targets announced in the Farm to Fork[ii] and Biodiversity Strategies[iii] and associated organic farming targets. The study's purpose was to examine the sustainable use of pesticides in promoting sustainable food systems and protecting public health and the environment. These targets include reducing the use and risk of chemical pesticides and more hazardous pesticides by 50 per cent by 2030. Another goal is to increase the proportion of EU agricultural land dedicated to organic farming to at least 25 per cent.

The study will help formulate an appropriate policy trajectory for the future, including how best to accomplish these ambitious pesticide-reduction targets. The study considers the European Union's (EU's) aims to protect food security, production and quality, and producers' incomes and viability in the EU and European Economic Area (EEA) while avoiding possible adverse consequences in non-EU countries, including developing countries. The foresight approach provides a mechanism for examining different pesticide-use variables and their potential policy implications under different future realities, providing valuable policy-development insights into managing future pesticide use.

1.2 Approach

The foresight study has four objectives:

1. To examine the most important variables that influence/will influence the sustainable use of pesticides in the EU to 2030 and beyond
2. To generate coherent future scenarios considering the most significant drivers of pesticide use and the over-arching ambition to comply with specific European Commission pesticide-reduction and linked organic-farming targets, as set in the Commission's Farm to Fork Strategy and Biodiversity Strategy
3. To describe the likely impact of timely, appropriate and adequate EU policies on the sustainable use of pesticides for each scenario and the main obstacles to their implementation
4. To summarise the discussion results and generate specific input informing policymakers preparing relevant initiatives.

The study takes stock of the existing context and gathers views from stakeholders about the priorities, needs and challenges regarding future pesticide use. This report sets out how each objective was met, gathering views from different stakeholders on:

1. Variables likely to influence the use of pesticides (objective 1)

[ii] The Farm to Fork Strategy is at the heart of the European Green Deal, and it aims to make food systems fair, healthy and environmentally friendly (https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en).

[iii] The Biodiversity Strategy is a core component of the European Green Deal. It aims to protect nature and reverse the degradation of ecosystems, putting Europe's biodiversity on a path to recovery by 2030 (https://ec.europa.eu/environment/strategy/biodiversity-strategy-2030_en).

2. Four scenarios for discussion of the different drivers for pesticide use (objective 2)
3. The policy impact for each scenario and the main obstacles to implementation (objective 3)

The report then summarises the results to provide insights for policymakers (objective 4).

1.3 Structure of the report

Chapter 2 provides an overview of the background and context for pesticide use, including policy and regulatory considerations. Chapter 3 presents the study findings, including the future scenarios. Chapter 4 provides the study conclusions and insights. More detailed information about the study's structure, methods and findings is presented in the accompanying annexes.

2 Background

The world's population is estimated to reach 9.4–10 billion people by 2050, leading to increased pressure on the food system[1], changes in land use and increased greenhouse gas (GHG) emissions.[2] As well as issues with shortages in the agricultural labour force,[3] more recent challenges include the price volatility of agricultural commodities due to global crises such as COVID-19[4] and the shifts in global trading arrangements following Brexit.[5] Innovations such as digitalisation and automation of agricultural processes, smart agriculture and alternative pest management strategies (e.g. Integrated Pest Management- IPM), are set to transform the agricultural sector and shape the debate on sustainable agriculture and pesticide use.[6]

This section presents the background and policy context driving trends in pesticide use and how these relate to the strategy and ambitions of the European Commission. It also provides an overview of how foresight is used in EU policymaking.

2.1 Trade-offs in pesticide use

Pesticides, as defined in Box 2, have played a critical role in the modernisation of agriculture and have enabled a substantial increase in agricultural yield through prevention and eradication of harmful organisms from plants.[7] This increase in food production supported population growth throughout the 20th century.[8] Without physical, biological or chemical intervention, it is estimated that agricultural production losses could reach 70 per cent on a global scale.[9] In addition to agricultural production, pesticides are also used to preserve food quality during storage and conservation[10] and maintain non-agricultural areas such as public green spaces and sport fields.[11] There are various categories of pesticides with different hazard levels, some of which have been proposed as less detrimental options for pest management (e.g. biopesticides derived from living organisms).[12]

Box 2. Definition of pesticides

Pesticides include a wide range of products that can be grouped in different ways, including by use (plant protection products and biocidal products) and target (insecticides, fungicides, herbicides, plant growth regulators and others). Some pesticides derive from chemical synthesis (synthetic or chemical pesticides) while others are produced by living organisms (biopesticides).[13] The hazards associated with pesticides also fall within different categories, ranging from 'extremely hazardous' to 'unlikely to present acute hazard', according to the WHO Recommended Classification of Pesticides by Hazard and guidelines to classification (2019).[14] This study uses the term pesticide to refer to plant protection products. Where applicable, a distinction is also made between chemical pesticides and biopesticides.

Some pesticides are known to have detrimental effects on human and environmental health. For example, exposure to some pesticides in an occupational context[15] or through residues found on food and in drinking water[16] can lead to significant health issues, including dermatological, gastrointestinal, neurological, carcinogenic, respiratory, reproductive, or endocrine effects.[17] Pesticide use can also impact on the environment through air, water and soil pollution, damaging habitats and the quality of ecosystem services.[18] In addition, pesticides can impact non-target species, resulting in biodiversity loss at a local, population or genetic level, and cause indirect effects on the food chain[19] and ecosystem dynamics (e.g. an absence of natural predators).[20] Another area of concern relates to the emergence of pesticide resistance, which can have public health, environmental and economic consequences.[21]

While these trade-offs in pesticide use have been widely debated,[22,23] various other factors may shape agricultural production in the future and hence influence pesticide use and associated consumer concerns,[24] as well as agricultural yield and farmer livelihoods.[25,26]

Agricultural production is of major importance for the EU,[27] and pesticides are likely to continue to play a central role in food production.[28] Moreover, the EU's pesticide market is one of the largest in the world, although there is considerable variation between Member States.[29] Nevertheless, pesticide use in the EU is strictly regulated to protect human and environmental health, as well as to ensure cohesion in the internal market's functioning and maintain or improve agricultural production.[30,31] Within this context, the EU and its Member States play a key part in reducing the risks and impacts of pesticides and encouraging the development and implementation of more sustainable approaches.[32] However, this introduces challenges at the Member-State level that may include potential regulatory burden and issues for ensuring a 'level playing field' for agricultural producers.[33] Additional challenges may include the suitability of current authorisation processes for pesticides, namely of low-risk products,[34] and access to scientific data to monitor pesticide use and impacts.[35]

Against this backdrop, EU policies and regulations on pesticides need to address multiple issues and stakeholders' aims to safeguard human health and protect the environment while sustaining agricultural production and supporting trade.

2.2 EU policy context

The challenges of achieving sustainable use of pesticides in the EU have been of growing concern for several years. The origins of the Sustainable Use of pesticides Directive (SUD) can be traced to the Sixth Environmental Action Programme (6th EAP) adopted in 2002.[36] The SUD brought relevant innovations to the pesticide framework, such as the concept of IPM and its principles (Box 3).[37] The Directive has been transposed to national legislation in all the Member States.[38]

Box 3. Definition of IPM[39]

IPM refers to the careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms. This includes keeping the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.

However, evaluation studies from the European Parliament and the European Commission agree with that Member States must improve the implementation of SUD provisions.[40] Shortcomings have been identified in the ambition and usefulness of the pesticide-use and risk-reduction targets and indicators outlined in the Member States' National Action Plans (NAPs). Challenges have also been found in implementing some aspects of the SUD across the Member States, particularly with IPM.[41] These issues have prompted the current SUD evaluation to assess the relevance and achievement of its objectives and explain the observed weaknesses in implementing and applying the legislation.[42]

The European Green Deal launched in 2019 aims[43] to make the EU's economy sustainable by 2030 and establish Europe as the first carbon-neutral continent by 2050. A set of strategies, action plans and missions have been devised as part of the Green Deal, including the Farm to Fork Strategy[44], the Biodiversity Strategy[45], the Chemicals Strategy[46], the Zero Pollution action plan[47] and the Horizon Europe's Mission on Soil Health and Food[48]. These initiatives have prompted a revision of the EU pesticide-policy framework to align with the Green Deal's ambitious environmental targets. Addressing the challenge of sustainable food systems, the Farm to Fork Strategy introduces two pesticide objectives: (i) to reduce by 50% by 2030 the overall use of and risk from chemical pesticides and (ii) to reduce by 50% by 2030 the use of more hazardous pesticides. These targets are also included in the Biodiversity Strategy,[49] which aims to reverse ecosystem degradation and protect nature by 2030. Supporting these initiatives, the EU launched two policy instruments relevant to these objectives: the Zero Pollution Action Plan,[50] which recognises the need to prevent and remedy pollution from the air, water, soil and consumer products, and Horizon Europe's Mission on Soil Health and Food,[51] which aims to ensure that at least 75 per cent of soil in every EU country is healthy and able to provide essential services. Certain pesticides are considered sources of pollution, i.e. harmful to the soil and general environment. As part of the need to ensure the safe and sustainable use of chemicals to protect public and environmental health, the European Commission has prepared the Chemical Strategy[52] for sustainability towards a toxic-free environment. This strategy calls for developing a more targeted methodology that considers the cumulative and synergistic effects of pesticides. The Farm to Fork and Biodiversity Strategies are also a fundamental part of the Commission's agenda to achieve compliance with the United Nations Sustainable Development Goals (UN SDGs).[53]

The current evaluation, and possible planned revision of the SUD, are crucial to achieving these objectives. However, it is not the only piece of EU legislation to be considered. The reform of the Common Agricultural Policy (CAP)[54] could also play an important role in achieving more sustainable pesticide use. Stakeholders across different categories do not believe that the current CAP appropriately captures the SUD objectives on pesticide alternatives and risk- and use-reduction.[55] The European Commission aims to make the new CAP fit for the European Green Deal, ensuring the reform succeeds in making the agricultural sector greener.[56] Financial incentives for climate and environmentally-friendly practices, including eco-schemes and Rural Development Programme (RDP) measures, are of paramount importance.[57] Stronger mechanisms to monitor Member States' progress in implementing their Green Deal objectives and National Strategic Plans are essential if these are to succeed.[58]

This diverse multiplicity of interests and views challenges the achievement of pesticide reduction targets. Coherence is needed across the EU legislation and policy initiatives potentially impacting this area, including the European Green Deal and related action plans. For example, as part of the Circular Economy Action Plan[59], the Carbon Farming Initiative can act as a tool to support and incentivise the Member States to fulfil climate change objectives. Reduced inefficiencies via precision farming technologies can also promote strategic alignments. Establishing channels to guide multi-stakeholder dialogue and prompt public consultation initiatives, such as on the SUD[60] or the Regulatory Fitness and Performance (REFIT) evaluation,[61] is also seen by the European Commission as a way to achieve the European Green Deal's ambitions.

2.3 Futures and foresight approach

Foresight approaches are a valuable tool in policy analysis. Studies using such approaches often involve the systematic consideration of different futures to understand the policy implications of uncertainties and disruptive changes, allowing exploration of potential risks and opportunities. Foresight methods apply a structured approach to gather existing information, analyse trends and compare expectations of a broad range of sectorial experts.[62] A key assumption of the approach is that different potential futures can be envisioned to explore policy implications and support priority setting.[63] Foresight processes are often highly participatory and can be used to foster stakeholder involvement and public engagement in policy development and implementation.[64]

Moreover, foresight methods can help assess how climate change and innovation might impact the current legislative framework in environmental policy. This methodology has also been applied to food safety[65] to support the creation of a robust food regulatory framework for ensuring safe and nutritious food for all EU citizens. The Standing Committee on Agricultural Research (SCAR), an advisory body for coordinating agricultural research across the EU, has also applied foresight methods to work on Agricultural Knowledge and Innovation Systems (AKIS).[66] Bioeconomic uncertainties, coupled with the expectations they raise among the EU Member States and industry sectors, have increased interest in foresight approaches.[67] This study used foresight methods to develop four scenarios for the future of EU agriculture to 2030 and beyond that explore different aspects of pesticide use and the influence external factors may have on relevant policies.

2.4 Study Caveats

The study draws on views from a range of relevant stakeholders and includes the analysis of grey literature. Since grey literature can present a specific viewpoint or agenda that has not been subject to a peer-review process, potential biases were taken into consideration during the analysis. Each study task aimed to gather views from a particular target group, e.g. citizens via the citizen engagement exercise and topical experts via the survey and stakeholder workshop. Despite efforts to recruit as broadly as possible for these exercises, contributions will have been made by a self-selecting sample with specific interests or motivations regarding pesticide use, potentially limiting representativity. Since the survey was necessarily conducted during the summer holiday period, wider stakeholders may also have been unavailable, which may have limited the views represented. A larger-scale engagement was not possible in the six months available for implementing the study but could be considered for future research. Despite this, the insights gathered helped gauge the views and perceptions of stakeholders in this complex area and were useful in developing and validating future scenarios.

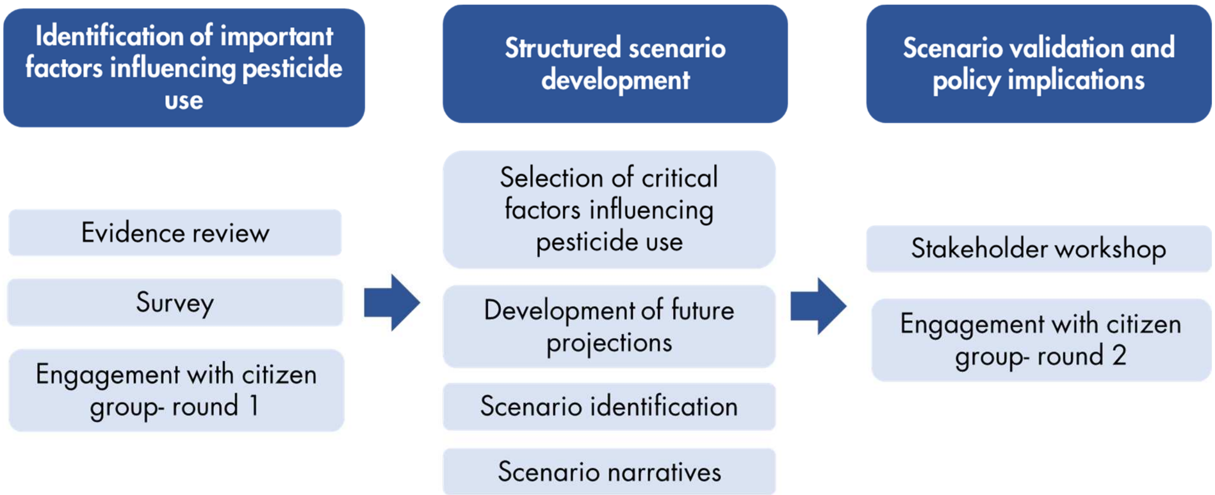
The foresight approach’s timeframe defined the future as 2030 and beyond, with 2030 being relatively soon in the context of many food-policy areas. Given the pace at which change is often implemented in this space, and the complexity of the topic, circumstances are unlikely to have evolved far by then. Indeed, several workshop participants suggested that this timeframe was unrealistic when considering significant developments in restricting pesticide use and introducing novel farming techniques. They felt that discussions were relevant to a timescale beyond 2030 to enable meaningful change. Nevertheless, given the urgency associated with climate change risks (e.g. food insecurity), rapid change is necessary and consideration of what can usefully and realistically be achieved by 2030 is crucial. Discussion with experts during the workshop allowed a more distant future to be imagined and medium and longer-term efforts to be compared.

The scenario approach used in this study aimed to capture potential futures to assess possible trajectories in pesticide use and policy implications. However, these scenarios are not intended as forecasts: they are designed to represent a wide range of possible future conditions rather than propose the most likely or preferred future based on current trends. As such, the scenarios can help identify common trends that are likely to be relevant in the future. Furthermore, the scenario methodology employs an evidence-driven qualitative approach informed by desk research and stakeholder engagement (the latter including a survey, citizen engagement activity and stakeholder workshop). To prevent any potential biases introduced by this type of approach, we followed a set of structured steps that used a scoring methodology to ensure transparency and reproducibility (as described in Annex A for the cross-impact analysis, consistency analysis and cluster analysis).

3 Findings

This section outlines the main findings and insights obtained from this study's methodological approach. An overview of the study approach is provided in Figure 1 and Box 4. Full details on the methods are provided in Annex A.

Figure 1. Overview of approach used in this study



Box 4. Summary of study approach and findings

- EU pesticide use is influenced by a broad spectrum of factors. A longlist of factors driving pesticide use was developed through an evidence review, structured according to five influence areas: political and legal, economic, social, technological and environmental.
- The longlist of factors was validated through a survey of stakeholder groups representing academia, industry, civil society, and the civil service. In parallel, a small-scale citizen engagement activity was conducted to assess the general public's views regarding pesticide use and broader agricultural and food-sustainability issues.
- The integration of the findings obtained across the different data collection activities allowed for a shortlisting of critical factors likely to shape the future of pesticide use. These included factors within the political, legal, economic, and societal spheres, as well as factors related to the use of technology and environmental impacts.
- The shortlisted critical factors served as building blocks to develop future scenarios for the ten years leading up to 2030. Scenarios are tools used to explore uncertainty and represent plausible futures across a spectrum of possibilities. For this study, four distinct future scenarios were developed: (1) Mixed Sustainable Approaches, (2) Commercial Sustainability, (3) Unsustainable Inertia, and (4) Widespread Sustainability.
- Each scenario is composed of a set of projections that differentiate it from the others in a way that aims to inform policymaking. The different scenarios have implications for the future of EU pesticide use and its policy context and position within the international landscape.

3.1 Key factors influencing pesticide use

Pesticide use in the EU is influenced by a broad spectrum of factors, ranging from driving forces within the political, legal, economic, and societal spheres to issues related to technology and environmental impacts. Several factors also extend beyond the EU's geographical boundaries and can be shaped by drivers exogenous to EU policymakers. To understand the different ways the future could unfold by 2030 and beyond, it is necessary to assess the trends underpinning such factors and their interdependency and uncertainty.

To identify the key factors driving pesticide use in the EU, the study team conducted an evidence review using the PESTLE framework as a guide to structure the approach and to identify potential factors across different influence areas (Box 5). However, it is important to note that these influence areas do not exist in silos; rather, they are highly interconnected and overlap across several factors. Since political and legal factors are particularly intertwined in agricultural production and pesticide use, these were merged into one influence area (political and legal).

Box 5. The PESTLE framework definition

The PESTLE framework PESTLE stands for Political, Economic, Social, Technological, Legal and Environmental. The PESTLE framework facilitates structured exploration of factors that may operate within each of these influence areas.[68]

The evidence review's findings are presented as a set of five scoping papers in Annex B. Each scoping paper addresses one of the five selected influence areas: political and legal, economic, social, technological and environmental.

Based on the trends identified in the evidence review, a longlist of factors was developed with our study team's subject experts. Prioritisation was given to those factors considered highly important for future food provision and pesticide use and uncertain in terms of future development (the longlist of factors is provided in Annex C).

The longlist of factors was further validated through a survey of stakeholder groups representative of academia, industry, civil society, and the civil service. Respondents scored factors according to (i) their perceived importance and uncertainty concerning food provision and pesticide use, and (ii) their likely development to 2030 and beyond. The resulting feedback enabled further refinement of the factor longlist to ensure it reflected the main stakeholder views. Including a range of stakeholders as survey respondents allowed for a comparison of views across the different expertise levels relevant to pesticide use. In parallel, we conducted a small-scale citizen engagement activity to explore the general public's views regarding pesticide use and broader sustainability issues around the agricultural and food sectors. This activity provided a useful benchmark for the survey by elucidating potential citizen views. The engagement consisted of an online discussion facilitated and moderated using Qualboard, an online dashboard provided by a market research partner, Schlesinger Group. Participants were recruited from France, Germany, Greece, Netherlands, Romania and Spain to obtain a snapshot of views from a selection of different European countries. The citizen group was consulted before and after future scenario development (described in Annex A) to explore whether their views of pesticide use changed in light of different future scenarios. Further details are provided in Annexes A and E.

Integrated findings from the different data collection activities are summarised below for each influence area (political, legal, economic, societal, technological and environmental), covering the main factors that could influence pesticide use.

Political and legal dimension

The evidence review provided several insights into the political and legal context of agricultural sustainability and pesticide use in the EU. Further detail and evidence underpinning these findings are provided in the political and legal scoping paper in Annex B. One important insight from the evidence review related to recognising the EU for its leadership on sustainability issues, which has been the focus of several specific pieces of legislation and policy initiatives. Making Europe greener and more resilient and taking advantage of opportunities to leverage innovation are the main priorities of the European Commission, as reflected in recent policy initiatives such as the European Green Deal and its associated Farm to Fork Strategy and Biodiversity Strategy.

The evidence review also showed that the EU has adopted measures to significantly reduce the risk of chemical pesticides. In this regard, the SUD represents a central piece of legislation that has brought relevant innovation to the pesticide framework. Namely, the SUD has aimed to reduce the risks and impacts of pesticide use on human health and the environment by promoting the use of IPM and alternative approaches/techniques, such as non-chemical alternatives, and by providing training in the sector, inspecting pesticide application equipment, banning aerial spraying, reducing the use of pesticides in sensitive areas and raising awareness on pesticide risks.

There are several uncertainties related to the political and legal landscape. Political support for environmental and pesticide policies in the EU varies by region, e.g. there is substantial divergence in the implementation of the SUD’s provisions. Additional political factors also impact pesticide use within the EU, with uncertain implications for future use. For example, trade agreements and trade relations with non-EU countries can undermine environmental and public health efforts to raise global standards if pesticides are exported to countries with more flexible regulations. It is unclear how changes to the EU’s pesticide will affect the agrochemical sector’s economy and research, potentially impacting regulatory and Research and Development (R&D) costs for new pesticides. In addition, achieving pesticide targets will rely on the accountability of prominent actors in the food supply chain that shape the market and influence consumers’ dietary practices through decisions about food types, suppliers, production methods, packaging, transport and marketing.

The survey identified Member States’ political engagement as one of the most important factors for the future of food provision and pesticide use, with medium to low uncertainty regarding its future development. This ranking reflects the importance of Member States’ roles in effectively implementing EU-level policy actions at a national scale. On the other hand, high uncertainty levels were reported for the future development of general legislation and policy instruments and for the geopolitical landscape and future trade agreements.

From a citizen perspective, the engagement activity indicated mixed views on the importance of issues such as pesticide use in national and EU-level political agendas. However, there was some agreement that measures should be introduced at the EU level rather than delegated to national governments. Nevertheless, the evidence review indicated that increased regulation, namely through the ‘greening’ of agricultural policies with reductions in external chemical inputs, could negatively impact farmers’ incomes. The evidence further suggested that these impacts will depend, in part, on consumers’ willingness to pay increased food prices or the willingness of governments or other actors in the food or governance chain to compensate for any associated income reductions.

Economic dimension

The evidence review provided several insights into the economic context of agricultural sustainability and pesticide use in the EU. Further detail and evidence underpinning these findings are provided in the economic scoping paper in Annex B. It was clear from the evidence review that several economic forces shape agricultural production and pesticide use. The overall economic context in which the Member States operate impacts consumers' purchasing power and can be a significant source of uncertainty for agricultural markets. Furthermore, farm typology[iv] and the structure of the agri-food sector – in terms of the size and number of companies controlling the food supply chain – influence the ability to buffer agricultural commodities' price volatility and partly determine product availability.

Pesticide use plays a driving role in agricultural productivity and food-production costs, with both factors impacting farmers' livelihoods via the output value of agricultural production. When economic factors interlink with the regulatory landscape, there are significant implications for trade agreements and competitiveness in the agricultural market that can also impact food prices. Changes in food prices, in turn, affect consumers' willingness to pay and global food security.

The survey indicated that food production costs were the most important economic factor for food provision and pesticide use, followed by agricultural-market competitiveness. Food production costs also ranked highest in terms of future development uncertainty, followed by price volatility. Other economic factors that were considered highly important and uncertain included food security, farmer livelihoods and pesticide use.

These economic factors are interconnected. For example, survey respondents highlighted how consumer demand drives supply, potentially changing consumer behaviour via abundance or shortage. Survey respondents also reported other factors that can shape pesticide use trends, including environmental concerns from consumers, changes in food production methods and availability of alternative pest-control methods (e.g. biocontrol).

However, the citizen-engagement activity indicated that consumers do not necessarily have sufficient information (e.g. on environmental impacts) to support their decision-making process when purchasing food. The citizen group ranked food quality as the most important factor when purchasing food, followed by food price. Participants also indicated they might be willing to pay more for pesticide-free food. The evidence review also suggested that political and socio-economic stability are significant factors influencing pesticide use and dependence, with uncertainties including fluctuations in the gross domestic product (GDP), price volatility, trade agreements and trade relations likely to continue playing a major role in shaping the agricultural-commodity-market landscape.

[iv] Farm typology refers to types of farms, focusing on size and ownership structure.

Societal dimension

The evidence review provided several insights on the societal context of agricultural sustainability and pesticide use in the EU. Further detail and evidence underpinning these findings are provided in the societal scoping paper in Annex B. The evidence review indicated that societal factors and values are important drivers for change in the food and agricultural sector. The world's population is larger and more mobile than it has been at any other point in human history. In parallel, consumer and farmer attitudes and behaviours towards food, agriculture and the environment are changing. Increasing concerns about the negative consequences of hazardous chemicals on the environment and health and heightened awareness of chemical residues in food have increased the demand for products with higher environmental and health standards. These trends have important implications for pesticide use.

Farmers' attitudes towards agricultural-production methods and pesticide use are influenced by factors such as knowledge and education levels, access to information and infrastructure, environmental values and the influence of knowledge on behaviour. R&D investments also influence wider developments in agriculture and pesticide use by increasing the effectiveness and safety of existing pest-control approaches and providing alternatives for crop protection.

The survey results suggested that R&D and citizens' attitudes to the environment were the most important societal factors determining future food provision and pesticide use. Additionally, both societal factors were ranked most uncertain in terms of their future development. Survey respondents further commented that citizens' attitudes to the environment are crucial for increasing the uptake of sustainable practices and shaping consumer trends.

Furthermore, according to the survey, most societal factors were considered of medium or low uncertainty. However, external inputs could increase uncertainty for factors such as citizen and farmer attitudes towards pesticides (e.g. an increase in environmental-degradation rate and further evidence on the adverse long-term human-health impacts of pesticide use). The evidence review indicated that other uncertainties, such as rural-urban migration, will likely change lifestyle trends, nutritional habits and food supply strategies, impacting pesticide-use trends in turn.

Technological dimension

The evidence review provided several insights on the technological context of agricultural sustainability and pesticide use in the EU. Further detail and evidence underpinning these findings are provided in the technological scoping paper in Annex B. The evidence review highlighted technological innovation as a major driver of transformation in the agricultural sector. Namely, the agricultural sector is now being permeated by a suite of emerging tools and technologies, including artificial intelligence (AI), machine learning (ML), internet of things (IoT), robotics, unmanned aerial vehicles, nanotechnology and biotechnology. Such technological advances have provided a means of improving pest management and reducing pesticide-use dependency through targeted approaches.[69] For example, management strategies based on precision agriculture have leveraged technologies such as remote sensing for real-time monitoring and forecasting of crop diseases. As well as monitoring and forecasting tools for pest management, technologies have been developed for targeted pesticide delivery to crops. Furthermore, R&D strategies are increasingly focused on alternative options to chemical pesticides, e.g. genetically modified (GM) crops, biologicals/plant biostimulants and precision/smart agriculture.

Although the adoption rate may vary between technologies, the evidence review indicated that these developments might present an opportunity to streamline food systems by increasing agricultural production and smart-farming effectiveness whilst lessening environmental impact. One important approach has been the use of alternative pest-control approaches such as IPM, considered one of the main tools for reducing the use of and dependency on more hazardous pesticides.

Survey respondents ranked biotechnology and nanotechnology as the most uncertain technological factors for future development, with lower importance for future food provision and pesticide use than other technology-driven approaches. Novel control agents ranked at a similar level of importance to biotechnology and nanotechnology, whereas robotics ranked the lowest.

The evidence review indicated that such rankings could be explained by several factors, including the need for certain technologies to prove their effectiveness, barriers related to the required investment level, unfavourable regulatory environments or public-acceptance issues (e.g. genetic modification (GM) technologies). Regarding public acceptance, the citizen-engagement activity revealed concerns about using new technologies such as GM and farming methods that rely on chemicals. Most of these concerns arose from potential detrimental consequences on health and the environment, which would need to be addressed to successfully implement new approaches.

Environmental dimension

The evidence review provided several insights on the environmental context of agricultural sustainability and pesticide use in the EU. Further detail and evidence underpinning these findings are provided in the environmental scoping paper in Annex B. Pesticides may pollute terrestrial and aquatic ecosystems and contribute significantly to the decline of biodiversity, negatively impacting soil health and quality and risking accumulations in non-human organisms that impact humans through the food chain. Policy discourse on food and farming has increasingly recognised the importance of alternative farming methods and systems to ensure the sustainability of the agricultural sector. Mitigation measures in agriculture are crucial to ensure sustainable practices limiting polluting activities (e.g. pesticide use and GHG emissions) and climate change impacts.

Several innovative approaches to sustainable food systems have been proposed, including climate-smart agriculture and more transformative agroecological and related approaches such as organic agriculture and conservation agriculture. Alongside tools such as IPM, these approaches have favoured the use of natural processes and focus on reducing external inputs (e.g. pesticides) and have been regarded as crucial to a more sustainable approach to agricultural production.

The survey indicated that IPM is considered a highly important factor for food provision and pesticide use with low uncertainty for future development. Survey respondents also reported that, despite its importance, IPM has not been widely implemented due to a lack of support, enforcement and training. More generally, farming methods were considered a key determinant of future food provision and pesticide use. However, factors such as biodiversity and pollution from hazardous chemicals followed closely in importance. Over half of respondents also considered climate change adaptation and mitigation as highly important influences on future food provision and pesticide use.

In terms of the uncertainty of future development, farming methods and biodiversity ranked highest in the survey. Respondents suggested this uncertainty would be driven by issues such as environment and climate change (i.e. changing demand for crop protection, risk mitigation strategies and ecological transition). The evidence review also showed that uncertainties related to farming methods could be due to knowledge gaps resulting from lower investment levels in alternative approaches. Other uncertainties concerned the integration of alternative approaches in public policy and their effectiveness in increasing food-production resilience in the face of climate change, as well as economic and social impacts.

Implementing new approaches can raise concerns among citizens. The citizen-engagement activity showed that environmental and health issues are major concerns driving the acceptability of food-production approaches. Further information is needed to ensure sufficient public knowledge regarding the environmental implications of different farming methods and technologies.

3.2 Shortlist of critical factors influencing pesticide use

We used the insights obtained from the survey and citizen engagement to validate the longlist of factors developed from the evidence review and select a list of critical factors likely to shape future pesticide use. Critical factors were selected in collaboration with our subject experts and validated by a cross-impact analysis, as described in Annex A. The cross-impact analysis also allowed us to assess mutual influence between factors. The shortlist of critical factors is presented in Table 1, while the longlist of factors and their definitions is provided in Annex C. The shortlisted critical factors served as building blocks for developing future scenarios (described in Annex A).

Table 1. Shortlist of critical factors influencing pesticide use.

Influence areas	Shortlisted factors	Definition
Political and legal	Political engagement of Member States	Politicians' willingness to prioritise pesticide-use and risk-reduction policies and devote sufficient resources to implementing them.
	Regulatory landscape	Includes the spectrum of national policies Member States implement to align with EU-level policy strategies around agricultural production (e.g. the EU Green Deal and associated Farm to Fork and Biodiversity Strategies, CAP, SUD and other related EU instruments for pollution reduction, environmental protection, biodiversity and human health).
Economic	Economic landscape	The level of economic growth at a national and EU level.
	Agricultural market competitiveness	Competition between EU producers in an increasingly international market.
	Agricultural prices	The price and volatility of agricultural commodities.
	Farm typology	Types of farms, focusing on size and ownership structure.
	Agricultural productivity (yield)	The quantity of agricultural output produced with a given quantity of inputs.
Societal	Food consumption trends and diets	Consumer preferences in relation to food choices (e.g. pesticide-free products).
	Farmers' attitudes	Farmers' willingness to engage with new agricultural practices and approaches.
	Farmer livelihoods	Employment rates in the farming industry, their ability to make a living and quality of life.
Technological	Technologies (including R&D)	Technologies that help monitor agricultural production, optimise decision-making regarding pests, and reduce pesticide use and its associated risks. These can include AI, ML), IoT, robotics, biotechnology and nanotechnology. This factor also considers R&D investments in technologies that foster national and international collaboration and data sharing for agricultural research.

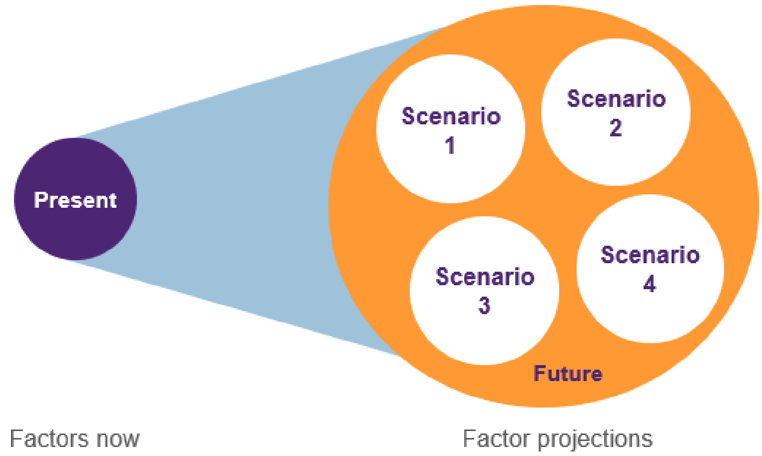
	Farming practices and techniques (including IPM)	Farming methods such as conventional agriculture, agroecology, conservation agriculture, crop diversification and rotation, organic farming and sustainable intensification of agriculture. It also includes approaches to pest management, namely IPM.
Environmental	Pesticide use (patterns of)	The pattern of pesticide use across countries.
	Climate change impact	The range of climate change effects on agricultural productivity and food supply chains.

* Factors are not presented in a particular order.

3.3 Future scenarios

Scenarios are tools used to explore uncertainty and represent plausible futures across a spectrum of possibilities (Figure 2). Scenarios are not intended as forecasts: they are designed to represent a wide range of possible future conditions rather than propose a preferred or most likely future based on current trends.

Figure 2. Plausible future scenarios should reflect a wide range of possible future states



For this study, scenarios were developed for the ten years leading up to 2030 and beyond. These scenarios aim to improve understanding of the factors that may shape the agricultural sector's future and sensitise stakeholders to the range of futures that may plausibly occur. Additionally, the scenarios provide a means for exploring policymaking implications across a range of futures.

Using the scenario methodology described in Annex A, four distinct scenarios were developed from a set of projections that allowed differentiating them in a way that could be informative from a policymaking perspective. Projections aimed to represent divergent future states for each factor to capture a broad spectrum of possibilities, developed from the results of the evidence review and stakeholder engagement activities. Table 2 below presents a synopsis of each scenario and its respective projections. Each scenario is presented in a different column with the relevant projections across the shortlisted factors.

Table 2. Factor projections underpinning each scenario

	Mixed Sustainable Approaches	Commercial Sustainability	Unsustainable Inertia	Widespread Sustainable Approaches
Political engagement of Member States	Mixed engagement	Mixed engagement	Decreased engagement	Increased engagement
Regulatory landscape	Increased EU regulation reflected in international trading policies	Centralised EU policy with a high level of subsidiarity to Member States	Centralised EU policy with a high level of subsidiarity to Member States	Increased ambition in Farm to Fork and Biodiversity Strategies
Economic landscape	Recession/ stagnation	Moderate growth of the economy	Recession/ stagnation	Strong economic growth
Agricultural market competitiveness	EU becomes less competitive	Levels of competitiveness maintained	Levels of competitiveness maintained	EU becomes more competitive
Agricultural prices	Prices fluctuate	Limited increase	Limited increase	Higher prices
Food consumption trends and diets	Gradual shift towards more environmentally friendly diets	Gradual shift towards more environmentally friendly diets	Continued consumption of less environmentally friendly foods	Adoption of environmentally friendly diets becomes more mainstream
Farm typology	Mixed typology	Increasing concentration of ownership and larger farms	Increasing concentration of ownership and larger farms	Different supply chain models/ collections of farms working together
Farmers' attitudes	Differential willingness to engage with new practices	Differential willingness to engage with new practices	Limited willingness to engage/adopt new practices	Increasingly positive attitudes to new practices
Farmer livelihoods	Continued trend away from employment	Continued trend away from employment	Continued trend away from employment	Stabilisation in employment
Technologies (including R&D)	Differential use of technology across sectors	Differential use of technology across sectors	Limited use of technology	More widespread use across sectors
Farming methods (including IPM)	Increasing share of sustainable practices	Increasing share of sustainable practices	Continuation of current practice	Rapid shift to environmentally sustainable farming practices
Pesticide use (patterns of)	Targeted reduction in pesticide use for some sectors	Targeted reduction in pesticide use for some sectors	Continued variation in pesticide use by sub-sector	Widespread reduction of all pesticide uses in EU
Agricultural productivity	Decrease in yield	Continuation of current yield	Continuation of current yield	Increase in yield
Climate change impact	Widespread negative impacts	Limited effect on within and outside EU	Limited effect on within and outside EU	Limited effect within EU but wider impact in some regions outside EU

The scenario projections were developed further as scenario narratives, refined according to feedback from the stakeholder workshop (as described in Annex A and Annex F). The scenario narratives are presented in Sections 3.3.1, 3.3.2., 3.3.3 and 3.3.4. These aim to provide a snapshot of the future with sufficient detail to showcase different possible future landscapes. However, the scenarios aim to represent trends in a broad sense and not all factors are covered in the same level of detail for each scenario. Additionally, as the scenarios aim to represent the future in 2030 (and potentially beyond), they are more conservative in considering dramatic shifts in trends within this short timeframe (e.g. climate change impacts).

3.3.1 Scenario 1: Mixed Sustainable Approaches

Adopting a more inward-looking economic approach, supportive policy aims and supportive consumer attitudes within the EU have led to a modest increase in sustainable practices. However, this has not been homogeneous given the differential willingness to engage with new approaches across sectors and Member States.

Political and economic context

During the 2020s, the EU began to adopt a more inward-looking economic approach to build resilience as geopolitical instabilities and rapidly worsening climate change effects increased the potential disruption of global supply chains. This approach resulted in political action to boost some activities, including agricultural production. Despite a relatively poorly performing economy over recent years, this sector has benefited from investment since food safety and climate concerns remain high on the EU policy agenda. However, food prices are somewhat volatile due to various interrelated causes, including increased energy prices and interest rates, high import costs and climate change impacts.

Consumers and policymakers

Climate change is expected to be a present-day reality in 2030, and consumers increasingly see the need to shift towards more sustainable plant-based and locally produced diets. However, because the economic climate is limiting their purchasing power, their decision-making is price-bound. While pesticides, genetically modified organisms (GMOs) and other chemical techniques are viewed negatively, there is wider public acceptance of innovative farming methods. Changes in consumer attitudes have been accompanied by political action at the EU level, with policy actions outlined in the reformed CAP focusing on increasing the sustainability of agricultural practices. However, the level of ambition in terms of implementation targets and effectiveness has varied across the Member States due to different national political priorities (e.g. addressing challenges in the economic landscape) and agronomic realities.

Agri-food sector

There has been a shift towards more sustainable practices and shorter, less capital-intensive supply chains that promote local consumption in the agri-food sector. However, this has been slow-moving. Larger farms still exist alongside this local farming model. As a consequence, trends in employment are divergent across the agricultural sector. While there is an increase in the demand for local labour favouring the domestic expertise of a younger generation in smaller farms, larger farms opt to cut costs in personnel and invest in automation. Labour supply remains a potential issue with more limited migration into the EU.

There is diversity in farmers' adoption of new farming methods and varying levels of acceptance of new technology across countries and sectors, reflecting different agronomic and environmental conditions across regions. The technology used in small farms in Southern-European countries more impacted by climate change prioritises precision agriculture, enabling more efficient utilisation of scarce resources such as water and land. The precision-spraying of pesticides through drones or robots reduces dosages and ensures efficiency, preventing the further degradation of biodiversity, water and soil resources and their associated economic impacts. In addition, there is an increased focus on organic and agroecological practices and low-tech alternatives. However, uptake of these approaches has relied on the suitability of environmental conditions and the availability of land resources. Indoor techniques to grow plants without soil (e.g. aeroponics and hydroponics) are potential alternatives to degraded land, particularly for high-value crops. However, the shift to indoor agriculture such as conventional greenhouses or vertical farming has not yet become mainstream. This is primarily due to the complexity of the necessary technology, the energy inputs and associated costs required, as well as challenges in implementing policy actions that support technological innovation. Elsewhere, large farms increasingly use autonomous robots such as unmanned aerial vehicles to protect crops. However, their focus is on increasing agricultural yield rather than reducing environmental impacts.

Implications for pesticide use

Although growing environmental concerns among farmers in the EU are reflected in reductions in chemical pesticide use, this trend has not been homogeneous across the Member States. Stakeholders show differential willingness to engage with new farming practices due to the associated costs, the need for proof-of-value, and behavioural and demographic factors influencing farmers' decision-making (e.g. resistance to change and knowledge in using new approaches). As such, implementing objectives outlined in the potential future-revised SUD – IPM practices, largely – has not been homogeneous. Whilst the technological landscape shows considerable promise for improving pest management and reducing pesticide dependency through targeted approaches such as precision agriculture, more robust policy measures are required to facilitate widespread adoption and effective implementation.

3.3.2 Scenario 2: Commercial Sustainability

Progress towards more sustainable practices within the agri-food sector has primarily been driven by commercial incentives; large, multinational firms across the food chain have invested heavily in alternative farming methods and technology.

Political and economic context

The EU economy has experienced moderate growth over the past decade with the continued globalisation of trade. As a result of national policy responses and economy-wide support measures, the EU economy has largely recovered to pre-COVID-19 levels. Current trends in imports and exports have largely been maintained, with agricultural prices remaining relatively stable. Extreme weather events related to climate change have continued to increase worldwide. However, technological advances (e.g. the development of pest-resistant crop varieties) have limited their effect on farming practices.

Consumers and policymakers

Alongside the availability and promotion of sustainable practices, the continued increase in consumer awareness of agriculture's environmental and health impacts has prompted a gradual shift towards more environmentally friendly diets. Consumers' growing demand for healthier and environmentally friendly products has also exerted pressure on the agri-food system to improve its sustainability. However, inequalities remain, with some consumers priced out of accessing food products with higher environmental standards. Increased recognition of the need to change and consumers' willingness to pay (due to a stable economy and prices) are also offset by a lack of dramatic climate effects within the EU. Therefore, change in consumer behaviour is less rapid than it might otherwise have been. On the policy front, the implementation of national strategies as part of the reformed CAP has not been fully effective, particularly as the implementation approach has primarily translated into 'business as usual'. As such, Member States are lagging in fulfilling the ambitions of the European Green Deal and its Farm to Fork and Biodiversity Strategies.

Agri-food sector

With the lag in action from the Member States to achieve the European Green Deal aims, sustainability and innovation in the agricultural sector have instead become increasingly driven by large enterprises. This trend has been further consolidated by mergers between companies and integration across the food supply chain. To meet consumer demand and build supply-chain resilience, these larger enterprises have voluntarily moved towards more sustainable practices and increasingly focused on alternative farming methods (e.g. better land management approaches and IPM).

As technology and alternative methods prove their economic and environmental viability, they are key to moving to more sustainable agricultural practices. In addition, a shift in R&D focus away from pesticides over the last ten years has meant that agrochemical companies have invested in pest-control alternatives (e.g. biologicals/plant-biostimulants) and new technologies for improved farming practices and better land-and-pest management (e.g. precision agriculture). Despite this, farmers remain differentially willing to engage with new practices in agricultural production methods, with smallholder farms facing increasing challenges competing with more prominent players given shortcomings implementing policy actions to support them.

Implications for pesticide use

Across the EU, overall pesticide consumption has continued to decrease at a similar rate to the early 2020s, chiefly driven by the strategies set by large multinational companies. Given growing levels of pest resistance and increasing consumer demand for food products with higher environmental and health standards, alternatives to pesticides are increasingly appealing for agrochemical companies. These include biologicals/plant-biostimulants and precision/smart agriculture techniques, which have improved pest management and reduced pesticide dependency. There has also been a reduction in pesticide use for crops where more pest-resistant varieties have been developed via conventional and new breeding techniques or production can be more effectively moved indoors or to a covered setting to manage more extreme climate and weather conditions. The reduction in pesticide use has also decreased environmental degradation and related economic impacts (e.g. costs sustained by water treatment companies and public health costs). Nonetheless, chemical pesticides continue to play a role in driving agricultural production (e.g. agricultural crops, feed crops). In the face of climate uncertainty, many fear large production and revenue losses due to pesticide reductions.

3.3.3 Scenario 3: Unsustainable Inertia

There has been little change in agricultural production, with reduced impetus towards alternative farming practices as economic pressures have resulted in a shift in policy focus to other areas of the economy, and consumers remain price-sensitive.

Political and economic context

The global economy plunged into a recession following a period of upheaval in the early 2020s. Despite financial measures adopted by governments in the EU and third countries, it has struggled to rebound over the past decade. As such, R&D investments have decreased and there has been limited scope for innovation across most sectors of the economy. This constraint has been particularly true of the agricultural sector, which was less prioritised by financial and other policy support measures than other sectors due to the greater resilience it showed.

Consumers and policymakers

With other parts of the economy requiring more substantial support, there have been significant delays in meeting the European Green Deal targets outlined in the Farm to Fork Strategy and Biodiversity Strategy– particularly as Member States show low engagement with new approaches for agricultural production. Furthermore, and despite increased awareness of the negative impacts of climate change, there is a continued lack of action from many consumers, who continue to favour lower prices in their purchasing habits due to financial pressures. This is reflected in the choice of cheaper food products, which in many cases do not conform to the standards required to improve environmental sustainability.

Agri-food sector

The agricultural sector has primarily been driven by the increased dominance of large multinational companies in the global market, which can respond better to fluctuations in demand and prices than small-scale producers. As such, large multinational companies have been able to buffer fluctuations in agricultural prices, maintaining competitiveness levels and trends in imports and exports. At the same time, and despite the impending adverse effects of climate change, effects have not yet been significantly felt across all EU regions. Therefore, the impacts on agricultural production have been lower than expected, allowing relatively stable yields. Where impacts have been more noticeable, large multinational suppliers with the financial resources and infrastructure to invest in technology have fared better than smaller, more local ones in coping financially with climate change effects.

Given insufficient government-led incentives and support, farmers' willingness and financial means to adopt new farming practices or invest in technology have been limited. Cases where such investment benefits large-scale operations to meet the demands of a growing population (e.g. automation) are the exception. Furthermore, with the increased expansion and integration of farms towards large-scale production, small-scale producers are being displaced, leading to increasing unemployment in the agricultural sector.

Implications for pesticide use

Given the lack of policy action to innovate pest -control methods used in farming practices, the market lacks alternatives for ensuring crop yields and managing pests in a more sustainable way. Additionally, with large multinationals being major suppliers of agricultural commodities, the availability and diversity of products going beyond the minimum environmental sustainability standards are limited. With Member States' lack of ambition to define pesticide-reduction targets, and challenges implementing pesticide-reduction strategies, there are significant shortcomings in achieving the SUD objectives – particularly in incorporating IPM in pest-control practices. Such trends have hindered progress in addressing environmental degradation, further challenging biodiversity conservation and risking public health due to environmental contamination by chemical pesticides.

3.3.4 Scenario 4: Widespread sustainability

Increased environmental awareness, green consumer attitudes and a strong EU environmental policy underpinned by technology have led to a rapid shift to more localised and sustainable farming practices.

Political and economic context

The early 2020s were marked by a major global pandemic that prompted governments worldwide to implement a series of economic recovery packages and policy measures to reduce trade disruptions, stabilise employment levels and lift the economy. As a result of these efforts, economic growth has resumed, and the capacity to address societal demands has increased. Such trends have been observed in the agricultural sector – particularly in the EU, which has become more competitive through increased market share domestically and internationally. In parallel, scientific evidence has led to increased political consensus on climate change issues, with policy efforts directed towards fostering a green economy. Technology[70] and consumer buy-in are important factors enabling sustainable economic growth to improve efficiencies in both large-scale and small-scale production processes.

Consumers and policymakers

Over the past decade, climate change effects have been felt worldwide in increasing occurrences of extreme weather events and natural disasters. The EU has also suffered from these impacts, albeit to a lesser extent than other regions. Nonetheless, increased global awareness of environmental challenges and a surge in associated impacts on health have led to a marked shift in EU consumer attitudes towards increasingly green behaviours. These include preferences for more localised living, environmentally friendly consumption patterns (including fewer 'food miles') and healthier diets, as well as an increased willingness to pay higher prices for products that align with such preferences. However, willingness may vary across different socioeconomic groups. Policy actions have kept pace with these trends, with the reformed CAP largely delivering across its key priority areas through ambitious targets and effective implementation of 'CAP national strategies'. As such, the ambitions outlined in the Farm to Fork Strategy, and Biodiversity Strategy, where relevant, have largely been met, leading the EU to increase its policy ambitions – both internal and external - to reflect its leadership in tackling environmental issues.

Agri-food sector

The political sphere's increased ambition to tackle environmental issues associated with food production has primarily been made possible through significant developments in technology and agricultural management approaches in the past decade. On the one hand, technology-driven approaches have allowed for better monitoring and forecasting methods based on smart farming approaches that use a combination of AI, ML and IoT methods. These approaches have provided a means of streamlining agricultural production both at a large scale, through developments such as automation, and at a small scale, through online platforms that facilitate farmers' commercialisation of agricultural products. The latter provided a means of shortening supply chains, connecting local producers to local consumers. Furthermore, the implementation of nature-based solutions and organic and agroecological practices has complemented technology-driven approaches, particularly for settings where these are less accessible.

Recognition of the synergy between technology and nature-based solutions across all domains of the food supply chain has led to their widespread use. This trend has also been made possible via policy measures and initiatives supporting the training of farmers in these new approaches. For agricultural production, this trend has been particularly evident in the rapid shift to environmentally sustainable practices. Such trends have positively impacted the preservation of ecosystems and biodiversity while reducing environmental degradation and its concomitant economic and public health costs. However, the costs of incorporating advanced technologies into agricultural production and the production constraints of sustainable approaches have led to increased food prices. This increase has been partially buffered by a decrease in overall food waste via more effective technology-driven production processes and changes in consumer behaviour driven by increasingly green attitudes. Moreover, as technology's affordability increases, food prices may soon begin to show a downward trend. However, whilst some consumers have been willing and able to pay for more environmentally friendly products, increased food prices have reduced options for more disadvantaged sectors of society.

Implications for pesticide use

Precision farming has become a more prevalent and essential enabler for approaches such as IPM, streamlining the identification, monitoring and treatment of pests. Organic agriculture and agroecological practices have also gained momentum as alternatives to pesticides where high-tech options are beyond reach. Given the range of technological and nature-based solutions, it has been possible to implement alternatives to chemical pesticide use (e.g. biocontrol) across most sectors and fulfil the objectives outlined in the potentially revised future SUD without compromising crop quantity and quality. Furthermore, technology has improved cooperation between stakeholders across the food supply chain, fostering a local sharing economy. As such, the EU is delivering on the pesticide-use and risk-reduction targets outlined in the Farm to Fork and the Biodiversity Strategies and has showcased the leadership required for ambitious environmental policies.

3.4 Stakeholder insights for policy development

The four scenarios presented in Section 3.3 showcase a range of potential futures for 2030 and beyond. While the scenarios are high-level and outline a broad context for the agricultural and food sector, they facilitate insights to aid policy formulation on the sustainable use of pesticides. This section integrates the key points emerging from a stakeholder workshop, where the four scenarios were presented and discussed, together with the findings from the evidence review, survey and citizen-engagement activity. Furthermore, this section addresses the future scenarios' broader policy implications for pesticide use and agricultural practices more generally.

3.4.1 Plausibility of the scenarios and EU policy context

The four scenarios were discussed and refined following a stakeholder workshop to capture diverse stakeholder views on likely future developments to 2030 and beyond. A total of 57 participants attended the workshop, representing National Competent Authorities from the EU Member States, industry, professional organisations, non-profit organisations, scientific experts, representatives from non-EU countries and the European Commission (including DG SANTE, Directorate-General for Agriculture and Rural Development (DG AGRI), Joint Research Centre (JRC), Directorate-General for International Partnerships (INTPA), DG for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW), Directorate-General for Employment, Social Affairs and Inclusion (DG EMPL). The workshop's purpose was to validate the plausibility of the developed scenarios and explore the policy implications of each potential future. The key points discussed for each scenario are summarised below.

Mixed Sustainable Approaches scenario

Stakeholders considered this scenario plausible and close to the present situation. However, participants highlighted that if this scenario were to prevail in 2030, it would imply that the EU Green Deal policy ambitions had not been sufficiently realised to tackle the challenges related to agricultural production and sustainable pesticide use. To avoid such outcomes, stakeholders stressed the necessity of policy strategies to consider the different socio-economic and agronomic realities of each Member State. The reformed CAP will be implemented nationally through a 'CAP strategic plan' for each Member State. Therefore, these plans should set ambitious and specific targets, identify implementation pathways and establish performance indicators to limit possible shortcomings. Examples of the latter include those reported in the Commission's 2017 and 2020 reports to the European Parliament and the Council on implementing the SUD and the use of targets and NAPs to achieve SUD objectives.[71]

Innovation in technology and agricultural management practices also present opportunities to increase sustainability. The reformed CAP focuses strongly on research and innovation in connection with the AKIS and Horizon Europe 2021-2027. Research outcomes must be translated effectively into practice by involving all key stakeholders in a 'multi-actor approach', which will continue as the focus of the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI).[v]

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[v] The European Innovation Partnership for Agricultural productivity and Sustainability (EIP-AGRI) was launched by the European Commission in 2012. It aims to foster a competitive and sustainable agriculture-and-forestry sector by bringing together innovation actors (farmers, advisors, researchers, businesses, NGOs, etc.) and support building links between research and practice. (https://ec.europa.eu/eip/agriculture/node/50)

Commercial Sustainability scenario

Stakeholders considered this a plausible future if policy strategies do not provide appropriate support and protection to smallholder farmers in the face of more ambitious sustainability targets. As indicated in the evidence review, the consolidation of large multinational companies' power along the food chain can create significant challenges for smallholder farmers and exacerbate the downward trend in agricultural employment. The reformed CAP aims to support a fairer distribution of income with a greater focus on small and medium-sized farms to strengthen their position in the marketplace. It also incorporates a social dimension by supporting young farmers and encouraging women's participation in farming. Such efforts must align with the 'on the ground' challenges faced in the agricultural sector to ensure environmental and social sustainability.

Unsustainable Inertia scenario

Stakeholders felt that the current EU agricultural policy strategy should prevent this type of future from materialising. They reasoned that the reformed CAP accounts for around a third of the EU's budget and has strengthened its approach to improving sustainability in agricultural practices through instruments such as eco-schemes. Stakeholders also highlighted that the public's increasing focus on environmental concerns would likely prevent such a future from unfolding. For example, environmental issues were consistently ranked as highly important in the citizen-engagement activity. However, as seen in the early 2020s, large-scale crises can shift priorities on a global scale. While the agricultural sector has shown more resilience during the COVID-19 pandemic than other sectors[72], it has reinforced concerns about potential future crises, particularly disruptions to food supply chains. As such, policy strategies must have a built-in capacity and flexibility to respond to short-term and long-term stressors to be future-proof.

Widespread Sustainability scenario

Stakeholders considered this scenario overly optimistic and challenging to achieve by 2030, raising concerns about the feasibility of achieving the Farm to Fork Strategy and Biodiversity Strategy targets within the current 2030 timeframe. Innovation can play a major role in accelerating a transition to more sustainable food systems which align with the EU Green Deal's ambitions, and can occur at a technological and agricultural-management level. A key focus of the reformed CAP is supporting innovation through funding instruments such as Horizon Europe and initiatives such as EIP-AGRI. However, these will need to elicit a sufficiently rapid transformation of current food systems to more sustainable practices while addressing pressing associated challenges such as required investment, knowledge, infrastructure and access.

3.4.2 Implications for pesticide use

The developed scenarios showcase a broad context for the agricultural and food sectors with different implications for pesticide use.

Mixed Sustainable Approaches scenario

In the Mixed Sustainable Approaches scenario, pesticide use remains non-homogeneous across the Member States, with differential adoption of new farming practices that could reduce reliance on chemical pesticides. Key drivers underpinning these trends include Member States' different agronomic realities, such as environmental, soil and weather conditions, and the risks and investments associated with implementing new practices – particularly for approaches yet to prove their effectiveness. There have also been challenges in achieving the SUD's objectives, namely incorporating IPM more widely into agricultural practices.

Despite potentially expected SUD revisions and some progress across the Member States, several important issues remain in ensuring compliance with IPM and defining and applying suitable indicators to measure progress in achieving pesticide risk-reduction targets. Alongside instruments such as the reformed CAP, the policy aims outlined in the Farm to Fork and Biodiversity Strategies have supported sustainable agricultural practices and led to reductions in chemical pesticide use. However, further action is required to ensure widespread adoption that is ambitious and targeted to the challenges faced by each Member State. Such action could include defining appropriate and measurable targets and indicators to assess the success of strategies aiming to implement SUD objectives, namely IPM adoption.

Commercial Sustainability scenario

In the Commercial Sustainability scenario, pesticide-use trends are mainly driven by large multinational companies' business strategies. Given growing pest-resistance levels, more efficient technological approaches and increased consumer demand for products with higher environmental and health standards, major agrochemical companies are increasingly investing in R&D to develop alternatives to chemical pesticide use. As such, investments in alternatives such as pest-resistant GM seed varieties, biologicals/plant-biostimulants and precision agriculture technology are increasing, while chemical-pesticide use is decreasing.

This trend has facilitated progress towards the aims of the Farm to Fork and Biodiversity Strategies regarding pesticide-use reduction (albeit non-homogenous, as some farmers continue to rely on chemical pesticides). Given the primarily business-led agenda for sustainability, a fundamental gap in the agricultural sector's social dimension could aggravate social inequalities. Namely, with mergers across large agrochemical companies and further consolidation in the agri-food industry, smallholder farmers have decreasing agency in the decision-making processes around their agricultural practices, including implementing alternative approaches to pest management and prevention. The reformed CAP outlines concrete action for supporting small and medium-sized farms and improving competitiveness. However, broader trends underpinning the structure of the agri-food sector and the role of large agrochemical companies must also be considered.

Unsustainable Inertia scenario

In the Unsustainable Inertia scenario, shifts in Member States' political priorities to address the economic crisis have hindered efforts to improve sustainable practices in pesticide use. Agricultural production continues to rely heavily on chemical pesticides due to the lack of alternatives. Progress in achieving the targets outlined in the Farm to Fork Strategy and in the Biodiversity Strategy is therefore lacking. Furthermore, and despite potential SUD revisions, major challenges in designing and implementing pesticide-reduction targets remain. Namely, these targets do not showcase the required ambition to achieve the objectives outlined in the Farm to Fork and Biodiversity Strategies and lack measurable indicators and clear guidance, particularly regarding IPM implementation. This scenario flags the need to ensure concerted policy action across the Member States in implementing strategies to reduce pesticide use and risk. Such implementation strategies and monitoring mechanisms require built-in resilience to withstand crises in the socio-economic and political spheres.

Widespread Sustainability scenario

In the Widespread Sustainability scenario, the EU is on track to achieve the pesticide-use and risk-reduction targets outlined in the Farm to Fork and Biodiversity Strategies, and success on this front is setting the stage for increased ambition in environmental policy. This shift has been driven by a favourable economic landscape, political consensus on environmental challenges and a strong focus on alternatives to pesticide use. In particular, technological innovation and alternative agricultural practices with a strong focus on IPM have provided a means to reduce reliance on chemical pesticide use while maintaining crop yields.

Such a trajectory in pesticide use would require a robust policy framework leveraging and investing in innovation and a strong commitment to guide and monitor implementation at the Member-State level. In addition to the reformed CAP, Horizon Europe has supported a EUR 9 billion investment in research and innovation across the areas of food, bioeconomy, natural resources, agriculture and environment (cluster 6). An essential component of such investments will be the development of alternatives to chemical pesticides, such as biologicals and the use of technology for precision agriculture. On the other hand, effective implementation of CAP strategic plans from each Member State and monitoring of compliance will be crucial to achieving the aims set out in the Green Deal.

3.4.3 EU position within the international context

Pesticide use within the EU sits in a complex political and socio-economic landscape. While there is EU-level ambition to achieve targets outlined in the Green Deal and Farm to Fork and Biodiversity Strategies, the principle of subsidiarity[vi] means the Member States are responsible for determining their criteria and approach to achieving these targets. Their engagement is therefore critical. Implementation of policy actions at the Member-State level is conditioned by the socio-economic context, agronomic conditions, diversity in farm typologies and farming methods. As such, workshop participants highlighted that is it important that the Member States have the appropriate incentives and conditions to engage and prioritise environmental-related issues such as pesticide use. Important challenges in adopting EU legislation arise when countries become more inward-looking and protectionist measures restrict international trade due to a less favourable economic landscape.

At an international level, consideration must be given to the consistency of regulations and the maintenance of a level playing field. Some of the futures presented in this study rely on stronger EU-policy regulation to achieve targets for sustainable agricultural practices and pesticide-use reduction while protecting farmer livelihoods. However, the regulatory burden can create bottlenecks for international trade and negatively impact businesses by hindering their ability to compete. Therefore, potentially increased EU regulation prompted stakeholders to question whether this would make Europe a global leader or isolate it from international markets, increasing the gulf between the EU and the rest of the world.

EU competitiveness with trading partners has important implications for the overall economy. As highlighted by stakeholders, soft diplomacy may have a role to play in conciliating different product standards between trading partners. For example,

[vi] The principle of subsidiarity in the EU rules out Union intervention when an issue can be dealt with effectively by the Member States at the central, regional or local level. The Union is justified in exercising its powers only when the Member States cannot achieve the objectives of a proposed action satisfactorily, and action at the Union level adds value (https://www.europarl.europa.eu/factsheets/en/sheet/7/the-principle-of-subsidiarity).

stakeholders indicated that although certain chemical pesticides have been banned from the EU, they are still traded internationally and used in non-EU countries. Residues or traces of some of these products may find their way back into the EU through food and feed imports from third countries. Stakeholders also pointed out that large multinational companies may exploit policy differences to operate outside the EU's regulatory framework in a way that is most profitable for their business priorities. This issue can create further challenges in ensuring compliance of food products with EU standards. Once companies abide by the appropriate regulatory requirements, this becomes less of an issue.

International initiatives such as the UN SDGs could have a role to play in ensuring a global move towards agricultural sustainability and, potentially, pesticide-use reduction. Namely, 6 out of the 17 SDGs are directly relevant for pesticide use as they address issues related to food safety and security (SDG 2: Zero Hunger), the health impacts of exposure and consumption of hazardous pesticides (SDG 3: Good Health and Wellbeing), issues related to water pollution (SDG 6: Clean Water and Sanitation), the safety of farmers using pesticides (SDG 8: Decent Work and Economic Growth), the impacts of pesticides for sea and ocean life when freshwater streams and rivers are impacted by contamination (SDG 14: Life Below Water) and issues related to the environmental degradation and disruption of ecosystems through pesticide contamination (SDG 15: Life on land). The global reach of such an international framework could facilitate the alignment of sustainability standards across countries. The Green Deal is a key component of the EU's strategy to implement the UN SDGs.

Emerging and developing economies have a vital role in shaping agricultural trade and pesticide use. In several of these countries, chemical pesticides tend to be viewed as the most reliable way of protecting crops and ensuring yield, particularly in areas prone to pests. As such, pesticide use has proliferated in these regions. Transitioning to alternative pest management strategies has been challenging, and EU leadership in regulation and enforcement has been highlighted as a critical factor in providing a proof-of-concept for alternative approaches[73].

From a societal perspective, the role of policy strategies in protecting farmers' livelihoods links with their willingness and capacity to adopt new approaches, which can be crucial for achieving the Green Deal's aims of sustainable pesticide use. Furthermore, as shown in the future scenarios presented in this study, farm typology can greatly influence stakeholders' ability to implement technological innovation and cope with price fluctuations in agricultural commodities. Stakeholders highlighted that whilst smaller farms can be more agile in adapting to change, larger farms typically have the resources and infrastructure to scale up solutions. Increased merging of large companies can further consolidate their dominance in the agricultural market, potentially driving smallholders out of business. Furthermore, the automation brought on by technological innovation and labour force migration to urban settings can exacerbate the downward trends in agricultural employment.

As seen with the COVID-19 pandemic, global crises such as pandemics and wars can further disrupt food supply chains through factors such as border closures and spikes in demand for food products. Therefore, stakeholders highlighted a need to build resilience in food supply chains to protect livelihoods and address social inequalities in a future-proof way. The reformed CAP incorporates a social dimension, including social conditionality, that aims to ensure fairness for all stakeholders in the agricultural sector. However, it is also important to build sufficient margin and flexibility for policy actions, such as those outlined in the reformed CAP, to prevail in a future where adverse developments such as an economic recession may shift trends and spike unemployment rates.

Farmers are continuously required to adapt to consumer demands, which may conflict with production processes. For example, consumers increasingly demand sustainable, healthy and locally produced food but might show limited willingness to pay the price of higher standards. Furthermore, population growth places increasing pressure on achieving the required agricultural yield to ensure food security. An important question raised by stakeholders relates to how farmers can cost-effectively increase agricultural production while complying with higher regulation standards, e.g. pesticide-use reductions.

Technology and alternative approaches to agricultural practices can play a significant role in addressing this conundrum. However, these need to be supported by robust and favourable policy and regulatory frameworks alongside incentives and consumer buy-in. The reformed CAP has a research and innovation dimension to explicitly support the modernisation of agriculture through knowledge exchange, innovation and digitalisation.[74] Each Member State is required to outline their strategy for fostering innovation and modernisation in their agricultural sector in their CAP strategic plan. To ensure that these plans deliver on their aims, they will need to consider how to implement and monitor strategies effectively and address potential challenges associated with changes in agricultural practices. For example, as highlighted in the technological scoping paper (Annex B), technology implementation may increase the digital divide within the population. In contrast, nature-based solutions may present challenges in achieving sufficient agricultural yields.

Climate change, environmental degradation and resource scarcity were considered key points across all stakeholder-engagement activities in shaping the future of food production. While this study assumed limited potential for dramatic shifts due to climate change impacts by 2030, workshop participants broadly agreed that these will eventually scale up and negatively impact global agricultural production. As indicated in the citizen-engagement activity, there are major concerns about how agricultural production will withstand the effects of climate change. Survey respondents also considered environmental factors to be important. As such, environmental challenges are likely to increasingly dominate the political agenda at a national and EU level.

Policy strategies must include adequate incentives and response measures to holistically address challenges in food production and pesticide use across all levels, including political, legal, economic, societal, technological and environmental. At the same time, they must take into account the inherent variation across regions and stakeholder needs in an increasingly globalised context.

4. Conclusions

This study has raised several issues relating to pesticide use. Though not necessarily new or surprising, these findings underline the need to place such issues at the forefront of future pesticide policies. The foresight approach provided a vehicle to explore the broader implications of pesticide policy in greater detail while allowing different stakeholders to discuss their points of view. This is particularly beneficial when examining potentially differing views on how to proceed.

Scenarios explore how existing trends may unfold in the future and help assess the implications of current policies in these future landscapes. Such explorations are particularly valuable when considering future pesticide use to ensure the broad range of factors that will be relevant in this sphere are appropriately reflected in discussion. The four scenarios developed in this study provided important insights into how key political, legal, economic, societal, technological, and environmental factors - and the trends underpinning them - may influence EU agricultural production and pesticide use in the short and medium-term (i.e. in the ten years leading up to 2030 and beyond).The foresight approach also provided a vehicle for discussing the practicalities of reducing pesticide use up to 2030 (linked to the targets established in the Farm to Fork and Biodiversity Strategies) and beyond. Future research should look further ahead for longer-term trends and policy implications to provide greater insight into potential policy-development directions for mitigating the slow pace of change across the sector. Furthermore, future research should consider the broader implications of pesticide use for other components of the food supply chain in more detail, including both upstream and downstream operations (e.g. input suppliers and retail, respectively).

A shared insight across the scenarios developed in this study was the need for a holistic policy approach to integrating the different factors influencing agricultural production and pesticide use. This study’s approach was built on the PESTLE analysis to consider the broader context for pesticide use. For example, consumer demand can influence product supply, which can influence production processes and technology implementation. Such drivers can then determine environmental impacts, which can influence decision-making in the political arena. Furthermore, the current interconnected and globalised landscape means such factors are interlinked on a national and global scale. For example, pesticide bans in the EU can have important implications for non-EU exports of products potentially produced using such pesticides, particularly if these countries do not have the financial resources or infrastructure to follow EU regulations. This interconnectedness is already well recognised within the sector. However, it is useful to reinforce the need for considering these multiple dimensions and the interplay between them when developing policy to meet future needs.

Member States face different realities regarding agronomic conditions, farming methods, farm typologies, socio-economic contexts and political priorities. Such variation can have important implications for concerted policy action across the EU when addressing the aims of the Green Deal, including pesticide-use and risk-reduction targets. The development of strategic plans at the national level will be an important component of the implementation strategy for the reformed CAP. These plans aim to determine how each Member State can meet the CAP objectives while considering local conditions and the needs of their agricultural sector.

However, the implementation of national strategies can face several challenges. An example is the implementation of NAPs to achieve SUD objectives: several shortcomings were reported by the Commission regarding the plans' level of ambition, the effectiveness of implementation strategies and approaches to measuring performance and monitoring compliance. Such issues can increase the variation found across the Member States in incorporating sustainability into agricultural practices. Furthermore, inadequate implementation of NAPs could have negative consequences for farmers, particularly if they are not appropriately supported by policy instruments to compete in the agricultural market. Therefore, EU-level strategies need to create the conditions and appropriate incentives for the Member States to engage with policy actions that promote environmental, economic and social sustainability within the agricultural sector. This is particularly relevant if the future landscape is characterised by instability in the political and socio-economic spheres, leading to protectionist trends across countries and changes in priorities for addressing policy actions set at the EU level.

This study aimed to examine the most important variables influencing the sustainable use of pesticides in the EU to 2030 and beyond. To achieve this aim, the study generated future scenarios and considered their likely impact on EU policies to support policymakers in assessing factors likely to influence and shape future pesticide use.

The foresight approach provided a vehicle for open discussion between stakeholders to draw out differing priorities and motivations and highlight potential challenges in reaching future consensus. The breadth of factors incorporated into the scenarios was vital to faithfully reflect the complexities faced in developing policy to accommodate all needs.

These discussions and findings have been coalesced into a set of five main insights intended to guide future policy development and reiterate the different elements needing consideration when tackling this complex area. While policy development will be initiated at an EU level, these insights are also relevant for policymakers at the Member-State level. The insights reflect stakeholder discussions and highlight the particular significance of the key themes raised during the study. It is therefore not an exhaustive list but provides valuable direction for stakeholder priorities.

1. **Pesticide use needs to be managed in the longer term**

An important insight from this study relates to the time required to achieve the targets outlined in the Green Deal and associated Farm to Fork and Biodiversity Strategies. Stakeholders felt that it was overly optimistic to expect these targets would be fully met by 2030. Technological innovation is a potential factor that may accelerate the agricultural sector's transformation, particularly when complemented by nature-based solutions and alternative agricultural practices.
A suite of alternatives to pesticides can potentially contribute to reductions in their use and/or risk, ranging from biologicals/plant-biostimulants to technology-driven approaches such as precision agriculture. Strong investments will likely be made in R&D through the reformed CAP. However, the outcomes of these research efforts must translate effectively into practice and address 'on the ground' challenges while considering issues such as required investments, knowledge, infrastructure and access. Initiatives such as the EIP-AGRI may provide a means of addressing these points, particularly if a 'multi-actor approach' is implemented, allowing consideration of different stakeholder views. Furthermore, policy strategies need to provide a strong framework for farmers to take risks in implementing new practices, particularly if these require significantly higher investment levels and are yet to prove their effectiveness and efficiency.

2. **Innovation should consider public understanding and consumer demands**

Agricultural innovation across food-supply chains needs to consider the broader public understanding of new approaches, including benefits and risks, and consumer demands. Alongside implementing innovative approaches to farming and developing policies to support their rollout, it is crucial to engage the public with activities designed to improve understanding. While environmental and health concerns have prompted a shift in food consumption trends and diets towards products with higher environmental and health standards, there may still be public resistance to new technologies and agricultural practices. For example, pest-resistant GM crops and new breeding/genomic techniques could help reduce pesticide use. However, there are some negative perceptions of technologies such as genetic modification, particularly in the EU. Moreover, the prices consumers are willing to pay do not always match the resources required to provide products with higher health and environmental standards. With increasing population growth and changing demands – particularly from emerging economies – there is a need to consider how farmers can adapt and meet consumer demand while maintaining their competitiveness in the global market. Improved public understanding of the realities of farming practices and their implications for consumers is an integral part of this.

3. **Regulation must support a level playing field for farmers across the EU**

The EU is recognised globally for its leadership on sustainability issues – including pesticide use – through its regulatory framework and policy actions. However, important consideration must be given to the regulatory burden, including trade-offs that may impact costs/benefits and influence the level-playing field and competitiveness of different Member States, particularly in the global agricultural market. For example, differences between EU and non-EU food-product standards could widen the gulf between the EU and the rest of the world. Furthermore, the costs/benefits of different policies will vary worldwide, such that application will further impact EU competitiveness.

4. **Future strategies need to accommodate large multinational companies alongside smallholder farmers**

With more extensive financial and infrastructure resources to adapt to change and buffer instability (e.g. price volatility), large multinational companies (including agrochemical, farming, distribution and retail companies) can play an important role in ensuring more sustainable food provision in the future. However, if the future agricultural landscape is mainly driven by a business-led agenda, there is a risk that the agricultural sector's social dimension will not receive due consideration and support. This possibility could have major implications for smallholder farmers, exacerbating a downward trend in employment. Furthermore, for pesticide use, the consolidation of large agrochemical companies and the emergence of large generic chemical companies could impact smallholder farmers' decision-making power by constraining the pest-control options available. Such issues need to be considered within policy strategies. As highlighted in the stakeholder workshop, several multinational agrochemical companies operate in countries not subject to EU pesticide regulations. Therefore, they may be producing products for other markets that would not meet EU standards, which may have implications for EU operations.

5. **Further research is required to reach a consensus on how pesticide use should be reduced**

Large-scale crises in socioeconomic and political spheres can act as global disruptors in food supply chains. Furthermore, climate change and environmental degradation are set to bring significant challenges across all future landscapes, despite the uncertainty in the timespan and scale of their effects. Therefore, policy strategies need to have a built-in capacity and flexibility to respond to short-term and long-term stressors to be future-proof. To ensure a shift towards sustainable agricultural practices and reduced pesticide use/risks, consensus across stakeholder groups on policy-agenda priorities is needed at a national and EU level. The study scenarios provided a tool for discussing stakeholders' differing viewpoints and understanding the key considerations when developing policy intended to reduce pesticide use in the future. This process has highlighted a significant need to converge to a clear stepwise action plan to reduce pesticide use and risk while considering the political, legal, economic, societal, technological and environmental factors relevant to each Member State.

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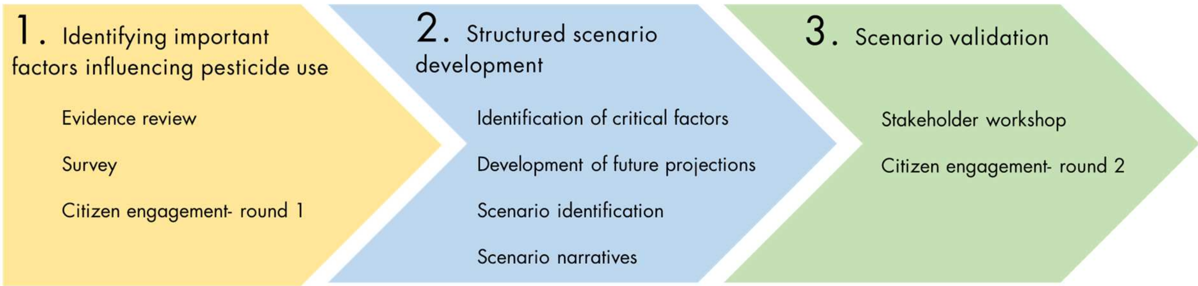
Annex A. Methodological approach

This Annex describes the overall methodological approach. It is structured according to the project implementation steps outlined in Figure 3. Each step is described in detail in the sections below.

Figure 3. Overview of methodological approach



A.1 Identification of a longlist of factors influencing pesticide use

An important component of the methodological approach was to develop future scenarios based on an interrelated multi-factor system that does not rely solely on one or two drivers. To this end, a structured, cross-cutting and expert-informed approach was implemented to identify a set of factors likely to shape future pesticide use. The approach included a desk-based evidence review, a survey and a citizen-engagement activity. The longlist of factors is provided in Annex C of this report.

A.1.1 Evidence review

The study team performed an initial document review to gather relevant evidence on factors influencing pesticide use in the EU. A PESTLE framework was used to define key influencing areas. PESTLE stands for Political, Economic, Social, Technological, Legal and Environmental. The PESTLE framework facilitates structured exploration of factors that may operate within each of these influence areas.

Search terms were developed to identify academic and grey literature and existing legal and regulatory documents (Table 3) published between 2010 and July 2021. Targeted searches complemented the initial evidence review to fill any evidence gaps for factors likely to influence pesticide use. Targeted searches were developed in collaboration with subject experts in the study team via ‘snowballing’ strategies to identify additional articles from reference lists of selected articles.

Table 3. Search terms used for identifying relevant academic and grey literature and existing legal and regulatory documents. Searches were conducted in Scopus, Google and Google Scholar.

Specific search terms		
#	*Search topic*	*Search terms*
1	Foresight studies	(Foresight OR scenario* OR futures)
2	Food systems	(“Food system” OR food OR drink OR agri* OR diet*)
3	Supply chains	(“Supply chain” OR retail* OR commodit* OR trade OR demand)
4	Plant protection products	(“Plant protection product” OR Pesticide OR Herbicide OR Fungicide OR “plant growth regulators” OR “synthetic pesticides” OR biopesticides)
5	Trends, current situation, policy actions	(Trend* OR pattern* OR shift* OR chang* OR progress* OR new OR current OR polic* OR intervention* OR transform*)
6	Agricultural market competitiveness within the EU	(pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (market OR econ*) AND (EU OR "European Union" OR Europe)
7	Agricultural markets at global level	(pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (market OR econ*) AND (global* OR world*)
8	Development of alternative food supply chains	(pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND ("supply chain*" OR suppl*)
9	Impact on farmers and other operators	(pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (industr* OR sector* OR product* OR distribut*)
10	Consumer demand	(pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (consumer* OR demand OR retail*)
11	Pesticide alternatives	(pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (alternat*)
12	IPM	(pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (IPM OR “integrated pest management”)

13	Alternative / innovative production systems	(agri* OR pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (automat* OR "genetic engineering" OR nanotech* OR "precision agri*" OR "unmanned aerial vehicles")
14	Data and digitalisation	(agri* OR pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (data OR digital*)
15	Alternative production systems	(agri* OR pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (alternativ*) AND (agroecolog* OR organic OR restorative OR sustainab*)
16	Land use	(agri* OR pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (land) AND (use OR utilization OR application)
17	Resource use	(agri* OR pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (resource OR water OR energy) AND (use OR utilization OR application)
18	Biodiversity	(agri* OR pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (biodiversit* or "crop divers*")
19	Climate change	(agri* OR pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (climate) AND (change OR varia* OR warming or emissions)
20	Pollution/degradation	(agri* OR pesticid* OR "plant protection" OR biopesticid* OR agrochemical*) AND (pollut* OR degrad* OR contamin* OR health OR quality) AND (air OR water OR soil)

The insights obtained from the evidence review were presented in a set of five scoping papers, each covering one of the five areas of influence listed above. The scoping papers are presented in Annex B of this report.

Based on the evidence review, a longlist of factors was developed for each influence area (the longlist of factors is provided in Annex C). In this context, such factors are defined as the driving forces likely to influence agricultural production, food provision and pesticide use. In collaboration with our subject experts, we prioritised these factors according to their importance for the agricultural sector and associated pesticide use and the level of uncertainty in their future development. Different stakeholder groups further assessed and validated prioritised factors through a survey (Section 6.1.2).

A.1.2 Survey

Engagement with stakeholders is an important part of the scenario-development process. While we acknowledge that pesticide use and agricultural policy are contentious issues about which entrenched views may be held, a structured survey can elicit relevant and useful information for the scenario-development process. Therefore, the study team conducted a survey with key stakeholders to assess and validate the factors identified in the evidence review. Stakeholders included in the survey were identified from: (i) our subject experts' networks and contacts, (ii) the evidence review carried out in step 6.1.1, and (iii) recommendations from DG SANTE. Given the potentially influential role of different stakeholders' attitudes in the successful implementation of agricultural policy actions, we included a wide range of stakeholder groups in the survey process. Of 124 stakeholders contacted, 26 responded to the survey (Table 4) – a response rate of 21 per cent. While low, this level of response is not unusual for this type of study. Although the study team followed up with each stakeholder to increase the response rate, responses are likely to have remained low due to the time of the year the survey was conducted (the summer holiday period).

Table 4. Stakeholder groups contacted for the survey and number of respondents

Stakeholder group	Number of people contacted	Number of respondents
EU Commission	15	5
National competent authorities from EU Member States	34	7
Distributors and sellers of pesticides	4	2
Farmers and other professional users of pesticides	10	3
Other stakeholders within sectors impacted by the SUD	18	3
Non-governmental and non-profit organisations	9	2
Scientific experts, advisory bodies and think tanks	19	2
Government representatives from non-EU countries and international organisations	15	2

The survey was administered electronically. Participants were asked to score the factors identified in the evidence review in terms of (i) their importance to future food provision and pesticide use, and (ii) the uncertainty of their potential future development to 2030 and beyond. Participants were also encouraged to provide their reasoning for the scores in the form of open-text answers.

A.1.3 Citizen engagement

Public engagement was carried out via consultation with a citizen group recruited by the Schlesinger Group, a market research partner. This activity aimed to provide a snapshot overview of citizen views on questions relevant to farming, food production and pesticide use in relation to the future of food provision. We recruited a total of 30 participants from a range of countries (France, Germany, Greece, Netherlands, Romania and Spain) to capture views from different European countries.

Two rounds of discussion were facilitated and moderated using Schlesinger Group's bespoke online community forum, Qualboard. The first round aimed to determine public attitudes regarding farming, food production and pesticide use to inform scenario development. The second round aimed to determine how different potential future scenarios influenced the views participants shared in the first round.

This small-scale citizen-group approach was considered to be the most appropriate for this study as it provided a valuable testbed of public views and responses to policy. However, it is not possible to draw conclusions about the wider European population from this non-representative sample.

A.2 Structured scenario development

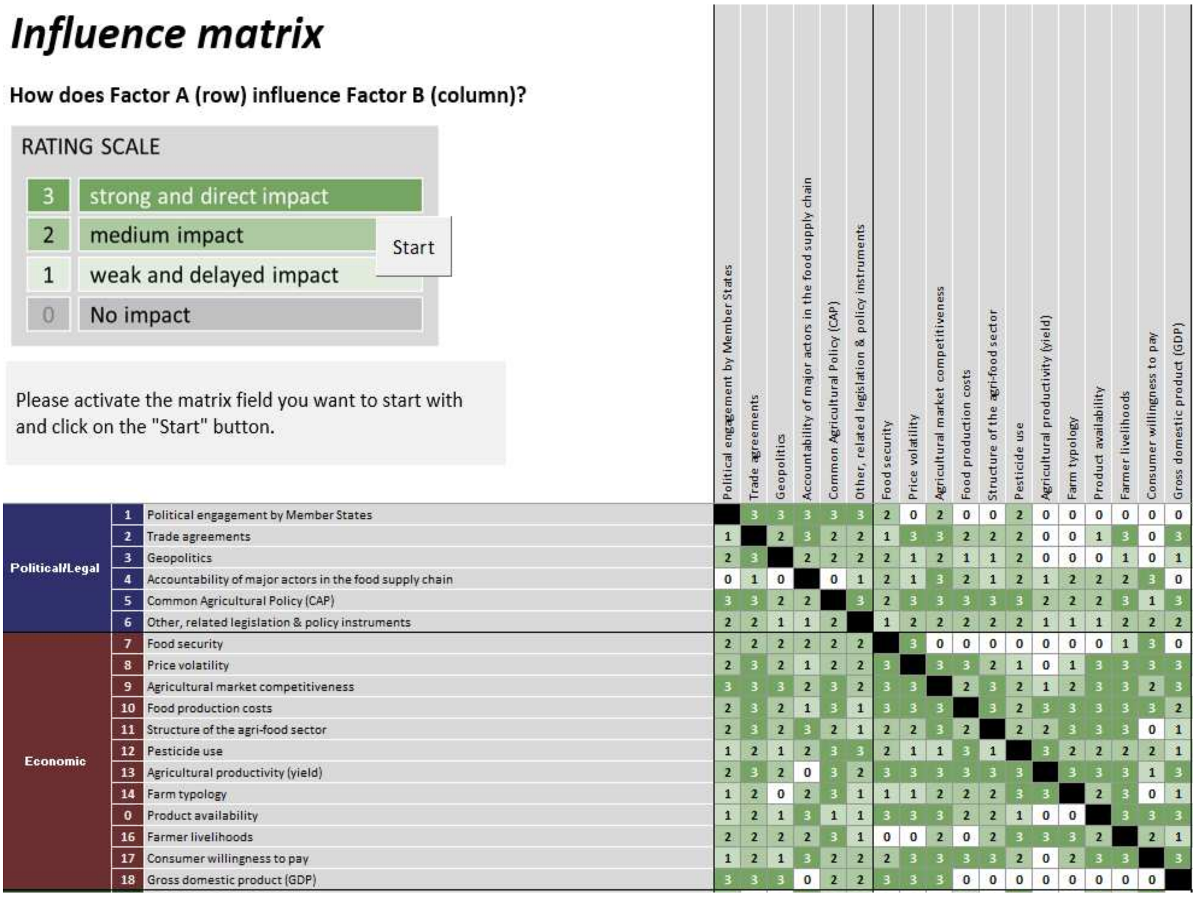
We developed the scenarios presented in this study by identifying key areas and critical factors and combining cross-impact analysis, consistency analysis and cluster analysis. We operationalised this approach through four main steps (Figure 3), describing each subsequent step in more detail. We used the ScMI software suite to support scenario development (Scenario Management International AG n.d.).

A.2.1 Selection of critical factors

We defined critical factors as variables that are both important and uncertain. To assess their mutual influence and validate the factors identified in Section 6.1, we conducted a cross-impact analysis in collaboration with our subject experts. We generated an influence matrix by inputting the critical-factor list into the ScMI software. The impacts different factors had on each other were recorded in the influence matrix using a scale from 0 (no impact) to 3 (strong and direct impact) (see Figure 4 for an example depicting a subset of the factors analysed). The influence matrix should be read from left to right. For example, political engagement has a strong and direct impact on trade agreements (score = 3), whereas trade agreements have a weak or delayed impact on political engagement (score = 1).

It should be emphasised that the scores represent qualitative judgements. Given the potential variation in different team members' scores, we held an internal workshop with the study team and the subject experts to reach a consensus on each score. This exercise also provided an opportunity to refine further the previously selected factors further.

Figure 4. Exemplar influence matrix used to conduct cross-impact analysis



Influence matrix

How does Factor A (row) influence Factor B (column)?

RATING SCALE

3	strong and direct impact
2	medium impact
1	weak and delayed impact
0	No impact

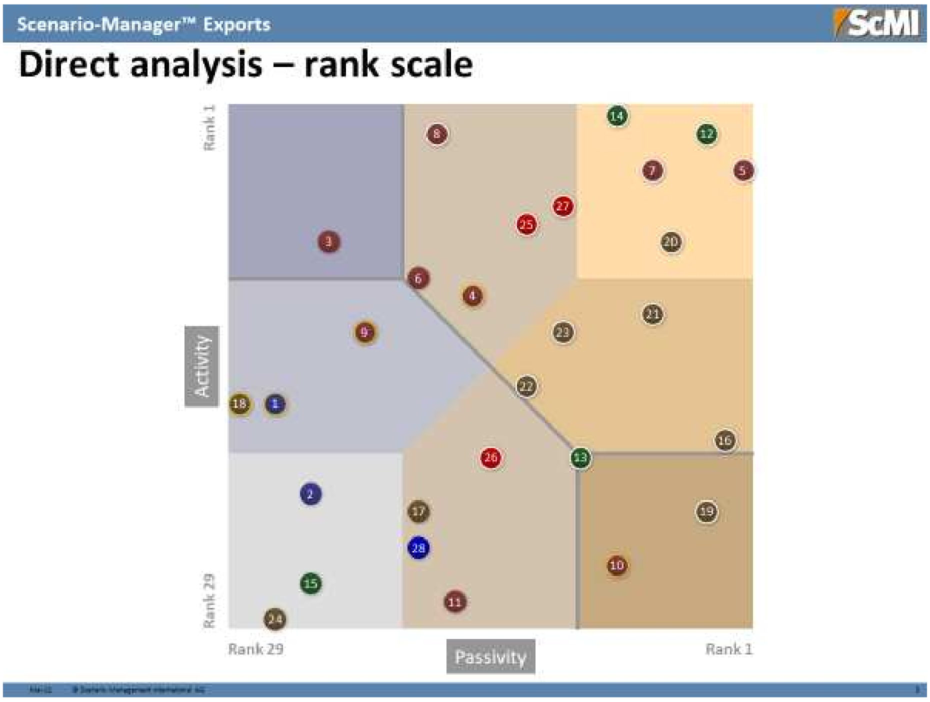
Start

Please activate the matrix field you want to start with and click on the "Start" button.

			Political engagement by Member States	Trade agreements	Geopolitics	Accountability of major actors in the food supply chain	Common Agricultural Policy (CAP)	Other, related legislation & policy instruments	Food security	Price volatility	Agricultural market competitiveness	Food production costs	Structure of the agri-food sector	Pesticide use	Agricultural productivity (yield)	Farm typology	Product availability	Farmer livelihoods	Consumer willingness to pay	Gross domestic product (GDP)
Political/Legal	1	Political engagement by Member States		3	3	3	3	3	2	0	2	0	0	2	0	0	0	0	0	0
	2	Trade agreements	1		2	3	2	2	1	3	3	2	2	2	0	0	1	3	0	3
	3	Geopolitics	2	3		2	2	2	2	1	2	1	1	2	0	0	0	1	0	1
	4	Accountability of major actors in the food supply chain	0	1	0		0	1	2	1	3	2	1	2	1	2	2	2	3	0
	5	Common Agricultural Policy (CAP)	3	3	2	2		3	2	3	3	3	3	3	2	2	2	3	1	3
	6	Other, related legislation & policy instruments	2	2	1	1	2		1	2	2	2	2	2	1	1	1	2	2	2
Economic	7	Food security	2	2	2	2	2	2		3	0	0	0	0	0	0	0	1	3	0
	8	Price volatility	2	3	2	1	2	2	3		3	3	2	1	0	1	3	3	3	3
	9	Agricultural market competitiveness	3	3	3	2	3	2	3	3		2	3	2	1	2	3	3	2	3
	10	Food production costs	2	3	2	1	3	1	3	3	3		3	2	3	3	3	3	3	2
	11	Structure of the agri-food sector	2	3	2	3	2	1	2	2	3	2		2	2	3	3	3	0	1
	12	Pesticide use	1	2	1	2	3	3	2	1	1	3	1		3	2	2	2	2	1
	13	Agricultural productivity (yield)	2	3	2	0	3	2	3	3	3	3	3	3		3	3	3	1	3
	14	Farm typology	1	2	0	2	3	1	1	1	2	2	2	3	3		2	3	0	1
	0	Product availability	1	2	1	3	1	1	3	3	3	2	2	1	0	0		3	3	3
	16	Farmer livelihoods	2	2	2	2	3	1	0	0	2	0	2	3	3	3	2		2	1
	17	Consumer willingness to pay	1	2	1	3	2	2	2	3	3	3	3	2	0	2	3	3		3
	18	Gross domestic product (GDP)	3	3	3	0	2	2	3	3	3	0	0	0	0	0	0	0	0	

The outcome of this analysis is provided by the ScMI software and illustrated in Figure 5 below, which ranks each factor based on its influence on others (Activity Index) or dependence on others (Passivity Index). The Activity Index represents the strength of influence a factor has on other factors. For example, 'Political engagement by the Member States' (row 1 in Figure 4) has a strong and direct impact across a large number of other factors, so it is specified as highly active (given the high scores in Figure 4 across its row). The Passivity Index represents the opposite relationship – the degree to which a factor is influenced by all the other factors. For example, 'Accountability of major actors in the food supply chain' (row 4 in Figure 4) has a lower impact across most other factors (it has lower scores across its row as shown in Figure 4). A factor with both a high Activity Index and a high Passivity Index (factors in the top right corner of Figure 5) is strongly interconnected in the system, being both a strong driver of other factors and strongly influenced by other factors.

Figure 5. Example of visualisation of key factor selection



A.2.2 Development of future projections

For each selected factor, we developed a set of future projections reflecting plausible outcomes for 2030 and beyond. These qualitative projections aim to represent divergent future states for each factor to capture a broad spectrum of possibilities. We developed these projections based on the evidence review and stakeholder engagement activities. Each factor was assigned up to three possible projections, as shown in Table 5Table 5.

Table 5. Shortlisted factors and corresponding future projections

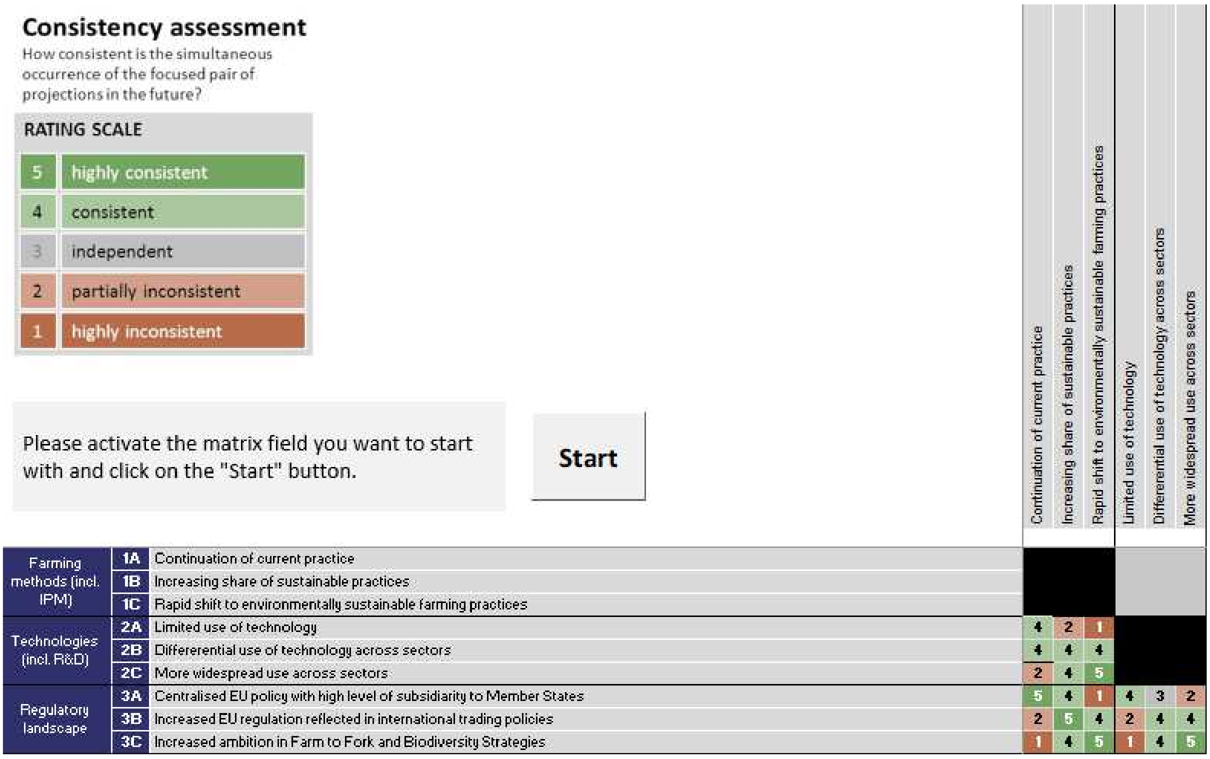
Factor	Projection
Political engagement of Member States	Mixed engagement across the Member States
	Increased engagement
	Decreased engagement
Regulatory landscape	Centralised EU policy with a high level of subsidiarity to Member States
	Increased EU regulation reflected in international trading policies
	Increased ambition in Farm to Fork and Biodiversity Strategies
Economic landscape	Strong economic growth
	Moderate growth of the economy
	Recession/ stagnation
Agricultural market competitiveness	Competitiveness levels maintained
	EU becomes more competitive
	EU becomes less competitive
Agricultural prices	Limited increase
	Higher prices
	Prices fluctuate
Food consumption trends and diets	Gradual shift towards more environmentally friendly diets
	Adoption of environmentally friendly diets becomes more mainstream
	Continued consumption of less environmentally friendly foods
Farm typology	Increasing concentration of ownership and larger farms
	Mixed typology

	Different supply chain models/ collections of farms working together
Farmers' attitudes	Limited willingness to engage/adopt new practices
	Differential willingness to engage with new practices
	Increasingly positive attitudes to new practices
Farmer livelihoods	Continued trend away from employment in the agricultural sector
	Stabilisation in employment
Technologies (incl. R&D)	Limited use of technology
	Differential use of technology across sectors
	More widespread use across sectors
Farming methods (incl. IPM)	Continuation of current practice
	Increasing share of sustainable practices
	Rapid shift to environmentally sustainable farming practices
Pesticide use (patterns of)	Continued variation in pesticide use by sub-sector
	Targeted reduction in pesticide use for some sectors
	Widespread reduction of all pesticide uses in the EU
Agricultural productivity	Continuation of current yield
	Increase in yield
	Decrease in yield
Climate change impact	Limited effect on within and outside EU
	Limited effect within EU but wider impact in some regions outside EU
	Widespread negative impacts

The next step was to assess the consistency of projections to determine which ones can occur together in future scenarios. Consistency here means how well the projections between two factors fit together and whether they might happen simultaneously. This assessment is critical for identifying which factors are likely to be interdependent. We used the ScMI software to generate a consistency matrix with a scoring system from 1 to 5. We assigned '5' to projections deemed totally consistent and '1' to projections deemed totally inconsistent (see Figure 6 for an example depicting a subset of scored factors). The projections in the consistency matrix should be considered together. For example, limited technology use is consistent with the continuation of current practice (score = 4). In contrast, increased ambition and its associated pesticide-reduction aims in the Farm to Fork and Biodiversity Strategies are highly inconsistent with the continuation of current practice (score = 1).

In consultation with our subject experts and study team, we assessed projection consistency by rating the plausibility of two projections co-existing. We undertook this for all pairs of factor projections in the consistency matrix. We used the results of the consistency analysis to generate hundreds of consistent bundles of projections across all factors, which we used as the building blocks for developing future scenarios.

Figure 6. Consistency assessment in Scenario Manager



A.2.3 Scenario identification

Cluster analysis with the ScMI software allowed us to identify clusters of projection 'bundles' with similar characteristics and generate a manageable number of distinct scenarios with consistent sets of projections across the critical factors. We combined projection 'bundles' into clusters based on the distance between the consistency rankings of projection pairs. Accounting for the trade-offs between how close the projection rankings are within a cluster and how distinct the clusters are, we used expert judgement to select an appropriate number of distinct clusters that form the scenarios. We identified four scenarios via this process, each distinct in terms of the key factor projections that characterised them.

A.2.4 Scenario narratives

We developed a short narrative for each scenario. We constructed each narrative from the perspective of 2030, building on the factor projections and bringing them to life to describe the agricultural sector and food systems within broader societal and environmental developments in the EU and internationally. The narrative provides an indicative pathway for how the 2030 future has been reached, designed to provide sufficient information for exploring policy implications without being prescriptive.

A.3 Scenario validation

A structured engagement with stakeholders was a vital component of our research approach to validate the scenarios' plausibility and explore the policy implications of each potential future.

Following the development and review of the scenario narratives, a stakeholder workshop was held online on 2 September 2021. The workshop included a total of 46 participants across the stakeholder groups initially identified for the survey and agreed in conjunction with DG SANTE (Table 6).

Table 6. Stakeholder groups present at the workshop

Stakeholder group	Number of invitations	Number of participants
EU Commission	18	17
National competent authorities from EU Member States	13	7
Distributors and sellers of pesticides	3	2
Farmers and other professional users of pesticides	6	3
Other stakeholders within sectors impacted by the SUD	9	5
Non-governmental and non-profit organisations	6	4
Scientific experts and think tanks	5	1
Government representatives from non-EU countries and international organisations	10	7

The RAND Europe study team facilitated the workshop in collaboration with the subject experts. The scenario narratives were shared with all workshop participants in advance of the workshop.

This workshop's purpose was to validate the consistency and plausibility of the developed scenarios and explore the policy implications associated with each potential future. To address these aims, we included two main discussion sessions: (i) scenario validation and (ii) exploring policy options.

In the scenario validation session, participants were allocated across four different breakout groups to discuss whether the scenarios assigned were plausible, whether there were any missing components and the impacts of each scenario on stakeholders. We used insights obtained in these discussions to refine the scenario narratives presented in this report.

In the policy-implications discussion, participants were also allocated across four breakout groups. Discussions centred on which external factors and assumptions are beyond EU control, as well as which are the policy goals, assumptions and trade-offs in the different scenarios. Furthermore, the discussions also considered how the scenarios would be influenced by EU and Member State policies and how can the different scenarios support these, considering potential overlaps and contradictions. We also asked groups to consider the impacts across different stakeholder groups. The insights obtained from this session were integrated in the overall study findings.

Annex B. Scoping papers

This Annex presents the evidence-review findings as a set of five scoping papers, each focused on a specific area of influence: political and legal, economic, societal, technological and environmental. Each scoping paper explores the trends, uncertainties and future projections for the main factors likely to influence future agricultural production, food provision and pesticide use.

B.1 Political and legal factors influencing pesticide use

Introduction

This scoping paper is one of a set of five papers produced for this study. The scoping papers are intended to support the scenario development process by identifying key factors influencing pesticide use in the EU and the achievement of its broader pesticide-use goals. The scoping papers broadly follow the PESTLE framework, covering political and legal, economic, societal, technological and environmental factors, respectively. Each paper considers evidence from the foresight literature, and reviews evidence on existing macro-level trends, explores uncertainties and discusses the implications for future development of factors.

This paper covers the political and legal factors influencing pesticide use. Several specific pieces of legislation and policy initiatives focus on pesticide use, which is broader than environmental policy alone. While there are specific policies and legislation on the sustainable use of pesticides, the scope is related to a wide body of environmental policy that has developed substantially in recent years. This paper focuses on providing an overview of the evolution of the EU's broader environmental policy and considering specific initiatives related to pesticides.

Background trends

The EU's environmental policy has become a defining element of its external and internal agenda.[3] Historically, EU environmental policy change has been incremental, advancing over a protracted period.[3] The most substantial growth in terms of the development of environmental legal instruments started in 1992 and intensified in 2007.[3] The European Green Deal was launched by the European Commission in 2019 to promote a wide number of environmental strategies aimed at making the EU economy more sustainable by 2030. The main priorities of the Commission are to make Europe greener and more resilient and take advantage of opportunities to improve digitalisation.[4] Central to the Green Deal is the Farm to Fork Strategy,[1] which addresses the challenge of sustainable food systems and introduces two objectives concerning pesticides: to reduce both the overall use and risk from chemical pesticides and the use of more hazardous pesticides by 50 per cent, respectively, by 2030. These targets are also included in the EU Biodiversity Strategy,[5] which aims to reverse ecosystem degradation and protect nature by 2030.

In support of the strategies, the EU has already launched two action plans relevant to these objectives: (i) the Zero Pollution Action Plan, which recognises the need to prevent and remedy pollution from the air, water, soil, and consumer products, and (ii) Horizon Europe's Mission on Soil Health and Food, which aims to ensure that at least 75 per cent of soils in each EU country are healthy and able to provide essential services.

The EU has taken significant measures to reduce the use and risk of chemical pesticides. Regulation of sustainable pesticide-use in the EU has been of growing concern since the 1970s. The EU's legal action in this area is justified by Articles 191 and 192(1) of the TFEU, which grant the power to preserve, protect and improve the quality of the environment and protect human health. Firstly, the Harmonised Maximum Residues Levels (MRLs)[168] and Council Directive 78/631/EEC[6] on the approximation of the laws of the Member States relating to the classification, packaging and labelling of dangerous preparations (pesticides) followed by its supporting directives up to 1990 were established. Subsequently, the Adoption of Council Directive 91/414/EEC[7] laid the groundwork for harmonising the legal framework for approving active substances and granting market authorisation for Plant Protection Products (PPPs). The origins of the Sustainable Use of Pesticides Directive can be traced back to the Sixth Environmental Action Programme (6th EAP) from DG Environment.[10]

In terms of EU legislation on pesticides use, **a crucial milestone was the so-called 'pesticide package' in 2009**. This package included (i) Regulation (EC) No 1107/2009 concerning the placing of plant protection products on the market,[6] (ii) Regulation (EC) No 1185/2009 concerning statistics on pesticides,[7] (iii) Directive 2009/127/EC regarding machinery for pesticide application[7] and (iv) Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides (SUD).[8] The regulations captured the increasing need to achieve sustainable pesticide use by reducing the risks and impacts of pesticide use on human health and the environment and promoting the use of IPM and alternative approaches or techniques, e.g. non-chemical alternatives to pesticides.

The SUD brought relevant innovations to the pesticide framework, such as the concept of IPM[9] and its principles.[8] The Directive has been transposed to national legislation in all Member States, which have drawn up NAPs to implement the range of actions set out in the Directive. However, substantial divergence in implementing its provisions has been observed in practice.[8] Current SUD implementation is largely coherent with existing legislation; for example, many of the actions taken by the Member States under the SUD are also relevant to the Biodiversity Strategy and Farm to Fork Strategy, including the adoption of pesticide-reduction targets. However, there is potential for improving coherence with chemicals and internal market legislation regarding the placement of low-risk products on the market.[8] An impact assessment of SUD's planned revision is ongoing. In the Evaluation of Regulation (EC) No 1107/2009 on the placing of plant protection products on the market[6] and Regulation (EC) No 396/2005 on maximum residue levels of pesticides,[7] it was flagged that Member States could do more to reduce pesticide use and implement IPM principles.[10]

The EU is recognised for its commitment to international obligations, particularly its leadership on sustainability issues and international cooperation on pesticide use.[11] This adherence to multilateralism continues today with its firm support for the UN 2030 Agenda for Sustainable Development.[12] Six out of 17 Sustainable Development Goals (SDGs) directly relate to the environment (SDG6, 8, 12, 14, 15 and 17),[13] which makes sustainability initiatives a fundamental part of the Commission's agenda to achieve compliance with the UN Agenda.[14] The Farm to Fork Strategy and the Biodiversity Strategy are also a fundamental part of the Commission's agenda to achieve compliance with the SDGs. In different ways, the use of pesticides is relevant to six of the seventeen SDG's:

- SDG 2 'Zero Hunger': pesticides play a key role in food safety and security
- SDG 3 'Good Health and Wellbeing': exposure and consumption of hazardous pesticides can have a harmful effect on human health
- SDG 6 'Clean Water and Sanitation': pesticides can be a source of water pollution

- SDG 8 'Decent Work and Economic Growth': the safety of farmers that make use of pesticides must be ensured
- SDG 14 'Life Below Water': pesticides can find their way into freshwater streams and rivers and end up in the sea and affect ocean life
- SDG 15 'Life on land': pesticides can be a source of pollution leading to environmental degradation and disruption of ecosystems.

<u>Uncertainties</u>

The Commission's strategy to promote compliance with environmental policies among accession countries has been considered successful.[3] **Nevertheless, political support for environmental policies varies by region in Europe.** The strongest support for climate action comes from Mediterranean and Scandinavian countries, while Eastern European countries are the least supportive.[15] There has also been considerable variation in the commitment of EU Member States to implement the rules on pesticide use.[16] For example, although the adoption of IPM principles is compulsory in the EU, their implementation has had limited effectiveness overall due to variable commitment by EU Member States.[16] Several factors underpin the reticence of these countries to implement rules related to pesticide use. Fossil-fuel dependency is one element that could necessitate additional economic effort to implement the EU Green Deal.

To increase support from Eastern European countries, the Commission has shifted to adopting less prescriptive and top-down instruments.[17] This approach is known as non-domination, which aims to respect the countries' sovereignty while supporting those states with weaker capabilities, leading to flexible environmental solutions that do not curtail the freedom of vulnerable countries.[17] These tools enable a more participatory approach that takes local concerns into account and adapts climate mitigation measures to the country's situation.[17] On the downside, it has been argued that this approach could slow down the strategy against climate change as voluntary instruments might not be sufficiently effective.[17] These approaches have also been used by the EU in international negotiations with third countries on environmental matters.[11] Their adoption has been reinforced by creating a permanent EU diplomatic body, the European External Action Service (EEAS).[17] The Green Diplomacy Network[18], an informal network of experts part of the foreign ministries of Member States created in 2003, also endorsed a style of politics more aware of local differences.[11]

Trade agreements and relations impact pesticide use. Stricter pesticide regulations within the EU have led agrochemical companies to focus on exporting EU-banned chemicals to countries with more flexible regulation.[21] For example, the EU supports the EU-Mercosur Free Trade Agreement, which, if ratified, would increase exports of dangerous pesticides from the EU to Mercosur[159] countries.[21] EU Member States approved the export of 10,945 tonnes and 13,667 tonnes of pesticides banned in the EU to Argentina, Brazil, Paraguay and Uruguay in 2018 and 2019, respectively.[21] Efforts to tighten sustainability requirements in the EU food system should be accompanied by policies that help raise standards globally to avoid the externalisation and export of unsustainable practices. The practice of exporting pesticides banned in the EU to third countries could undermine environmental and public-health efforts regarding EU pesticide use. EU-banned pesticides have been detected in food in the EU through imports from third countries (which may use EU-banned pesticides produced in the EU).[169]

Future projections

Studies demonstrate that the 'greening' of agricultural policies, particularly the Common Agricultural Policy, has had few negative (and sometimes even positive) impacts on farmers' income.[22-25] **However, further reductions in external chemical inputs could negatively impact farmers' incomes. The outcome will depend in part on consumers' willingness to pay for higher quality products or possible financial compensation that farmers might receive from other sources such as governments**. .[22-25] Research regarding the Common Agricultural Policy (CAP) reform indicates that achieving the EU Green Deal targets requires introducing strong incentives to compensate for the costs of adopting environmentally-friendly agricultural practices.[22] Expected future changes to EU policy on pesticides present both an opportunity and a challenge that will affect the agrochemical sector's economy and research, which may affect regulatory and R&D costs for new pesticides.[26]

Achievement of pesticide targets will also rely on the accountability of major actors in the food supply chain. Many actors in the food system - such as food producers, processors, food-service operators and retailers - shape the market and influence the dietary practices of consumers through their choices about food types, suppliers, production methods, packaging, transport and marketing.[27] Due to information asymmetries in the food system, where power is concentrated in progressively fewer and larger private-sector organisations, it has become increasingly difficult for consumers to make informed and ethical food choices.[28] For example, since half of the food consumed in the EU is imported, ensuring the reduction of pesticides and more sustainable food supply chains overall will require everyone involved in the supply chain to respect standards and regulations (e.g. organic rules and standards).

B.2 Economic factors influencing pesticide use

Introduction

This scoping paper is one of a set of five papers produced for this study. The scoping papers are intended to support the scenario-development process by identifying key factors influencing pesticide use in the EU and achieving its broader goals in terms of pesticide use. The scoping papers broadly follow the PESTLE framework[7], covering political and legal, economic, societal, technological and environmental factors, respectively. Each paper considers evidence from the foresight literature, reviews evidence on existing macro-level trends, explores uncertainties and discusses the implications for future development of factors.

This paper covers the economic factors influencing pesticide use.

Background trends

Several economic forces shape agricultural production by driving the supply and demand of agricultural commodities.[29] In the short term, fluctuations in raw material prices, interest rates and energy prices can influence farmers' decisions to supply commodities, which can create price volatility for agricultural commodities. Factors such as economic and population growth, biofuel demand, urbanisation, changes to consumer preferences and investments in agricultural R&D can influence agricultural markets in the long term.[29,30] Furthermore, the policy context of agricultural markets influences their competitiveness, e.g. in terms of how regulation and trade agreements can impact food prices.[31] Changes in food prices, in turn, affect consumers' willingness to pay and global food security.[31]

Global primary crop production has increased over the last two decades, primarily due to a combination of factors such as improved farming practices, increased use of agrochemicals, new technologies and increased consumer demand. In parallel, **trade in the agricultural sector has also increased** with the implementation of trade agreements and the lowering or removal of technical, economic and policy barriers.[30] Such trends have allowed more efficient allocation of agricultural production across countries[30] and increasing globalisation of the agrifood chain.[32]

Globalisation has also created employment opportunities across the agri-food supply chains while also increasing its integration via mergers, acquisitions and collaborations at the same supply-chain level (**horizontal integration**) and across its different components (**vertical integration**).[32] Whilst this integration facilitates the response of large multinational companies to fluctuations in demand and allows prices to remain stable, it also impacts small-scale producers who struggle financially to meet the demands of these capital-intensive integrated-value chains.[32]

Additionally, new trends in online shopping are gradually shifting the **balance of power between producers and distributors**. At the same time, alternative and shorter supply chains between producers and consumers are emerging to counteract such trends.[32,33] Structural changes in the food-supply chain influence the **price volatility of agricultural commodities**, which have undergone considerable fluctuations in the past few decades.[33] Examples include the considerable increase in prices during the 2007/2008 food-security crisis and again in 2010/2011[160], returning to pre-surge levels only in 2016.[34]

The COVID-19 pandemic has further exposed how uncertainty shapes agricultural commodity markets and decreases global GDP.[36] These trends have negatively affected purchasing power and food security,[36] although agrifood trade and food prices remained more robust than in other sectors.[37] Furthermore, combined with measures to halt the spread of the virus, national policy responses have shifted consumption patterns and trade flows. For example, a few major agricultural exporters implemented quotas and bans on international shipments of food products.[35] Additionally, local food production/shorter supply chains are increasingly regarded by governments, policymakers and opinion leaders as a means of improving resilience when there are disruptions in international commodity trade.[170] Moreover, global consumption patterns shifted towards home-prepared meals leading to a decline in demand for agricultural products in the restaurant and hospitality sectors.[35]

Despite the impact of the pandemic, **economic growth is projected to rebound** as countries adjust and improve management of the pandemic through national measures aimed at stimulating economic recovery.[35] This recovery will likely be uneven across countries, with the US, China, Canada, Mexico and East and South Asia showing a stronger recovery in terms of GDP.[35] **The COVID-19 pandemic has had less impact on food systems** due to government policy responses facilitating domestic and international trade through green corridors and alleviating restrictions on people's movement to address agricultural labour shortages. Despite initial disruptions in the international food market at the onset of the COVID-19 pandemic, the food system has therefore shown resilience coping with the changes brought on by the crisis.[38,39]

Although average agricultural production has continued to increase worldwide over the past several decades, this has not been the case in the EU. In contrast, **the EU's agricultural sector has seen a decline in both agricultural production per capita and output value**.[31,40,34] These changes have been attributed to a decline in the prices of agricultural goods and services and the volume of output across the key Member States.[40] In parallel, there was a **downward trend in total agricultural labour productivity in most Member States** from 2005-2020 – a trend also reported globally (with a 16 per cent decrease overall between 2000 and 2019).[40] This has been attributed to increased mechanisation and efficiency, better opportunities for the agricultural labour force in other sectors of the economy[40] and an ageing workforce, particularly within rural communities.[32]

The policy landscape also has marked effects on agricultural trade and the economy. Several countries are currently applying policy measures to mitigate GHG emissions and improve the use of agrochemicals while implementing import and export measures through trade agreements.[37] Furthermore, since farm typology[161] and size are important factors for agricultural modernisation, policies and subsidies have also targeted land consolidation and large-scale farming efforts, particularly in more populated countries.[41] Overall, total net support[162] for agriculture has decreased in OECD countries but increased in emerging and developing economies.[37] Additionally, public investments in agricultural R&D have decreased in countries like the USA. However, investments from the private sector have increased and are vital in driving innovation and new technologies.[42]

Pesticides continue to play a role in driving agricultural production. Despite the increased focus on sustainable agriculture and new advances in technology,[43] the global dependency on chemical pesticides has continued to increase over the past decades in terms of pesticide production, consumption and trade.[44] High levels of pesticide use continue to be widespread across developed countries, [45] and most developing countries are increasing their pesticide-application rates.[43] The value of global pesticide imports (a proxy for use) reportedly increased three times faster in the 2000s than the 1980s and 90s,[44] although global pesticide use has plateaued since 2012.[34]

While the increase in pesticide use is a global phenomenon, patterns of pesticide consumption vary across regions. China accounts for almost half of pesticide consumption worldwide, followed by the US, Brazil and Argentina.[34, 47, 48] In the EU, pesticides consumption has decreased slightly from 14 per cent of pesticide applications in 2000 to 12 per cent in 2018. In contrast, pesticide sales for agricultural and non-agricultural uses have remained moderately unchanged since 2011.[34,40] The variable use of pesticides has been attributed to the costs of chemicals and labour and the variation in pests by climate/geographic region.[49] Additionally, it has been proposed that pesticide use correlates positively with economic development, with higher levels of affluence per capita potentially associated with increased use of agrochemical inputs.[50]

Alongside increased pesticide resistance, the continuous widespread application of pesticides can increase the annual costs of pest control.[51] **These trends can considerably impact farmers' livelihoods**, as seen in developing countries**.**[52] For example, pesticides have allowed farmers to increase their agricultural output. Increased supply of agricultural commodities in the market may lead to a decline in food prices, which may increase farmers' vulnerability to bankruptcy.[43] On the other hand, yield loss due to climate change can lead to higher prices for agricultural commodities, impacting food security.[171] Furthermore, as pest resistance increases and new pesticide varieties are required, farmers become increasingly dependent on pesticide use and locked in a 'chemical dependence treadmill'.[43] Pesticide dependency has further economic impacts in terms of costs associated with the deterioration of environmental resources such as water, soil and biodiversity (e.g. costs sustained by the drinking water treatments companies), and public-health costs due to the reported impacts of pesticides on human health.[172]

Market incentives have been implemented for reducing pesticide dependence.[43] These include pesticide taxes, output subsidies, liability rules, revenue insurance, assignments of property rights and tradeable permits in pesticide-use rights.[43] Such instruments have predominantly been found in developed countries within the EU[53] and the USA[54], and more recently in developing countries.[43] However, they have not been widely used. For example, pesticide taxation schemes have only been established in a few European countries (e.g. France, Sweden, Denmark and Norway). The outcomes have not necessarily met expectations in terms of reducing total pesticide use.[43] The lack of success with market incentives has been attributed to factors such as challenges addressing stakeholder concerns about loss of farm income due to pesticide taxes.[55] Therefore, market mechanisms could be complemented by appropriate instruments and policy frameworks to reduce pesticide use more effectively.[43]

The agrochemical industry has undergone structural transformations due to the increased consolidation through mergers and acquisitions between key research and development companies.[56] Moreover, the increased regulatory costs and shift to consumption of generic pesticides primarily produced in China and India also impact the agrochemical industry's structure.[44] **More recently, agrochemical companies are investing in new approaches to pest control**, namely agricultural biologicals, and new technologies for improved pest management, such as precision agriculture.[56] The increasing costs of product development also impact the crop-protection industry, making pest-control alternatives more appealing. For example, the development cost of a new agrochemical is currently estimated at approximately $290 million, requiring 11 years from discovery to commercialisation.[56] On the other hand, a new plant biotechnology trait (e.g. GMOs) costs approximately $135 million, with 12-16 years from lab to commercialisation.[56]

Uncertainties

The agricultural market is shaped by uncertainties in both supply and demand. In terms of supply, agricultural yields are set to become more uncertain in a climate change context and in the face of new pests and increased pest resistance.[30, 57] This will likely increase price volatility for agricultural products.[32] Furthermore, the role of new technologies and management approaches for supporting agricultural production is still uncertain due to a changing regulatory landscape and issues such as public perception and citizen concerns.[58] On the demand side, social and demographic factors are likely to impact the agricultural market further. Namely, population growth, urbanisation, increased household incomes and increased awareness of health and sustainability issues can drive considerable changes in demand levels and diet trends, which can lead to price hikes in agricultural commodities.[30]

The crisis caused by the COVID-19 pandemic has heightened several of these uncertainties. Despite the current projections on the timing and length of economic recovery from the COVID-19 pandemic, some uncertainties remain as economic recovery will likely be shaped by political decision-making regarding economic recovery pathways.[35,57] So far, governments across the globe have developed economic recovery packages that have included specific financial support measures and initiatives for the agricultural sector. However, their success and implications for trade distortion and global food availability remain to be seen.[38]

Besides COVID-19, **other uncertainties will continue playing a pivotal role in defining the agricultural commodity market landscape**. These uncertainties include fluctuations in GDP, commodity-price volatility, biofuel demand, purchasing power, inflation, and exchange rate and the impact of energy prices (including oil price) on production costs.[29] For example, a stronger Euro may lead to a reduction in the competitiveness of EU production, as the higher price of EU products can negatively impact exports.[57]

Furthermore, **political and socio-economic stability are important factors influencing pesticide use and dependence**. For example, reduced pesticide dependence is reported to strongly correlate with democracy, bureaucratic quality, the agrochemical industry's political influence and civil society, both nationally and internationally.[43] For example, studies have shown that democracy can create a favourable political and social landscape for environment-focused policies – particularly when there is a decentralisation of power and local authorities are empowered to implement environmental policies addressing local concerns.[59,60] **Trade agreements and trade relations also impact pesticide use**. For example, stricter pesticide regulations within the EU may lead agrochemical companies to focus on exporting EU-banned chemicals to countries with a more flexible regulation. This shift, in turn, undermines environmental and public health efforts in such countries regarding pesticide use.[21]

Future projections

The development of current trends and uncertainties associated with macro and micro-level economic factors will shape future projections.

The outcomes of the COVID-19 pandemic are likely to play a key role in shaping the development of the world economy over the next few years.[35] In the short term, disruptions across the food system will likely lead to contractions in the supply and demand of agricultural products. The decline in disposable income and purchasing power could lead to lower demand due to a decline in agricultural prices.[30] The economy-wide support measures, including targeted support for the agriculture and agri-food sector implemented by most countries due to COVID-19, are expected to shape the economy in the long term.[37] For example, one study reported that OECD countries had prioritised relief measures such as earmarked funds, whereas emerging economies have focused more on loans and credits for the agricultural sector.[38]

Current macroeconomic projections indicate that the global economy will rebound in 2021-2022 and level off at an annual average growth of 3 per cent by 2030.[57] If so, agricultural trade is predicted to continue expanding between 2021 and 2031.[35] However, the expansion will be slower than the previous decade due to a slowdown in demand growth from emerging economies. Limited growth in the demand for biofuels may be another contributing factor due to a shift in political support towards electric and hybrid vehicles, which are more efficient in terms of GHG emissions.[30] Importantly, divergent productivity growth, climate change impacts on production and developments in animal or crop diseases may affect supply potential across countries.[30]

On the other hand, increased consumer awareness of food products' health and environmental impact, alongside more robust policy measures for promoting healthy and sustainable diets, are expected to shape demand patterns and lead to changes in demand for specific products.[30] Therefore, it has been noted that **appropriate trade policies may be necessary to mitigate regional imbalances**, particularly for ensuring food security and supporting rural livelihoods in resource-constrained countries.[30]

The EU economy is expected to recover its pre-COVID-19 level by 2023.[57] Rising production volumes and prices are expected to positively impact EU farm income. However, this improvement may be constrained by concomitant rises in costs.[57]Moreover, **the increased focus on policies for increasing agricultural sustainability via pesticide-use reduction could reduce food supply.** In turn, this may increase food prices for items such as fruit or vegetables, impacting consumer budgets, food security and GDP.[31,35] **The size of the EU agricultural workforce is expected to decline** from approximately 9 million workers in 2020 to 7.9 million workers in 2030, influenced primarily by technological progress in machinery and equipment.[57]

In Asia, Europe and North America, there are likely constraints to increasing agricultural area sustainably. Therefore, **increases in crop production may derive primarily from yield improvements due to technological innovation and better agricultural-management approaches.**[61,30] On the other hand, there may still be land-availability opportunities for increasing agricultural yield in South American and parts of Africa.[61]

R&D investment is also likely to play a vital role in providing alternative solutions to chemical pesticides. With companies increasingly moving away from chemical pesticides due to their more stringent regulatory framework and increased costs, new approaches emerging from R&D efforts, including biopesticides, GM crops and precision agriculture, could impact the pesticide-market outlook.[62]

The organic food market is also increasingly shaping the EU agricultural sector, responding to increased consumer demand for sustainable food products and farming practices.[30,63] EU land used for organic farming increased by 70 per cent in the last decade.[63] Such trends are likely to shape the future pesticide market by potentially reducing pesticide use, particularly when supported by policy frameworks and actions promoting the production and consumption of organic products, e.g. the EU's Action Plan for developing organic production.[2]

Economic growth in developing countries will be a primary factor shaping the demand for agricultural products; these countries account for approximately 80 per cent of the projected increase in world demand for grains, oilseeds and meats.[35] In the next few decades, developing economies are expected to drive significant agricultural-market changes due to their population growth, rising incomes and urbanisation.[61] Higher-income countries are reportedly less likely to see changes in consumption trends due to a tendency towards more established diets, which is predicted to lead to slower growth in agricultural trade in these countries.[35]

The pandemic has impacted countries across the globe in different ways, reflecting a diverse set of economies with different response capabilities and resulting in a varied range of economic impacts and forecasts.[35] **The economy's future trajectory and cross-sector recovery pace, including in agriculture, will ultimately depend on the measures and policies implemented to mitigate and adapt to the changed circumstances brought by the pandemic**.[35]

B.3 Societal factors influencing pesticide use

Introduction

This scoping paper is one of a set of five papers produced for this study. The scoping papers are intended to support the scenario-development process by identifying key factors influencing the EU's pesticide use and achievement of its broader pesticide-use goals. The scoping papers broadly follow the PESTLE framework[8], covering political and legal, economic, societal, technological and environmental factors, respectively. Each paper considers evidence from the foresight literature, and reviews evidence on existing macro-level trends, explores uncertainties and discusses the implications for future development of factors.

This paper covers the societal factors influencing pesticide use.

Background trends

Societal factors and values are important drivers for change in the food and agricultural sector. For instance, developments in technology, urbanisation and innovations in food-production systems have improved human welfare.[64] This scoping paper focuses on three main areas of particular significance to developments in the food and agricultural sector generally and pesticide use more specifically: (i) population growth, change and mobility, (ii) consumer and farmer attitudes and behaviours, and (iii) R&D in the agrochemical industry.

The global population is growing in size and mobility. The world's population is larger and more mobile than it has been at any other point in human history.[64] Although annual percentage growth has decreased since 1961, the world's population has increased from 3,034 billion in 1961 to 7,874 billion in 2021.[66] Such population growth and mobility have increased energy, food and income demands.[67, 68] For the agricultural sector, population increases have generally resulted in land-resource scarcity, fragmentation of farm plots and ecological degradation, including deforestation, overuse of natural resources, increasing GHG emissions and soil erosion.[67,68] Population growth increases demands on crop production and agricultural resources. Land degradation from increased demands on agricultural resources also accelerates crop-production challenges,[69] potentially increasing demand for agrochemicals in the EU and third countries.[69] Increased human exposure to pesticides from imported foods may also heighten risks to human health. [69] Imported foods can have higher levels of pesticide residues and residues of pesticides not currently allowed in the EU.[69]

Urbanisation has simultaneously increased, leaving fewer farmers as people move to urban areas.[70] From 1961 to 2018, the proportion of Europe's population living in rural areas declined relative to the total population. In contrast, the population of towns and cities has steadily increased.[70] As of 2020, 72 per cent of Europe's population lives in cities.[71] Although urbanisation generally increases a country's food insecurity risk, this varies according to the country's level of development.[72] Urbanisation also reduces agricultural-land availability due to urban expansion, with a predicted loss of 1.8-2.4 per cent of global croplands by 2030.[73]

The world's demographic make-up is also changing, with the proportion of the global population aged above 65 expected to increase from 9.3 per cent in 2020 to 16 per cent by 2050.[75] These changes occur alongside other social and economic changes, including declining fertility rates, changes in patterns of cohabitation and divorce, increased education levels among younger generations, population development and rapid economic development.[75] In the agricultural sector, ageing generally tends to start earlier than national averages, with negative implications for the agricultural labour force, production patterns, social organisation, land tenure and general socio-economic development.[64] In addition, older farmers are also often discriminated against in terms of access to credit, training, and income-generating resources.[32] The challenges created by the agricultural sector's ageing population are accompanied by climate change, limited agricultural-technology access and environmental degradation, which tend to affect older farmers more than their younger counterparts.[64]

Population mobility also plays an important role in sustaining the agricultural sector. The EU's agricultural sector is heavily reliant on high numbers of migrant seasonal farmworkers.[76] Between 2011 and 2017, the inflows of intra-EU and extra-EU workers increased by 58,500 (36 per cent) and 83,700 (31 per cent), respectively.[76] However, although the numbers of migrant seasonal workers have been increasing in the EU, they only partially compensate for the decline in national agricultural workforces.[76] Furthermore, agriculture can also provide solutions to population growth, as pesticides and innovative farming methods play a crucial role in feeding the world's growing population by helping increase food productivity.[77]

Citizen, consumer and farmer attitudes and behaviours around food, agriculture and pesticide use are changing. Citizens' concerns about the adverse effects of pesticides on human health and the environment have increased in the past decade.[78] However, this has not always translated into choices that align with such concerns.[79] For example, many external and societal factors influence trends in diets, some of which depend on consumer attitudes to the environment and food-production methods. Consumers generally tend to reject innovative agricultural technologies (e.g. sensors, automation and robots) that are perceived to be overly intrusive or unnatural.[80,81] Consumers' greatest concerns about pesticides relate to health and the environment, and have been increasing in the past decade.[78] Consumers are concerned about broad exposure to pesticides as well as pesticide residues in food products more specifically.[65] For example, over a third of respondents in the 2019 Eurobarometer on food safety included pesticide residues in food as one of the three issues most likely to concern them.[163] Consumer attitudes to agricultural production methods are also influenced by the broader policy-and-regulatory environment, and consumer satisfaction with EU pesticide-related legislation has declined in the past decade.[78]Moreover, increased globalisation of the food system has widened the disconnect between food production and food consumption. [82]

As consumers have become increasingly concerned about the adverse effects of hazardous chemicals on the environment and human health, awareness of chemical residues in food has increased the demand for food products with higher environmental and health standards.[49] The demand for 'clean food' is part of a changing pattern of food consumption behaviours and diets, impacting resource demands in the agricultural sector.[73] Consumer interest in ready-to-eat food with higher food-safety standards has also increased, boosting fruit and vegetable consumption.[83,84] Meat consumption has been declining in high-income countries but increased in low- and middle-income countries.[83] Consumption of seafood products has also increased steadily since the 1960s, driven by population growth, rising incomes and changes in food habits.[83] Consumer demand has also increased for food products that can enhance health, including functional foods.[83]

A range of factors influence farmers' attitudes towards agricultural-production methods and pesticide use in Europe, including farmers' knowledge (influenced by education[85]), access to information and infrastructure, environmental values (related to, for example, biodiversity) and the influence of knowledge on behaviour.[86,64] For instance, improved access to local infrastructure – including roads and the power grid – and urban centres and supermarkets are drivers of change in the food system, particularly in low- and middle-income countries for small and medium-size producers.[73]

Farmers' attitudes to pesticides are influenced by other farmers' behaviour, their perceptions of limited capacity and autonomy to reduce their pesticide use and environmental considerations.[87] Farmers in the EU perceive that decreased pesticide use could create risks for crop performance and profitability. However, the relative importance of risk was offset by their environmental concerns.[87]

R&D is a central driver of pesticide-use and influences broader food and agriculture developments.[88] Agrochemical R&D focuses on innovative farming methods and increasing the safety and effectiveness of existing approaches. R&D progress has primarily focused on increasing the effectiveness and safety of existing approaches and products rather than introducing new ones.[62,88] Increasingly, the agrochemical industry is looking to alternative technologies and techniques for crop protection, including GM crops and precision agriculture. R&D restructures and investments by big players in the crop protection industry have resulted in novel active substances, the adoption of GM crops, new techniques for applying crop-protection products, new and unique ranges of biopesticidal products and formulations providing patent protection for older products.[62,88] This has shifted the R&D focus away from pesticides. R&D costs represent a barrier to investing in alternatives to pesticide use in low-value crops.[89]

Uncertainties

It is uncertain how each of the three societal areas discussed above will develop and what impact they could have on future pesticide use.

Regarding population change and mobility, the main uncertainties relate to urbanisation and migration's impact on the agricultural sector. Exact estimates are difficult, but demographic change is predicted to increase demand for agricultural products .[76,90] Urbanisation and rising income levels have been predicted to generate higher food consumption per capita,[32] and rural-urban migration is likely to impact lifestyles, nutritional habits and food-supply strategies.[72,90] However, urbanisation can both increase and decrease populations' food security. On the one hand, rapid urbanisation can create food-provision challenges in urban environments previously unsuitable for agriculture, thereby increasing food insecurity risks.[72] Diets in urban environments also generally have a higher environmental footprint than rural diets.[73] On the other hand, urbanisation could also increase food security by improving access to the food supply infrastructure.[72] Urban populations have access to greater diversity in the food environment, including more processed and convenient foods.[48]

Likewise, migration is an important factor influencing food-supply continuity in certain EU countries, but it is uncertain how migration will develop. For instance, migration patterns can change drastically following economic and social shocks such as the COVID-19 pandemic,[76,90] e.g. urbanisation has not been happening at the same rate because people are changing their ways of living and increasingly looking to work outside the city.[91] In addition, several European countries faced a shortage of foreign labour in their agricultural sectors during the pandemic, which caused disruptions to food supply and harvesting in the EU.[76,90] Although the links between population mobility and pesticide use will depend on the policies adopted at a farm, local and national level to adapt to these changes, population change and mobility are likely to affect the agricultural sector's size and scale in the future.[69]

The extent to which farmers can act on their attitudes and values is uncertain. Although farmers may wish to reduce pesticide use in the EU agricultural sector, factors beyond their stated beliefs or values often influence their decision-making.[87] Barriers to farmers decreasing their pesticide use, – even if they wish to – include (i) the absence of non-chemical alternatives, (ii) lack of knowledge, (iii) biased information from chemical companies, (iv) insufficient provision of services providing advice on pesticide use, and (v) the perception that there is a risk of large production losses due to pesticide reductions.[87] Other barriers potentially inhibiting farmers from acting according to their stated preferences and values relate to farmers' technological lock-in based on their financial investments in the past.[87]

One uncertainty related to consumers' food-consumption attitudes and trends is the 'value-action gap', whereby consumers might declare sustainable and ethical preferences but base their decision-making on satisfying other needs (e.g. affordability, origin and convenience).[92] Other issues often prove more important than consumers' values concerning the environment or food-production methods (e.g. the origin and price of food).[92-94, 84-85] The speed that consumer acceptance of food technology will increase and the extent that science and technology for food and agriculture in the future will be accepted in a post-pandemic world is also uncertain.[95] Therefore, there is uncertainty about the individual trade-offs that consumers and farmers have to consider and act on when making decisions related to food, agriculture and pesticide use.

Difficult-to-predict challenges such as climate events and pandemics also influence attitudes, behaviours and the adoption of alternative crop-protection methods. For instance, the classification of the herbicide glyphosate as a 'probable human carcinogen' by the International Agency for Research on Cancer in 2015 significantly increased public distrust of pesticides in the EU.[78] The reapproval of glyphosate as an active substance in 2017 precipitated further public concern regarding the EU's regulatory framework for ensuring public health and environmental protection.[78]

It is also uncertain how R&D in the agricultural and agrochemical sectors will develop in the future. Despite increased R&D investment in crop protection, Europe lags behind other regions and countries, e.g. R&D growth in Brazil and Argentina.[78] Barriers include increasing regulation levels in the EU and diluted R&D investment, which both challenge strategic vision and product innovation.[88]

Future projections

In the long term, the trends and uncertainties associated with societal change will impact the food and agricultural sector, including future attitudes and pesticide use.

Demographic changes and shifts in population dynamics will likely impact the future make-up of society and the agricultural sector. Although population growth is slowing down in Europe, the global population is forecast to reach 9.8 billion by 2050.[32,66] Estimates suggest that global food production will need to increase by 50 per cent to feed an additional 2.3 billion people.[32] The number of people who live in cities versus rural areas is projected to increase as the population grows,[64] with an estimated 70 per cent of the population living in cities by 2050.[32] Europe's urbanisation level alone is expected to reach approximately 84 per cent by 2050. Both urbanisation and ageing populations are predicted to reduce the availability of the agricultural labour force and challenge the socio-economic cohesion of rural communities.[64, 74] The EU working population is expected to decline every year until 2060.[96]

Demographic changes and shifts in population dynamics will likely decrease the share of the population living in rural areas.[70] Agri-food value chains are also predicted to become more global.[32] This will likely increase migration flows and create employment opportunities while increasing barriers for small-scale producers with distribution channels becoming consolidated.[32]

Food consumption patterns will continue to change in the future, although there will likely be differences between regions. A rise in gross domestic product per capita could result in a change in food consumption patterns. However, there will likely be significant differences between regions, with overproduction and overconsumption in high-income countries and malnutrition in some Asian and Central African countries.[32] Food systems are likely to be challenged due to more segmented consumer demand, with healthy eating, sustainability and food-production ethics becoming more important.[97] Consumers' attention to diet and health-related issues is anticipated to be one of the most important future drivers on the demand side of the food system.[73] For example, health and environmental concerns in the EU might lead consumers to look for locally-produced, GM-free and organic food.[92] Convenience is also expected to increase throughout the food supply chain,[97] putting pressure on the food system. If the current trend of increasing demand for healthy and sustainable foods continues, it has been estimated that the food system in its current form will only be able to feed 10 billion people in 2050.[32,98]

New technologies are also predicted to become increasingly important to consumers' purchasing decisions in the future as they enable traceability and transparency.[99] Some experts also predict greater acceptance of innovations in the future as tools that can strengthen the food supply.[95,100] Moreover, although public distrust for pesticide regulation has increased in the past decade, public support could increase if systematic post-authorisation monitoring and review are introduced for pesticide regulation in the future.[101]

The agriculture value chain will likely have to adapt to rapidly changing consumption and distribution patterns. In parallel, environmental concerns are expected to become more important for farmers, increasing the likelihood that farmers will want to reduce their pesticide use in Europe.[87] This shift may increase the need for alternative crop-protection methods.[102] The extent to which there is a successful reduction in pesticide use in the future will depend on whether farmers receive support from other stakeholders (e.g. wholesalers and retailers) and consumers' willingness to pay higher prices.[102]

B.4 Technological factors influencing pesticide use

Introduction

This scoping paper is one of a set of five papers produced for this study. The scoping papers are intended to support the scenario-development process by identifying key factors influencing pesticide use in the EU and the achievement of its broader pesticide-reduction goals. The scoping papers broadly follow the PESTLE framework, covering political and legal, economic, societal, technological and environmental factors, respectively. Each paper reviews evidence on existing macro-level trends, explores uncertainties and discusses the implications for future development of factors. The final scoping paper considers evidence from the foresight literature.

This paper covers the technological factors influencing pesticide use.

Background trends

Technological innovation has been a key driver of transformation in the agricultural sector. For example, the Green Revolution from the 1950s to the 1980s led to significant increases in global agricultural production, particularly in South and Southeast Asia and Mexico,[103] through improved crop varieties and chemicals and more efficient machinery, cultivation methods and supporting policies.[104,105] **Despite these advances, the agricultural sector faces increasing challenges in ensuring global food security.** On the one hand, climate change and extreme weather events are increasingly exposing the vulnerability of agricultural production. On the other hand, population growth and increased demand for healthier and environmentally friendly products are continuously exerting pressure on the system.[22]

The agrochemical industry has played an essential role in buffering food security challenges by protecting crops from pests and diseases, thus preventing losses in crop production.[65] However, **agrochemical use may decrease in the long term** due to the associated health and environmental hazards, the decreasing average pesticide lifetime and increasing pesticide-resistance levels.[65]

Other sectors' rapid and widespread digitalisation is now permeating the agricultural sector with a suite of emerging technologies, including AI, ML, IoT (including sensor technology), cloud computing, robotics, unmanned aerial vehicles, nanotechnology and biotechnology. In addition, developments in agricultural machinery (i.e. robotics and sensing technology) present an opportunity to streamline food systems by increasing agricultural production and smart-farming effectiveness while lessening environmental impact.[106-108] Due to movement restrictions and labour issues, the **impact of the COVID-19 pandemic** on the logistical side of food supply chains is paving the way for accelerated technological innovation within the agricultural sector.[109]

The policy context also plays a crucial role in facilitating the technological transformation of the agricultural sector. **Governments across the globe are investing in the digital transformation of the agricultural sector** – an investment projected to grow exponentially in the next ten years.[110] For example, the EU has invested significantly in digitalising the farming sector through funding instruments such as the €79 billion Horizon 2020 fund (2014-2020) and the €100 billion Horizon Europe fund (2021-2027); these are considered of key importance in supporting R&D and technological innovation in the agricultural sector.[111,112]

Another example is the UK, which has committed £90 million to digitalise food production technologies and achieve zero emissions by 2040 through its 2017 Industrial

Strategy Challenge Fund (Transforming Food Production).[113] Similar initiatives exist globally. For example, Australia has seen substantial government investments in agricultural R&D (approximately A$1.8 billion each year) and the development of dedicated food and agriculture innovation hubs.[114]

Several of these technological advances have also improved pest management and reduced pesticide dependency through targeted approaches. For example, **management strategies based on precision agriculture[164]** have leveraged technologies such as **remote sensing for real-time monitoring and forecasting of crop diseases**.[173] Such technologies make use of sensors fitted on ground-based or aerial platforms (e.g. drones), alongside GPS/GIS and AI-based image processing tools.[115,116] The large data volumes produced by such technologies can be stored, processed and distributed using cloud computing systems, while ML and big data analytics can be applied to interpret the data.[116] Other technologies such as virtual reality have provided additional tools for farmers to scan their crops in more detail, enabling them to monitor diseases in less accessible areas.[117]

Besides pest-management monitoring and forecasting tools, technologies have also been developed for **targeting pesticide delivery to crops**. As well as reducing pesticide use and operator exposure, such technologies prevent drift to non-target areas.[115] For example, actuation drones can be deployed for precision-spraying pesticides in disease hotspots and precision-releasing natural enemies as a form of biological control[165], reducing the number of pesticide applications required and improving efficiency.[115] The use of nanotechnology in target-specific pesticide delivery also holds great promise for reducing the environmental and health impacts of pesticide application, using nanocarriers or nanoencapsulation as smart-delivery systems that prevent chemical runoff into the surrounding environment.[118]

Biotechnology, 'omic'-based technologies and advanced breeding technologies can also play an essential role in crop protection.[104] Alongside transgenic techniques and gene-editing tools such as CRISPR-Cas9 technology, the increased availability of genomic data has paved the way for engineering pest resistance into crop genomes. Pest-resistant crops were among the first GMOs used in agriculture and remain some of the most widely used GMO traits across several crop species, allowing for a reduction of chemical pesticide sprays without compromising on yield.[119] However, the adoption of transgenic GMOs and gene-edited crops has not been uniform across countries, with transgenic GMOs more widely adopted in North and South America. In contrast, Europe and Africa have seen a stricter regulatory environment and less public acceptance due to concerns about unexpected adverse effects of genetic manipulation and large companies' potential seed monopolisation leading to negative societal consequences.[120]

Technologies such as aeroponics and hydroponics also provide new options for growing crops in urban settings via vertical and high-rise farming. Such technologies allow crops to be grown without soil and provide controlled conditions that significantly reduce pesticide use.[121] **Urban agriculture** is considered a promising option for addressing food-security issues that also taps into the increased demand for locally produced food. Estimates from a 2018 study indicate that urban agriculture could contribute to approximately 5 per cent of global crop production, provided maximal space utilisation and intensive production practices.[122]

Besides its direct use in improving agricultural production, technological innovation has also brought transformation at a broader level. For example, **digitalisation through mobile applications and digital services has improved cooperation between**

farmers in sharing the benefits and costs of new technologies and agricultural equipment.[117] This has been particularly relevant in the EU, where farms are smaller and have fewer financial resources to implement large-scale technological innovation.[117] From a business perspective, **digital platforms have changed supply-and-demand dynamics**, with business-to-business transactions shortening food supply chains by reducing the number of business intermediaries.[32] Moreover, **technology has the potential to impact regulatory mechanisms**. For example, remote-sensing technology could allow better and more transparent monitoring of farmers' compliance with environmental legislation,[117,107] whereas blockchain could prevent the illicit trade of pesticides by monitoring traceability and authenticity of products.[45]

Overall, **the agricultural sector's adoption of technological innovation has been driven by factors at different levels**. At the farm level, the need to ensure profitability whilst adhering to environmental legislation and addressing issues such as the reduced rural workforce have been important drivers for farmers to implement new technologies.[117]At the consumer level, increased awareness and demand for healthy and environmentally friendly food products and expectations of greater service customisation have also shaped technological innovation in food production.[117]

Trends in technology adoption differ by geographical context. For example, constraints on land availability in Europe have translated into the prioritisation of new production technologies and precision farming. In contrast, the focus in the US is on automation to manage large farm sizes.[32] The US has also embraced more biotechnology approaches than Europe, e.g. gene editing.[32] Furthermore, some low-income countries such as Rwanda have focused on encouraging a sharing economy as a means of supporting farmers without the financial resources to invest in innovation.[32,123]

Overall, **stakeholders ranging from farming cooperatives to big multinational companies have increased their investments in agricultural technology (agritech)**. Large companies increasingly direct their investments towards new players, such as agritech start-ups, which provide the technology, data and expertise required for implementing technological innovation.[117] Therefore, mergers, acquisitions and collaborations between companies at the same level of the food chain (horizontal integration) have increased. On the other hand, new technologies and data access have allowed companies to control different stages of production previously operated by separate companies (vertical integration).[117] This trend has particularly favoured large food suppliers investing in agritech due to their greater investment resources.[124]

Another factor accelerating the agricultural sector's technological transformation is **stakeholders' R&D investment and access to research outcomes**. Collaboration between countries is a critical factor for fostering developments on this front, namely through an innovation-friendly regulatory and legal landscape.[117] Within the pesticides sector, R&D strategies are increasingly focused on alternatives to chemical pesticides, e.g. GM crops, biologicals/plant biostimulants and precision/smart agriculture. This trend is due to the rising costs and increased regulatory requirements of agrochemical R&D alongside increased pesticide resistance and the appeal of more efficient technology alternatives.[62] As such, the number of new agrochemical introductions to the market has been decreasing.[62]

Given the demographic and environmental pressures facing the agricultural sector[166] – alongside decreasing technology prices and increasing levels of data, computational power and connectivity – experts agree that **advanced technology will be increasingly prominent in ensuring food security and sustainability**.[117,56]

Uncertainties

Technological transformation holds significant promise for addressing the short and long-term challenges faced by the agricultural sector. However, there is uncertainty about whether it will be possible to leverage new technologies fully and how successfully they can address the challenges they aim to tackle.

Several new technological developments have yet to prove their effectiveness, and consideration must be given to functionality, scalability and reliability. For example, IoT can provide more effective monitoring approaches for pest control by collecting real-time data on the incidence and spread of crop pests and diseases in the field or greenhouses.[125] However, IoT-based technologies require high levels of interoperability and connectivity and the distribution of broadband coverage and internet connectivity can be fragmented, particularly in remote rural areas.[107,117] As well as the more common challenges faced by advanced technologies, e.g. data quality, reliability, integrity and cyber-security,[107,117] they confront additional issues associated with the harsh and complex agricultural environment they operate in, which is subject to both biotic and abiotic interference.[125]

New advanced technologies also require considerable investment in hardware and general infrastructure such as broadband networks.[107,117] Investment in agritech has increased over the past decade, particularly in sensing and IoT, novel farming systems (e.g. indoor farms), robotics and gene editing.[126] However, the **macroeconomic shock created by the COVID-19 pandemic** highlights key uncertainties on this front.[126] In the context of the 'new normal', some technologies are more likely to benefit from the change in circumstances, i.e. digital platforms supporting local food supply chains (e.g. e-commerce channels enabling farmers to supply directly to consumers) or robotics to deal with the labour shortage.[126] Nonetheless, it is uncertain which technology categories will have the most impact on defining economic recovery pathways.

Despite increased technology use in agriculture, **Europe still shows lower implementation levels than other economies such as the US.[117]** Barriers include the high investment levels required, the uncertain outcomes and distrust of technology.[58] EU Member-State strategies addressing the incorporation of ICTs in agriculture are also lacking.[127] Importantly, several current technological innovations such as AI, sensor networks and blockchain deal with issues related to the scale of production, tending to target larger farms and stakeholders and bypass the smallholder farms[127] that represent over half of all farms in the EU.[128]

In developing countries, where agriculture relies extensively on smallholder farmers, technology adoption for agricultural production is also low. The uptake of technological innovation in these countries is primarily constrained by imperfect information, risk aversion, institutional constraints, limited human and financial capital, small farm sizes and infrastructure problems.[129,117] Other influences include age, education status and the broader socio-cultural context.[129,117] In the agrochemical sector, constraints to adopting alternatives to chemical pesticides include the lack of skills to implement innovation and differences in crop readiness to transition to an alternative system (e.g. crops with lower chemical dependence are more suited to changes in the production system).[31] Therefore, technology uptake and implementation in agricultural production is a complex issue with several levels of uncertainty. Furthermore, **technological transformation of the agricultural sector risks widening the digital divide** between rural and urban areas and across age groups, genders and educational attainment.[130]

There is also **uncertainty regarding the public acceptance of new technologies** if these do not match consumer expectations for food production,[32,110,131] as was the case for GM technologies. New and emerging biotechnologies (the so-called 'new breeding techniques' or 'new genomic techniques') may face similar challenges if the public's views are not sufficiently considered.[132] Additional issues that can create public mistrust are societal disruption of technology impacts on rural employment, ethical challenges related to power asymmetry between farmers and large corporations, and data misuse.[131,133]

Technological innovation brings changes across the whole agricultural value chain. As such, **there is a need for good governance and information distribution to avoid potential asymmetries and unfair competition**.[117] For example, there is a risk that big data may create an imbalance by providing more decision-making power to private companies controlling the data than farmers.[110,131] Furthermore, new technological developments are often associated with a complexity level that is not always translatable or accessible for end-users due to a **lack of knowledge or skills**.[104,32,107,117] This is particularly challenging in an ageing rural workforce, which may lack the resources, skills or energy to invest and adapt.[32,107] Therefore, there is a need to foster skill development and competencies and promote knowledge transfer between research and industry[134] to optimise agricultural technology transformation. [32,107,117]

Future projections

In the long term, the trends and uncertainties associated with technological transformation will play a vital role in the agricultural sector's future innovation landscape, including technologies that could impact pesticide use.

Globally, **the agritech market is expected to grow steadily** from US$ 17,442.7 million in 2019 to US$ 41,172.5 million by 2027, despite the decline in 2020 due to COVID-19.[135] This growth will be driven by increased agricultural technology use, increased horizontal and vertical integration of food chains and further agritech investments.[32] North America currently leads the agritech market, followed by the Asia-Pacific and Europe.[135] This trend is projected to continue, while population growth and increased agricultural-yield demands in Asia will likely lead to increased investments in agritech in these regions.[135] For example, India recorded the highest number of agritech deals concerning tech-solution investments in the agricultural sector in 2019, and experienced an 87 per cent year-on-year total funding growth in this sector.[135]

In Europe, due to land availability constraints, agricultural yields are predicted to derive primarily from enhanced farming practices and continuous R&D.[57] As such, agritech will be the main driver for yield-productivity gains, improved labour conditions and adherence to environmental standards.[57] European start-ups will likely continue playing an important role in delivering key agritech innovation, including natural alternatives to chemical-based pesticides,[136] urban agriculture, self-sufficiency and shorter supply chains.[137] New players entering the agritech sector will further influence its structure, e.g. via horizontal and vertical integration.[32] **High-tech companies' influence is expected to be greater in the future as they hold the technology possibilities and solutions**.[117] For example, the increasing consolidation of the agricultural industry and the rising influence of technology companies such as Microsoft and Amazon in this sector allow corporations to further control processes and influence trends in the agricultural-production landscape.[138] Additionally, decreasing technological prices are expected to increase demand.[117]

Technological innovation is likely to have a considerable impact on the pesticides sector. **Major agrochemical companies are increasingly focusing on alternatives such as GM seeds and precision-agriculture technologies**.[139] It is predicted that an average farm will generate 4.1 million daily data points from IoT platforms by 2050, up from 190,000 in 2014.[104] Drones are also expected to be a key technology due to investment and a more relaxed regulatory environment, and are predicted to be used/owned by an increasing number of farmers over the next few years.[104,115] Furthermore, technologies such as autonomous harvesting and picking robots could decrease costs and time and increase the yield of organic products, which will be an important factor as European demand for organic products is anticipated to accelerate over the next few years.[140] Moreover, advanced data analytics could improve early warning systems for crop diseases and advanced preventive pest-control management.[117]

B.5 Environmental factors influencing pesticide use

Introduction

This scoping paper is one of a set of five papers produced for this study. The scoping papers are intended to support the scenario-development process by identifying key factors influencing pesticide use in the EU and the achievement of its broader pesticide-use goals. The scoping papers broadly follow the PESTLE framework, covering political and legal, economic, societal, technological and environmental factors, respectively. Each paper considers evidence from the foresight literature, reviews evidence on existing macro-level trends, explores uncertainties and discusses the implications for future development of factors.

This paper covers environmental factors influencing pesticide use.

Background trends

Agricultural intensification to meet the global food demand has had significant impacts on the environment.[141] Agriculture's positive environmental impacts include trapping GHG within crops and soils and mitigating flood risks via certain farming practices.[142] Similarly, pesticides have provided various environmental benefits, including increased crop yields, reduced soil disturbance, reduced fuel use for weeding, and invasive species control.[143] However, the intensity of production (including the excessive use of pesticides) on agricultural lands (including the excessive use of pesticides) has reduced their efficiency by removing or degrading environmental necessities and services (such as groundwater for irrigation, pollinators and beneficial insects).[141] The intensity of agricultural production rose substantially during the 20th century: global fertiliser consumption grew four-fold and nitrogen fertilisers seven-fold.[141] Synthetic pesticide use currently approximates 2.56 billion kg per year.[141] In the EU, the use of fertilisers and pesticides has been relatively stable since 1990, and pesticide sales remained stable over the 2011-2018 period at around 360 million kg per year.

Agricultural production is a major source of GHG emissions.[144] Food and agriculture are estimated to be responsible for up to 50 per cent of global GHG emissions.[145] The global food system relies on the intensive use of fossil fuels for fertilisers, agrochemicals, production, transport, processing, refrigeration and retailing, representing a primary contributor to climate change and air pollution.[145] Climate change (e.g. warming winter months) has also been found to alter pests' incidence, abundance and effects, necessitating additional or alternative pesticide use.[146] In turn, climate change-induced alterations in pesticide expenditures have worsened the effects of climate change on US agriculture by US$ 100 million.[146]

Pesticides pollute terrestrial and aquatic ecosystems and are a primary cause of the decline of biodiversity.[49,147] Pesticide application to crops can contaminate the environment locally and globally.[49] In particular, poor pesticide use and management and other agricultural practices have caused the global degradation of soil health and quality.[148] Many pesticides and applied hazardous pesticides can be environmentally persistent, remaining in the soil for long periods, accumulating in non-human organisms and impacting humans through the food chain.[49] Residues from pesticide use can contaminate terrestrial and aquatic ecosystems, impacting human food, water, soil and air quality.[49] Chemicals applied to crops can also remain in the soil and reach ecosystems outside the application area via surface runoff [49], exerting toxic effects on non-target species and causing damage to biodiversity and ecosystems.[49] For example, chemical pollution (including pesticides) has been recognised as an important driver for the global decline in insect populations.[147] Evidence of environmental contamination and adverse effects on biodiversity have led to efforts to develop new environmentally friendly chemicals that are less bio-accumulative and improve pesticide formulations to reduce contamination.[49] Additionally, EU regulation on Persistent Organic Pollutants (POPs) aimed to comprehensively monitor the levels of harmful contaminants in the environment and facilitate the assessment of control measures. Nonetheless, despite application cessation, the persistent chemicals used in the past are still present in soils, contributing to the high levels of pesticides in the environment.[49]

Food-and-farming policy discourse has increasingly recognised the importance of alternative farming methods and systems to ensure the agricultural sector's sustainability.[145] Agricultural mitigation measures are crucial to ensure sustainable practices limiting polluting activities (e.g. pesticide use and GHG emissions) and climate change impacts. Agricultural climate change mitigation involves shifting to agricultural practices that maintain the same intensity of food production while reducing negative environmental impacts, e.g. in ways that are less 'GHG intensive'.[144] A key feature of many such approaches involves more sustainable soil management (through a pesticide-use reduction) to ensure better soil health and quality.[148]

Several innovative approaches to sustainable food systems have been proposed. Sustainable intensification of production systems and related approaches (including climate-smart agriculture, nutrition-sensitive agriculture and sustainable food value chains) generally involve incremental transitions under the assumption that productivity per unit of land needs to increase sustainably.[151] On the other hand, more transformative agroecological and related approaches (e.g. organic agriculture) favour natural processes and reduced external inputs.[151] In addition, agroecological and related approaches focus on social and political transformation to improve ecological and human health and address issues of equity and governance.[151] The EU has seen a 70 per cent increase in the organic farming area in the last decade.[63] **IPM**[167] is one of the tools used for low-pesticide-input pest management. It aims to limit pesticide use to economically viable and ecologically justified levels and minimise risks to human and environmental health, as outlined in the SUD. IPM considers chemical control a last-resort pest-management option and thus encourages alternative control techniques such as crop rotation and mechanical weeding. IMP will be a primary tool in reducing dependency on chemical pesticides in general and more hazardous pesticides in particular.[9] **Conservation agriculture** is a set of practices promoting a permanent soil cover, minimum soil disturbance and plant species diversification.[152] These practices aim to enhance the productivity of existing farmland and regenerate land left in poor condition from intensive crop production.[152]

<u>**Uncertainties**</u>

Climate factors have altered pesticide effectiveness, often necessitating additional applications or alternative compounds with external environmental and health costs.[146] Therefore, it is possible that climate change may impact pest management and lead to increased pesticide demand.[146] It is also possible that **increased food demands due to population growth may intensify agricultural production further and increase demand for agrochemicals** (in the EU or third countries).[69]

Uncertainty remains about the extent of human and environmental health risks of pesticide usage.[147, 69]; indicators such as pesticide sales are not an adequate proxy for the harmful effects of pesticide use on human health and the environment.[69] Accurate assessment of the human and environmental health risks requires information on the use and toxicity of the pesticide sales groups, currently unavailable at the European level.[69]

There are also uncertainties around whether alternative farming methods such as agroecology and organic farming can feed the global population in the future.[151] This is partly due to less research on agroecological approaches than other innovative farming methods, resulting in knowledge gaps. The latter includes agroecological practices' relative yields and performance compared to other alternatives, linking agroecology to public policy, the economic and social impacts of agroecological approaches, the extent to which agroecological practices increase resilience in the face of climate change, and how to support transitions to agroecological food systems (including overcoming lock-ins and addressing risks that may prevent them).[151]

Although the European Commission promotes IPM as part of its sustainable pesticide policy, **there remain challenges to its implementation by the Member States.**[153] The Member States have not set clear criteria to ensure all professional users implement IPM's general principles.[153] The Member States have also highlighted barriers to using IPM tools, particularly a lack of financially viable, effective non-chemical control techniques compared to the chemical pesticides available.[153] Farmers are reluctant to alternative methods that risk economic viability and may not work.[153] In addition, because farmers are not required to keep IMP application records, enforcement is weak.[154]

<u>Future projections</u>

Several conflicting trends are expected to influence future pesticide demand.[69] The agricultural sector will need to transition to more sustainable practices to mitigate its impact on climate change.[27]

Modelling projections for 2030 show that **EU agriculture's GHG emissions will largely remain unchanged from current levels** because the projected decrease in livestock will be balanced by an increase in nitrous oxide emissions due to higher crop yields.[92] Beyond 2030, the adverse agricultural impacts of climate change are predicted to intensify, with significant yield losses in most parts of the world and substantial negative impacts on global food security in terms of food supply, quality, access and utilisation.[144] Climate change is also likely to extend the seasonal activity of pests and diseases and the risks associated with these effects.[155]

The WHO European Region has high chemical production and consumption rates with some of the most important chemical-producing countries.[156] **Agriculture and intensive food production are predicted to continue using current agrochemicals over the next few years**.[49] Some studies indicate that new chemicals may also need to be developed due to crops' reduced tolerance to chemicals due to climate change factors.[146] However, technological innovation measures, e.g. precision irrigation and agrochemical application, could mitigate non-target effects on biodiversity.[49]

Therefore, **producing food while positively impacting natural, social and human capital will be a crucial future challenge**.[141] It will be necessary to develop alternative strategies to reduce environmental chemical pollution and improve soil health and quality while maintaining the quantity and quality of agricultural yields.[148]

Sustainable intensification – defined as a process or system that increases yields without adverse environmental impact or additional land cultivation – is expected to be key to this.[141]

Sustainable and cost-effective measures for the prevention and recovery of soil degradation will be necessary to minimise its negative social, economic and environmental consequences.[148] Future efforts should develop processes to remove contaminants from soils and effluents and prevent them from contaminating aquatic systems and bioaccumulating in food chains.[49] The Biodiversity Strategy has set several commitments and actions to be delivered by 2030, including establishing a network of protected areas, restoring degraded ecosystems, reducing the risk and use of pesticides and fostering the uptake of agro-ecological practices and organic farming.[157] Advancements in science and technology, including soil biology, information and communications technology and data analysis techniques, are also expected to improve sustainable land management.[148]

Complementary and alternative modes of pest control will be critical to the future of agriculture and food systems.[141] IPM, in particular, will remain essential.[141] Member States' implementation of SUD NAPs should foster the sustainable use of pesticides in the long term and promote IPM and organic farming.[69] Despite the upward trend in organic farming in the EU and its potential for reducing pesticide demand, the proportion of organic farming in agricultural production differs significantly between EU Member States.[69]

To address these challenges, the European Commission has proposed a range of agricultural mitigation measures as part of its Green Deal.[157] A key component will addressing soil pollution as part of the Farm to Fork Strategy and Biodiversity Strategy. The objectives set for 2030 include a 50 per cent reduction in the risk and use of chemical pesticides and in more hazardous pesticides, a 50 per cent reduction of nutrient losses in soils leading to a 20 per cent reduction in fertiliser use, and organic farming in 25 per cent of agricultural lands.[157] **Enhancing soil management is cost-efficient and could deliver significant emission reductions in the short-term future**.[158]

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159. The EU has concluded a trade agreement with the four founding members of Mercosur (Argentina, Brazil, Paraguay, and Uruguay) as part of a bi-regional Association Agreement.
160. The 2007-2008 global food crisis occurred due to a spike in food prices of key cereal crops that affected predominantly developing countries. This crisis was attributed to several interrelated factors, including increased oil prices, increased demand for biofuels and trade shocks in the food market, namely export restrictions (as of 19 October 2021: https://ec.europa.eu/environment/integration/research/newsalert/pdf/225na1_en.pdf). Although global commodity prices lowered in 2009, they spiked again in 2010 due to factors such as the use of agricultural crops and land for energy, dietary shifts and population growth in developing countries, climate change impacts and other issues (As of 19 October 2021: https://www.iucn.org/backup_iucn/cmsdata.iucn.org/downloads/temti_ep_06_2013_1.pdf).
161. Farm typology refers to types of farms, focusing on size and ownership structure.
162. Total net support refers to the Total Support Estimate (TSE) as defined by the OECD. This includes policy expenditures in general services for primary agriculture that benefit the entire sector (General Services Support Estimate or GSSE), policy transfers

to individual producers (Producer Support Estimate or PSE), and budgetary support to consumers included in the Consumer Support Estimate (CSE) (as of 19 October 2021: https://www.oecd-ilibrary.org/docserver/928181a8-en.pdf?expires=1624984461&id=id&accname=ocid56013842&checksum=89E3BEC24CCBD497127CA87E0EF181A0)

163. 39% of respondents were most likely to be concerned about pesticide residues in food, compared to the misuse of antibiotics, hormones and steroids in farm animals (44%) and food additives (36%).

164. Precision agriculture refers to the application of modern information technologies to provide, process and analyse multisource data of high spatial and temporal resolution (e.g. can support decision-making and operations in crop production management).

165. Biological control of pests is an alternative to pesticide use that utilises pathogenic organisms' natural enemies to control pests. Biological control organisms can include insect-killing fungi, entomopathogenic nematodes and other organisms.

166. Demographic pressures include factors such as population growth, changes in consumer demand and diet trends. Environmental pressures refer to issues such as climate change, increased pollution and pest resistance.

167. IPM aims to keep the use of pesticides and other forms of intervention only to economically and ecologically justified levels that reduce or minimise risk to human health and the environment (as of 19 October 2021: https://ec.europa.eu/food/plants/pesticides/sustainable-use-pesticides/integrated-pest-management-ipm_en).

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Annex C. Longlist of factors influencing pesticide use

Influence area	Factors	Definition
Political and legal	Political engagement by Member States	The willingness of politicians to prioritise pesticide-use and risk-reduction policies and devote sufficient energy and resources to implementing them.
	Trade agreements	EU's trade requirements in food and agriculture goods with third countries. Implementation of sustainability and safety standards to avoid trade distortion based on Agreements on Technical Barriers to Trade (TBT) and Sanitary & Phytosanitary Measures (SPS).
	Geopolitics	Make-up of the geopolitical landscape, including international cooperation on pesticide use and risk policy with third countries and the levels of trust in the multilateral system. It also includes Initiatives already underway or to be undertaken by international organisations such as the UN, FAO, WHO and OECD.
	Accountability of major actors in the food supply chain	Food retailers, manufacturers, processors and restaurant chains' accountability and adherence to ethical practices on environmental, social and governance aspects by (including CSG/ESG policies and responsibilities).
	Common Agricultural Policy (CAP)	The capability of the EU to use the CAP as an instrument to achieve the EU pesticide use and risk and wider environmental targets. The effectiveness of funding mechanisms to incentivise a change in practices through IPM and adoption of Green Deal ambitions in the Member States' CAP strategic plans.
	Other related legislation & policy instruments	The degree related EU instruments in pollution reduction, protection of the environment, biodiversity and protection of human health among others can reduce pesticide use and risk and ensure a fully integrated approach to achieving a sustainable food system.
Economic	Food security	Reliable access to a sufficient quantity of affordable, nutritious food.
	Price volatility	Unpredictable price fluctuations on food products.
	Agricultural market competitiveness	Competitiveness of EU producers in an increasingly international market.
	Food production costs	Costs incurred by farmers to produce agricultural outputs.
	Structure of the agri-food sector	Size and number of companies controlling the food supply chain and vertical integration across the food supply chain.
	Pesticide use	The pattern of pesticide use across countries.
	Agricultural productivity (yield)	Quantity of output produced with a given quantity of inputs.
	Farm typology	Types of farms, focusing on size and ownership structure.

	Product availability	The extent to which retailers make available and promote different types of products (e.g. organic products).
	Farmer livelihoods	Employment rates in the farming industry, their ability to make a living and their quality of life.
	Consumer willingness to pay	Consumers' willingness to pay for different types of food products (e.g. organic products, pesticide free products).
	Gross domestic product (GDP)	A monetary measure of the market value of all goods and services produced in a specific period.
Societal	Public acceptability of modern technology and innovative farming methods (involving chemical and biological approaches)	Public acceptability of new food technologies (such as nanotechnology, irradiation, genetic modification, and new breeding techniques) and innovative farming methods involving chemical and biological approaches using enzymes, metabiological engineering, and nanoencapsulation.
	Public attitudes to the environment	Public attitudes to risks of pesticide use, climate change, renewable energy, environmental sustainability and biodiversity protection.
	Demographic change and population mobility	Changes in a population's age structure, ability to work or live in a different country, and urbanisation.
	Food consumption trends and diets	Consumer preferences regarding food choices (e.g. vegetarian and vegan diets).
	Infrastructure and information access	Farmers' ability to access information relevant to sustainable pesticide use. Farmers' access to infrastructure to implement farming approaches (e.g. data, equipment).
	Education, training and skills	Farmers' education levels and skills (both hard and soft skills), which can impact their willingness to adopt sustainable farming practices.
	R&D for agriculture	National and international collaboration and data sharing for agricultural research and development.
Technological	Tools and technologies for data analytics	Technologies such as AI, ML and IoT that can support farmers in monitoring crop fields, optimising pes-management decision-making and reduce pesticide use and its associated risks.
	Robotics	Equipment that enables task automation (e.g. weed picking, growth monitoring, harvesting, sorting, and packing). Includes drones (unmanned aerial vehicles that can support farmers in monitoring processes such as irrigation, soil and infestation problems).

	Biotechnology and nanotechnology	Biotechnology-related tools that use biological systems, living organisms (or parts of them) to develop or create different products, e.g. GMOs. This factor also includes nanotechnology with applications such as nanoformulations of agrochemicals for applying pesticides and fertilisers and nanosensors in crop protection for diseases diseases and agrochemical residues.
	Precision agriculture	Application of modern information technologies to provide, process and analyse multi-source data of high spatial and temporal resolution (e.g. can support decision-making and operations in crop-production management).
	Novel control agents	Alternative crop protection tools and products (e.g. biological control agents).
Environmental	Farming methods	Farming methods such as conventional agriculture, agroecology, conservation agriculture, crop diversification and rotation, organic farming, and sustainable intensification of agriculture.
	Integrated Pest Management (IPM)	The careful consideration of all available plant-protection methods and subsequent integration of those that discourage populations of harmful organisms, are economically and ecologically justified, and reduce or minimise risks to human and environmental health. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems, encouraging natural pest-control mechanisms.
	Biodiversity (non-target effects of pesticide use)	Biodiversity refers to the millions of unique living organisms on Earth and the interactions among them. Biodiversity can be affected by the non-target effects of pesticide use.
	Mitigation	Efforts to reduce or prevent emission from all GHG. These include using new technologies and renewable energies, making old equipment energy-efficient, changing consumer behaviour and management practices.
	Adaptation	Actions to prepare for and adjust to climate change effects, now and in the future. These include reducing pesticide sensitivity under changing environmental conditions. Actions may also tackle issues such as pest resistance and the introduction of new pest diseases.
	Pollution due to hazardous chemicals	Pesticide pollution of terrestrial and aquatic ecosystems and its impact on water, soil and air quality.

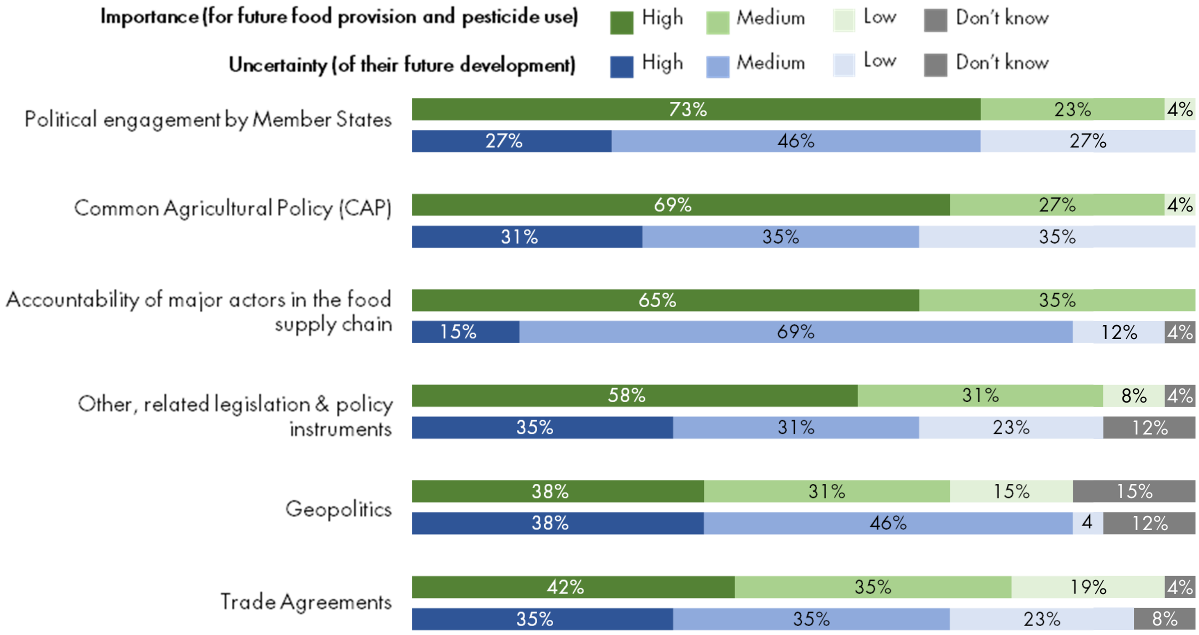
Annex D. Survey results

The survey aimed to assess and validate the factors identified in the evidence review (as described in Section 6.1.1). We defined the sample frame using (i) our subject experts' networks and contacts, (ii) the evidence review, and iii) recommendations from DG SANTE. This process led to a sample of 124 stakeholders that included EU Commission Services, national competent authorities from the EU Member States, distributors and sellers of pesticides, farmers and other professional users of pesticides, other stakeholders within sectors impacted by the SUD, non-governmental and non-profit organisations, scientific experts and think tanks, government representatives from non-EU countries and international organisations. From this sample, 26 stakeholders responded to the survey (Table 4 in Annex A). The survey was informed by the of our factor analysis. To undertake the latter, we grouped factors by PESTLE (Political, Economic, Social, Technological, Legal, Environmental) areas and asked stakeholders to rate each factor according to (i) its level of importance for future food provision and pesticide use and (ii) how uncertain its underpinning trends might be up to 2030 and beyond.

D.1 Political Factors

Member States' political engagement was considered the most important factor, with 73% (n=19) of respondents rating it as highly important for the future of food provision and use. Political engagement was also given a medium (46%, n=12) to low (27%, n=7) uncertainty rating regarding its future development. Member States' political engagement was highlighted as an important factor; respondents recognised that Member States' commitment would be needed to uphold EU law and deliver the results intended by the Sustainable Use Directive (SUD). The two most important factors after political engagement were the Common Agricultural Policy (CAP) (69%, n=18) and the accountability of major actors in the food supply chain (65%, n=17). Nonetheless, the CAP was considered significantly more uncertain than important (in terms of the measures of uncertainty and importance recorded in the survey) compared to major actors in the food supply chain (31% n=8 for the former; 15% n=4 for the latter). Just over half (58%, n=15) of respondents rated other related legislation and policy measures as highly important. Other related legislation and policy measures listed by the respondents included increased political engagement from the Commission and European Parliament, pesticide risk assessment by the European Food Safety Authority (EFSA) and rules about independent assessment or conflicts of interest. In turn, 35% (n= 9) of respondents reported high levels of uncertainty for the future development of these general legislation and policy instruments. Respondents also suggested high levels of uncertainty around the future development of geopolitics (38%, n=10) and trade agreements (35%, n=9). However, both factors were rated as the least important political factors regarding future food provision and pesticide use, with 42% (n=11) of respondents reporting low importance for trade agreements and 38% (n=10) for geopolitics (Figure 7).

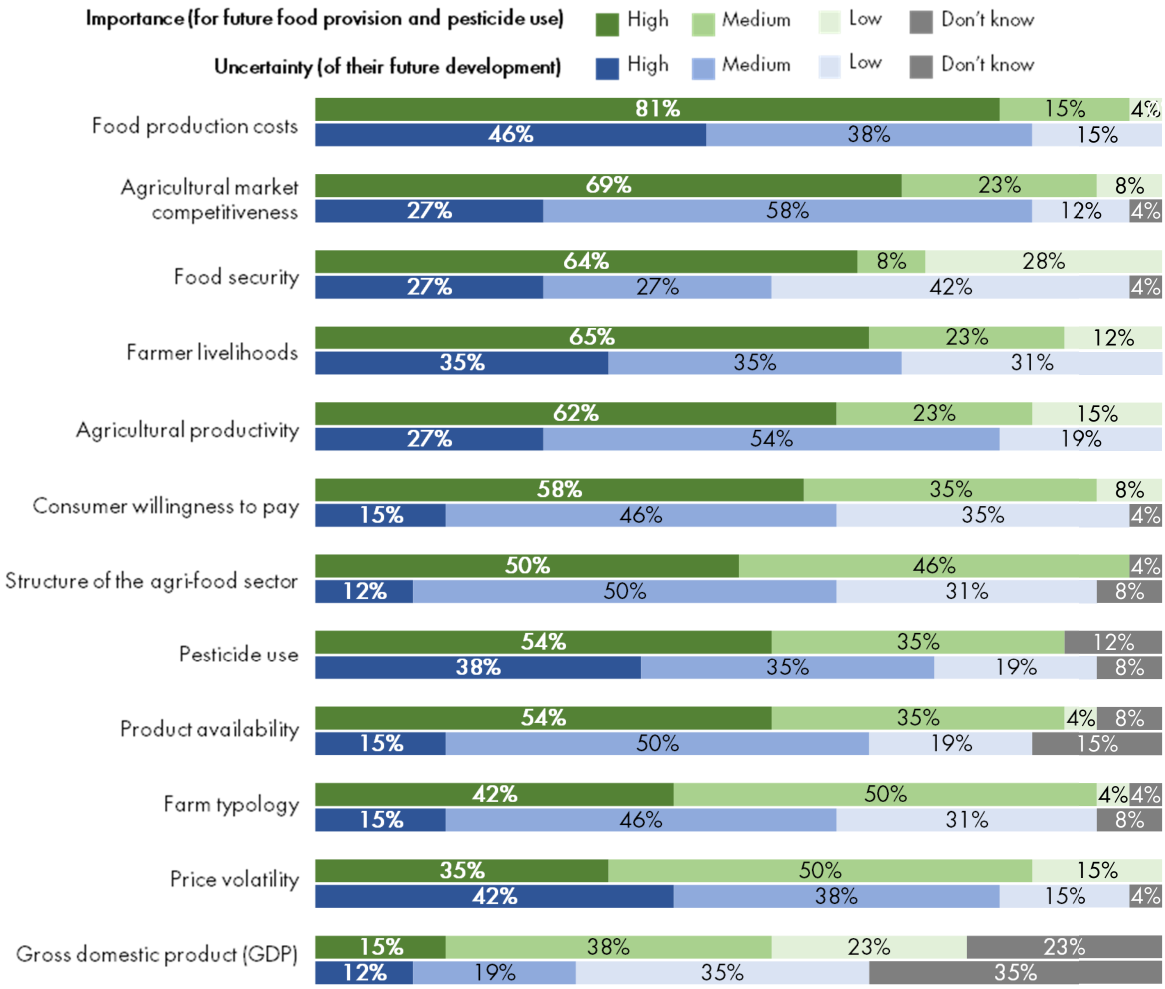
Figure 7. Political Factors: 'Please rate the political factors listed below according to their level of importance for future food provision and pesticide use, and the uncertainty of their future development (how they might change to 2030 and beyond)'. N=26



D.2 Economic Factors

A total of 81% (n=21) of respondents rated food-production costs as a highly important issue for the future of food provision and pesticide use. Food production was rated as the most uncertain factor (46%, n= 12) due to varying demand levels and potential new rules affecting food-production costs (which in turn could influence pesticide use, productivity/yield and farmers' livelihoods). In comparison, price volatility was less likely to be considered highly important (35%, n=9). However, it scored higher in terms of uncertainty (42%, n=11). Pesticide use and farmer livelihoods were also considered highly uncertain, with 38% (n=10) for pesticide use and 35% (n=9) for farmer livelihoods. However, they were also considered to have relatively high levels of importance, with 54% (n=14) for pesticide use and 65% (n=17) for farmer livelihoods. The highly uncertain factors appeared to be interconnected, with respondents highlighting how intertwined consumer demand/ social demand are in driving supply – and how supply (abundance or lack of) could change consumer behaviour. Other external factors were also considered, including the environmental concerns driving demand, the need to diversify food products, changes in food production structures and the need to find alternative pesticide methods and products, e.g. IPM and biocontrol (Figure 8).

Figure 8. Economic Factors: 'Please rate the economic factors listed below according to their level of importance for future food provision and pesticide use, and the uncertainty of their future development (how they might change to 2030 and beyond'). N=26



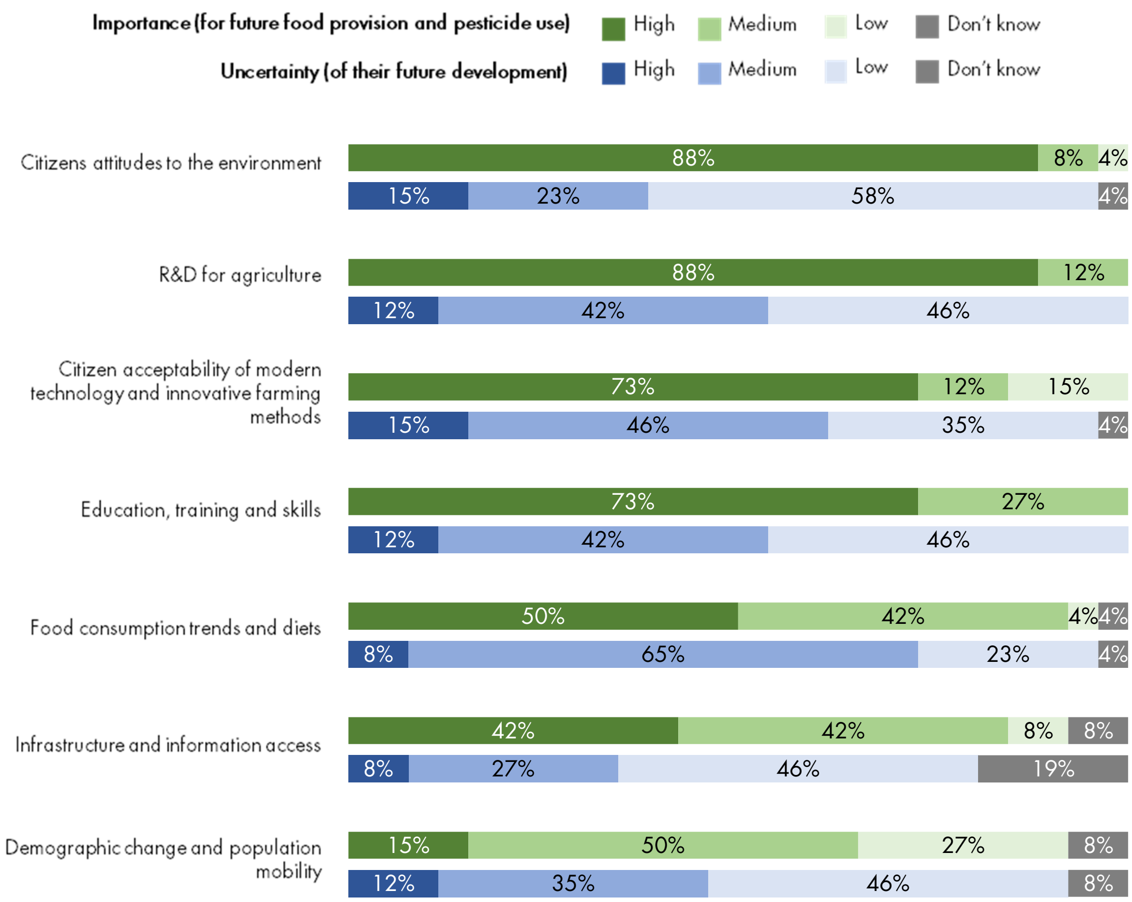
D.3 Societal factors

Respondents consistently ranked public attitudes to the environment and agricultural R&D as highly important (both 88%, n=23, respectively). In addition, 73% (n=19) of respondents highlighted that public acceptability of modern technology and innovative farming methods was important for future food provision and pesticide use. On the other hand, public attitudes to the environment were considered key to increasing the uptake of sustainable practices and shaping consumer trends. However, while public attitudes play a role in shaping EU agriculture discussions, shifts in public awareness and attitudes would need to translate into changed eating and buying behaviours. Public attitudes to the environment and agricultural R&D were considered relatively low in uncertainty, with three-fifths (58%, n=15) rating the uncertainty of public attitudes to the environment as low equal proportions rating agricultural R&D as having medium and low uncertainty levels (46%, n=12).

No societal factors were considered to have high levels of uncertainty, with only 8-15% (n=2-4) of respondents rating any single societal factor as highly uncertain. These results suggest that respondents consider these social factors less uncertain in terms of their future development, with one exception: food consumption trends were not considered highly uncertain (8%, n=2). However, the majority of respondents rated this factor at a medium level of uncertainty (65%, n=17) (Figure 9).

Survey respondents also suggested that some factors were missing from the societal factors list. These included the degradation of production potential (i.e. soil, water, biodiversity and environment), adverse long-term health impacts (e.g. associations between pesticide use and chronic diseases), broadband expansion in rural areas to allow farmers to monitor and optimise pest-control approaches, and public attitudes regarding pesticide acceptability.

Figure 9. Societal Factors: 'Please rate the societal factors listed below according to their level of importance for future food provision and pesticide use, and the uncertainty of their future development (how they might change to 2030 and beyond)'. N=26

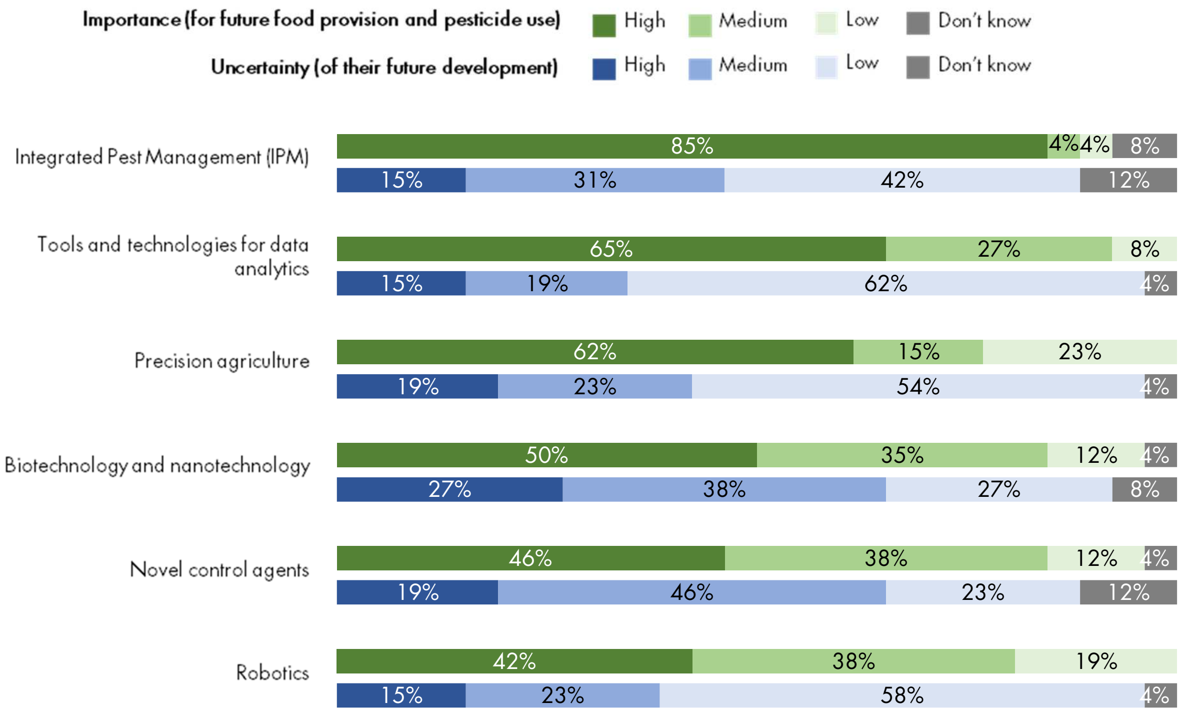


D.4 Technological factors

Over four-fifths (85%, n=22) of survey respondents rated IPM as an important factor for the future of food provision and pesticide use. In addition, two-fifths (42%, n=11) of respondents rated the uncertainty of IPM's future development as low. IPM can potentially reduce pesticides use and will be vital for fulfilling the EU commitment to transition towards sustainable food systems. One respondent suggested that while IPM was key to reducing pesticides, it was also about returning to traditional strategies. Several other respondents pointed out that IPM has not been widely adopted due to a lack of support, training and solutions.

Data analytics tools and technologies were rated as highly important (65%, n=17), with low uncertainty in future development (62%, n=16). Similarly, precision agriculture was scored as highly important (62%, n=16), with low uncertainty (54%, n=14). The technological factor considered to have the greatest uncertainty was biotechnology (27%, n=7), and half of the respondents rated it as highly important (50%, n=13) for future food provision and pesticide use (Figure 10).

Figure 10. Technological Factors: 'Please rate the technological factors listed below according to their level of importance for future food provision and pesticide use, and the uncertainty of their future development (how they might change to 2030 and beyond)'. N=26

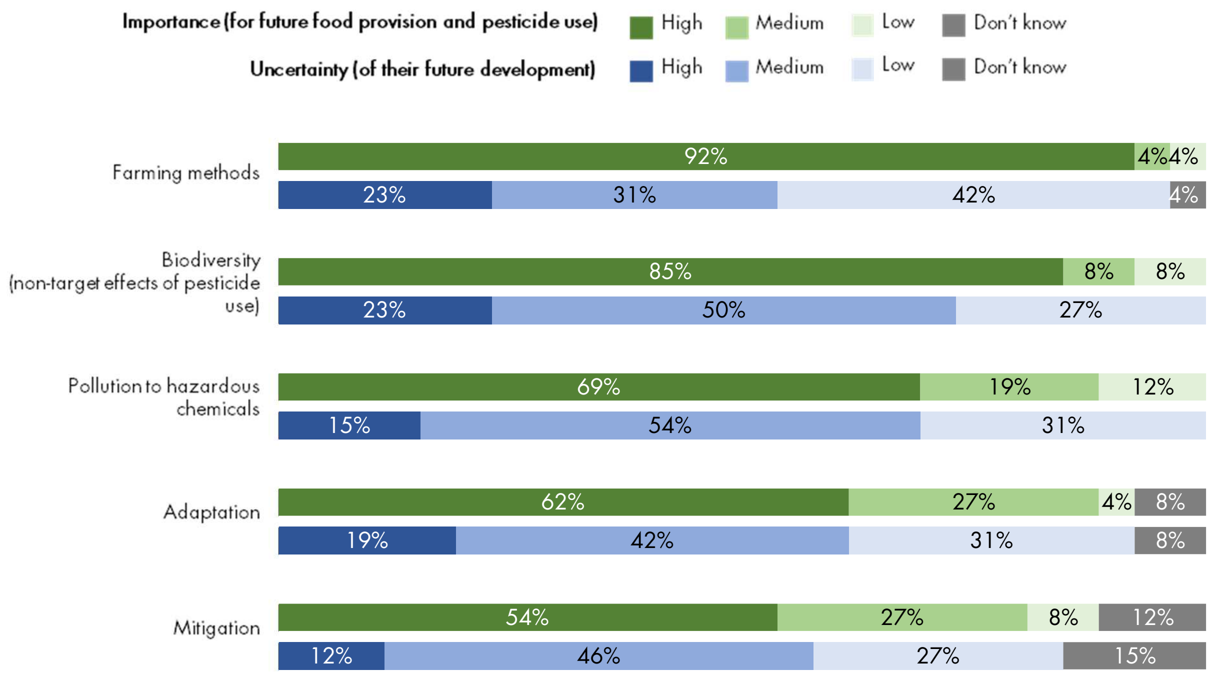


D.5 Environmental factors

Most survey respondents agreed that farming methods are a highly important factor for future food provision and pesticide use (92%, n=24). However, this trend was found across all environmental factors, with most rated as highly important: 85% (n=22) of respondents rated biodiversity as highly important, 69% (n=18) rated pollution due to hazardous chemicals use as highly important, and 62% (n=16) rated adaptation as highly important. Mitigation was rated the lowest, with just over half (54%, n=14) of respondents considering it of importance.

Farming methods were rated of the highest importance, with biodiversity the second highest. Both factors were also considered highly uncertain (at 24%, n=6) (Figure 11). Respondents explained these results by pointing to uncertainty around the environmental impacts of future climate change, farmers' ageing population and lack of recognition of farmers contract work. Regarding biodiversity, respondents stressed that healthy agroecosystems and plant-care strategies require a rich, resilient and self-regulating biodiversity. Pollutants from hazardous chemicals can impact soil and ecosystem health, increase water pollution and adversely impact the food systems' resilience.

Figure 11. Environmental Factors: 'Please rate the environmental factors listed below according to their level of importance for future food provision and pesticide use, and the uncertainty of their future development (how they might change to 2030 and beyond)'. N=26



Annex E. Citizen engagement

Engagement with the general public was an essential part of the study. Future developments in agriculture, including pesticide use, are potentially contentious. Therefore, it is critical to ascertain the views and attitudes of stakeholder groups and the public as these may affect the implementation and acceptability of policy in this area.

The citizen group was consulted twice during the course of the study. Firstly, during the scenario development stage to help ascertain how public attitudes influence future factor projections. The group's views complemented the insights collected in the survey, helping to validate and construct the scenarios. Secondly, the citizen group helped explore how citizens may assess policies when shown their effectiveness against the backdrop of different scenarios.

We subcontracted Schlesinger Group, a market research partner, to recruit participants to an online community. A total of 39 participants were recruited from six European countries (Spain, Germany, Greece, Romania, France and the Netherlands). Of these, 33 participants took part in both the first and second phases of the survey. Participants were asked questions at the start and end of the study (alongside the survey and after the stakeholder workshop, respectively). The questionnaire included multiple-choice, ranking (from very important to not important) and open-text questions that allowed participants to expand on their reasoning behind each response. The two rounds of discussion were facilitated and moderated asynchronously using Schlesinger Group's bespoke online community forum, Qualboard.

Although this small-scale, citizen-group approach is considered the most appropriate for this study, providing a useful testbed of the general public's views and responses to policy, it is not possible to draw conclusions about the wider European population from these results.

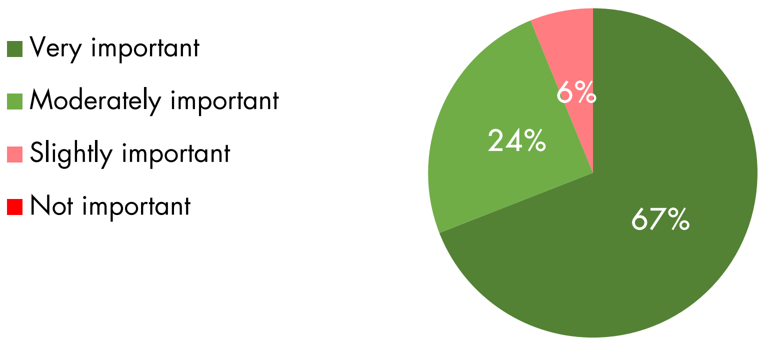
This Annex presents an analysis of the main findings from the citizen engagement activities, structured according to the following sections: (i) Food production, (ii) Current knowledge of pesticide use, (iii) Pesticide policies, (iv) Perceptions of pesticide use (health, economics, farming methods and technology), (v) EU policies and strategies, and (vi) Future policies.

E.1 Phase 1: public attitudes regarding farming, food production and pesticides

E.1.1 Food production

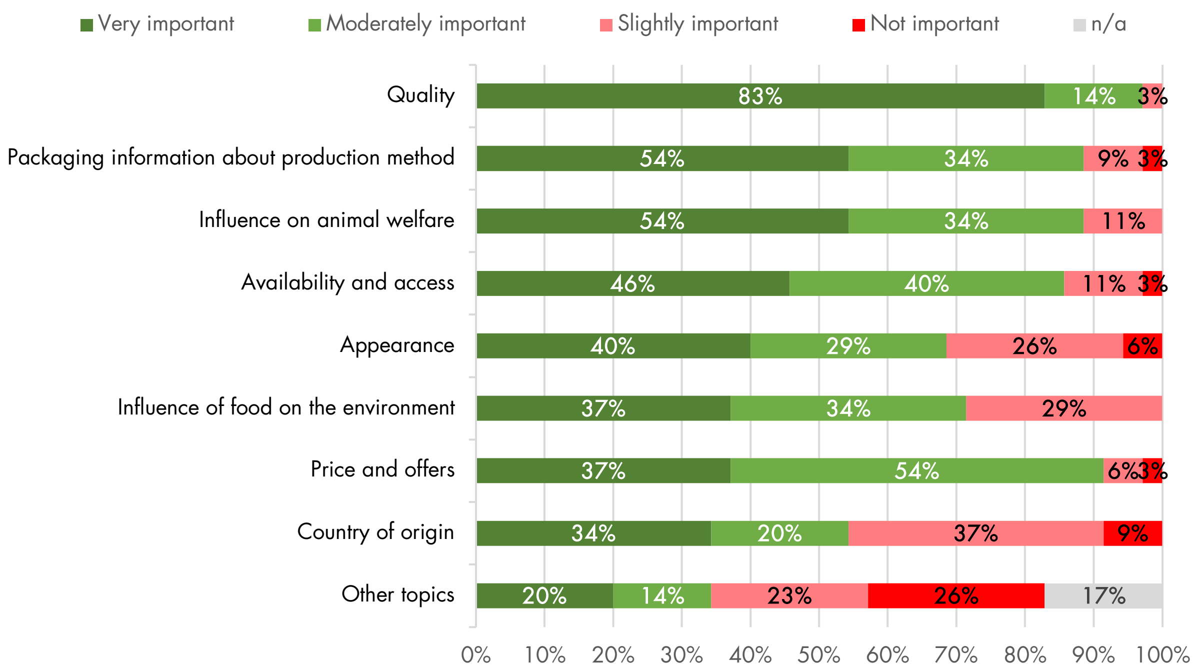
Environmental issues (including climate change, biodiversity and local environmental pollution) were rated as 'very important' across countries and citizens. Only 6% scored environmental issues as 'slightly important', and 0% considered it 'not important' (Figure 12).

Figure 12. 'How important are environmental issues to you (including climate, biodiversity and local environmental pollution)?' N=33



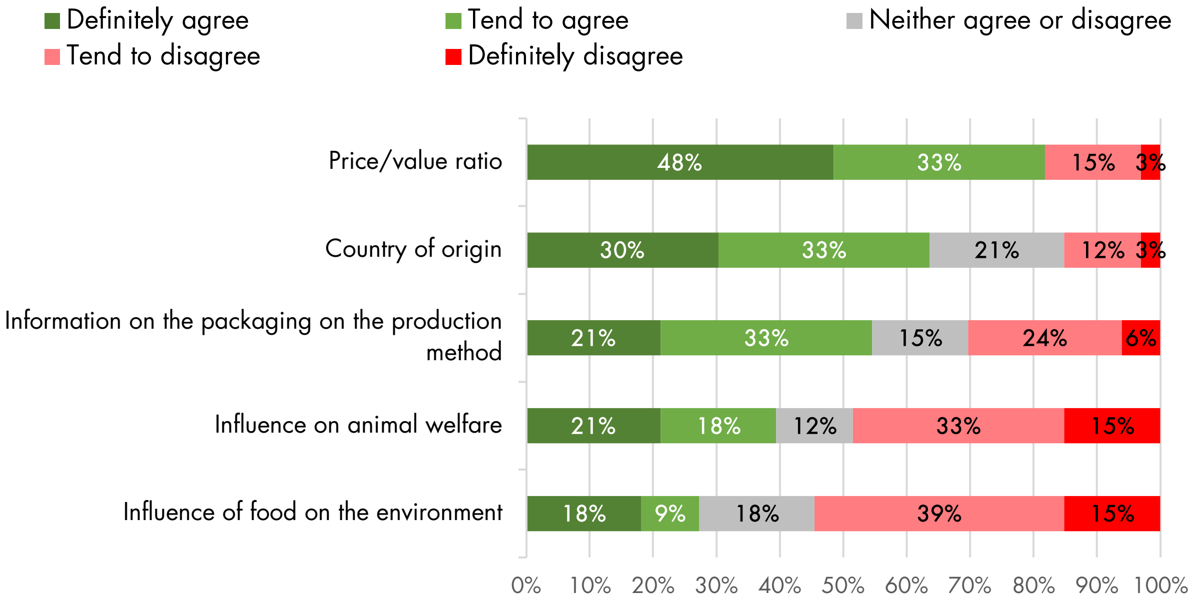
Citizens scored food quality as the most important element when buying food, with 85% rating it as very important and 12% as moderately important). The next most important factors when purchasing food were considered to be information on the packaging about the production method, the influence on animal welfare and availability and access. While only 36% of respondents classed prices and offers as a very important consideration when buying food, 55% rated price as a moderately important factor. Other considerations included seasonal availability of fruits and vegetables, expiration dates and dietary preferences, e.g. fat-free (Figure 13).

Figure 13. Phase 1: 'Thinking about food production more broadly, what is important for you when you buy food?' N=33



When purchasing food, respondents felt they had enough information about price/value ratio of food (48% strongly agreeing) and the country of origin (30% strongly agreeing). However, they were less likely to agree that they had enough information about foods' influence on animal welfare or the environment (Figure 14).

Figure 14. Phase 1: 'How much do you agree with the following statements? I think I have enough information about…' N=33

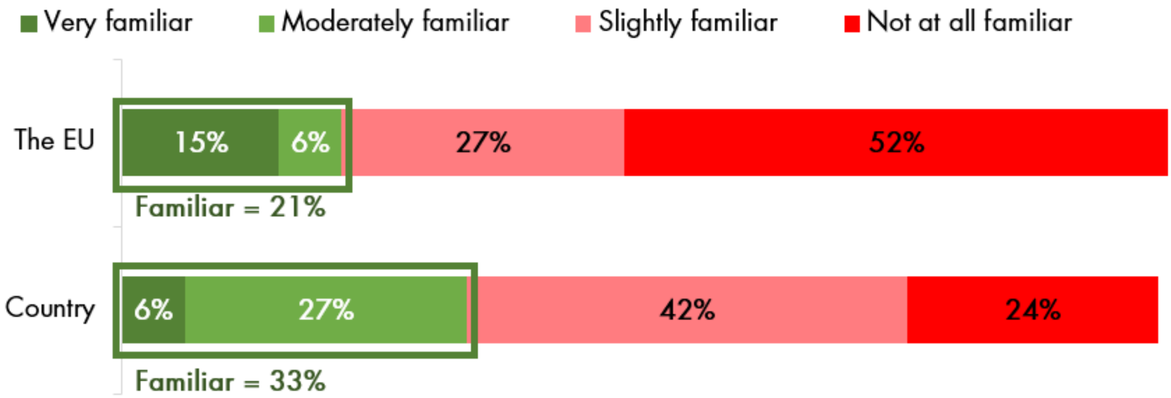


When considering the most significant risks to food quality and safety (both in the respondent's country and the EU), chemical pesticides were repeatedly mentioned. Respondents expressed concern that using chemical pesticides (and chemicals generally) in food production would harm humans, animals and local ecology. There were also concerns regarding the long-term consequences of these chemicals on the environment. In addition, a few concerns were raised about viruses in food and animals. One respondent wrote that 'the most important risks are viruses, diseases that can be ingested.' Another recurring concern was the lack of supply chain resilience and potential issues with food imports, with some respondents concerned about the variation in standards between the EU and other countries. The remaining issues included the genetic modification of food, excess food production and how agricultural production will withstand the effects of climate change.

E.1.2 Current knowledge of pesticide use

Baseline familiarity with pesticide use in the respondent's country or the EU was low. Respondents were more likely to be familiar with pesticide use in their country (33%) than in the EU (15%), and more than half (52%) of respondents said they were not at all familiar with pesticide use in Europe (Figure 15).

Figure 15. Phase 1: 'How familiar are you with pesticide use in your country or in the EU?' N=33

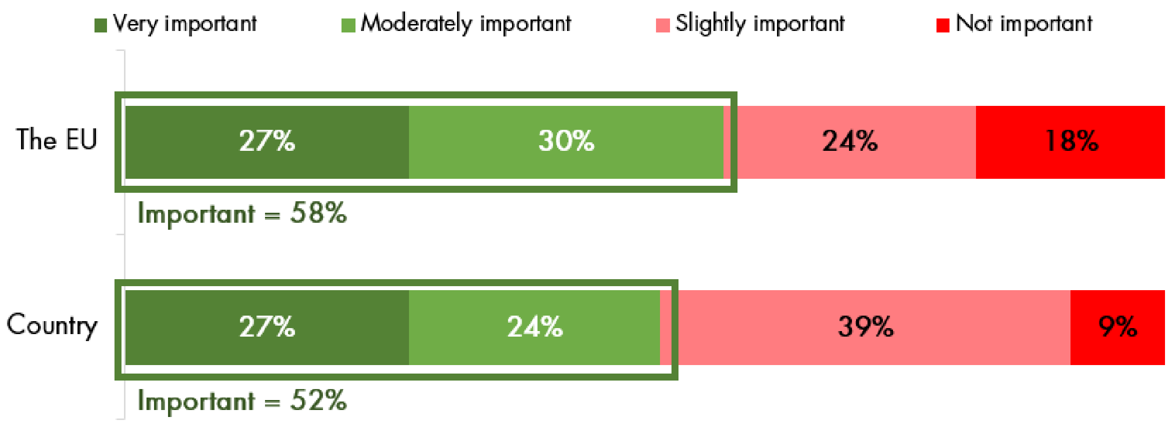


When asked to identify strategies, initiatives or actions related to pesticide use in their countries, several participants did not know of any. Respondents who did demonstrated varying levels of knowledge about such initiatives and actions, with some having only a vague understanding of pesticide use (e.g. 'I know from my parents that the level of pesticide use is high, and they are trying to moderate it'; 'If I am honest, I do not feel well informed about the subject of 'strategies and initiatives on pesticides in Germany'; and 'All I know is that there are initiatives that seek to curb the spread of pesticides in order to protect biodiversity.')

E.1.3 Pesticide policies

In general, respondents across Europe were evenly divided on the importance of pesticide use to the political agenda in their country and the EU: 58% rated it as important on the EU's political agenda, while 52% rated it as important on their country's political agenda). French respondents considered pesticide use an important policy issue in France and the EU. German respondents considered pesticide use a slightly important issue in Germany and the EU. However, respondents from most other countries demonstrated mixed responses (slightly, moderately important) at the national and EU levels. In general, respondents who considered pesticides an unimportant policy issue in their own country also felt it was not an important issue at the EU policy level (Figure 16).

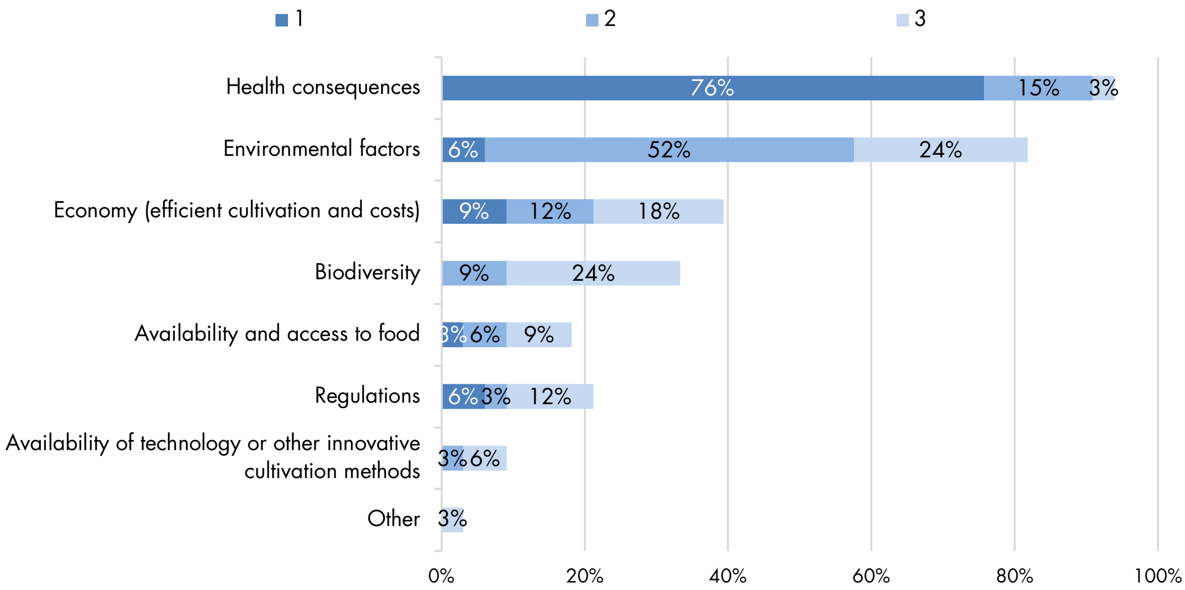
Figure 16. Phase 1: 'Do you think pesticide use is an important issue on the political agenda in your country or the EU'? N=33



E.1.4 Perceptions of pesticide use

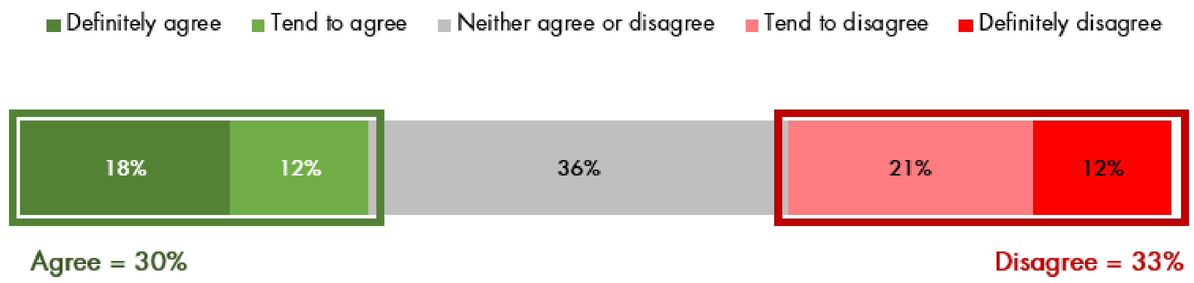
The health consequences and environmental impacts of pesticides were the top two issues affecting respondents' attitudes towards pesticides. Environmental factors were most likely to be rated as important (52%), followed by the economy (12%) (Figure 17).

Figure 17. Phase 1: 'Please give us more details about what affects your attitudes towards pesticides. Please rank the various topics in order of priority'. (Top 3 responses) N=33



Regarding the perceived risks versus the benefits of pesticide use in the EU, respondents were relatively evenly split, with 30% agreeing the benefits outweigh the risks, 33% disagreeing and 36% neither agreeing nor disagreeing (Figure 18).

Figure 18. Phase 1: 'How much do you agree or disagree with the following phase? I believe the benefits of using pesticides in the EU are more than the risk of using them' N=33



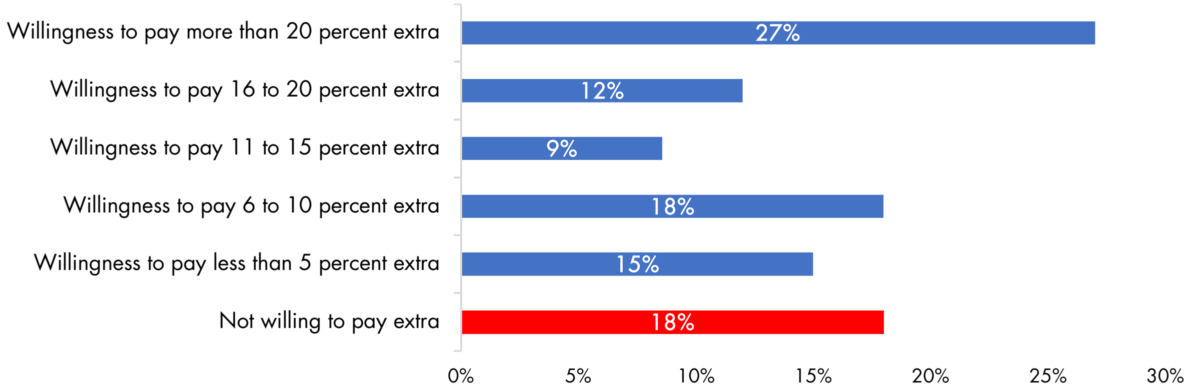
E.1.5 Health perceptions

Citizens were concerned about the perceived health effects of pesticides, particularly the adverse impact on peoples' health and rise of health complications and concerns about the nutritional value of food. Several citizens cited a link between pesticide use (and chemicals in pesticides) and cancer. Other health concerns included infertility, allergies, stomach and intestinal problems, long-term poisoning due to small amounts of chemicals and DNA alternations due to mutations. Participants also highlighted a lack of information about the effects of pesticide use, and that, despite some research, the medium to long-term effects of pesticide use are still uncertain.

E.1.6 Economic perceptions

The majority of respondents were willing to pay more for pesticide-free food and agricultural products, with only 18% of respondents unwilling to pay extra. Indeed, 27% were willing to pay more than 20% extra for pesticide-free products, and only 15% said they would pay less than 5% extra for pesticide free-products (Figure 19).

Figure 19. Phase 1: 'Would you agree to pay more for pesticide-free food and agricultural products?' N=33



E.1.7 Perceptions about farming methods

Respondents were asked about four types of farming methods/agriculture: conventional agriculture[9], organic farming[10], conservation agriculture,[11] and agroecological approaches[12]. Respondents best understood organic farming practices in food production (82%), followed by agroecology (73%), conservation agriculture (61%), and conventional agriculture (52%). However, for some of these farming methods, respondents were less sure they would support their use. For example, respondents were relatively evenly split between feeling comfortable and uncomfortable about the use of organic farming and agroecology in food production (36% reported being uncomfortable about organic farming and 33% comfortable, while 42% reported feeling uncomfortable about agroecology and 42% feeling comfortable). More respondents were comfortable (45%) over uncomfortable (36%) regarding conservation agriculture in food production, while 61% of respondents agreed they were uncomfortable with the use of conventional agricultural methods in food production systems (Figure 20).

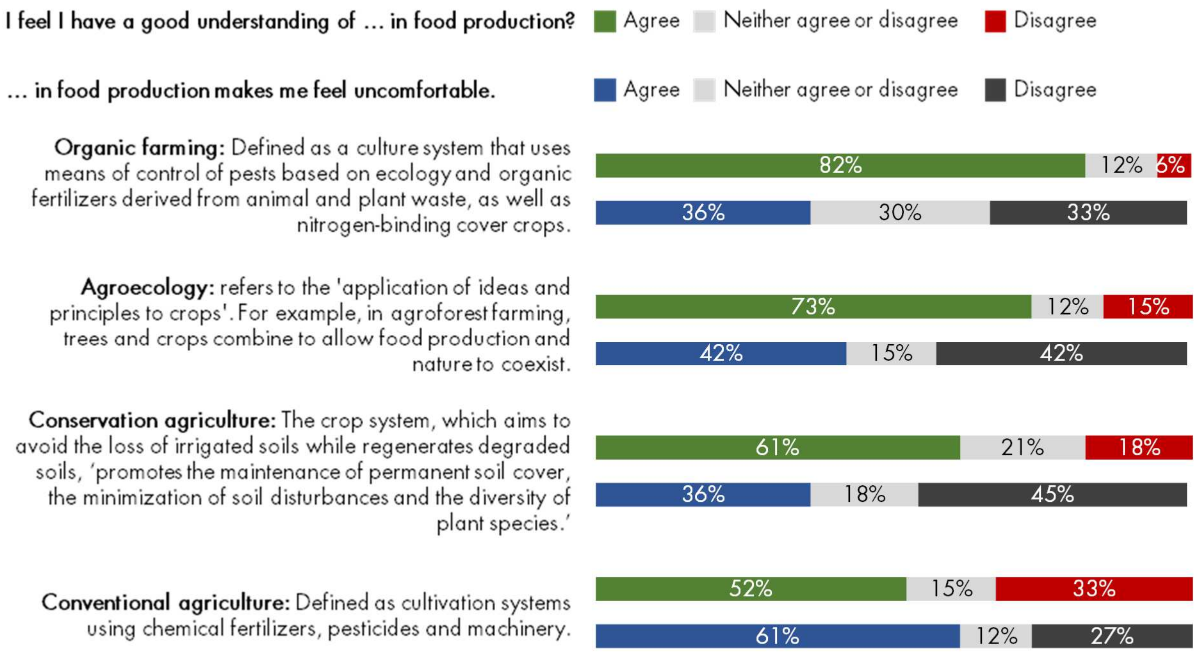
[9] Conventional agriculture is defined as farming systems that use chemical fertilisers, pesticides and machinery (As of 19 October 2021: https://www.oxfordreference.com/view/10.1093/oi/authority.20110803095636280).

[10] Defined as an agricultural system that uses pest controls that are ecologically based and biological fertilisers that are produced from animal and plant waste, as well as nitrogen-fixing cover crops (As of 19 October 2021: https://www.britannica.com/topic/organic-farming).

[11]Conservation agriculture: a farming system that aims to prevent losses of arable land while regenerating degraded lands. 'It promotes maintenance of permanent soil cover, minimum soil disturbance, and diversification of plant species' (FAO. (2021). 'Factsheet on Conservation Agriculture'. Food and Agriculture Organization of the United Nations. As of 19 October 2021: https://www.fao.org/3/i7480e/i7480e.pdf

[12] Agroecological practices refer to 'the application of concepts and principles in farming'. For instance, in agroforestry, trees and farming are combined to help food production and nature co-exist. Animals get shelter and fodder under the trees whilst they provide nutrients to the soil through manure. The trees also offer crops and protect the soil from erosion. (As of 19 October 2021: https://www.soilassociation.org/causes-campaigns/a-ten-year-transition-to-agroecology/what-is-agroecology/)

Figure 20. Phase 1: 'There are several farming methods that are now being used or may be used in agriculture in the future to reduce the use of pesticides. How much do you agree or disagree with the following phrases?' N=33



When asked why citizens were uncomfortable with some food production methods, respondents answered in general terms, tending to focus on the impact of pesticide use and highlighting health and environmental concerns about the use of pesticides in food production systems. Specifically, they worried about the use of chemicals that may be harmful to people's health and the adverse impact pesticides can have on soil, local biodiversity and ecology.

E.1.8 Technology perceptions

Participants were also asked about their views regarding GM food[13], new technology[14] and irradiation[15]. Respondents agreed they had a good understanding of GM food (52%) and new technology (45%). There was less consensus regarding irradiation, as more respondents disagreed that they had a good understanding of irradiation in food production (27% agree versus 45% disagree). While genetic modification of food had the highest levels of understanding, it also had the highest levels of negative perceptions from citizens when used in a food production system, with 52% of respondents agreeing that the use of genetic modification in food production made them feel uncomfortable. Irradiation also had high levels of agreement, with 39% of respondents agreeing that the use of irradiation made them feel uncomfortable. Regarding new technologies in food production, 36% of respondents agreed that new technologies would make them feel uncomfortable, 30% disagreed that they would feel uncomfortable, and 33% neither

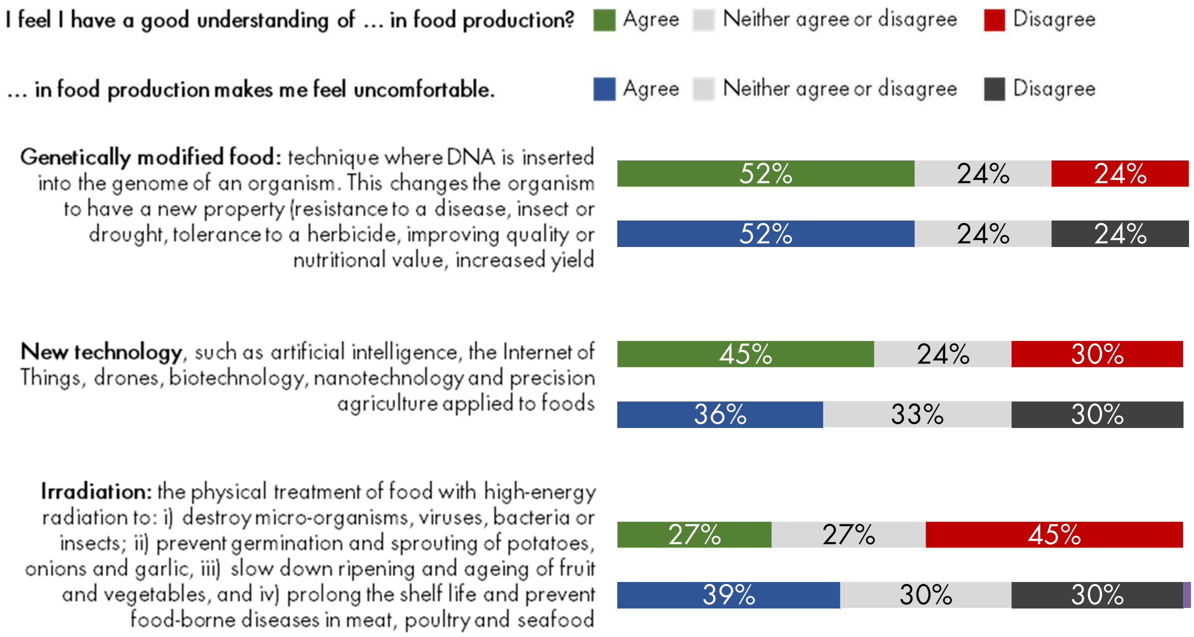
[13] GM food is a technique where DNA is inserted into an organism's genome to introduce or improve advantageous characteristics, e.g. disease, insect or drought resistance, herbicide tolerance, improved quality or nutritional value and increased yield.

[14] New technology refers to technologies such as Artificial Intelligence, Machine Learning, Internet of Things, drones, biotechnology and nanotechnology.

[15] Irradiation is the physical treatment of food with high-energy radiation to (i) destroy micro-organisms, viruses, bacteria or insects, (ii) prevent germination and sprouting of potatoes, onions and garlic, (iii) slow down fruit and vegetables' ripening and ageing, and (iv) prolong shelf life and prevent food-borne diseases in meat, poultry and seafood.

agreed nor disagreed. Some citizens commented that they felt that some of the long-term effects of these practices were unknown, and thus they would not feel comfortable with their use (Figure 21).

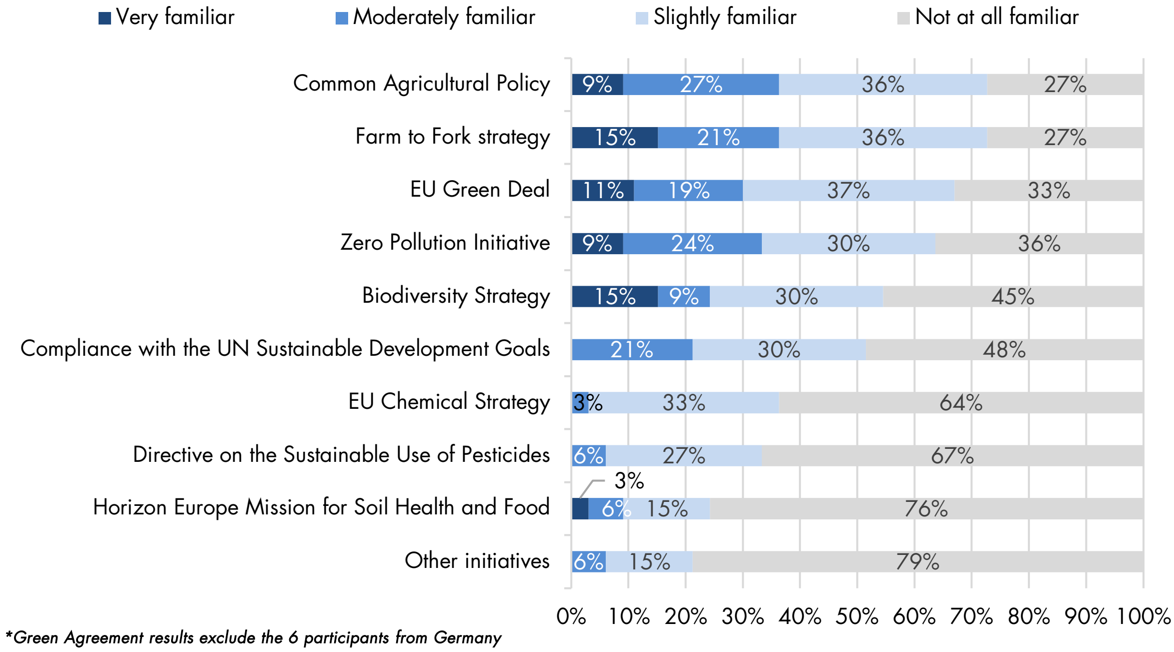
Figure 21. Phase 1: 'How much do you agree or disagree with the following statements? I have a good understanding of the use of … in food production, and … in food production make me feel uncomfortable'. N=33



E.1.9 EU policies and strategies

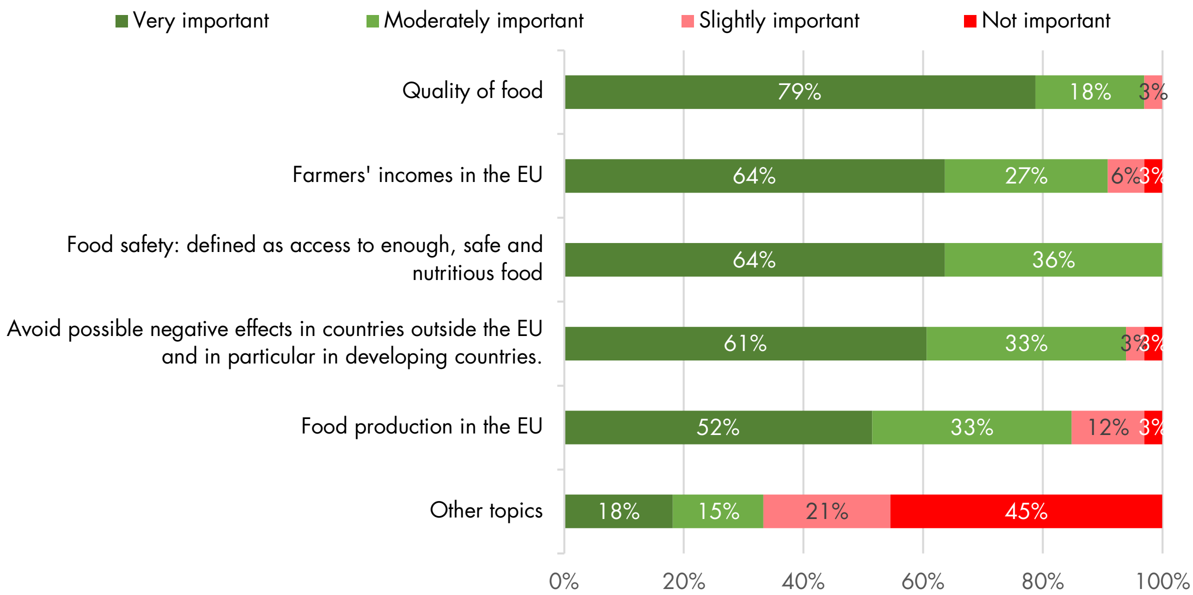
Several initiatives could influence pesticide use and food production in the EU. Most respondents were familiar with five of them, with more than 50% of all respondents reporting being either 'very', 'moderately' or 'slightly' familiar. These were the Common Agriculture Policy, Farm to Fork Strategy, Green Agreement, Zero Pollution Initiative and Biodiversity Strategy. The Respondents were most familiar with the Farm to Fork Strategy and Biodiversity Strategy, each with 15% of respondents reporting being very familiar (Figure 22).

Figure 22. Phase 1: 'There are a number of initiatives that may influence pesticide use and food production in the EU. How familiar are you with the following initiatives?' N=33



In addition to pesticide-use and risk-reduction targets, the EU aims to protect food security, food quality, food production and the wellbeing of agricultural producers in the EU/EEA while avoiding possible negative impacts in non-EU countries and developing countries. More than three-quarters of respondents (79%) considered food quality a very important issue, followed by farmers' income in the EU (64%), food safety (64%) and avoiding possible adverse effects in countries outside the EU (61%). Other important issues raised included environmental concerns and maintaining the affordability of food products (Figure 23).

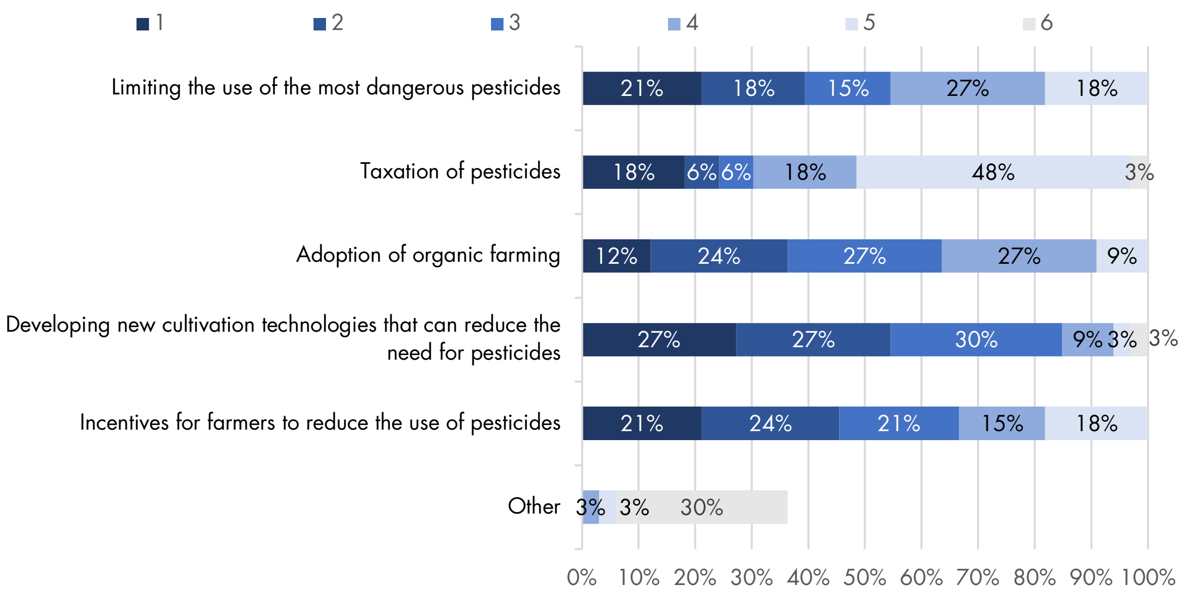
Figure 23. Phase 1: 'In addition to pesticide use and risk reduction targets, the EU aims to protect food security, food quality, food production and the wellbeing of agricultural producers in the EU/EEA. It also aims to avoid possible negative effects in countries outside the EU and in developing countries. How important do you think these issues are?' N=33



E.1.10 Future policies

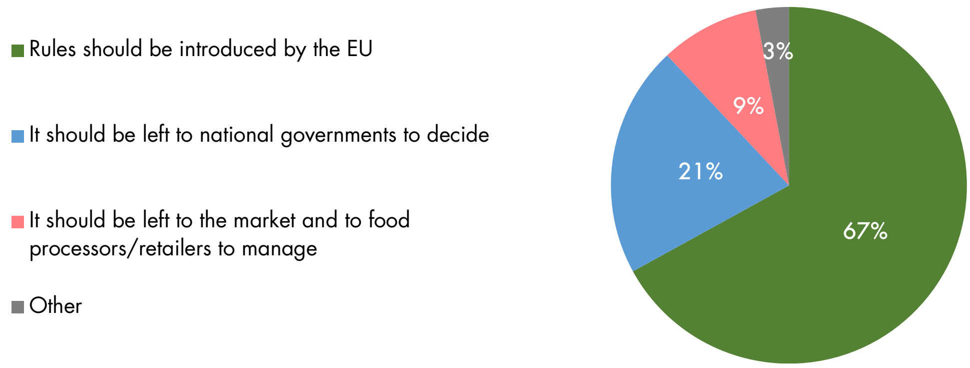
Respondents were most likely to rate developing new cultivation technologies as the most effective strategy for achieving target reductions in pesticide use (27%), followed by limiting the use of the most dangerous pesticides and incentives for farmers to reduce the use of pesticides (21% for both). Pesticide taxation (18%) and adoption of organic farming (12%) were rated as less effective (Figure 24).

Figure 24. Phase 1: 'In order to achieve target reductions in pesticide use and risk which measure do you think is most effective?' N=33



Regardless of which measure was chosen ('Limiting the use of the most dangerous pesticides', 'Taxation of pesticides', 'Adoption of organic farming', 'Developing new cultivation technologies that can reduce the need for pesticides', 'Incentives for farmers to reduce the use of pesticides', 'Other'), the majority of respondents (67%) believed such measures should be introduced at the EU level. In comparison, 21% felt they felt they felt they felt they should be left to national governments to decide. Only 9% suggested these measures should be left to the market and food processors/retailers to manage (Figure 25).

Figure 25. 'How do you think these measures should be taken?' N=33. Measures include taxation of pesticides, incentives for farmers to reduce the use of pesticides, developing new cultivation technologies that can reduce the need for pesticide, adoption of organic farming, limiting the use of the most dangerous pesticides, or other measures.



In the open-ended follow-up question, respondents suggested banning dangerous pesticides worldwide as the main strategy to protect food safety, food quality, food production and agricultural producers' well-being in the EU while preventing possible adverse effects in third countries. Regarding the non-agricultural use of pesticides, most citizens felt its use should be reduced in private settings. Citizens were also unaware of whether more dangerous pesticides are used outside the EU compared to inside.

E.2 Phase 2: how different potential future scenarios influence the public views shared in the first round of discussion

Phase 2 of the citizen-engagement activity aimed to explore the Phase 1 group's views on pesticide use against a backdrop of different scenarios. Participants were presented with four different future scenarios and a sub-set of questions from the Phase 1 questionnaire. Questions from Phase 1 were selected and merged in Phase 2 to focus specifically on issues related to pesticide use. For each future scenario, citizens were asked about EU policies and strategies, food production systems, pesticide policies, perceptions of pesticide use (economic and farming methods) and future policies. The four scenarios were:

1. **Future 1 (Mixed Sustainable Approaches):** 'Imagine yourself in a future where the political landscape is unstable and climate change is getting worse. Europe is trying to build resilience in its food system by increasing the use of sustainable practices in agriculture, however this has been slow-moving. Although there have been some reductions in chemical pesticide use, this has not generally been the case across the agricultural sector. Financial and other

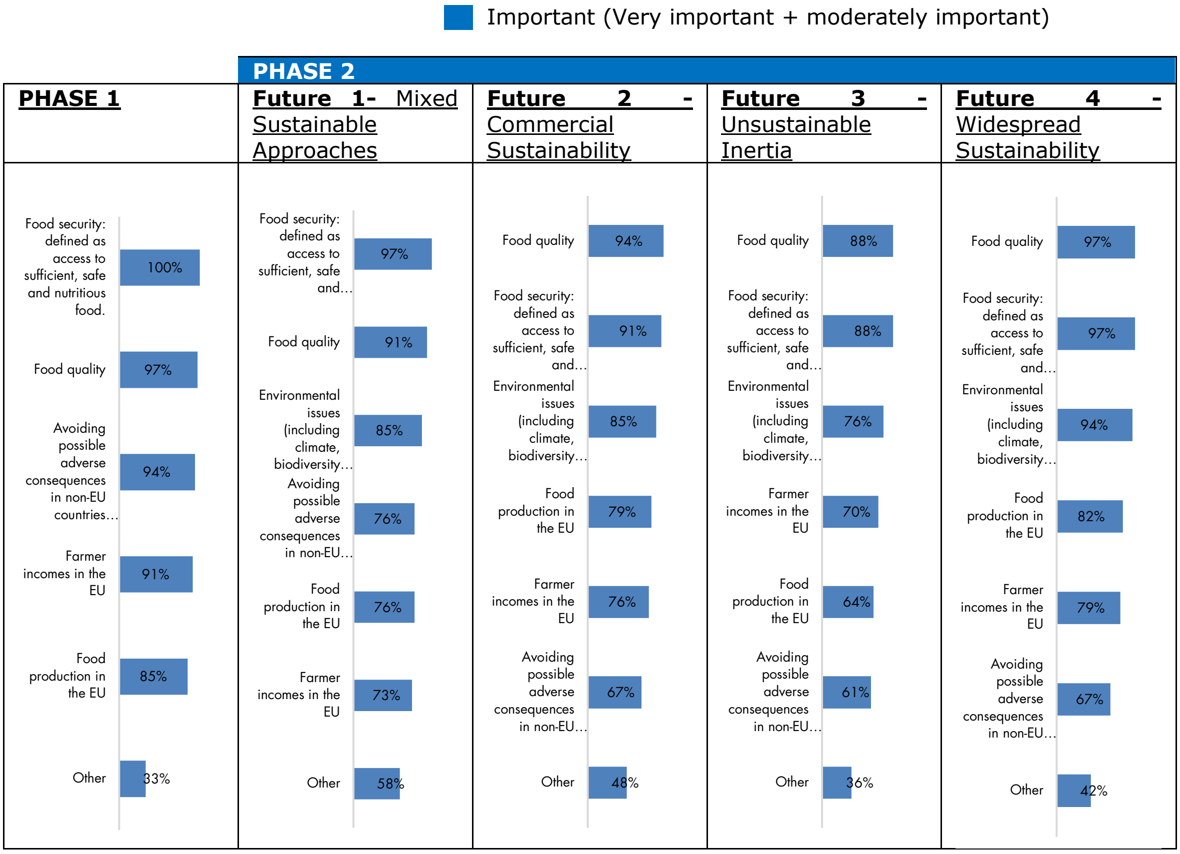
policy support measures are needed to encourage wider adoption of technology to further reduce pesticide use.'

2. **Future 2 (Commercial sustainability):** 'Imagine yourself in a future where the EU has seen moderate growth in its economy and agricultural prices have remained relatively stable. Although consumers have gradually shifted to more environmentally friendly diets, change is slower than expected. There is a lack of strong regulatory and legal incentives from the EU, therefore sustainability and innovation in the agricultural sector have instead become increasingly driven by large agricultural enterprises. Overall, EU pesticide use has continued to decrease; however, they continue to play a role, with some farmers unwilling to engage with new practices.'
3. **Future 3 (Unsustainable Inertia):** 'A global recession has shifted political priorities away from innovation and sustainable practices. This has made it difficult for farmers to adopt new approaches and they continue to rely on hazardous chemical pesticide products. Consumers prioritise affordability over environmental sustainability. Large companies dominate the global agri-food sector, leading to the displacement of small-scale producers. Climate change has yet to significantly impact agricultural production, which has remained stable in terms of yield, prices and competitiveness.'
4. **Future 4 (Widespread Sustainability):** 'Imagine yourself in a future where EU policies reflect a stronger ambition to foster sustainable economic growth and address environmental issues. Technology is recognised as being important, and therefore is used across all domains of the food supply chain. EU consumers are also more supportive of protecting the environment. These trends have allowed for a rapid shift towards environmentally sustainable practices, including reductions in pesticide use. Consumers' willingness to pay and improved production processes have limited the impact of increased food prices, underpinned by costly advanced technologies and sustainable approaches.'

E.2.1 EU policies and strategies

In Phase 1 of the citizen-engagement survey, all participants identified food safety as an important issue. However, in Phase 2, responses differed depending on the scenarios presented to citizens. Food security remained the most important issue (97%) in future 1 (Mixed Sustainable Approaches), joint-first with food quality for future 3 (Unsustainable Inertia) (with food quality and food security both at 88%) and future 4 (Widespread Sustainability) (with food quality and food security both at 97%). Food security was the second most important issue for future 2 (Commercial Sustainability) (91%) behind food quality (94%). Environmental issues (including climate, biodiversity and local pollution) were the third most important issue, after food security and food quality, across future 1 (85%), future 2 (85%), future 3 (76%) and future 4 (94%). While avoiding possible adverse environmental impacts for non-EU countries was ranked lower for futures 2, 3 and 4, 76% of citizens considered it important for future 1, ranking it on a par with EU food production, e.g. agricultural yield (Figure 26).

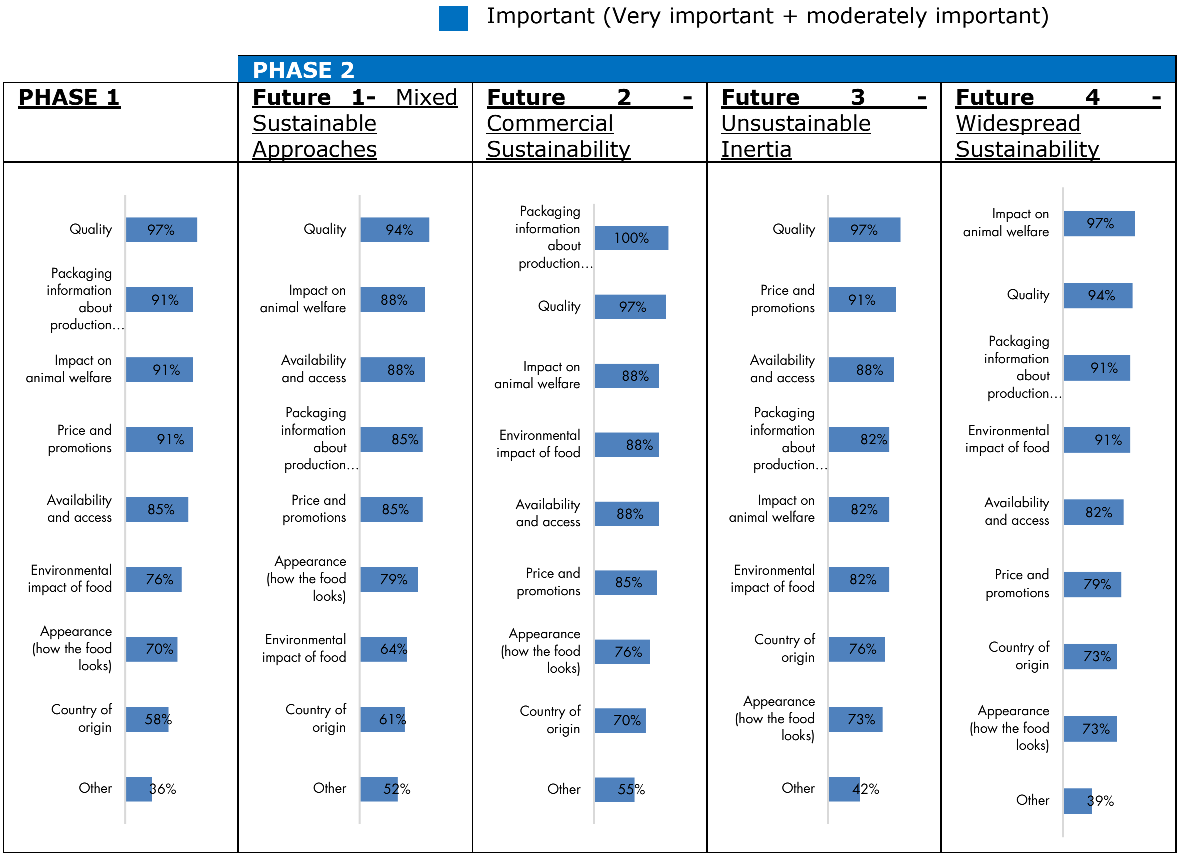
Figure 26. Phase 2: 'In the future described above, how important would the following issues be in your view?' N=33



E.2.2 Food production

In Phase 1, citizens identified food quality (97%) and packaging information about production methods (91%) as the two most important issues when buying food. In Phase 2, food quality remained an important issue, though it varied slightly across scenarios. In future 1 (Mixed Sustainable Approaches) and future 3 (Unsustainable Inertia), food quality was most likely to be considered a topmost important issue (94% and 97%, respectively). In future 2 (Commercial Sustainability), quality (97%) was secondary only to packaging information about production methods (100%). In future 4 (Widespread Sustainability), quality (94%) was second only to the impact on animal welfare (97%). One outlier is the difference between the scenarios regarding the environmental impact on food, which is ranked lower in future 1 (64%) but higher in future 2 and future 4 (88% and 91%, respectively) (Figure 27).

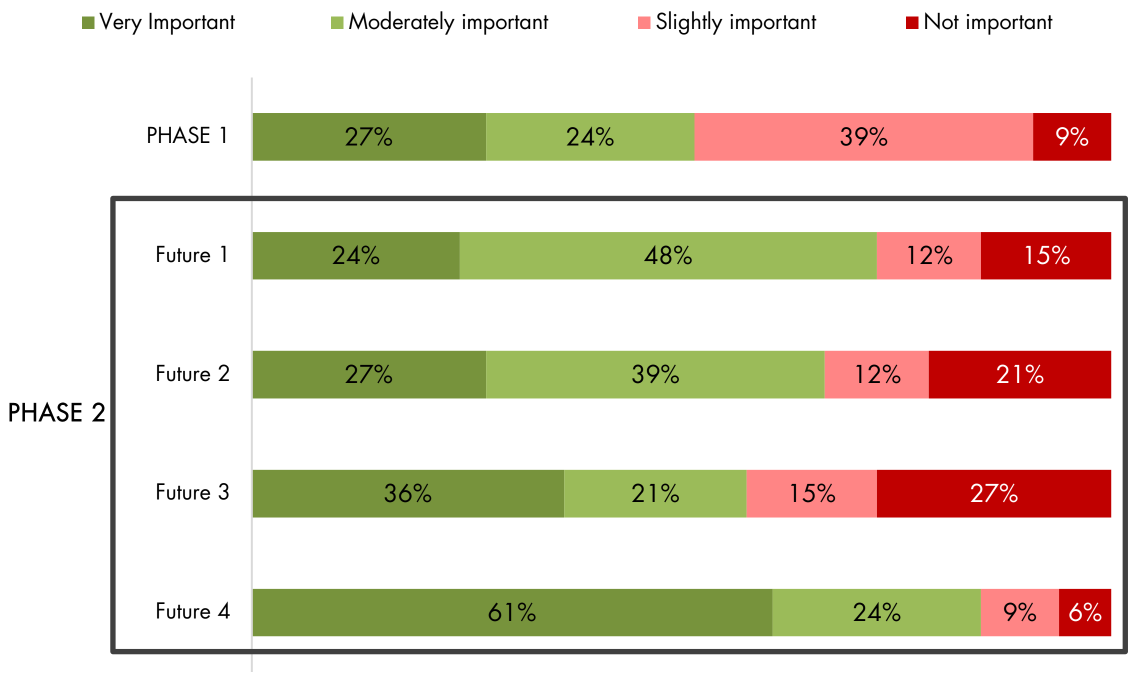
Figure 27. Phase 2: 'Thinking about food production more broadly, what would be important for you when you buy food in the context described above?' N=33



E.2.3 Pesticide policies

In Phase 1, citizens' considered pesticide-use an important issue on their country's political agenda, with 27% rating it 'very important' and 24% 'moderately important'). In Phase 2, pesticide use remained an important issue on the country's political agenda. This was particularly true for future 4 (Widespread Sustainability), where 61% of citizens rated pesticide use as a 'very important' issue and 24% said it was a 'moderately important' issue. However, in future 3 (Unsustainable Inertia), 36% reported pesticide use as a 'very important issue and 27% considered it unimportant (Figure 28).

Figure 28. Phase 2: 'Do you think that pesticide use would be an important issue on the political agenda in your country?' N=33 Future 1: 'Mixed Sustainable Approaches', Future 2: 'Commercial Sustainability', Future 3: 'Unsustainable Inertia', Future 4: 'Widespread Sustainability'



E.2.4 Perceptions of pesticide use

Regarding perceptions of pesticide use, Phases 1 and 2 assessed citizens' attitudes to pesticides, their views on the main consumer benefits of pesticide use, and whether they agreed that the benefits of pesticide use in the EU outweighed the risks. Seven factors were used to measure influences on attitudes to pesticides. These included health consequences, economy, environmental factors, regulations, availability and access to food, biodiversity and technology availability or other innovative cultivation methods. In Phase 1 and across all scenarios in Phase 2, the health consequences of pesticide use were most likely to influence citizens' attitudes to pesticides, followed by environmental factors. Biodiversity was the third highest-rated issue in almost all scenarios except future 2 (Commercial Sustainability), where availability and access to food ranked third (Figure 29).

Figure 29. Phase 2: 'In the future described previously, please provide more details on what influences your attitudes to pesticides. Please rank the different options' (Top 3 responses) N=33

Top response for the phase/future scenario

	PHASE 1			PHASE 2											
				Future 1- Mixed Sustainable Approaches			Future 2 - Commercial Sustainability			Future 3 - Unsustainable Inertia			Future 4 - Widespread Sustainability		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Health consequences	76%	15%	3%	73%	6%	12%	76%	9%	0%	76%	3%	0%	64%	9%	18%
Economy (efficient cultivation and costs)	9%	12%	18%	6%	12%	12%	9%	15%	18%	9%	21%	18%	0%	3%	18%
Environmental factors	6%	52%	24%	0%	39%	6%	3%	33%	18%	0%	36%	15%	12%	36%	12%
Regulations	6%	3%	12%	9%	12%	6%	9%	21%	9%	0%	9%	12%	3%	15%	6%
Availability and access to food	3%	6%	9%	12%	12%	18%	3%	9%	24%	12%	15%	18%	0%	18%	3%
Biodiversity	0%	9%	24%	0%	9%	27%	0%	9%	18%	3%	6%	21%	0%	18%	33%
Availability of technology or other innovative cultivation methods	0%	3%	6%	0%	9%	18%	0%	3%	12%	0%	9%	15%	21%	0%	9%
Other	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

In Phase 1, citizens were most likely to rate the reduction of crop pests as the main benefit of pesticide use to customers (30%), with the cost of food and reduction in competition from crop weeds jointly ranking second (24%) and yield and reduced crop pests ranking jointly third (21%). However, this changed across all scenarios in Phase 2. The reduction of crop pests was not rated as the main benefit of pesticides in any of the future scenarios. However, it was mentioned as a secondary effect, e.g. high-quality food may be due to a reduction of crop pests supporting a more reliable food supply chain. Responding to the open-ended follow-up question, several participants noted weed reduction and crop protection as benefits of pesticide use.

Instead, in future 1 (Mixed Sustainable Approaches) and future 4 (Widespread Sustainability), food quality was ranked as the primary benefit. In future 2 (Commercial Sustainability) and future 3 (Unsustainable Inertia), the reliability of food supply was ranked as the primary benefit. Similarities between futures 1 and 4, and 2 and 3, remained; in futures 1 and 4, the reliability of the food supply was rated as the second main consumer benefit of pesticide, while in futures 2 and 3, yield (availability) was ranked as the second main consumer benefit of pesticide use. In futures 1, 2, and 4, the cost of food was rated as the third main consumer benefit of pesticide use. However, in future 3, the reliability of the food supply and food quality were jointly ranked as the third main consumer benefit of pesticide use. In future 4, the cost of food was jointly rated third with food quality (Figure 30). However, none of the responses achieved a majority, and, in most cases, less than a third of citizens ranked any one factor as a primary benefit of pesticide use. This could suggest that citizens are not yet in agreement with, or lack awareness of, the main consumer benefits of pesticide use.

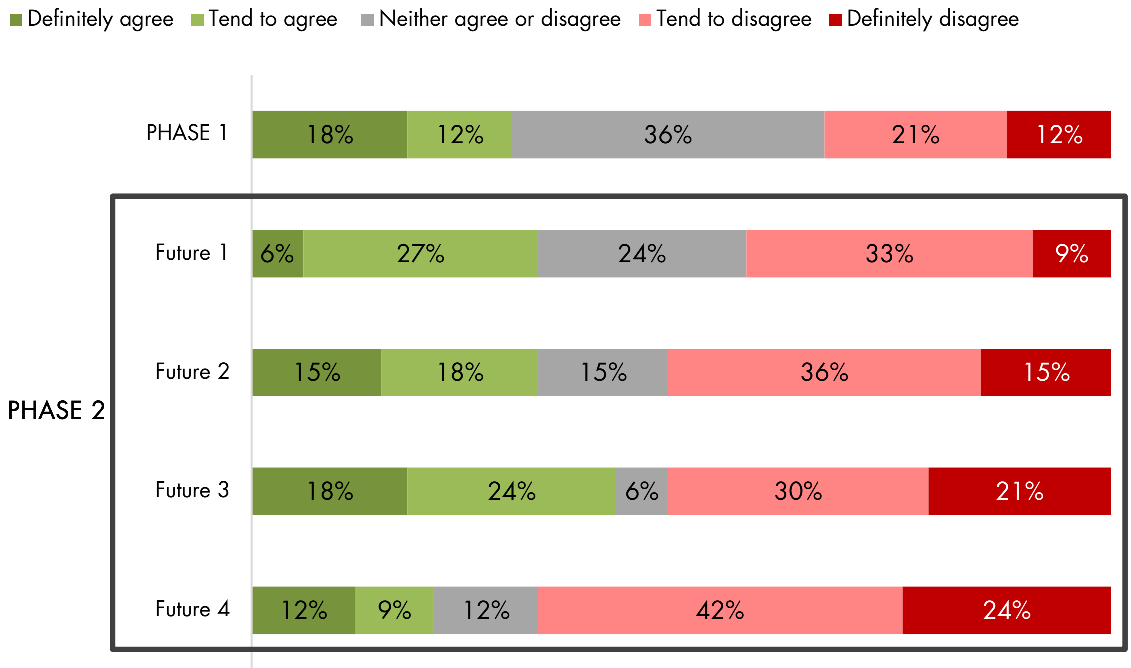
Figure 30. Phase 2: 'In that future, what do you think would be the main benefits of pesticide use to consumers? Please rank the different options' (Top 3 responses) N=33. Light blue highlighting indicates the top response for the phase/future scenario

Top response for the phase/future scenario

				PHASE 2											
	PHASE 1			Future 1- Mixed Sustainable Approaches			Future 2 - Commercial Sustainability			Future 3 - Unsustainable Inertia			Future 4 - Widespread Sustainability		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Reduction of crop pests	30%	12%	21%	9%	21%	9%	9%	24%	6%	9%	6%	15%	9%	18%	12%
Yield (availability)	24%	15%	21%	18%	24%	15%	12%	27%	27%	15%	39%	18%	18%	21%	6%
Reliability of food supply	18%	6%	18%	18%	27%	15%	30%	12%	6%	27%	9%	21%	12%	24%	21%
Cost of food	6%	24%	12%	9%	9%	24%	9%	12%	39%	15%	21%	18%	12%	15%	24%
None	9%	3%	6%	3%	3%	6%	9%	0%	0%	9%	0%	0%	12%	0%	0%
Reduction in competition from weeds in crops	6%	24%	12%	9%	6%	18%	9%	12%	12%	9%	12%	6%	12%	15%	9%
Food quality	3%	15%	9%	30%	9%	9%	21%	3%	9%	15%	6%	21%	24%	0%	24%
Other	3%	0%	0%	3%	0%	3%	0%	9%	0%	0%	6%	0%	0%	6%	3%

Regarding the benefits versus risks of pesticide use in the EU, there were mixed views: 30% of citizens agreed that the benefits outweigh the risks, 33% disagreed and 36% neither agreed nor disagreed. However, in Phase 2, citizens were more likely to disagree than agree that the benefits of pesticide use in Europe outweigh the risk of their use in all scenarios. Disagreement was especially strong for future 4, with 24% 'definitely' disagreeing and 42% 'tending' to disagree). Only in future 3 were levels of agreement higher than Phase 1 (with 17% 'definitely' agreeing and 23% 'tending' to agree). Nonetheless, these agreement levels were still lower than the disagreement levels (with 21% 'definitely' disagreeing and 30% 'tending' to disagree). In Phase 1, citizens were, therefore, somewhat divided on the benefits versus risks of pesticide use. However, in Phase 2, they were more likely to consider that the risks of pesticides outweigh the benefits – which was consistent across all future scenarios (Figure 31).

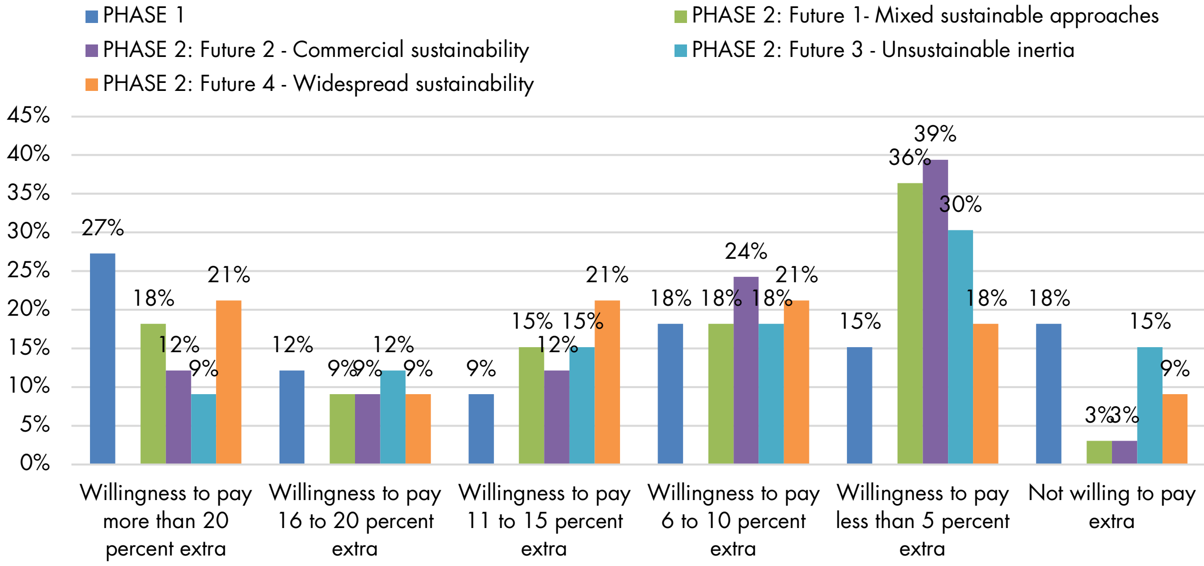
Figure 31. Phase 2: 'How much would you agree or disagree with the following statement? I think the benefits of pesticide use in the EU would outweigh the risks of their use'. N=33. Future 1: 'Mixed Sustainable Approaches', Future 2: 'Commercial Sustainability', Future 3: 'Unsustainable Inertia', Future 4: 'Widespread Sustainability'



E.2.5 Perceptions of pesticide use – economic

In Phase 1, citizens were more willing to pay more than 20% extra for pesticide-free food and agricultural products (27%). However, 18% of citizens also said that they would not be willing to pay extra. Phase 1 thus had more polarised views (paying over 20% or not willing to pay extra). In contrast, Phase 2 responses were more moderate (with fewer participants reporting that they would either pay more than 20% or not pay any extra). However, responses varied across the future scenarios. Willingness to pay 20% extra or 11-15% extra was most prevalent in future 4 (Widespread Sustainability), whereas willingness to pay 16-20% extra was more evenly distributed across the future scenarios. Willingness to pay 6-10% extra, or less than 5%, was more predominant in future 2 (Commercial Sustainability). Future 3 (Unsustainable Inertia) was most likely to elicit unwillingness to pay extra (15%) (Figure 32).

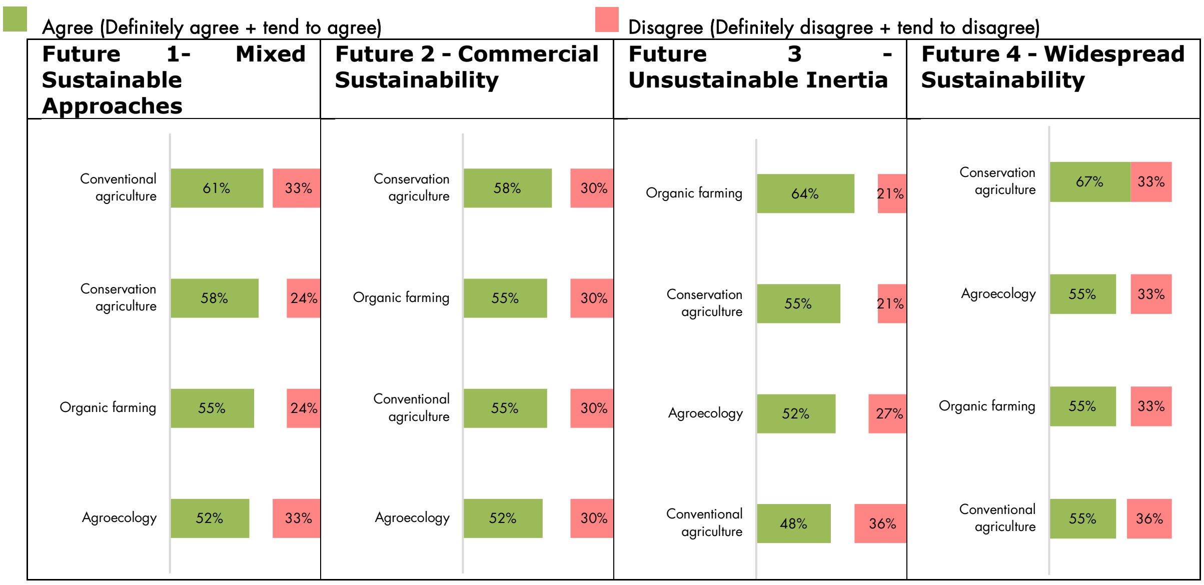
Figure 32. Phase 2: 'Would you be willing to pay extra (a premium price) for pesticide-free food and agriculture products?' N=33



E.2.6 Perceptions of pesticide use – farming methods

Certain farming methods and technologies used in food production were more likely than others to make citizens feel uncomfortable. However, this varied across the four future scenarios. In future 1 (Mixed Sustainable Approaches), citizens were most uncomfortable with the use of conventional agriculture (61%). In future 2 (Commercial Sustainability), citizens were most uncomfortable with conservation agriculture (54%). In future 3 (Unsustainable Inertia), citizens were most uncomfortable with organic farming (64%). In future 4 (Widespread Sustainability), citizens were most uncomfortable with conservation agriculture (67%) (Figure 33).

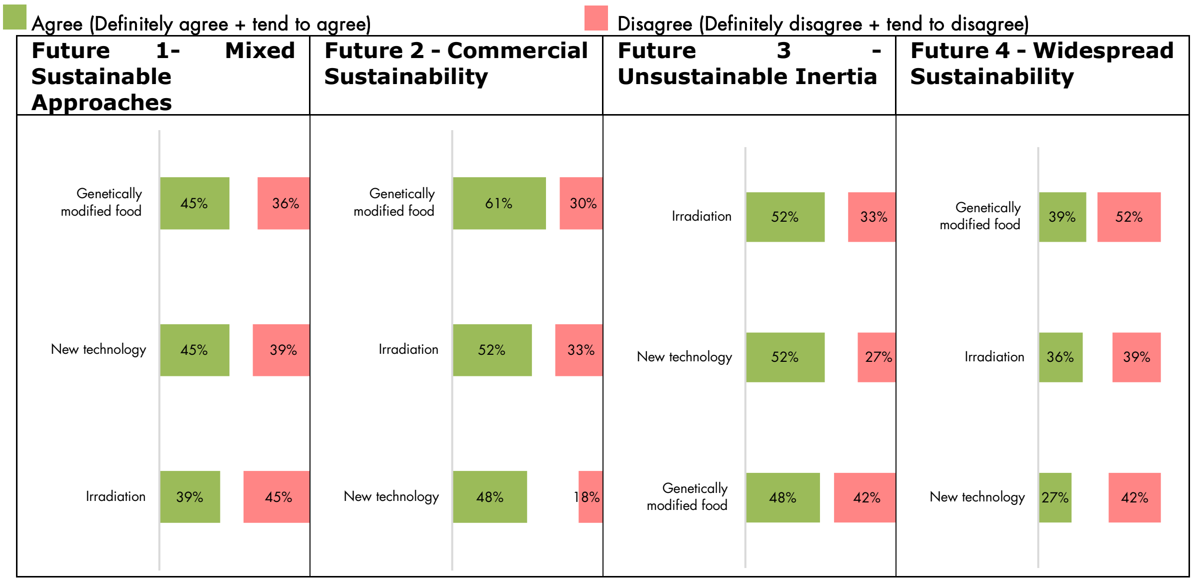
Figure 33. Phase 2: 'How much do you agree or disagree with the following statements? … in food production makes me feel uncomfortable'. (Farming methods) N=33



E.2.7 Perceptions of pesticide use – technology

For future 1 (Mixed Sustainable Approaches), citizens agreed that GM food and new technologies in food production made them feel uncomfortable (45%). Citizens were also less concerned about the use of irradiation (with 45% disagreeing and 39% agreeing). For future 2 (Commercial Sustainability) and future 4 (Widespread Sustainability), citizens agreed that GM food in food production makes them feel uncomfortable, although they were more concerned about GM food in future 2 than future 4 (61% for future 2; 39% for future 4). Future 4 also elicited more disagreement than agreement that food production makes them feel uncomfortable, suggesting that citizens were less concerned about the use of new technologies in a widespread-sustainability future scenario. In future 3 (Unsustainable Inertia), 52% of citizens agreed that irradiation and new technology made them feel uncomfortable, whereas views were less marked regarding GM food (with 48% agreeing and 42% disagreeing) (Figure 34).

Figure 34. Phase 2: 'How much do you agree or disagree with the following statements? … in food production makes me feel uncomfortable'. (Technology) N=33



E.2.8 Future policies

In Phase 1, citizens considered the development of new agricultural technologies as the most effective measure to achieve target reductions in pesticide use and risk (27%), whereas restricting the use of more hazardous pesticides and introducing farmer incentives to reduce pesticide use ranked jointly as the second most effective measure (21%). For Phase 2, the development of new agricultural technologies was also ranked in future 1 (Mixed Sustainable Approaches) as the most effective measure for achieving target reductions in pesticide use and risk (27%). On the other hand, introducing farmer incentives to reduce pesticide use was ranked as the top measure for future 2 (Commercial Sustainability) and future 3 (Unsustainable Inertia). For future 4 (Widespread Sustainability), pesticide taxation was ranked as the most effective measure (30%) (Figure 35).

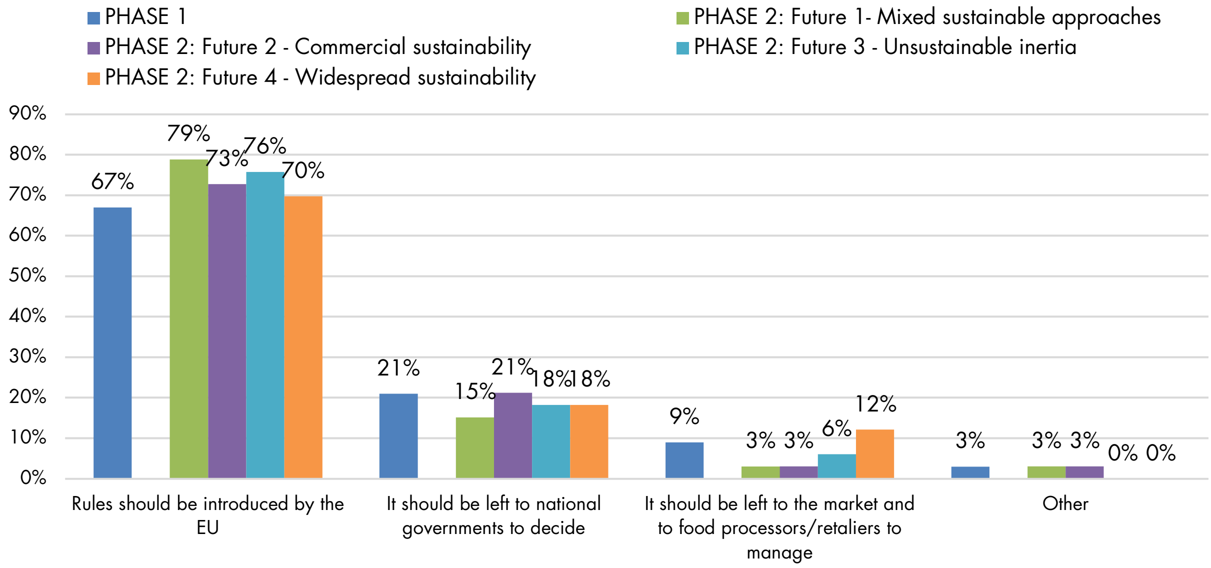
Figure 35. Phase 2: 'In order to achieve target reductions in pesticide use and risk which measure do you think would be most effective?' N=33. Light blue highlighting indicates the top response for the phase/future scenario

Top response for the phase/future scenario

	PHASE 1			PHASE 2											
				Future 1- Mixed Sustainable Approaches			Future 2 - Commercial Sustainability			Future 3 - Unsustainable Inertia			Future 4 - Widespread Sustainability		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Restriction of the use of more hazardous pesticides	21%	18%	15%	18%	27%	15%	18%	27%	24%	12%	9%	27%	15%	12%	6%
Taxation of pesticides	18%	6%	6%	15%	3%	12%	18%	9%	6%	18%	12%	3%	30%	0%	12%
Adoption of organic agriculture	12%	24%	27%	15%	18%	27%	12%	15%	27%	12%	24%	24%	12%	21%	36%
Introduction of incentives for farmers to reduce pesticide use	21%	24%	21%	21%	21%	33%	39%	18%	12%	36%	18%	18%	24%	39%	6%
Development of new agricultural technologies that can reduce the need to use pesticides	27%	27%	30%	27%	30%	12%	12%	27%	27%	18%	36%	24%	18%	27%	39%
Other	0%	0%	0%	3%	0%	0%	0%	3%	3%	3%	0%	3%	0%	0%	0%

The clear majority opinion among surveyed citizens was that the EU should introduce measures, with more than 66% of citizens reporting this across both phases and all future scenarios. Support for national governments to implement these measures was low (equal to or less than 21% for each phase and across all future scenarios). Citizens were less supportive of market and food processors/retailers managing measures to achieve target reductions in pesticide use and risk (Figure 36).

Figure 36. Phase 2: 'How do you think that these measures would need to be implemented?' N=33



Annex F. Workshop insights

F.1 Discussion on future scenarios

Scenario 1: Mixed Sustainable Approaches

Against a backdrop of geopolitical instabilities and rapidly worsening effects of climate change, the EU has started to adopt a more inward-looking economic approach to build resilience in its agricultural sector. The agri-food sector has seen a shift towards more sustainable practices; however, this has been slow-moving. Although there have been some reductions in chemical pesticide use, this trend has not been homogeneous across the agricultural sector. Financial and other policy support measures are needed to encourage wider adoption of technology to further reduce pesticide use.

Workshop participants broadly agreed that this scenario is plausible. However, they also felt that it broadly represents the status quo, and one participant felt that this scenario presents a protectionist approach to international trade. Participants also discussed:

- **The diverse nature of EU agriculture (differences between the Member States)**: participants questioned whether all Member States would apply mixed sustainable approaches homogeneously, given the diverse nature of European agriculture (e.g. different agronomic conditions, climatic conditions, soil structures, etc.). They thus highlighted that differences in volumes of pesticide use do not necessarily reflect a lack of Member States' willingness to reduce consumption but are the result of different agronomic realities, which need to be acknowledged.
- **The importance of innovation uptake:** participants discussed the use of new farming technologies and techniques and how farmers could be encouraged to use various technologies that could help produce more sustainable agriculture (e.g. digital or precision technology). Current uptake is relatively low since farmers are older and more reluctant, and it is uncertain whether uptake will happen fast enough for this scenario to materialise.
- **The importance of regulation:** Regulation often does not keep up with the pace of technology development. Participants discussed how investment in new technologies requires a regulatory system that encourages the uptake of innovation. One example mentioned was drone applications of pesticides. While the Swiss government allows drone application on specific crops (e.g. slope fields), some stakeholders interpret drone application of plant-protection products in Europe as entirely prohibited and unlikely to change since the term drone is not mentioned in the SUD.

Scenario 2: Commercial Sustainability

The EU has seen moderate growth in its economy, with agricultural prices remaining relatively stable. Although consumers have gradually shifted to more environmentally friendly diets, change is slower than expected. In the absence of strong regulatory and legal incentives from the EU, sustainability and innovation in the agricultural sector have instead become increasingly driven by large agricultural enterprises. Overall, EU pesticide consumption has continued to decrease; however, their use continues to play a role, with differential willingness amongst farmers to engage with new practices.

Workshop participants considered this scenario generally plausible, though some felt it was undesirable as currently presented. They also discussed:

- **Market drivers**: participants considered that this scenario requires appropriate market drivers and incentives to be more effective. This would help understand the effect of the market in this future. They also expressed concerns that leaving big business to control the market may decrease the potential for diversification.
- **Technology trends**: this scenario assumes the uptake of new technology, but it would be useful to consider the uptake levels of other methods, too, e.g. land management and IPM, and their impacts on biodiversity.

Scenario 3: Unsustainable Inertia

A global recession has shifted political priorities away from innovation and sustainable practices. This has translated into limited capabilities for farmers to adopt new approaches and continued reliance on hazardous chemical pesticide products. Consumers prioritise affordability over environmental sustainability. Large companies dominate the global agri-food sector, leading to the displacement of small-scale producers. Climate change has yet to significantly impact agricultural production, which has remained stable in terms of yield, prices and competitiveness.

Workshop participants agreed this scenario is somewhat plausible and generally reflects the status quo, although some felt it is pessimistic and not necessarily realistic. They also discussed:

- **The role of crises**: participants felt that other societal crises - such as COVID-19 (and other pandemics) and wars, amongst others - could result in a similar scenario.
- **Farm size**: participants questioned whether larger farms would benefit from such a scenario. On the one hand, larger farms have greater access to financial and other resources and survive better than smaller farms. In contrast, smaller farms are more able to react and change practices and adapt more quickly.
- **The role of climate change**: participants were unclear why climate change effects would not impact this scenario. In a scenario of 'unsustainable inertia', agricultural production is likely to be even more exposed to the effects of climate change, and there will be issues with post-mitigation and adaptation.
- **Large multinational firms:** participants cautioned that the behaviour of large multinational companies could create challenges in ensuring food products' compliance with EU standards. Such companies may exploit policy differences to operate outside the EU regulatory framework in a way that is most beneficial for their business priorities, for example. In such cases, the EU would have less opportunity to check the products origin and chemical inputs.

Scenario 4: Widespread Sustainability

EU policies reflect a stronger ambition to foster sustainable economic growth and address environmental issues. Technology is considered a key enabler on this front, leading to its widespread use across all domains of the food supply chain. EU consumers also show increasingly green attitudes. These trends have allowed for a rapid shift towards environmentally sustainable practices, including reductions in pesticide use. Consumers' willingness to pay and improved production processes have buffered the impact of increased food prices, underpinned by costly advanced technologies and sustainable approaches.

Workshop participants felt this is an implausible scenario, considering it overly optimistic, idealistic and unachievable. They also discussed:

- **Technological focus**: respondents felt the scenario focuses too much on technologies at the expense of social factors. Technological innovations such as precision farming and drones can support a reduction in pesticide use but require incentives and support. Technology can only happen alongside other facilitative factors, such as supportive agricultural policy (e.g. the CAP), regulation, infrastructure and the availability of alternatives.
- **Agricultural yield**: the assumptions around yield should be nuanced. There is no evidence that yield would increase under this scenario. The connection between pesticides and agricultural yields are central and could be better specified.
- **The role of the pesticide industry**: one participant felt that, in addition to highlighting farmers' roles as the primary users of pesticides, the pesticide industry's role and pesticide-use behaviour should be mentioned. The pesticide industry is an important actor whose behaviour significantly impacts political strategies and prices, for example.

F.2 Cross-cutting discussion

Participants discussed policy implications across the four scenarios.

What external factors and assumptions are beyond EU control?

- **The approach of third countries**: although the EU may establish trade policy targets and participate in multilateral processes, much depends on third-country policies since they may not be consistent. While the EU has banned certain substances, for example, these can still be used in other countries. If the EU decides to ban certain products or farm in particular ways, it may have less authority to expect the same standards of other trading partners.
- **The behaviour of large transnational companies**: companies across the whole supply chain, including input companies, agri-food companies and retailers, conduct transnational activities beyond the EU. There may be differences in EU strategies if some products are banned in the EU but not elsewhere in the world.
- **Climate change**: this important megatrend impacts pesticide use beyond EU control. It is important to consider its future impact on pest and disease control.

- **War and its impacts**: war could impact pesticide use via migration and labour. Since some pesticide alternatives require labour, labour, agriculture and migration are connected in some areas.

What are the policy goals, assumptions and trade-offs in the different scenarios?

- **Competition and trade policy**: if the European Commission makes the Farm to Fork and Biodiversity Strategies' pesticide-use and risk-reduction targets mandatory, which disadvantages EU farmers competing with other farmers globally, the EU could be side-lined. However, it could also become the leader in food production systems, which is the objective currently in the Green Deal. To ensure consistency, a level playing field is necessary to ensure EU farmers remain competitive.
- **Assumptions across the scenarios**: the assumptions behind the scenarios are not always clearly stated in terms of impacts on agricultural production, prices and food availability. In addition, the impact of policies such as the CAP, Farm to Fork Strategy and Biodiversity Strategy on each scenario is missing.

How would the scenarios be influenced by EU and Member State policies?

- **Differences between the Member States**: participants noted differences between the Member States in terms of their starting point and implementation of EU policies, e.g. CAP reform, the Green Deal. The scenarios focused on the European context but left space for national differences. There are differences in the conditions under which the Green Deal's big strategies will be implemented across the Member States. Such conditions include developments in the organic sector, production and demand, public and private R&I policies and partnerships between stakeholders across the whole supply chain.

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