Pesticide lock-in and barriers to transition towards sustainable plant protection

Authors: Ana Frelih-Larsen, May Hobeika, Antonia Riedel, Josselin Rouillard, Jane Mills, Charlotte Chivers, Nelson Abrantes, Abdallah Alaoui, Virginia Aparicio, Isabelle Baldi, Josefina Contreras, Matjaz Glavan, Paula Harkes, Jakub Hofman, Daniele Mandrioli, Trine Nordgaard, Igor Paskovic, Marija Polić Pasković, Daria Sgargi, Anne Vested

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Overall Project coordinator	Prof. Dr. V. Geissen +31317485144 (violette.geissen@wur.nl)
Scientific Project Manager	V. Felix da Garca Silva, MSc (vera.felixdagracasilva@wur.nl)
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Principle Author(s)	Ana Frelih-Larsen, Josselin Rouillard, Jane Mills, Charlotte Chivers, May Hobeika, Antonia Riedel
Principle Author e-mail	ana.frelih-larsen@ecologic.eu
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7.1, Figure 6. To increase clarity, the text on regulation now reads: "Regionally differentiated authorization and availability of synthetic pesticides on an open market".

The barrier of "differentiated regulation" refers primarily to variation in authorisation at the national level. While PPP Active substances are authorised at the EU level, pesticide products are authorised at zonal and member-state levels (EU Regulation (EC) 1107/2009, Articles 36, 44). This allows for stricter control in some member states than others, adapting to local environmental and agricultural conditions, as well as national health standards and capacity for monitoring. As discussed in deliverable 7.1 (p.43), farmers and stakeholders from countries with smaller markets (e.g. Croatia and Slovenia) identify this variability as a barrier to changing practice. Less hazardous PPPs or biological controls may be approved slowly or not at all, reducing flexibility for producers to reduce reliance on hazardous synthetic chemical pesticides.

Abstract

Historically, plant protection in agriculture relied primarily on ecological diversity within the farm agroecosystem and some limited naturally occurring substances. Since the mid-20th century and the widespread availability of synthetic pesticides, the dominant form of plant protection gradually became the application of specifically developed products, made from different mixtures of active substances, which are applied to reduce weeds, pests, and diseases. This reliance on synthetic pesticides has come at a significant cost to both human and ecosystem health. The need to reduce reliance on chemical pesticides is closely intertwined with the broader environmental and climate crises facing the agri-food system, and the urgent need to shift the agri-food system towards a sustainable and resilient state.

In this report, we draw on mixed qualitative methods to explore the different dimensions of the pesticide lock-in situation, i.e., the barriers and the underlying mechanisms that are holding back the transition towards sustainable plant protection in the European Union (EU). Combining a literature review, EU level stakeholder interviews, and workshops and farmers' questionnaires in SPRINT case study sites, we identify a wide range of barriers and lock-in mechanisms. The results outlined confirm that progress towards reduced reliance and dependence on synthetic pesticides is very much hindered by the pesticide lock-in situation. There are many interrelated processes and more direct barriers that mutually reinforce each other to limit or substantially slow down the possibility of a wider transition away from reliance on synthetic pesticides.

We have identified the key lock-in mechanisms and barriers corresponding to the following dimensions: 1) agronomy & research, 2) economics, 3) knowledge, 4) policy, 5) regulation, and 6) cognitive dimensions. An overview diagram of the key lock-ins and barriers is available in Figure 6 on page 51.

The underlying lock-in mechanisms are relevant across the different farming systems in SPRINT case study sites. Although the specific expressions of barriers can vary, most barriers also apply across SPRINT case study sites. There are also some differences and specificities. For example, there are no biological alternatives for herbicides, so that access to machinery and different trade-offs from machinery use are particularly strong in arable / cereal systems; excessive visual requirements from retailers and consumers are a key barrier for fruit growers, and there is also a higher financial risk with transitioning away from chemical pesticides with cash crops, such as fruit, vegetables, and viticulture.

How the lock-in mechanisms and barriers interact and reinforce each other creates for a very complex picture. For example, in a situation where no biocontrol is available or the cost of it is very high, there is limited openness to non-chemical alternatives and willingness to

experiment. At the same time farmers have already invested capital, time, and knowledge resources in machinery for pesticide applications, authorities rely on emergency authorisations and do not consider the possibility of substantial change, such as shift to growing other crops, or the redesign of farming systems because the cost and effort associated with these is very high and the possibilities beyond immediate emergency authorisations simply are not considered or imagined.

In the next steps of the SPRINT project, we will explore together with stakeholders what kind of possibilities and opportunities there are for breaking the pesticide lock-in situation, by identifying different transition pathways to better support the emergence and diffusion of alternatives to synthetic pesticides. This report clearly shows that such pathways need to take a systemic approach, addressing multiple lock-ins and barriers at the same time.

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Glossary

Active substances: "A plant protection product (pesticide) usually contains more than one component. The component that works against pests/plant diseases is called an "active substance". Active substances can be chemicals or micro-organisms." (European Commission, n.d.)

Barrier: A direct limiting factor as part of a broader system lock-in. For instance, an example of a barrier to sustainable plant protection is the lack of biocontrol products that can replace 1-for-1 chemical pesticide product for treating a specific pest of disease. This barrier in turn is part of a broader lock-in mechanism, historical dependency on current patterns of industry funding which does not favour radically new technologies and approaches.

Biological control: "the control of organisms harmful to plants or plant products using natural means of biological origin or substances identical to them, such as micro-organisms, semiochemicals, extracts from plant products as defined in Article 3(6) of Regulation (EC) No 1107/2009, or invertebrate macro-organisms" (European Commission, 2022). Biological control is also referred to as biocontrol or biocides.

Case Study Sites (CSS): 11 country regions where data was collected as part of the SPRINT project.

Integrated pest management (IPM): "careful consideration of all available means that discourage the development of populations of harmful organisms, while keeping the use of chemical plant protection products to levels that are economically and ecologically justified and minimise risks to human health and the environment" (European Commission, 2022)

Lock-in mechanisms: Underlying and more invisible causal processes that lead to the occurrence of direct barriers, either on their own or in combination of other processes. Together they provide a systemic stabilizing dynamic that reinforces business-as-usual and hinders transition of a system to a different regime. The main categories of lock-in mechanisms identified in this report include: Research & Development, Economic, Knowledge, Political, Policy, Regulatory, Social & Cognitive processes.

Lock-in situation: A system's state of inertia, rigidity, and resistance to change (Geels, 2002; Klerkx & Begemann, 2020; Ollivier et al., 2018; Weituschat et al., 2022). This refers to the alignment of mechanisms and barriers that drive stabilisation and the status quo, restricting change. Lock-in is systemic because of strong interdependency and mutually reinforcing mechanisms and barriers. In the case of pesticides, the use of synthetic chemical pesticides is such a standard and dominant approach to plant protection that change seems too costly and difficult.

Plant Protection Products (PPP): "Pesticides used to protect plants or plant products against pests/diseases, before or after harvest; influence the life processes of plants; preserve plant products; or destroy or prevent the growth of undesired plants or parts of plants. PPPs are used chiefly in agriculture, but also in forestry, horticulture, amenity areas and home gardens. They can be grouped into different categories, depending on their target (herbicides against weeds, fungicides against fungi and mould, insecticides against insects, etc.), the origin of their active substances (chemical or non-chemical, e.g., microorganisms), or their hazard to health and the environment." (European Parliament, 2022). They include both chemical-synthetic pesticides and biological control.

Product substitution: Replacement of a more hazardous product with a product that has a lower hazard profile. Includes, but is not confined to, the replacement of chemical pesticides with biological control.

Sustainable Use Regulation Directive: "Directive 2009/128/EC (SUD) aims to achieve sustainable use of PPPs by reducing the risks and impacts of PPP use on human health and the environment, and promoting IPM, as well as alternative approaches or techniques, such as non-chemical alternatives to pesticides" (European Parliament, 2022).

Transition pathways: The process of transitioning from one socio-technical system to another through transformation, reconfiguration, technological substitution, and de-alignment or re-alignment. It involves actors, technologies, and rules and institutions (Geels & Schot, 2007).

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1. Introduction

Plant protection is a core element of agricultural management. It responds to the need to ensure that plants grown for food or fiber can deliver sufficient yield levels. What makes for sufficient yield levels is relative to the type of farming system, the economic situation of the farm, the climatic conditions, the overall affordability, and access to food, as well as other socio-cultural and political factors. Historically, plant protection in agriculture relied primarily on ecological diversity within the farm agroecosystem and some limited naturally occurring substances. Since the mid-20th century and the widespread availability of synthetic pesticides, the dominant form of plant protection gradually became the application of specifically developed products, made from different mixtures of active substances, which are applied to reduce weeds, pests, and diseases. This reliance on synthetic pesticides has come at a significant cost to both human and ecosystem health (Rani et al., 2021).

Scientific evidence demonstrates, for example, that 64% of global agricultural land is at risk of pesticide pollution from more than one active ingredient, pesticide residues are widespread even in organically managed soils, and groundwater pollution risk has previously been underestimated (Geissen et al., 2021; Hartmann et al., 2021; Tang et al., 2021). The public attention, however, has mostly been galvanized with the growing recognition of the risk that impacts on non-vertebrates, in particular steep insect declines, poses for agriculture and other ecosystem services that societies rely on (Gunstone et al., 2021; Hallmann et al., 2017). The widespread awareness of these impacts, along with the questioning of their efficacy and cost-effectiveness, have resulted in calls for reduced reliance or even a full transition away from synthetic chemical pesticides (Davis & Frisvold, 2017; Melander et al., 2017).

Against this context, in May 2020, the European Commission adopted the Farm to Fork (F2F) Strategy, as a key strategy of the European Green Deal, thereby setting two quantitative targets to reduce the use of and risks from pesticides. These two targets are to: 1) reduce by 50% the use and risk of chemical pesticides by 2030, and 2) reduce by 50% the use of more hazardous pesticides by 2030 (European Commission, 2020). In June 2022, the Commission further presented a proposal for a Regulation on the Sustainable Use of Plant Protection Products (SUR), which would turn the Farm to Fork Strategy targets on reducing the use and risk of chemical pesticides into legally binding targets for EU Member States (European Commission, 2022). This draft has since then been in discussions and political negotiations in the EU Council and the European Parliament (see, for example, Wiener, 2023).

The need to reduce reliance on synthetic pesticides is closely intertwined with the broader environmental and climate crises facing the agri-food system, and the urgent need to shift the agri-food system towards a sustainable and resilient state. A systems approach is needed because changes at farm level are strongly constrained by wider processes, such as consumer demand, the cost of reconfiguring agri-food value chains and dominant social and collective norms (Oliver et al., 2018). Many authors consider that the current agri-food system in Europe (and globally) is in such a socio-technical "trap", that unsustainable farm practices are mutually reinforced, reproduced, and maintained. This is exemplified with an excessively slow transition with regards to reaching climate and pesticide use targets, leading scholars on food systems to argue that continuing with the status quo will lead to systemic collapse (FAO & Tim G. Benton, 2017; Homer-Dixon et al., 2015).

As Kuokkanen et al. (2017) points out, the ignorance of the lock-in situation and the underlying mechanisms can create institutions and feedbacks that only further complicate and resist the change of the status quo. Hence, there is a need to review and map the lock-in situation in relation to synthetic pesticides, including the barriers and lock-in mechanisms to transitioning to sustainable plant protection. Conducting such an assessment can enhance our understanding of the changes that can disrupt the dominant patterns of production and consumption. This knowledge can inform the design of strategies and pathways to expand the widespread uptake of more sustainable plant protection strategies.

1.1. Objectives and structure of the report

This work is part of the EU-funded research project, SPRINT, most specifically the work of WP7 on translating SPRINT's scientific results into workable policy proposals and a supporting research agenda by building on a structured process of engagement with stakeholders. WP7 has three specific objectives:

- To identify lock-in mechanisms and barriers in existing farming systems and in the governance of PPPs that prevent the sustainable use of PPPs.
- To explore transition pathways with stakeholders towards sustainable plant protection in the context of a global health approach.
- To develop innovative policy approaches and formulate a supporting research agenda.

This report presents the findings related to the first objective, i.e., the systematic screening of the key lock-in mechanisms and barriers to the transition to sustainable plant protection in the EU farming systems. As such, the report provides the basis to then explore solutions and develop transition pathways towards sustainable plant protection.

How 'sustainable plant protection' is defined is a matter of much discussion among stakeholders, and the subject of our further research in SPRINT project. In the next step, we will be applying the backcasting method to explore transition pathways, and as part of this method first identify the preferred vision(s) for plant protection in 2030 (Bengston et al., 2020). To explore barriers and lock-in mechanisms, we define the general direction of travel as one where the aim is to minimize reliance on synthetic chemical pesticides with methods that have minimal potential trade-offs for other environmental media. This means that we focus on two options: 1) product substitution (substituting a more harmful chemical pesticide with a less harmful one), and 2) non-chemical treatment alternatives. The latter is a slightly adjusted Integrated Pest Management (IPM) concept, whereby prevention actions are combined with non-chemical treatments to create a toolbox of options (see Figure 1).

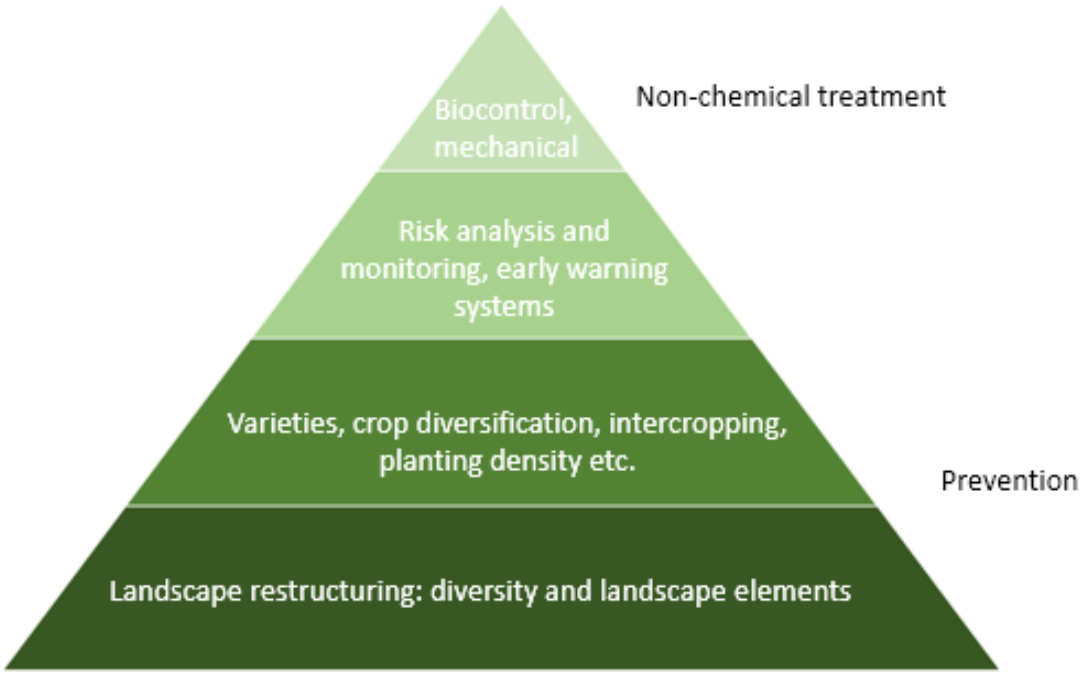

Figure 1 Non-chemical alternatives to plant protection (adapted from Naranjo, 2011)

We begin with the question why are farmers unable and/or unwilling to transition away from reliance on synthetic chemical pesticides to other approaches, either to substituting more harmful chemical pesticides with less harmful ones, or to combining different non-chemical alternatives, including: preventive measures, diversity and landscape elements, varieties, crop diversification, reliance on early warning systems, complemented by mechanical

treatments and biocontrol? The combination of these different measures makes for an ambitious implementation of the Integrated Pest Management.

Drawing on a mixed qualitative method we explore commonalities across as well as more specific barriers characteristic for the different farming systems included in the SPRINT project.

The structure of the report is as follows. Chapter 2 provides an overview of the methods and SPRINT case studies. Chapter 3 outlines the conceptual framing for the analysis. Chapter 4 includes the presentation of the results, exploring the relative importance of the different overarching categories of barriers and lock-in mechanisms, the commonalities across different farming systems and differences, as well as specificities relating to different farming systems, especially those with critically high PPP applications. Chapter 5 includes a reflection on the key findings and conclusions.

2. Methodology

To assess farm-level and systemic barriers and lock-in mechanisms to reducing reliance on chemical pesticides, we first conducted a **literature review** to identify the main themes that limit the transition towards sustainable plant protection and to build a conceptual framework.

Secondly, **EU level stakeholder interviews** were conducted using an in-depth semi-structured interview guide (see appendix A). Prior to commencing the interviews, a Project Information Note and Consent form were drafted. The Project Information Note provided a summary of the project, reasons why interviewees had been asked to participate in the interviews, what taking part in the interview involved, the possible benefits and disadvantages of taking part, their rights to withdraw from the interview and confidentiality issues. These forms, along with the interview guide were sent to the University of Gloucestershire's Research Ethics Committee for approval and received ethical clearance on 27th June 2022.

A total of 13 interviews were carried out between July 2022 and March 2023. In these interviews, 26 interviewees were consulted since some interviews included multiple representatives from the same organization. The interviewees were approached to be representative of different stakeholder types. They included policy officers from three Directorates of the European Commission, representatives of farmers and industry associations, as well as representatives from civil society organisations. The interviews typically ran for 60-minutes, were recorded, transcribed (Kuckartz & Rädiker, 2019) and transferred into QDA software NVivo (QSR International Pty Ltd., 2020) for a qualitative content analysis. Using a priori deductive codes, the data were first coded into broad categories following the interview schedule. The second stage of the analysis took an inductive approach to further coding, capturing different patterns and themes within the broad categories.

The following organization types were represented (the code name for the organisation is given in brackets):

- European Commission (EC), n= 3
- Farmers' organisations (FarmOrg), n=2
- Industry organisations (Industr), n=5
- Civil Society (CivilSoc), n=4

Thirdly, we worked with farmers and stakeholders in SPRINT case study sites (CSS) to explore barriers across the different farming systems: 10 case study sites in Europe and one in Argentina, with each location including organic and conventional farms. The CSSs in SPRINT cover a range of regional farming systems, from livestock farms to permanent crops (apple orchards, viticulture, olives), cereal farming and horticulture. An overview of CSSs with the location and respective farming system can be found in Figure 2.

In the first two years, the activities in SPRINT case study sites focused primarily on the field sampling campaign, creating the basis to assess mixtures of PPP residues & their distribution in the environment (soil, water, sediment, air), crops, animals (livestock, earthworms, fish, bats) and humans and the related health state. The data also feeds into estimating the PPP residue exposure levels for selected organisms, crops, livestock, and humans in the case study sites. Furthermore, based on these data laboratory tests for measuring the effects of PPP residue mixtures on aquatic and terrestrial organisms, and on human health are carried out. Together these results contribute to a Global Health Risk Assessment Toolbox for risk and impact assessment of PPP residue mixtures on the environment, crops, livestock, and human health, linking exposure to PPP residue mixtures to health impacts.

As part of the field sampling campaign, CSS researchers also conducted interviews with farmers. This included two main parts. First, detailed data on the farm agronomy were collected as a basis for assessing integrated risks, costs, and benefits of PPP use in different farming systems at micro- and macroeconomic level, including internal and external costs of PPPs.

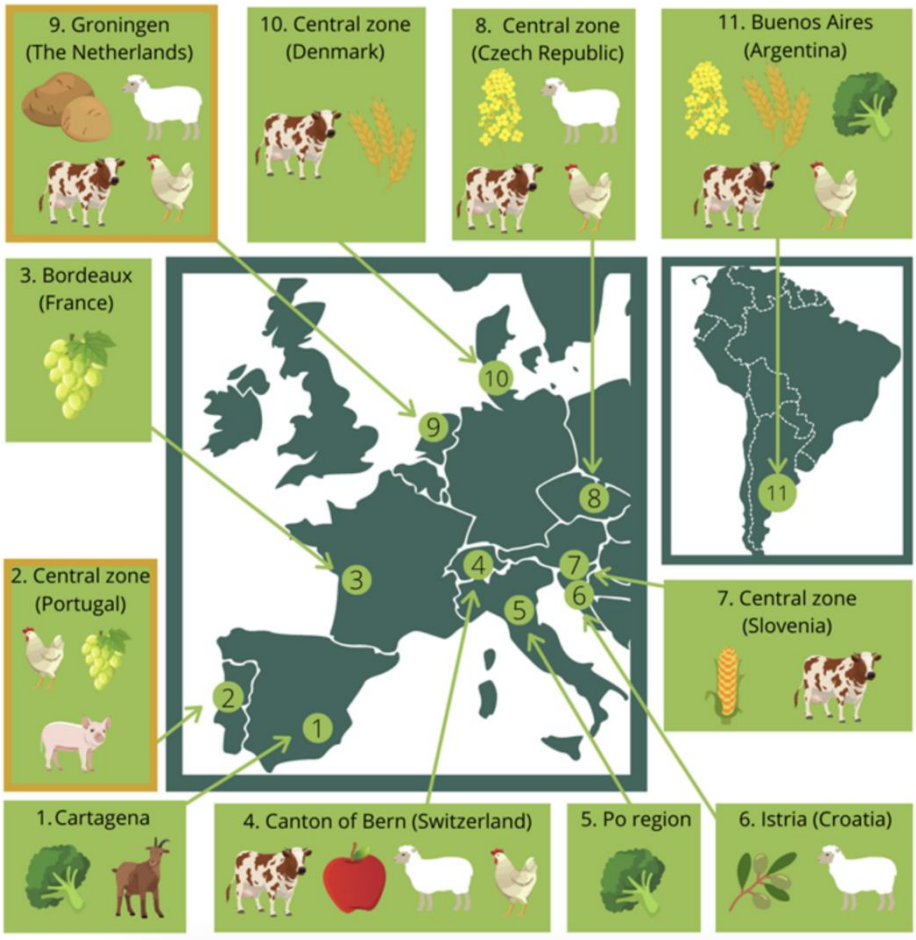

Figure 2 CSS overview and farming systems (SPRINT, 2021; Design: C. Chivers).

Note: Outlined in orange, CSS 2 (Portugal) and CSS 9 (Netherlands) are reference CSS for modelling. At these reference locations, additional water, sediment, and air samples have been collected.

Secondly, farmers also responded to a **farmers' questionnaire** (see Appendix B) that supports the work on transition pathways and dissemination of SPRINT results (WP7 and WP8 respectively). Directly engaging with farmers is important to understand how farm-level influences and barriers interact with the broader economic and regulatory environment, the biophysical and economic conditions on the farm, and farmers' agency, including their views, perceptions, and norms (Mills et al., 2017). Given the large volume of other data being collected from farmers and the exploratory and early stage of the work on transition pathways, the questionnaire only included seven questions. A total of 174 questionnaires were available for analysis, 94 of which are conventional farmers and 80 are organic. The following questions from the questionnaire were relevant for this report:

- How would you rank the levels of pesticide application on your farm?
- How would you rank the levels of pesticide application on your neighboring farms?
- What are the main reasons for the current levels of pesticide application on your farm?
- What are the three main questions you need to be answered when deciding whether to take up a new practice on your farm and why?

Respondents' identities are kept anonymous through a unique code that identifies the country and the farming system (conventional or organic farming). For the purpose of data processing and analysis, inductive categories were formulated to code and explore the barriers to reducing reliance on chemical pesticides. A total of four overarching categories and 22 subcategories were inferred from the responses.

Finally, CSS researchers conducted **stakeholder workshops** with 271 regional and national stakeholders to discuss barriers and solutions for reducing reliance on chemical pesticides in the farming systems in each CSS. Stakeholders included farmers' representatives, NGOs, local industry representatives, local policymakers, and local farming cooperatives (Figure 3).

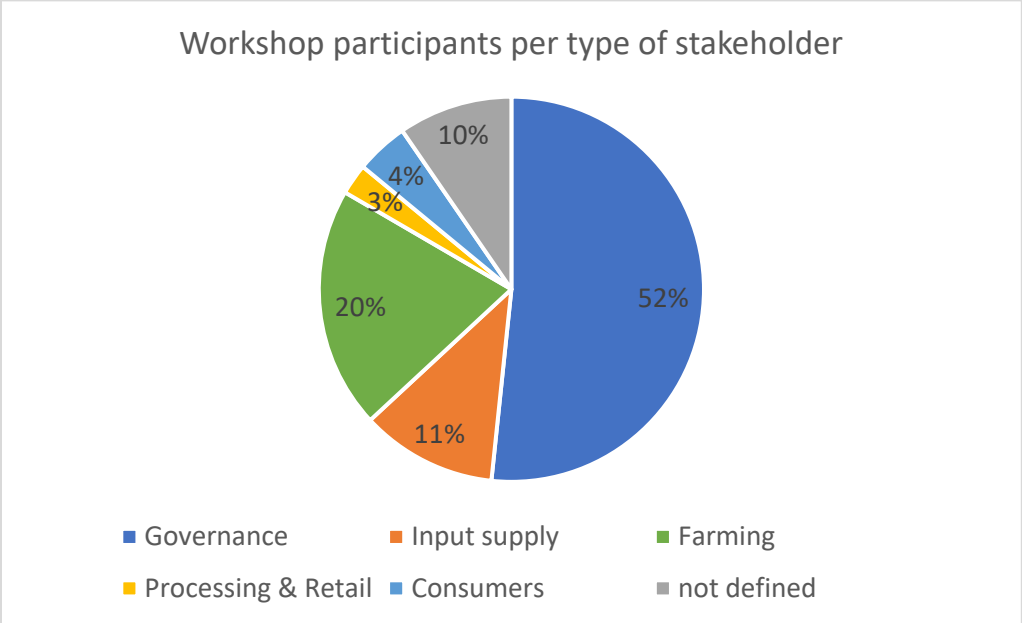

Figure 3 Participants in stakeholder workshops, presented in % (n=271)

The workshops took place between March and September 2022, ranging from large online workshops (e.g., 66 participants in Slovenia and 85 in Argentina) to smaller, in-person gatherings (e.g. six participants in Italy). In preparation for the workshops, WP7 prepared guidance and a training on the virtual collaboration tool, how to contact local stakeholders and how to moderate and conduct group discussions. Case study site researchers prepared workshop reports following a template. A template for the online collaboration board and the invite to stakeholders is available in appendix B. The following questions were discussed in the workshops:

1. What are the top 3 strategies that you find most relevant for reducing pesticide use and risk in the farming system (cover both conventional and organic in the production system in your case study)?

2. Where are the limitations of these strategies in terms of achieving reduction in use and risk?

3. What are the barriers to their development and/or implementation?

4. What are the top three changes that are needed to improve the development and/or implementation of these strategies (policy, research, economics or other)?

The analysis for this deliverable focused on questions 2 & 4. The coding used for the farmers' questionnaire was used as a basis. The final list of barriers was defined in an iterative process, by drawing on EU stakeholder interviews, farmers' questionnaires, and workshop results.

3. Conceptual framing

The research presented in this report uses the multi-level perspective developed by Geels and colleagues to examine transitions towards sustainable plant protection. The multi-level perspective is an approach to study transformations to sustainability in socio-technical systems. Socio-technical systems refer to the mix of "consumer practices, cultural meanings, public policy, business models, markets and infrastructure" delivering key functions for human society, i.e., agri-food products, energy, transport, and housing (F. W. Geels, 2019).

The multi-level perspective posits that existing socio-technical systems are stabilised by the alignments between system components (e.g., technologies, policies, user patterns, infrastructures, cultural discourses) that have been created in previous decades (F. W. Geels, 2019). In socio-technical systems, change is incremental and path-dependent as perceptions and actions of actors are shaped by dominant power relations, and increasingly entrenched rigid rules and institutions. Changing to another social and technical "regime" is hindered by self-reinforcing feedbacks, where deviation from the dominant path becomes increasingly costly (Pierson, 2000, 2004).

The multi-level perspective provides the conceptual tools to analyse barriers to change in socio-technical systems, in particular system "lock-ins" (Groen et al., 2022). A lock-in situation is defined as a system's state of inertia, rigidity, and resistance to change (Geels, 2002; Klerkx & Begemann, 2020; Ollivier et al., 2018; Weituschat et al., 2022). The emergence and diffusion of alternatives and innovations are restricted, business-as-usual is preserved, and actor's decisions are constrained (Geels, 2002; Ollivier et al., 2018).

While a barrier is a direct limiting factor, a systemic lock-in mechanism refers to the underlying causal processes and systemic stabilizing dynamic that reinforces business-as-usual and hinders transition of a system to a different regime. For instance, a barrier to sustainable plant protection is the lack of specific non-chemic alternatives for treating a pest, which is part of a broader lock-in, namely the dependency of research on current patterns of industry funding which does not support other approaches.

Drawing on inspiration from research on socio-technical systems (Klitkou et al., 2015 cited in Geels, 2019), available literature on transitions towards pesticide-free agriculture, as well as inductive analysis of data from SPRINT research, we can identify several categories of lock-in mechanisms. In Table 1, we illustrate these with examples of specific barriers.

Table 1 Overview of types of lock-in mechanisms and barriers related to reducing reliance on synthetic chemical pesticides.

TYPE	EXAMPLES OF LOCK-IN MECHANISMS	EXAMPLES OF BARRIERS
Research & Development	Funding and infrastructure are focused on supporting major crops, chemical and technological solutions	Lower progress on breeding for minor crops and local varieties Investments in machinery, such as spraying equipment, make it more efficient and profitable to continue using chemical pesticides (possibly also conducting contractual work for spraying) than to consider alternatives, which could possibly be more efficient
Economic	International trade & power relations in integrated agri-food supply chains, with limited added value and capital available at farm level. Specialization of production. Long supply chains and retailers' preferences for just-in-time deliveries.	Higher logistical and transaction costs for minor species; Absence of quality standards for minor crops; Poor negotiation position of farmers on price and quality, limited options to increase value
Knowledge	Increasing shift from public to private advisory system, dominance of industry advice Agricultural education system geared towards chemical plant protection, which influences the kind of approaches that farmers are willing to consider.	Lack of knowledge and support on crop rotations and agro-ecological practices more broadly Lack of awareness on environmental and health impacts of chemical plant protection
Political	The current distribution of political power and persistence of power relations that support the status quo. Agricultural exceptionalism in agricultural policy.	Lack of regulatory baseline and insufficient incentives for complex crop rotation within the Common Agricultural Policy
Policy	Agricultural exceptionalism and the focus on optimizing income via agricultural policy	Lack of a systemic approach to support transition to diversified cropping and farm systems (research, advice, supply chain, consumption, health)
Regulatory	Complex authorization and risk assessment system focused around single active substances	Slow process and delays in the registration for biocontrol alternatives Resource allocation to risk assessment over monitoring of use and environmental impacts in cropping systems
Social & Cognitive	Consumer demand for visually perfect products. The routines and mindsets that "blind" actors to (the benefits of) alternatives such as the dominant narratives on what farming is about. The concept of a 'good farmer' which gives social status within the peer group is based on 'clean' and weed-free fields.	Quality rules and standardisation of products that lead to criteria which are difficult to meet without chemical pesticides. Lack of openness to experiment with crop diversification or biological control.

Source: based on Geels, 2019; Lamine, 2011; Meynard et al., 2018; Sutherland et al., 2012; Weituschat et al., 2022

Beyond the assessment of barriers and lock-in mechanisms, the multi-level perspective provides guidance on examining the opportunities for breaking lock-ins and disrupting

dominant socio-technical arrangements to support the diffusion of innovations, and the reconfiguration into a different socio-technical regime (Geels, 2002; 2011). The assessment of transition pathways will be examined in the next steps in the SPRINT project.

4. Assessment of barriers and lock-in mechanisms preventing transition to reduced reliance on chemical pesticides

This chapter presents the results of the analysis on barriers and lock-in mechanisms that prevent transition to reduced reliance on chemical pesticides, drawing on the data from the questionnaires, workshops, and EU level interviews. First, an overview is given of farmers' perceptions on the level of pesticide use on their and neighbouring farms, as well as the relative importance that farmers give to different types of barriers. In the remainder of the chapter, the results are then presented along the different categories of barriers. The source of data is indicated in the following way, unless otherwise stated. Results from the workshops are accompanied by the acronym of the country (e.g.SI for Slovenia), for farmers' statements from questionnaires the unique identifier of the farmer is included (e.g., SL07_Farm04_H19). For the EU stakeholder interviews, the quotations include reference to the type of stakeholder. Due to high numbers of reference statements to certain topics, not all statements by farmers are referenced.

4.1. Farmers' perceptions of the level of pesticide use

Farmers were asked about their perceived level of PPP application on their own farm and on their neighbours' farms on a scale from 1 (very low) to 7 (very high) (see Figure 1 2). In European farming systems, Portuguese, and French farmers (both viticulture), Spanish (horticulture), and Dutch farmers (mixed, potatoes) estimated the highest levels of pesticide use on conventional farms, as well as on neighbouring farms. This is not surprising since these tend to be the systems with the highest levels of pesticide application in general. Organic farmers see the levels of pesticide applications on their own farms as much lower than conventional farms (difference: 3,0 points). Swiss and Spanish organic farmers estimate their levels of pesticide use to be higher than in other organic systems. When considering the neighbouring farms, organic farmers ranked their neighbours' pesticide application levels higher than conventional farmers did (difference: 0,5 points). However, conventional farmers still think their neighbours have higher application rates than themselves (difference: 0,5 points). This indicates that in general farmers are aware that pesticide applications are not low, but also that they do not think that these levels are very high.

Table 2 Farmers' views on pesticide application on their own farm and on their neighbours' farms (mean value per CSS)

CSS	**Estimated level on own farm** (n=173)		**Estimated level on neighbouring farms** (n=171)	
	by conventional farmers	**by organic farmers**	**by conventional farmers**	**by organic farmers**
DK	2,6	1,0	4,1	4,9
AR	4,7	1,4	5,5	4,8
HR	3,2	2,0	3,3	3,8
FR	4,3	1,0	4,7	5,4
NL	4,4	1,0	4,8	5,4
ES	3,4	3,6	3,5	4,6
SL	3,3	1,3	3,8	4,1
CH	5,2	3,4	2,8	4,7
PT	4,3	1,0	4,7	5,4
IT	2,5	1,8	3,5	4,2
CZ	3,2	1,0	5,1	4,2
All	**3,7**	**1,7**	**4,2**	**4,7**

Note 1: scale from 1 to 7, with 1- very low and 7 - very high,

4.2. Farmers' views on the importance of different types of barriers

Table 3 and Table 4 show the average rank that conventional and organic farmers assign to each of the six reasons for the current levels of pesticide application in each country (174 farmers provided the ranking for this question, 94 of which are conventional farmers and 80 are organic). Farmers were asked to rank the following six reasons from 1 to 6 by order of importance: risk of yield losses, lack of available alternatives, lack of knowledge about alternatives, concern about impacts on the environment and/or human health, regulatory restrictions, funding to support use of alternatives (see Question 2 in the questionnaire, appendix B). Rank 1 refers to the most important reason and rank 6 to the least important reason.

The average rank for each reason per country was determined. The heat map represents an average ranking for the whole group of farmers per country. For some case studies there is no rank 1 because some farmers ranked several reasons at the same rank and some farmers did not assign all the reasons to a specific rank. Using a conditional formatting analysis, the

three most important reasons were highlighted in the shades of blue, with the main reason (the reason assigned to rank 1) highlighted in the darkest shade of blue.

Table 3: Ranking of top 3 reasons for the current level of pesticide application, conventional farms.

Country – Farming System	Risk of yield losses	Lack of available alternatives	Lack of knowledge about alternatives	Concern about impacts on the environment and/or human health	Regulatory restrictions	Funding to support use of alternatives
ES - Vegetables (Broccoli)						
PT - Vineyards, Arable Crops						
FR - Vineyards						
CH - Orchards (Apples)						
IT - Vegetables, Orchards, Rice						
HR - Olives						
SI - Maize, Dairy, Beef						
CZ - Oilseed Rape, Dairy, Chicken						
NL - Potatoes (Rotation Cereals)						
DK - Cereals						
AR - Cereals, Oilseeds, Vegetables						

Legend
Rank 1
Rank 2
Rank 3

Note: The total number of observations is n=174.

Table 4 Ranking of top 3 reasons for the current level of pesticide application, organic farms

Country – Farming System	Risk of yield losses	Lack of available alternatives	Lack of knowledge about alternatives	Concern about impacts on the environment and/or human health	Regulatory restrictions	Funding to support use of alternatives
ES - Vegetables (Broccoli)						
PT - Vineyards, Arable Crops						
FR - Vineyards						
CH - Orchards (Apples)						
IT - Vegetables, Orchards, Rice						
HR - Olives						
SI - Maize, Dairy, Beef						
CZ - Oilseed Rape, Dairy, Chicken						
NL - Potatoes (Rotation Cereals)						
DK - Cereals						
AR - Cereals, Oilseeds, Vegetables						

Legend
Rank 1
Rank 2
Rank 3

Note: The total number of observations is n=174.

Results show that conventional farmers in most countries rank "risk of yield losses" as the most important reason (rank 1) for the current level of pesticide application (PT, FR, CH, IT, DK), followed by "regulatory restrictions" (PT, FR, IT, DK) and "concerns about impacts on the environment and/or human health" (PT, FR, DK). Organic farmers in most countries ranked "concerns about impacts on the environment and/or human health" as the most important (IT) or the second most important reason for current levels of pesticide application (PT, FR, CH, SI, DK). On average, organic farmers also ranked "risk of yield losses" as the most important (HR) or the second most important reason (CH, ES) for the current level of pesticide application.

In addition to ranking, insights on the relevance of different types of barriers can also be seen from the analysis of open-ended statements that farmers provided to the question "*What do you think are the main reasons for the current levels of pesticide application on the farms in your area?*" (See Figure 4; Question 2 in the questionnaire, appendix B). Of 174 farmers who ranked the barriers, 47 farmers provided additional open-ended statements. These statements were then coded according to different types of barriers. Because the statements were often complex, multiple codes could be assigned to each statement. This coding process resulted in a total of 43 coded answers for conventional farmers and a total of 55 coded answers from organic farmers.

The same analysis was undertaken with responses to the question "*What are the 3 main questions you need answered when deciding whether to take up a new practice on your farm and why?*" (See Figure 5; Question 7 in the questionnaire, appendix B). 153 farmers provided responses to this question. As with the previous question, the same reply could be coded for multiple categories when it contained segments relevant to multiple categories. A total of 143 coded answers were inferred from conventional farmers' responses and 159 coded answers from organic farmers' responses.

Figures 4 and 5 provide an overview of the coded responses by conventional and organic farmers. Responses from conventional farmers are shown in light green, responses from organic farmers in dark green. Because the number of answers from conventional and organic farmers are not equal, the percentage share of coded answers for each category was calculated over the total number of answers by farming system (conventional or organic).

The aim of the analysis was to determine the relative weight given to different types of barriers and concerns that farmers have, and to build additional granularity compared to Table 3 and Table 4.

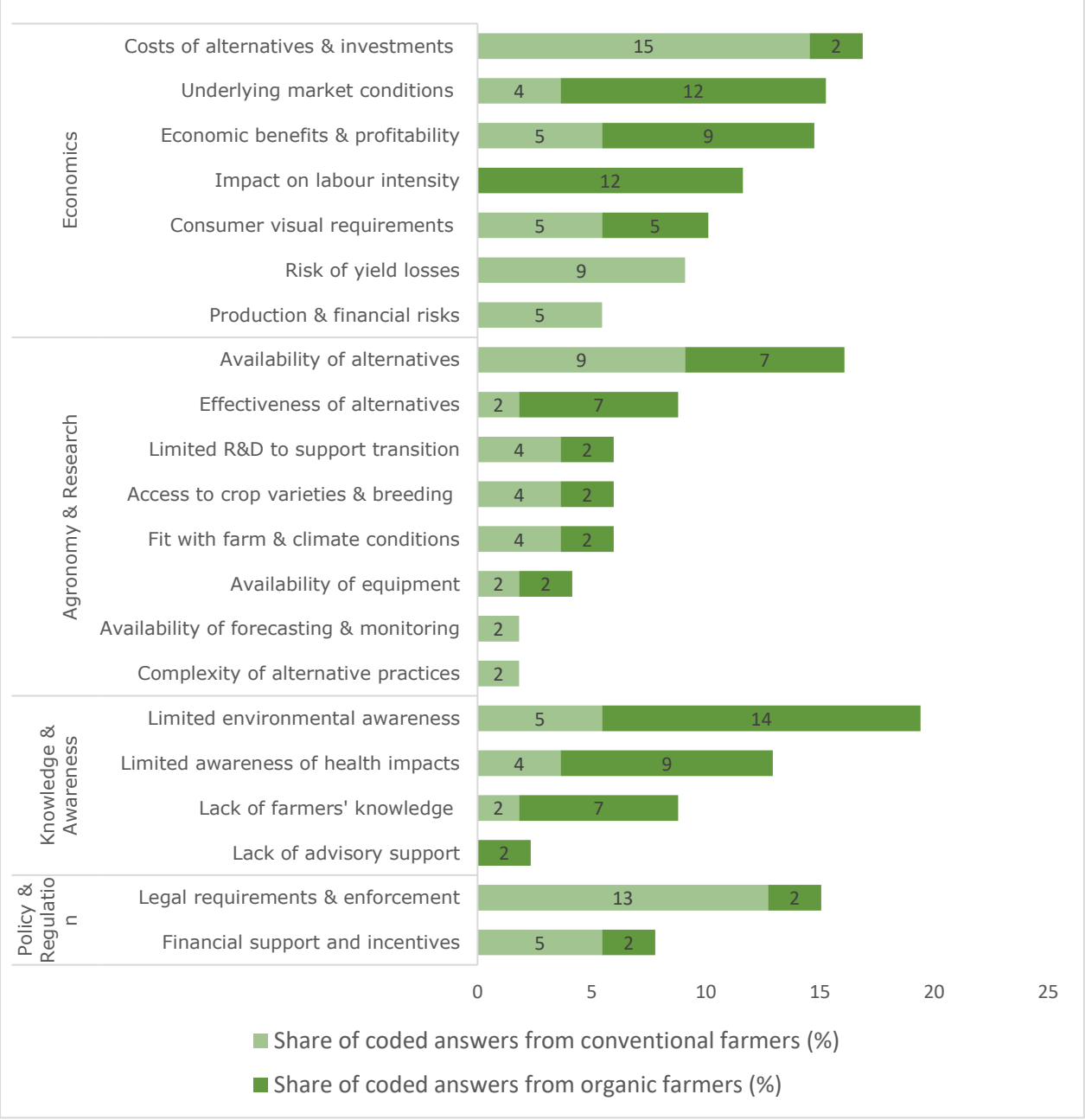

Figure 4 Share of coded answers per category per farming system (conventional or organic) (%) regarding the main reasons for the current levels of pesticide application on their farm, all countries aggregated.

Note: The share of coded answers was calculated based on the total number of coded answers per farming system: 43 coded answers for conventional farmers; 55 coded answers for organic farmers. The subcategory "trade-offs for soil health" was removed because it did not include any coded answers.

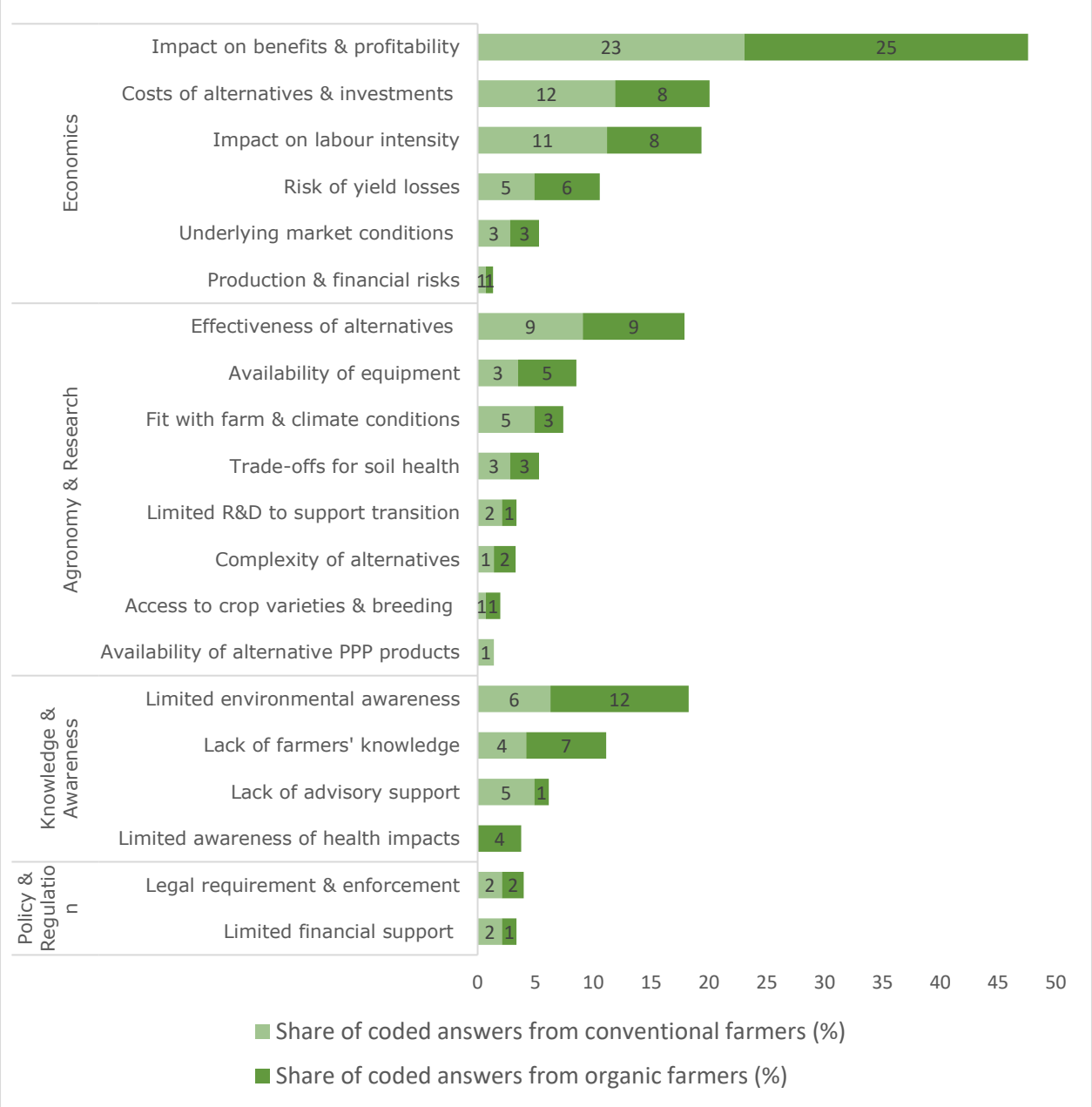

Figure 5 Share of coded answers per category per farming system (conventional or organic) (%) regarding the main questions farmers need answered when deciding whether to take up a new practice, all countries aggregated.

Note: The share of coded answers was calculated based on the total number of codes per farming system: 143 coded answers for conventional farmers; 149 coded answers for organic farmers. The subcategories " Forecasting/ monitoring" and "Consumer awareness / visual requirements" were removed because they did not include any coded answers.

What we see is that while economics dominate, there are also a range of other obstacles that exist according to the perspective of interviewed farmers. Impact on farm profitability broadly, concerns about increase in labour intensity, availability of alternative products for plant protection (biocontrol), and uncertain effectiveness of alternative practices or products are all important. Lacking environmental awareness and knowledge of health and especially environmental impacts are perceived as important.

There are some differences between conventional and organic farmers' perspectives. Organic farmers tend to emphasize more limited environmental awareness, and limited awareness of health impacts, as well as lack of knowledge skills. Conventional farmers emphasize more costs of alternatives, the risk of yield loss and different legal requirements or conditions that they feel reduce the interest in non-chemical alternatives. Along with legal requirements, this category includes focus on approval and authorization of substitute products.

These results point to a complex mix of barriers and the need to understand these from a systemic perspective. To explore the barriers and lock-in mechanisms, we combine the analysis of farmers' statements, workshop results, EU-level stakeholder interviews, and literature review.

The following sections present for each dimension, the most relevant and salient observations.

4.3. Agronomy and research

The availability and access to alternatives to chemical pesticides is a central issue both in agronomy and research. These alternatives include alternative chemical products which are less hazardous or biological control products, mechanical treatments, use of resistant crop varieties or alternative crops, or agro-ecological practices. Some stakeholders also mentioned the role of digital technologies, precision agriculture (including machinery), and gene editing (new genomic techniques).

The main categories of agronomic and research barriers and lock-in mechanisms that have been identified are discussed below.

Fit with existing practice, farm, and climatic conditions. This category first relates to how well the alternative to chemical pesticides fits with the current farming system or biophysical conditions on the farm. The specificity of farming systems requires adjusted methods.

For example, biological alternatives are more challenging to apply in settings such as indoor cultivation, farming in tunnels, or on very large-scale fields (IT). The structure of the fields or the size of the farm may also restrict the options for new machinery use (SL07_Farm04_H19),

or the new practice does not match the current farm philosophy more broadly (IT_H_11). Some crop rotations may be incompatible with the specific combinations of ecological, climatic conditions and the farming system which is in place (AR). Crop diversification, for example, may be more challenging in semi-arid or water scarce areas since it may increase farm water needs (ES). On smaller farms, the impacts of new practices on existing practices and other crops may be larger and more difficult to accommodate than on larger farms (PT). In mixed or livestock systems, the cropping choices are closely linked to how well the crop satisfies feeding requirements for the livestock. In this case, lower protein supply in fodder crops can be a barrier to their integration (DK009). If a new crop with lower pest susceptibility is introduced, its adaptability and compatibility to the farm conditions is essential (FR_EF06).

There are also potential trade-offs that are specific to environmental and farming conditions. For example, in Denmark:

> "Protecting the environment from nitrogen leaching from the cropland is not always easy to combine with reduced use of environmentally harmful pesticides. Often efforts to reduce emissions of climate gases and nutrients go in the opposite direction of reducing pesticide use. In particular, rules on tillage in conventional farming make mechanical control of root weeds cumbersome, referring conventional farmers to glyphosate instead. Organic farmers are free to till in the autumn. Legislative change would be needed if mechanical methods are to be used more." (DK)

The difficulty of finding the right solution for the right context is a challenge that increases complexity over the application of single products that work across multiple contexts and represent a much more simplified approach.

> "You cannot just work with a checklist to be implemented on a field without knowing the field. For instance, you need to consider what are the conditions of the field, where is this field located, what are the possibilities that you can actually apply based on climate, on soil, on landscape, on geography, etc. In summary, based on everything that surrounds the place, and can be assessed from a technical and scientific point of view. The best way to do so is with a person that is an expert, for instance, an independent advisor who has an agronomic training. Also, we need to consider what is actually feasible for that field considering all the circumstances mentioned above. We cannot just generalise and consider all the EU can be treated as the same, because sometimes not even a region next to the other in the same Member State or province have the same agronomic and productive situation" (FarmOrg2)

Limited availability or access to alternative (substitution) products is a significant theme that arises. In most cases, farmers and stakeholders refer more broadly to lack of availability of alternatives. However, when looking more closely this is focused on alternative

products to substitute currently used chemical products. This can mean that there is no clear chemical product alternative on the market with a lower hazard profile, or it can also refer to the lack of biological alternatives.

This also suggests that farmers' who state that there are no alternative solutions, do not consider the other elements of the IPM pyramid to be an option for their farm. At the same time, the alternative of growing something else is not at all considered, possibly because of its lack of feasibility (change in permanent crops and changes in crop rotations have a lot of economic risks as discussed below). For example:

> "The regulations are not in line with the reality on the ground. We remove products while waiting for the same yields without alternative solutions." (FR_EF06)

> "I think one of the main challenges is not knowing when alternatives such as biopesticides may be available for the farmer or be on the market for the farmer, due to the approval process. Having that kind of clearly set out for them would also enable them to know what's coming and when they can move towards these things, over the course of the next few years, I would say." (Industr1)

Even where products are in theory available, the authorisation of products at national level means that farmers in different countries have different access to product substitutes. For countries with smaller markets (for example, in Croatia and Slovenia), the availability of new and less hazardous PPPs is more limited, which reduces the flexibility for producers to substitute products.

For biological alternatives, it could mean that species or microorganisms do not address some types of crops or locations, i.e., these alternatives have limited universality to certain crops and edaphoclimatic regions (ES).

> "It's not always the case, but quite often you need two or three different biologicals to do the same job as one chemical because depending on the situation, you might not use the same one. And they tend to be more specific than chemistry, and therefore you can't simply use one, you might need a different one depending on the pest and disease present from one day to another day, or in one season one and in another season, you need a different a one, whereas it would be the same chemistry use on each occasion." (Industr4)

In arable cropping a large gap is that microbiological products are available for fungi and pests, but there are no available biological products to substitute currently used herbicides (DK, Industr3). Depending on the perspective of the stakeholder, the relevance of this barrier varies. Some argue that this is a significant problem, for example:

> "… the main bottleneck that we have seen until now, and maybe that is what gives the simplistic impression that we are not applying IPM is that we are short on tools to do so. And this is something that has been quite highlighted with the new provisions of the Sustainable Use Regulation. And, and it's one of our first battles on this policy, that is the availability of alternatives. I mean, we will be happy to not use chemicals or use them as IPM marks always 100% of the cases, as a last resort. The problem is when you must face reality in the field. Farmers do not use these products unless absolutely necessary. In most cases, you do not have alternatives to protect the crops." (Industr1)

Others disagree and point to the availability of other alternatives that substitute products, and the importance of speeding up the availability of biological alternatives on the market.

> "And there's this strong idea that, first, that there are no alternatives, which is not the reality because there are farmers that are doing it. And second, that if you do that (i.e., IPM), then yields are going to go down. And you have some studies in the field showing that you can reduce, and you don't lose yields, at least to a certain extent. So those two things are very, very important for getting things moving forward." (CivilSoc4)

Uncertain effectiveness of alternative products. Related to the availability of products is also the concern about the effectiveness of alternative products. This may refer to the limited universality of biocontrol products (not adapted to all crops), increased pest resistance over long term, for example, also in the case where the PPP market is small and only a few active substances are available, or in general uncertainty and perceived risk efficacy of biological alternatives (HR, ES, CZ, CZ_H21). There is also the concern about the effectiveness of biological controls under extreme climatic conditions and the possible resistance of pests to beneficial insects (IT), or even potentially negative impact on human health (ES). In some cropping systems, products are more effective than in others.

> "In general, lower efficiency is known for biological PPP, but it depends on the entire strategy of use in the context of the crop, the given area of cultivation, combination with other protection systems and e.g., use of synergistic effect." (CZ)

The relevance of this barrier is also illustrated by the fact that many farmers see the question of how effective the alternative non-chemical practice (product or agronomic approach) is likely to be as a key question that guides their decision-making on new practices (e.g., PT_F2; NL_H21, CH_F28). Farmers commented on being forced to continue using conventional products (HR_H19, FR_EF04) in the absence of alternative products; or because alternatives do not seem to be as consistently reliable as conventional PPPs (SL07_Farm06_H07).

Complexity of agro-ecological practices and IPM as alternatives. This category illustrates clearly how the agronomic barriers are inextricably linked to the economic and other

aspects. For example, for crop rotation there is a lack of clear choices for crops to be included into rotation with financial profitability, or if these are available, they are not known to farmers (ES). An additional aspect is that to replace chemical treatments with the alternative of the agro-ecological practices increases the complexity of decisions to be made by farmers and this is closely linked to the need to support these choices both through research and testing, and through improved availability of knowledge and guidance, such as crop management plans adapted to crops and pests (ES, AR_H55). For example, when introducing a new practice such as strip cultivation (tarwe + kool), strip width must be adjusted to machinery or vice-versa, and still carries some open questions about the extent it can limit plant diseases (NL).

Potential trade-offs for soil health. When deciding on a new practice, several farmers pointed to the need to consider how a practice will affect soil health and the importance of new practices to improve the soil condition, including soil organic matter, soil structure, water retention and fertility (CZ_H07, SL07_Farm10_H55, NL_H09). In particular, the trade-offs or limitations for soil health can pose a barrier to tillage and mechanical weeding as an alternative to herbicides, especially if done too frequently. Tillage affects soil biodiversity (AR). The creation of false beds[1] requires that the soil is not too wet, which can limit the feasibility of this practice under certain climatic conditions (NL). In Denmark limitations on tillage as a means of controlling weeds were raised both by farmers and in the workshop:

> "Protecting the environment from nitrogen leaching from the cropland is not always easy to combine with reduced use of environmentally harmful pesticides. Often efforts to reduce emissions of climate gases and nutrients go in the opposite direction of reducing pesticide use. In particular, rules on tillage in conventional farming make mechanical control of root weeds cumbersome, referring conventional farmers to glyphosate instead. Organic farmers are free to till in the autumn. Legislative change would be needed if mechanical methods are to be used more." (DK)

Diversification practices may also increase farm water needs, especially in semiarid and water scarce areas (ES).

Access to crop varieties and breeding. Sometimes access to seeds of resistant varieties is a barrier (AR), or lack of information on the intrinsic characteristics of cultivars of alternative crops (AR). Here too there are potentially some trade-offs as some adapted varieties could result in poorer organoleptic characteristics (ES). In the Spanish workshop, stakeholders raised the issue that the restrictive European legislative framework for transgenic or genetically modified products makes the development of new varieties that are more resistant

[1] The seed bed is first prepared to allow weeds to grow. After that, it is prepared again, and this time sown with the actual crop.

to pests challenging (ES). Several industry representatives pointed to new genomic techniques as an opportunity. I.e.:

> "The upcoming proposal by the Commission set for June on new genomic techniques is potentially a huge opportunity to contribute to those objectives that we spoke about in the Green Deal and can accelerate the development of resilient plants, increase yields, and improve food quality as well. So, we don't know what the Commission is going to come out with now. Still a few months away. But that is an opportunity and something that we've seen in other parts of the world, I believe, Japan and the US that could contribute as well to our goals, but also to add to EU competitiveness." (Industr1)

However, the environmental risks associated with these techniques means that they are a controversial option and there is a large opposition to these from environmental stakeholders (AgriOrg1, CivilSoc3, CivilSoc4).

Problems with availability of machinery and equipment as alternatives. There is general agreement that machinery and equipment play a role in reducing reliance on chemical pesticides. Some emphasize opportunities for weed management, whereby the availability of specific types of machinery that is needed is a barrier. For example, that different approaches and machinery are needed for different soil types (sandy vs clay soils) (SI). Others also point to possibilities of reducing the overapplication of chemical pesticides where these continue to be used via precision technologies. Uptake of new practices is very much dependent also on the compatibility with the current machinery that farmers already have (CZ_H21). Introducing cover crops and changing crop rotation requires changes in machinery for harvesting. Farmers are also concerned about the limited offer of machinery for smaller producers and/or access to sharing machinery: "Lack of modern technology/technologies for small farms, most are designed for processing of large volumes/areas. The use of large machines for small productions becomes inefficient, unnecessarily costly, we miss some alternatives." (CZ_H21).

Limited research to support transition to reduced reliance on chemical pesticides. Respondents point out a lack of research on alternatives, on environmental risks of chemical pesticides and on the implementation of alternatives.

From the farmers' perspective the topic of technology and machinery came up frequently as a research area that needs more attention. Some farmers referred to this in terms of general needs for improved technologies or the development of robotics. In more specific terms, improvements in spraying technologies were mentioned by conventional farmers (CH_H13, DK006, FR_EF06), and in the EU level stakeholder interviews.

> "When a product is used for an actual need identified, there might be ways of reducing risk, via several means. And one thing we should also mention is the application, the application

> technique, when we see some new precision application equipment linked to digital farming and where again: we seem to hear from authorities, everybody likes it, everybody would like to see something in that direction, but we still have regulatory hurdles. And what's needed in the dossier to really get through with something in that direction, but that's really, really promising. That would reduce quantities that would make things much more adapted. So, it fits with the whole IPM approach as well. And really speaks to this concept of "as little as possible, but as much as necessary". (Industr1)

Danish farmers pointed to the possibility of intelligent robot technology:

> "If the sprayers were equipped with a capability to recognises weeds and different kind of weeds, so that only the (infected) weed plants would be sprayed. Kind of a robot-controlled sprayer to minimise the use of pesticides only to areas/weeds really needed (DK006).

The adaptability of technologies (machinery) more broadly to smaller farms was raised in the Czech context:

> "Technological complexity for small farms. Lack of modern technology/technologies for small farms, most are designed for processing of large volumes/areas. The use of large machines for small productions becomes inefficient, unnecessarily costly, we miss some alternatives." (CZ_H21)

Others pointed to insufficient investment in plant breeding, for example, resistant varieties to downy mildew (FR_EF_F16) or resistant types of apples (CH_F23, CH_F26). Genetically improved plant breeding as a need with potential to decrease plant diseases and resistances was mentioned by several conventional farmers and industry representatives (DK_005, Industr1, Industr3).

Further, the practicalities of accessing research results and processes are claimed to be untransparent and lack the participation of farmers in the innovation processes.

In the workshops, other types of missing knowledge were identified.

- Lack of information about alternative production approaches and their profitability
- Knowledge about crop combinations, despite the recent increase in this knowledge (ES)
- Limited data on PPP exposure and insufficient transparency in sharing data with researchers and the public (CH)
- Very little research in the basic biology and ecology of pests, which limits the development of good warning and decision support systems (DK)
- Insufficient research on methods for plant protection that enable production of quality products (CZ)

- More data based on comparative epidemiological studies on the actual benefits of organic farming on farmers/workers health is needed, due to the high cost of data collection (IT)
- Knowledge gaps in relation to fate and toxicity of PPPs, and knowledge on high-risk PPPs, which would allow to improve the risk assessment of PPPs and develop a better approval system (CH)
- Lack of knowledge for auxiliary insect use, or for combating specific pests, especially in non-covered crops (ES)

Specific barriers were also identified that lead to low incentives in the agro-chemical industry to conduct research and development to develop product substitutes: basic substances cannot give rise to patents that generate royalties for their exploitation, and difficult and long process for the registration and marketing of basic substances further disincentivizes new research (ES).

The lack of robust indicators hinders the monitoring of environmental and health impacts of pesticide applications, as well as economic costs and benefits of different approaches at farm level. This has implications for understanding the scale of the impacts, to increase awareness among the public, as well as to develop and monitor policies.

In the context of the legal proposal for the Sustainable Use Regulation, several EU level stakeholders pointed to the **Harmonised Risk Indicator 1 as being a poor indicator to monitor chemical pesticide reductions** and the achievement of pesticide reduction targets set out in the Farm to Fork Strategy and the SUR proposal. An important aspect in facilitating transition to reduced reliance on chemical pesticides is to understand and be able to monitor changes in pesticide use. The F2F Strategy target to reduce by 50% overall use and risk from chemical pesticides by 2030 is based on the use of the Harmonised Risk Indicator 1 methodology. The proposal for the Sustainable Use Regulation (European Commission, 2022) proposes to make this indicator legally binding. The indicator itself, however, has been criticized:

> "... the harmonised risk indicator, HRI1 basically is an indicator based on the volume. So, in this case, it discriminates against natural substances that are used in a larger volume, because they are in general less toxic. So basically, we have an issue with this, and it has also been pointed out that several environmental NGOs and the European Court of Auditors back in 2020. Because then, if you have one indicator which is unfit, and that cannot properly assess the pesticide use reduction procedures and risk reduction, then it's useless to have targets because the indicators cannot measure properly. So, this is something that we are working on changing it. To really achieve the 50% targets of the reduction it will be needed to change the indicators, to have a faster reduction where the registration process

for natural substances and to also promote organic farming as a concrete alternative." (FarmOrg1)

"So, it means that if you use a 2gramm of pesticide per hectare, which is a very toxic one, it seems less than if you use copper of five kilos. So, it is an indicator which is harming the organic sector because it's not correcting for the fact that certain products in organic can be used in much bigger quantities, so, it's a very bad indicator. So, for us, you know, what is being proposed does not makes sense if we don't correct the indicator first. So, this is why we, of course, we are happy with the 50 percent reduction and we're happy that it's there. But if we miss it badly, it doesn't mean anything in the end. So, for us to really have the "road of travel "being different, we would need a date to just make it simple. We would like to have a date for the final phase out." (CivilSoc1)

The monitoring of impacts and progress is also limited by the **scarce availability of data on pesticide use at farm level as well as lack of data for other indicators.**

"So, the position of the [CivilSoc4] is that we want also indicators to measure the impact on nature, diversity and on soil. Because it has to be taken into account the effect that the use of synthetic pesticides has, for example, for pollution of the soil, or for killing the living organism, or for the effect on pollinators, or water pollution. So, we do want some more indicators there and that is what we were asking for. So, as you know, there is a lot of problems with the harmonised risk indicators, they were adopted very, very late and are very bad. Ideally, I mean, obviously, that's also linked to having data on pesticides. Now there is no adequate data. But then, we would like to see other indicators that take into account other effects." (CivilSoc4)

The lack of data for making progress towards reduced reliance on synthetic pesticides is also used as part of political negotiations and specifically as an argument for not setting legally binding and ambitious targets on pesticide reductions, because the data is not seen to be sufficiently good to set the right kind of targets and to measure progress well.

"There is a paradox when we hear that the Commission acknowledges that they want to reduce the use of pesticides, but they do not have data on use but only on sales. They recognise that they still need to have data on use and that's what they aim for with the Sustainable Use Regulation. Besides, they aim to have in particular indicators for the use that can be better used. Harmonised risk indicators exist now for sales, assessing more the weight of the respective substances, but not considering the actual volumes used on the fields. I feel that tweak that will be very important. Making a direct assumption is not the way for us (farmers or the EU) to move. Maybe there should be a little bit of fine-tuning, before deciding exactly how many targets and of which nature should be set." (FarmOrg2)

How important political will is even in a situation of better data availability to make progress is illustrated by the following quote. Even in countries where data on pesticide impacts is more advanced, the lack of political will means that limited progress is made:

> "Some other countries don't want to do it because they have to restructure, they need to put a lot more resources into monitoring, into the transfer of information and all these and they didn't count on that. So maybe they don't have the resources in the public authorities to do that. But yes, luckily at least for transparency, the two main agricultural countries in Europe, are transparent. So, pushing the others to be transparent as well. And then it's very funny because you can be super, super transparent, and then don't care about what the indicators tell you. Like, for instance, the Netherlands, one of the most transparent countries, is one of the more data-driven or auditory or data available countries. You even have an atlas of pesticide contamination of water publicly available for everyone interested. And it shows a catastrophic situation. So, are they changing anything? No. But the information is there, and the information is there to be shocked and alarmed. But that doesn't mean that--. I mean, when they do this science-based policy and everything, I think people idealise completely the thing. Like, I agree, this is the way we have to go. Don't get me wrong. But we have a lot of data now on our tables to take the right decisions and the right decisions are not taken." (CivilSoc2)

Finally, another aspect linked to the lack of data collection and evaluation of costs and benefits that was raised is the more underlying problem of **overreliance on annual yield as a metric of success and farm well-being.** If research does not intentionally and explicitly examine other aspects, and broader benefits of impacts of alternative practices and products for plant protection, but solely focuses on impacts on yields in a single year this is a very reductionist and compartmentalized view that limits the understanding and openness to deeper and more systemic solutions.

> "So, at least if you start monitoring your income instead you might have less pesticide expenditure, first of all. But many of the people that we interviewed have actually also, discovered other values like what it means to work in a group, because sometimes when you use alternative to pesticides, you have to coordinate it. It is not enough that it's only you who is fighting a pest, you have to do it as a group. So, then you that it gets a whole new development. So, you start working as a group with the other farms around you to manage a business jointly, and it makes you happier, makes you feel less alone and makes you maybe one of the farmers are even saying that he's much better able to plan as he has much more free time. So, you know, it's of course about income rather than activity, but it is also, about well-being for the farm, I would say." (CivilSoc1)

4.4. Economics

The economic implications of taking up alternative products and practices are an important limiting factor on farmers' ability and willingness to reduce reliance on chemical pesticides.

Unclear economic benefits & negative impacts on profitability. A central concern for farmers is that avoidance or reduction of PPPs does not have immediate or clear economic benefits, or they are concerned about their ability to continue having a profitable business. Many farmers responded that when deciding on a change in their practice they ask themselves 'what kind of effects will this have on profitability'. Others phrased it as questions of 'what the costs and benefits' are, 'what will it bring economically', or 'can I survive financially.' Many different aspects affect the economic outcome.

Conventional farmers in the case studies ranked **the risk of yield losses** as by far the most important reason for the current levels of applications of pesticides on their farms. In addition to a decrease in yield quantity, the negative impacts on yield quality are also a concern since this could lead to limited marketability due to the visual appearance of the product (CZ_H25), or a changed nutritional value in fodder production (SL07_Farm03_H13). The practitioners fear crop losses and the implicated income loss (PT_F4, AR_H54, HR). The financial concerns are especially strong in the first years of transitioning away from chemical pesticides.

Increased labour intensity. Alternative practices can imply additional effort and labour requirements (labour intensity) which is associated with higher costs, or the additional labour may also not be available regardless of the cost (ES, HR, AR, AR_H54, NL_H05). Some farmers also indicated that when evaluating a practice, the impact of timing and how the changed practice affects well-being is important.

The profitability can also be affected by the **higher costs for alternatives** and **required investments** compared to the status quo. For example, seeds of more robust or resistant varieties can be more expensive (NL). The cost of biological control is also seen to be higher than conventional pesticides (CH_F28). In the case of permanent crops, such as olives, changing varieties requires investment and a longer period before the crop becomes productive (IT). The cost of upfront investments is especially relevant for machinery and equipment and is perceived to be very high (CZ_H25, CH_F05, DK, CZ, HR). Mechanical weeders can be much more expensive than the application of PPPs. A Swiss farmer illustrated this point in the following way:

> "to replace the (synthetic) product when possible. But it is cheaper to spray 2 times herbicides (200 CHF) compared to buy a mechanical machine (20,000 CHF)" (CH_F10).

Machinery cost is especially relevant for the case of weed management since there are currently no available biocontrol alternatives to synthetic herbicides and farmers must rely on mechanical weeding and improved crop rotations as the main alternatives. Although machinery is being developed, the costs are often very high.

> "Weeding is a very labour-intensive process. But there is a renewed interest for weeding resulting in different new ways of eliminating weeds, from mechanical weeding, electric weeding, laser weeding, to the use of heat, water steam, etc. And in addition, there is the increasing trend of robotisation; in specific cultures and specific operations like crop care, robotics is gaining ground. The uptake is still very low. However, reduction of herbicides, could be an easier target for some cultures by means of new weeding methods." (Industr3)

In addition to weeding machinery, cost and affordability is also a concern for other equipment. For example, a Czech farmer referred to the costs of crop drying equipment as an alternative when desiccants are banned. Increased use of precision technologies for the application of pesticides requires often expensive equipment (DK). Changing crop rotations will also have implications for the harvesting of crops that have been added (AR).

Access to sufficient machinery can be improved if there are opportunities for sharing or renting equipment, however, these are not automatically available which presents a barrier (CH_30, CH_F28, CH_F10).

Limited or unavailable market outlet for alternative crops. The economic impacts can be positive even with increased costs, provided that the farmers can accrue a higher price or income from the sales of their outputs. If this is not the case, or if there is not a clear outlet for their products this is an important barrier. For cropping systems, taking up improved crop rotation is a cornerstone of IPM and the basis to reduce reliance on chemical pesticides includes the introduction of new crops and therefore the need to find a market outlet for these crops. However, practitioners face a difficult market avenue for the newly introduced crops, as well as a reduced output of the previously economically beneficial/profitable main crop (ES, AR). Linked to this is also the lack of processing capacity to be competitive on the international market (ES). The lack of potential customers caused by introducing new, unknown species leads to a worse market position for the farmer and the question of: "Who will buy it?" (CZ_H09).

Limited consumer awareness and excessive visual requirements. Answers in this category are related to a lack of consumer knowledge of production systems and a limited awareness about the health and environmental risks of pesticide application (HR, AR, CZ_H08), as well as excessive visual requirements of agricultural products by retailers and consumers. For instance, one farmer mentions that consumers are "too demanding in visual quality and availability of all products at any season [… and they] should consume seasonally

and accept that products don't look perfect" (CH_F07). Consumers are used to certain varieties, their taste and appearance and adapted varieties may have changed characteristics that are not accepted (CZ, ES). For example, one farmer stated: "The quality of the product is very important to sell. Supermarkets are not open yet to alternative species of apples." (CH_F23).

Increased production and financial risks. Reducing reliance on chemical PPPs and switching to alternatives carries with it risks. In the first instance this involves not knowing how certain or reliable alternative products or practices are compared to the current practice or product, and what negative impacts they may have on yield. Some alternatives also have not been tested extensively (CH_F10). There is a risk of not having a comparable protection from a pest or disease when trying a new product or practice. The perception of this risk is quite individual and can involve concerns around practicability and feasibility of new practices (IT_H_19, IT_H_03), or more broadly perception of the financial risks to the profitability of their business (HR_H02, CH_F10, CZ_H16).

Avoiding or reducing the use of PPPs poses a higher economic risk, especially for speciality crops with higher margins:

> "To grow wheat with less PPP, the risk of loss of yield is lower. Special culture loss of yield leads to more risk so the risk to lose income is higher. Also, the risk of losing income is higher because the specialty cultures are worth more money" (CH_F05).

Increased risk may also be associated with having to change the structure of the production.

> "Crop rotations are often optimized based on economics, the desire for forage production or the farmer's interest in special crops, etc. A cattle farm needs roughage and a high degree of self-sufficiency to be financially secure. For example, if cattle farms have to incorporate crops other than roughage into the crop rotation, this may result in roughage having to be purchased from others, which is an economic risk and may result in cost increases" (DK).

The risk and uncertainty are higher in the transition period (CH_F05, SP_F_12), which can present a strong deterrent if the risk is not buffered.

> "The first years can be very tough, making it difficult either to survive as an economic activity, or to persist in the path adopted (IT)."

> "And often, if you're trying biocontrol, you might give the biocontrol a Go on your worst field, with your worst yield, that nothing ever works in any way. So, you have to be honest … it takes two seasons, the first one because you've got to persuade someone to make a change and use it in the first place." (Industr4)

Managing risk is also linked to the overapplication of synthetic pesticides because farmers want to avoid any risks of crop failure, to the extent that they feel they can control this.

> "If they follow the calendar, applying the substance x mid-March and substance y at the beginning of April, then they know their costs and that everything will go well, regardless of whether there would have been the possibility of applying less of the substance. Farmers want certainty." (EC1)

A central problem is that the financial risks associated with transition are primarily borne by farmers and not shared with consumers or the government (CH_F22) and can also be seen to be too high for the economic benefit (CH_F05). One farmer, for example shared their experience in this way:

> "Migros approached me to join a sustainable programme and I would get additional 0.06 CHF/kg of apples. Of only 0.03 CHF/kg would go to me so this would give me a benefit of 3000 CHF but the investment to a mechanical de-weeder is 7800 CHF so there is too much risk and not enough financial incentive". (CH_F04)

Addressing this risk is an important challenge to address:

> "I'm an economist by training. And the first thing you learn is that farmers are very risk adverse. They're very afraid of taking a risk, taking a chance. And it is true sometimes when the road of travel means that you have to go out and invest in using alternative to pesticides. So, in many systems, you go from using pesticides and you start working with smaller companies for having other kind of products in which you're often buying packages. So, you buy a product, but you also buy the monitoring and then you are on a road to travel, where you don't know where you're going because what happens when you take away the very toxic pesticides and you introduce a non-chemical, sometimes other pests that you have no clue because you've killed it all before, they appear. So, you need to introduce another one and then another one. The road of travel seems very risky for maybe many farmers. Well, if you turn it around and you say: OK, you will do what we're asking you to do, and we will compensate you financially in case you have a loss. I think it is a very important step, you know, because we are in company to transition and the farmer feels less exposed, less afraid. But I also think that we have a certain tendency in always monitoring everything we do in Europe in terms of yield and productivity. And it is about time that we stop doing that. … And the thing is, when you start reducing pesticides, you find a lot, you might go down a bit in yield. But then you are compensated for other things." **(**CivilSoc1)

Another way of phrasing this is that there is an absence of a safe space for trial and error that would enable farmers to" fail without harming the company or family business" (AR_H59):

> "In a safe space. So, in other words, you kind of need to do it with a group of people and with the relevant knowledge in there, you've got to know that you're going to still get your money at the end of the day, if you're the person growing the crop." (Inddustr4)

Lack of economic certainty reinforcing poor generational renewal. The issue of slow generational renewal and the older age of farmers was brought up as a barrier in several countries (HR, SI, IT, NL). As an example of an interconnected and at least partially self-reinforcing feedback loop, generational renewal means that farmers have less knowledge and expertise on biological alternatives and other agronomic alternatives, since they were educated and have been over many years supported by advice favouring chemical protection. On the other hand, economic uncertainties and risks in agriculture as an occupation means that this further limits younger farmers entering agriculture and this further slows down generational renewal. One industry stakeholder illustrated this point with the following example:

> "A clear issue is the lack of economic certainty for farmers. As a result, the average age of farmers will keep increasing and more and more young, smart, and motivated people, will leave the business or will not start a farm business. 20 years ago, as a bioengineer in research, many of my fellow PhD colleagues came from farms. Many of these smart farmer sons, went for bioengineering with the idea to take over the farm and bring in novel ideas. Even then many of them were questioning if they should engage in the family farm as the money is simply not there.' So, that needs to be targeted somehow. It should be tackled either directly within the farm business on labour cost, the cost of land, size of farms, or more money should be made available for new services. If everything becomes one big garden for the citizens, without consideration of the economic reality of the rural community, you should at least pay them more for delivering on the services of placing hedges, of set-aside land, for the increased risk from lowering pesticide use etc." (Industr3)

The underlying economic model and market conditions. Several stakeholders and farmers pointed to the underlying problems and lock-in mechanisms in the existing economic model and market conditions, with reliance on exports (DK), high concentrations in agricultural supply industry (ES), the power of trade and retailers to set standards and lower prices (SI), situation of unfair competition which is not being regulated sufficiently (NL), as well as bank and loans systems which favour chemical over non-chemical plant protection (NL).

> "The whole war in Ukraine shows how dangerous it is to be dependent on export markets. I mean, you know, the same happened when the Danes, they were very dependent on selling feta (cheese) to the Arabic world until we had we had a blockage. Do you remember that? So, there was a guy who was making fun of Mohammad, it

was a Danish newspaper, and from one day to another, there was a total loss." (CivilSoc1)

"The EU's high standard is based on cheap food, imports of cheap products from third countries, and non-existent money (leasing, subsidies, loans), all these at the farmer's expense." (SI)

"Reductionist food systems that do not take these varieties into account, as in the case of flour. No one is going to choose to feed on something they don't know exists." (AR)

"We know this is not an easy process, many farmers are locked in their solutions, certain solutions having been promoted for decades by pesticide industry. It takes time. But the urgency is increasing every day and we need to start taking action. Implementing legislation is key, supporting farmers in their efforts is important. This means also to discuss power of retailers, big chains who dictate prices. We need to look at the whole value chain. The fair food chain initiative from the Commission is important as an entry point. It's a very important piece." (Industr2)

Integrated supply chains and the requirements to deliver 'just in time' is also linked to longer storage of crops, which may be incompatible with reducing the use of certain substances (AR, SI), or retailers setting quality standards which are not always possible to meet with organic methods (NL). Workshop participants also point out the underlying low willingness to pay for or also lacking affordability of food, and the resulting limited demand for better quality and sustainable food (ES, CZ, SI).

4.5. Knowledge and awareness

Lack of farmers' knowledge and skills. The lack of knowledge and skills is an important barrier across all farming systems. Alternative practices increase complexity as well as uncertainty compared to individual synthetic plant protection products, as discussed above. Alternatives to chemical pesticides require extensive knowledge of the specificities of each crop, the available and most relevant alternatives for their farm (whether product, agronomic practices, systemic approaches), and various strategies for how to ensure that the risk to plant health is minimized. Higher uncertainty of alternatives means that higher levels of knowledge are needed to reduce the pest and disease risk (ES).

The knowledge and skill barriers are emphasized by farmers, stakeholders at national and EU level (e.g., ES, IT, SI, HR, CZ, PT_F8; IT_H_07, CH_FO7) in relation to alternative plant protection practices and products, including biocontrol and crop rotation, prevention and now technologies (ES, HR, AR, SI). Lack of knowledge is relevant also in the other direction: as a

basis to only make applications where necessary and "lack of knowledge of the use of pesticides means that applications are made unnecessarily" (AR_H61). Farmers phrased the knowledge need also in relation to time: "If I start with new practices, how long will it take me to learn? ", or how much "time for learning" will be needed (CH_30).

Knowledge, if available and used, can buffer against the risk of loss of yield during the transition period. For example, one farmer stated that there is "an absolute ignorance" and missing skills to achieve acceptable yields with conservation agriculture (AR_H70).

The slow uptake of highly technical skills is also linked to slow generational renewal in the farming community (HR, IT, NL):

> "The poor knowledge of more sustainable alternatives and the general scepticism from most workers involved in farming. This is even more true given the old age of farmers, and the limited generational turnover in the sector. It is recognized that the transition is not a simple adoption of different products or practices, but it must be first a "mental" step, an overall acceptance of a totally different framework, that is probably impossible until a new generation of farmers is active." (IT)

Limited awareness of the impact of chemical pesticides on health. An important barrier is also the limited awareness of the effects on health exposure to pesticides, both in the farming community and more broadly. Farmers perceive the lack of information about the long-term effects of PPP and of new practices for human health as a barrier to the reduction of chemical pesticide use. Practitioners for instance stress the need for a "greater diffusion of the damage pesticides produce on health" (AR_H69) and "greater sensitivity to human health" (IT_H_07). Moreover, national workshop participants indicate that reduced pesticide application is limited by the poor understanding of stakeholders of the effects on health of the exposure to pesticides because:

> "First, it is difficult to identify pathologies directly linkable to these exposures, so their epidemiological relevance might be highly underestimated; then, there are few data based on comparative epidemiological studies on the actual benefits of organic farming on farmers/workers health, due to the high cost of data collection, and stakeholders doubt that experimental studies can be exhaustive in substituting them." (IT).

> "More generally, we need more pressure from consumers. They don't want pesticides in products and playgrounds. But they need to make the link to the quality of food they purchase – they need a better understanding of what they can do to reduce pesticide use." (Industr2)

National stakeholders also mentioned that people are scared about the use of GMOs (CZ) and pheromones (SI) in agriculture as alternatives to pesticides.

Limited environmental awareness and concerns about environmental impacts. According to interviewed farmers the reduction of pesticides is associated with lacking environmental "conviction" (CH_F23) and environmental "sensitivity" (IT_H_07). In particular, farmers mention that the reduction of pesticide use is limited by a lack of concern for specific environmental impacts, such as the conservation of "ecosystems" (AR_H55), "biodiversity" (AR_H61), "nature" (CH_F22), "sustainability" (AR_H58), "reduced carbon footprint" (AR_H53), "methane emissions" (DK005), "climate change" (FR_EF06), or "pollution" (AR_H53). Insights from the national workshop participants reinforce the perception that a lack of awareness and interest in environmental impacts are barriers to the reduction of pesticide applications (HR, AR, CH, CZ). The limited awareness permeates through all the levels, including EU level:

> "Something I have been told by other actors that might be more open to discussions like, is that this is a complex issue. And they think that there is a lot of information that is lacking. I don't know, to what extent they are informed about everything. And this is also regarding farmers in the field. So, I am very surprised because sometimes I've talked about this with some political actors. I'm not saying the actors that are actively boycotting and have been very vocal against, but sometimes I've spoken with political actors that are surprised by some facts because they don't know them. For example, they don't know that pesticides can be spread by the wind and can reach some distances. I've been presented with arguments like for example: « Okay, now we start to this thing, start considering that there's a health problem linked to that ». And then they talk about: « okay, so then the situation, the solution would be to reduce the bad pesticides, which are the ones that cause cancers, but we don't need to reduce the others ». So, they don't seem to know, of the toxic cocktails that are not included in the risk assessment, they don't seem to know about accumulation, and they don't seem to know about different ways of being exposed to pesticides. So, for example, there seems to be an awareness about pesticides, causing problems for farmers, but they don't seem to be that much of an awareness about the problems for people living near areas, or for children, or for other effects on pregnant women, etc. So, this information seems to be lacking." (CivilSoc4)

Farmers that have been interviewed are also concerned about the environmental impact of new products and techniques. They are worried to introduce more risks and damage to the environment. One farmer asks: "What would the use be for the environment - would it lead to environmental benefits?" (CH_F26). A few practitioners state that they specifically do not perceive any risks for the environment by synthetic PPP application.

Lacking advisory support and demonstration. Insufficient advisory support from experts, advisors, peers, and basic education are highlighted as barriers to reduced reliance on chemical pesticides. Knowledge transfer and exchange among stakeholders is limited (CH, HR).

There is a lack of consulting services of companies dealing with PPPs in organic farming (CZ_H21), absence of adequate training on biocontrol options more broadly, as well as a lack of specific integrated crop management plans adapted to crops and pest (CH, EC1, AR).

National workshop participants emphasise that advisory services are often provided by private agro-chemical companies, where the focus is exclusively on the sale of products without environmental considerations, and farmers do not get enough access to independent advice (HR, NL, CZ, AR_H70). They also underline the lack of professional advisers trained by universities and the need for more and better interaction between producers and agricultural engineers (AR).

Furthermore, farmers highlight the barrier that references and contextualisation from peer groups about new practices and products are non-existent or limited and more demonstration of alternatives is needed (PT_F7, (AR_H68).

The importance of peer-to-peer demonstration and direct advice for farmers is also important because of underlying distrust that farmers' have towards top-down approaches and regulatory restrictions. The following two quotes from a farmers' organisation and civil society are illustrative in this regard:

> "It is always easy to talk about money and the economic side of things, but in this case is a crucial part of the equation. Of course, we need investments, and they are a fundamental part of any productive system, but always linked with the social side of farming. Many people do not understand that for a farmer, their farms are their lives. It's not just the work or the "business". It's their way of living and they are going to protect that whatever happens until the last consequences. On the other hand, they cannot be felt alone and just imposed by rules made by people that never set foot on a farm before". (FarmOrg2)

> "Yes. And something else I've been told is that farmers can be sceptical about things that are coming from the European Union. And that was very interesting, because there's this report from the Court of Auditors, saying that this rule had not been applied, and there are many problems etc. And I've been told "Yeah. But that's like, you know, they don't know what's going on in the field" which I mean, I can't imagine that if the Court of Auditors is doing a report, that is not it is well done enough to take into account of what's actually going on. I've been told, again, by somebody working with a farming community that what they trust is what another farmer is doing. If they see that another farmer is doing that,

and they see the results, then they believe and then they would go into doing that (i.e., IPM)." (CivilSoc4)

Agricultural education does not support non-chemical approaches. Furthermore, farmers and national & EU stakeholders refer to a lack of basic training and education that farmers receive about non-chemical alternatives, how to farm without the use of PPPs and on the risks arising from excessive use of harmful pesticides (CH, HR, IT, NL, CZ).

"The basic training is focused on the use of PPP. To learn about alternatives, you must attend extra courses, which you have to finance yourself. In my view it would make more sense to focus the basic training on all possible alternatives without the use of PPPs. Farmers that would want to learn about PPP use should be attending extra workshops and not the other way around." (CH_F22)

"Organic farming and agroecological practice have been criticized for lower yields. One can counter a lot of these negative effects. But it requires high skills, which not all farmers have. Apparently, our education system is also not fit to equip farmers with the necessary skills." (EC1)

4.6. Policy

Limited financial incentives and support. Given the barriers examined earlier in the report, it is not surprising that farmers point to financial support and incentives as a key need and many of them state explicitly that the existing financial support is not sufficient (e.g., CZ_H03, AR_H68, CH_F22) and should be increased. Many farmers also stated that the issue of availability of additional financial support is front and centre for them when deciding on changes in their production system.

"Main barrier is that farmers are not compensated for the additional work/service. Because what is requested with the pesticide reduction targets is to reduce pesticides for the effect it has on waterways, on the biodiversity, etc, That's an additional service which is to the benefit of the society but there is no certainty that the benefits will flow back to the farmers as a return of investment, at least not directly. And if this is not implemented outside of the EU, there is unfair competition, because EU farmers produce products that are traded on the global market. So how do you compensate for that? How do you compensate them adequately for being a provider of ecological services?" (Industr3)

The cost increase is particularly problematic, when farmers cannot because of changes in practice accrue a higher value for their output, for example, when a 'market with a differential price for products with less (or no) use of agrochemicals' is not available (AR_H66). Whereas organic farmers have the possibility to get a higher price, conventional farmers have no incentive to reduce pesticide applications via a rise in price (NL). Alternatively, retailers might

set higher standards for minimum residue levels (Industr5), but this does not automatically result in a higher price for their produce.

Financial support can be in the form of payments for conversion to organic farming or environmentally friendly practices (HR, PT_F11 PT_F10, NL_H07), or some farmers also refer to offsetting the costs of increased prices for biocontrol compared to chemical products. Some farmers also called for improved support for investments in technologies:

> "We lack support (e.g., faster depreciation/write-offs, subsidies, etc.) from the state to alternative methods to pesticides in conventional agriculture (robotic weeders, bar harrows, crop drying equipment when banning desiccants, etc.)." (CZ_H07)

Even when financial help is available, it does not automatically cover all the costs related to switching to using fewer PPPs, especially when upfront investments are needed (CH_F04). The increased cost is also stated by some to be problematic when considering switching to organic farming: "To switch to Bio you would need a lot of changes, machines and manpower, which is not fully covered" (CH_F07).

More broadly, the lack of sufficient incentives for agro-ecological practices which are not strictly within the organic farming definition were raised by EU stakeholders:

> "We do not have good incentive mechanisms for agroecology that go beyond organic farming. Now that is certainly a shortcoming. Member states would really have to dig into this and provide dedicated support tools under the CAP, either via eco schemes or second pillar measures. But this is more difficult to regulate, essentially because the local conditions influence the feasibility of different options. We really believe that member states should see what they can do in terms of support measures to achieve pesticide reduction targets." (EC1)

Some also referred to **negative incentives** provided by policy, such as 'excessive support of collective large-scale farming' (CZ_H18) or that investments in machinery for PPP application should not be supported but instead should focus on innovations and labour in mechanical weeding (NL_H07). In terms of alternative policy instruments, one farmer pointed to the need to have a 'zero tax rate for ecological products for plant protection' (HR_H19).

Political barriers refer to the current position of key interest groups regarding alternatives to pesticides for food production, while political lock-in mechanisms include, in particular, the current distribution of political power and the persistence of power relations that favour the status quo.

The use of food security and feeding the world narrative following the Ukraine War as an argument to delay concrete action. Several EU level stakeholders, representatives of

commercial interests, stated that there is a potentially negative impact on food security from setting the targets on reducing chemical pesticides.

> "The situation that we have right now, as you mentioned, the high inflation, the high prices for the consumers, for sure will not favour the implementation of the ongoing legislative proposals on the ground, at least until the socio-political situation in Europe stabilises. The farmers will be keen to move forward, but having the right timing and means in place. On the other hand, it is true that if consumers will look at their pockets first, at the time of buying, they will not be willing to pay more for their food. Anyway, even in times of necessity, you can try to educate them on sustainable practices, why not. In any case, they will think with their heads and not their hearts most of the time, as you and I do as consumers. Maybe three years or four years ago, it was different. Could have been different before the COVID, before the invasion of Ukraine, but right now, food security is a matter of state." (FarmOrg2)

In the context of the political discussions around the Commission Proposal for the Sustainable Use Regulation, the narrative that 'reducing chemical pesticide use threatens food security' has been strongly amplified also in the discussions in the European Parliament and the European Council since the publication of the SUR in June 2022 (Dahm, 2022; Foote, 2022). The shift towards dominance of food security narratives as the driver of political negotiations was illustrated by Civil Society stakeholders in the following way:

> "So actually, I don't know if you realise but after the pandemic, we came as a better society, really, we were taking care of the locals, we were consuming, taking care of our health, we were consuming local products that were fair, trying to help our networks and eating more organic, doing more sports, paying attention to our health and to the health of who were around us. And that was great. Because this is really the logic now to act locally. And then this is really the logic to put health in front of anything else. So that's what we were all here for, I guess. So, in this context, the Green Deal, and the CAP and all the discussions on F2F and everything, it was going great. It was going just in the way they must go. And then we have the Ukraine war. And then suddenly, there was a very big interest to re-structure the narrative. And to come back to a narrative of war, war is devastation, and devastation is hunger. We need to produce no matter how, we don't care about health, all we want to do is survive. So, we have changed the whole logic. And this narrative of war has come and completely permeated decision-making. And now we are in is in a logic of war. And in the logic of where we don't care about sustainability, we just want to eat. We will care later for the water, for the soil and everything." (CivilSoc2)

> "It's like we're back in the 90s impulses, you know, we've moved away from it and now it's all back and it's very, very strange. Everybody, even the chemical companies stopped talking about feeding the world, and now we're back to the feeding-the-world-narrative." (CivilSoc1)

The Food Security narratives are questioned both by a Commission representative and Civil Society stakeholders. However, they become amplified due to the existing power relations and resource capacities despite calls by the scientific community to the contrary, i.e., that continued reliance on chemical pesticides threatens food security in the mid-to long term (Candel, 2022; IPES Food, 2016; Pe'er et al., 2022).

> "First to remark on your previous impression of food security versus the reduction of pesticides. I think for the EU, or even Europe in general, we should not speak of food security, but food affordability probably. This seems a bit a different perspective. Global worries, of course, there is a question of food security, but then it's the question if we should take the international trade in. The discussion in this case on the conflict should be the topic. I don't know if we want to go into this discussion now. But if we speak of the EU, there is a problem of food affordability because the cost of production will we rise. On a foresight there will be an impact on the cost, on the prices for the consumers. I would say that certain basic elements of the discussion of the debate for the EU should be how to do to address the rising costs of maybe also imported products? On top of that, of course, for the climate change, it does not help. And the trend was not only with Ukraine, but it's also now a structural trend that the cost of production will rise and fall on any imported products. So how to address that with a CAP?" (EC2)

> "Yes, but you know, it is not because we are producing more in the EU that would stop world hunger. And if you try to look at our level of productivity and self-sufficiency, I think we have a self-sufficiency rate in Europe, 120 percent. And, you know, it's not because our wheat should not go to the countries in hunger, they should not be eating necessarily wheat. They should be eating other things. So, I think it is not very well used. I mean, it is not an argument. It's not because we will be … of course, we must help, but we have to help beating world hunger by helping people where they are. I mean, we must do a complete … it's not because we produce more than we will stop having any problems in the world... But I also, think that we still have the Common Agricultural Policy of spending 60 billion every year. So, at least we should also, be thinking about our long-term food security. And if you keep on treating our soil and biodiversity the way we would now with our kids and our grandkids will probably not be having a lot to eat because we are not treating it very well. So, I think, we will not solve the problem of world hunger by producing

more. Well, we might solve it by producing better. We might help where it's needed to be helped." (CivilSoc1)

Agricultural exceptionalism and power relations in Brussels. Limited research and evidence on alternatives and exploration of new economic models that diverge from integrated supply chain approaches means that the dominant narratives are more difficult to challenge because of the ongoing dominance of agricultural stakeholders as influential stakeholders in agricultural policy and the underlying power relations in Brussels:

"So, I live in a Brussels world and the chemical companies, they go to see everybody every day. OK, so, if you know, if the chemical companies talking to all the civil services, it's only so, there are very few who doubt that the narrative is no longer right because there's not so many people who are showing another model is possible then. So, and it is true, especially in the central and eastern European countries. You know, organic has not been developed so, much. So, there's not even a model." (CivilSoc1)

In the case study sites, the lobbying of agrochemical companies and farmers' associations was identified as a barrier to change (ES, NL).

Compartmentalized thinking and lacking coherence in policy to support systemic transition policy. Another limitation that was raised is the short-term, compartmentalized thinking and fragmented policy-making that does not enable the support for longer term changes.

"I think, you know, that European Commission decided now to not apply the greening measures, so, for 2022 to feed the world, even though we look at marginal land very often, which you know, and now they are also, just making a proposal that they have agreed that we should also, have a derogation for 2023. So, we keep on pushing the transition, you know, rather than started thinking longer term, which is a big pity in Brussels, we think always short-term we are not able to govern longer-term." (CivilSoc1)

Given the political landscape and the vested interests in the status quo, **policy making results in piecemeal and incremental patchy policy fixes**, which restrict farmers in their current practices without offering coherent support for moving to alternative models for the production systems:

"... the worst crop is sugar beet On the one hand, the bulk of the emergency authorizations that are granted for application of substances no longer approved at the EU level are used on sugar beet. On the other hand, this isa crop which is supported under the CAP. I think 11 or 12 member states grant coupled payments for the cultivation of sugar with a total of 180 million euros in 2021. Farmers get these 180 million specifically for growing sugar beet

and not something else. So, you have a double impact of an enormous economic cost and environmental cost attached to it because without the neonicotinoids, apparently in many regions farmers say that they cannot grow sugar beets." (EC1)

"At the moment, there is no incentive for concentrating on those crops that would require less input and less protection. On the other hand, it is seen as favourable that farmers have the free choice and do not have to take into account the environmental impact that this has on biodiversity or on human health. Ideally, in the future that would be better taken into account. It would require a feedback mechanism where the farmer is incentivized for not using plant protection products and in particular for not using the particular dangerous substances. Now, if farmers say "we have a problem with aphids on sugar beet, they are transferring viruses. If I don't spray, I can't grow this crop.", the response is not "grow something else". Instead, the response is "OK, we have to help you and we have to get neonicotinoids back on the market". Member states are still very generously providing the approval or the authorization for the emergency authorizations. We cannot change that. It is a widespread practice, used increasingly because we are phasing out substances and it, of course, . undermines the phasing out of dangerous substances in practice. This needs to change by ensuring a greater coherence, with environmental authorities and agricultural authorities working better together in the decision of whether a certain pest protection product can be made available or not." (EC1)

Improved cooperation between policymakers, researchers and growers is needed to support the replacement of substances which are being phased out without reverting to incoherent policy decisions.

This example also illustrates the pesticide lock-in. The high dependence on specific active substances aligns with other processes and mechanisms (emergency authorisations, limited openness to non-chemical alternatives, investments in mechanisation for pesticide applications etc) to limit the possibility of substantial change, such as a shift to growing other crops, biocontrol alternatives (because they might not be available) or the redesign of farming systems (because, for example, there is not sufficient support for whole system transition).

4.7. Regulatory

There are several barriers and lock-in mechanisms related to regulatory processes.

Differential regulations and availability of synthetic pesticides in an open market. Farmers and stakeholders in the SPRINT CSSs referred to the differential regulations and availability of products in an open market. The absence of a non-unified regulation and approval of active substances in the context of an open market means that prohibition in one

country leads to the import of harvest from another country. Similarly, global imports exacerbate the problem with increasing risk of exposure to new pests. For example, one Swiss farmer (CH_F07 conv) gave the example of an active substance being removed from the market in Switzerland, with no alternative synthetic active substance to replace it. This has led to the situation where due to the absence of an effective treatment against worms, the plums grown by the farmers could not meet the high-quality standards and consumer preferences, which prevented them from being sold. Consequently, plums were imported from Germany where the same active substance banned in Switzerland was still available (CH). Farmers believe that this is a significant problem in Switzerland.

The restriction of active substances is not a barrier to reducing reliance on chemical pesticides, as one could argue that it can further encourage farmers to look to other non-chemical alternatives. However, implementing restrictions without support (incentives, knowledge, improved outlet for products etc) to facilitate the transition to non-chemical alternatives, can create an unfair disadvantage for farmers in different countries. This is especially true in smaller markets, where there are fewer alternative chemical products available, either because of restricted capacities to approve the products (SI, CR), or because industry may be reluctant to register new products due to the small market size and lengthy approval process, or due to stricter legislative situations and restrictions (CZ_H11, DK). Such scenarios could potentially be linked to increased risk of pest resistance. This point was raised by stakeholders in Slovenia and Denmark:

> "The concept of candidates for substitution is difficult especially in Denmark where we have relatively few active substances approved compared to the other EU countries. This is because the "few" active substances we have that are approved often are essential in terms of counteracting the development of resistance to the active substances that can be approved in DK (where we have national requirements in terms of the use of active substances, persistence in soil, as well as the risk of washing out to groundwater, both for active substances and metabolites)." (DK)

> "The lack of a variety of active substances in Slovenia may cause resistance of harmful organisms to the active substances of existing available pesticides on the market." (SI)

Complicated and lengthy authorisation process for new substances. Both EU level stakeholders, national stakeholders and farmers referred to the complicated and lengthy authorisation process as a limitation to getting new alternative, whether lower hazard or biocontrol, substances on the market.

> "In general, the authorization process is highly criticized. It's quite heavy. It's quite thorough and time-consuming. Of course, with a goal to assure that the substances are thoroughly checked and controlled. " (EC2)

This lengthy process is on the one hand linked to the detailed requirements to get a product authorised, and on the other hand also to the capacity needed to assess and process these requirements.

> "... it has inflated in the last 15 years. We've come from maybe 200 pages of guidance, cumulated being on the water, health, soil, earth, you name it, all the different things. And now we might be at about 1000 to 2000 pages. So, if you're a new company, and you want to enter the EU, it's a steep curve, just in terms of learning things you need to do. That's one part. Another part would be requirements. Sometimes requirements are clear. Fine, we know what to provide in terms of data for safety. But sometimes for innovation, and I'm thinking here about technologies, we are not so familiar with in Europe yet, linked to biopesticides like peptides, and RNA-based products, or neuropeptides, antibodies based – very specific types of biopesticides. The current guidelines will not really fit, because they were designed initially for conventional chemistry. There are specific ones done for microorganisms by the Commission that are very good that go in the right direction. But we would like this kind of thing for other types of technologies. Because today as an applicant, you wouldn't see exactly what you would need to provide in your lab or on your field when testing. It doesn't work the same way. So those technical adaptations would be necessary to help streamline the evaluation. So that's more on the science bit. In the process, we see a bottleneck with resources. As I mentioned, member states' evaluation of drafting assessment reports, and the preparation of those reports can take time. In some countries, they have big teams in others, it's just two to three persons making the checks. And then, in the end, it subjects everything to peer review, but still a capacity issue. We know we are doing a mapping and for some countries, if you have a brand-new solution and you want to apply, some will say: yes, don't come to us before two and a half years now to submit. Because our pipeline is already full. They are already completely booked, workload-wise. So, this kind of thing about resources is not helping. We know the commission is trying to unlock some funds that could help member states to increase some capacities, that would be a plus. But that would not solve everything." (Industr1)

Slow and undifferentiated registration process for biocontrol alternatives. The risk assessment process for biocontrol is currently not differentiated from that for synthetic and chemical pesticides, which slows down the registration process for biocontrol. As explained by one industry representative:

> "The mode of action is different. The way it works is different, therefore, your risk assessment should be different." (Industr4)

However, stakeholders appear to agree that setting up a completely different system for biocontrol at this point would not be feasible (Industr4).
The underlying problem is a general lack of expertise and capacity available for the registration of biocontrol products, as not enough countries in Europe have the capacity to assess microbiological active substances.

> "The modifications would be to address data requirements, which we are making proposals on. We've shared some of those with the Commission. The microbials, the Commission has looked at that then are looking at semiochemicals and natural substances to try and improve the data requirements, so the data requirements are-more appropriate. But that's only a part of the story to get biocontrol products onto the market within 10 years, when two, or three years should be feasible. And so having enough experts in the authorities, who can evaluate biocontrol, if you've only ever looked at the chemical, then the mode of action of biocontrol is so different, you know, the assessment needs to be treated differently. So that's why there is the need for experts both across the Commission, EFSA, particularly, and the Member States." (Industr4)

> "We work closely with the industry, but we are all aware that there's still a lot of research to be done. That there is a bit of a lack of expertise in the institutions and agencies about this on their teams to be created to specifically assess, to facilitate this fast-track system that I mentioned. For sure, we hope that this will be created soon. We know that the Commission answers as fast as they can on this and I guess it is something that will take time, because proper research takes time. " (FarmOrg2)

Poor implementation of existing legislation. Several stakeholders pointed to the poor implementation of regulations that already exist. Farmers made references, for example, to the "lack of controls and the lack of knowledge of the use of pesticides means that applications are made unnecessarily" (AR_H61), "legal requirements" are needed to improve the situation (CH_F04), and that "restriction of products that form a risk by authorities" should be improved (CH_F05). Stakeholders stressed that the current situation is largely also an implementation problem, in particular the Sustainable Use Directive, which has been in place since 2009 has been widely criticized for its ineffectiveness to deliver on pesticide reductions (see also Helepciuc & Todor, 2021):

> "From a political point of view, we are in a situation where we have a proposal, which largely is an implementation problem of the current Sustainable Use Directive. And with regards

to methods, the Sustainable Use Directive says that integrated pest management is mandatory, and it has been mandatory since 2014. And integrated pest management means that you only apply synthetic pesticides as the very last resort. There has been an enormous amount of implementation problems, which is why the commission has put this proposal on the table. - CivilSoc4

"Without stringent legislation things don't move at all or move too slowly. We need legislation. This also concerns the implementation of existing legislation. There are already requirements in place to withdraw a product if it leads to problems. But today this is not happening. And we need an ambitious SUR, to trigger real changes in farming practices." – Industr2

An important aspect that limits the effectiveness of currently available legislation is the **overuse of emergency authorisations.** There are some substances that do not get reapproved after their approval period expires due to additional scientific insights and due to changes in the risk assessment process. For example, the risk assessment of plant protection products on bees is undergoing changes, with the revised EFSA guidance on the risk assessment of plant protection products on bees (honeybees, bumblebees, and solitary bees) expected to be published in May 2023.[2] By better accounting for effects on non-target organisms, this can lead to a situation where substances with strong adverse effects would less likely be re(approved). As the availability of approved active substances is restricted, this can lead to the increased use of emergency authorisations:

"From the normal reapproval we, ideally, the phase out because some substances are no longer approved. However, the result we see is an increasing and very high number of emergency authorisations, which is very worrying. The number one offer of emergency use authorization is a neonicotinoid. The worst substances are still re-approved because farmers believe that they lack alternatives. By just improving on the risk assessment, we are not making much progress if we do not at the same time get alternatives to the substance on the market. That is where we really need to make progress." (EC1)

At the same time, adjusted risk assessments can also lead to restrictions on the conditions of use that potentially makes the use of active substances in practice less feasible. An example given by a Commission stakeholder is that of cypermethrin, from a group of pyrethroids:

"They are extremely poisonous to insects, and cypermethrin was reapproved last year. EFSA undertook a risk assessment reviewing the available literature and concluded that the presence of contamination of a level of 5.8 (five point eight) mg per hectare should not be exceeded in neighbouring fields. This is very, very difficult to achieve because it is so toxic,

[2] https://www.efsa.europa.eu/en/topics/topic/pesticides-and-bees-guidance-review

which means that you would need to have an isolation distance of 270 (two hundred seventy) meters around a potato field. One product on the market in Germany applies a zero-metre isolation distance to hedges and to organic fields. . The substance has now been reapproved under the condition that Member States will adopt measures not to exceed 5.8 (five point eight) mg/ha in the neighbouring fields. I do know how they will do it. This is practically impossible." (EC1)

4.8. Cognitive

Cognitive barriers relate to current perceptions of farmers regarding the benefits and costs of chemical versus non-chemical plant protection, as well as the underlying mindsets and routines that "blind" actors to the possibilities or benefits of alternatives such as the dominant narratives on what farming is about and what for.

There is dominant **reliance on the singular metric of success, the yields, and single off / seasonal yields**.

"And there's the big elephant in the room, which is that for farmers, you know, yields are like the magic word. And then they get, you know, very happy with it (high yields). And these are being taught by somebody working for an Agriculture Organisation. Yield is the magic word (for them), and productivity (not biodiversity)." (CivilSoc4)

The reliance on yields is linked to the emphasis given to yields in both research and knowledge systems, whereby gross-yield calculations are likely to dominate over the estimates of what makes for an economic-optimum (see also Vanloqueren & Baret, 2008).

The change from reliance on individual products which have a specific way of working to other products, such as biological control, or to changes in farming practices requires a significant shift also in the way farmers think about what effective control is and what is a successful way of farming, which is challenging because it is closely linked to economic risks. Without addressing both at the same time, change is difficult.

"With ferric phosphate, it doesn't harm birds but what happens is that the slugs go underground to die. So, the farmers said "I do not see any dead slugs. Does it work, I cannot see anything", whereas the question is 'Is your crop eaten?" "Well, no, but it can't possibly work." You know, it took 10 years for the market for this product to develop but it is now a leading biocontrol in arable partly because it's effective and now other products are withdrawn, so there isn't anything else. When we consider that this is an easy one, because you haven't got to change much, you just put one different product in the tank. Even in this case the concerns were many, "But I can't see slugs dying, it is the wrong colour", and that's an easy switch. So, changing people's practices and behaviour is difficult.

> And, because it's risky, you have one profit chance a year as a farmer, maybe two, if you're in a double cropping scenario, of course you're going to be worried. I get it." (Industr4)

The shift towards agro-ecological practices and biocontrol **requires a different perception of the value of nature and its benefits for farming:**

> "So, what we have been telling them is like: No, don't leave 10% for nature. Use 100% of your land for nature, and production. Like, there is another way of producing that doesn't need to be so harmful to nature, and it can be productive. A lot of the proposals that we have been putting forward in the agricultural model were in this direction. And we were fighting a lot for non-productive areas, a very appealing name for a producer to have a non-production area, when and on top of that when it is not a non-production area. Because you can have their capital for nature in pest control or pollination. And even you can have trees and produce something else. Like you can have chestnuts, you can produce. But the way the whole system is set up. It just creates that we are not going forward. And so, I think we lost an opportunity. And the member states work very hard to completely destroy the CAP." (CivilSoc2)

It also means that there is an underlying **need to shift from short-term profitability focus to more longer-term view of farm sustainability**. The first step in this direction is also cognitive, there must be a willingness and openness, followed by an opportunity to consider a longer-term perspective:

> "We really must shift from the short-term profitability thinking, focusing on getting out of the maximum today and not thinking about losing soil carbon, which in turn means a loss of water retention capacity and reducing nutrient retention in the context of climate change. If we invest into soil fertility via crop rotation, by accepting maybe some opportunity costs in terms of not only growing the crops that are giving the highest economic yields, but by applying more long-term thinking, we will certainly improve the situation in the long term." (EC1)

The shift also requires a degree of **openness to try things out**, which is often lacking. In addition to having financial safety to do it and advisory support, it also requires a different and open mindset:

> "Yes, very slow. I was talking to somebody the other day, and he said "Well, didn't you do IPM when you were at university?", I said "Sure. I did IPM." He said "So can you imagine all those other people that did IPM at university with you? And they've now been working in a distributor for as long as you've been working in the industry and imagine changing

them on farm?" I said, "yeah, they're tough nuts to crack" You know, the people that did the same education as you, but they've got a closed mindset about it." (Industry4)

The open mindset, however, is important also at the level of policymaking.

"Change is always hard. Change always puts you in an uncomfortable situation. And not everybody deals with change in the same way, let's say. Especially the right wing is not very good with change. Conservative people, it's conservative. They don't deal well with change. And they can agree they could eventually get to change, but it takes longer. They need to be convinced or they need to be pushed. And it takes much, they are not early adopters. Then there is a lot of economic interest in the model not changing, of course. And then you realise all people that are closer to being liberalists, they don't want to change either, because it changes the economic strengths, let's say, so then that that is a limitation. Then afterwards, some people were just against everything. I don't know. I mean, there is a lot of nationalism. And this is what we experienced in the parliament (...) sometimes you go to these kinds of forums, and it doesn't matter how much data you are you bring from how many field observations. Also: How good are the measures? Are the measures that you propose how well structured and intelligently created they are, the people just don't want to listen to you, because you are not in their line." (CivilSoc2)

5. Conclusions

In this report, we have drawn on mixed qualitative methods to explore the different dimensions of the pesticide lock-in situation, i.e., the barriers and the underlying mechanisms that are holding back the transition towards sustainable plant protection. Combining a literature review, EU level stakeholder interviews, and workshops and farmers' questionnaires in SPRINT case study sites, we identified a range of barriers and lock-in mechanisms.

The results outlined in the previous chapter confirm that progress towards reduced reliance and dependence on synthetic chemical pesticides is very much hindered by the pesticide lock-in situation. There are many interrelated processes and more direct barriers that mutually reinforce each other to limit or substantially slow down the possibility of a wider transition away from reliance on synthetic pesticides: i.e. 'the build-up of numerous negative factors creates a lock-in situation' (Vanloqueren and Baret 2008).

We have identified the key lock-in mechanisms and barriers corresponding to the following dimensions: 1) agronomy & research, 2) economics, 3) knowledge, 4) policy, 5) regulation, and 6) cognitive dimensions (see Figure 6 for an overview).

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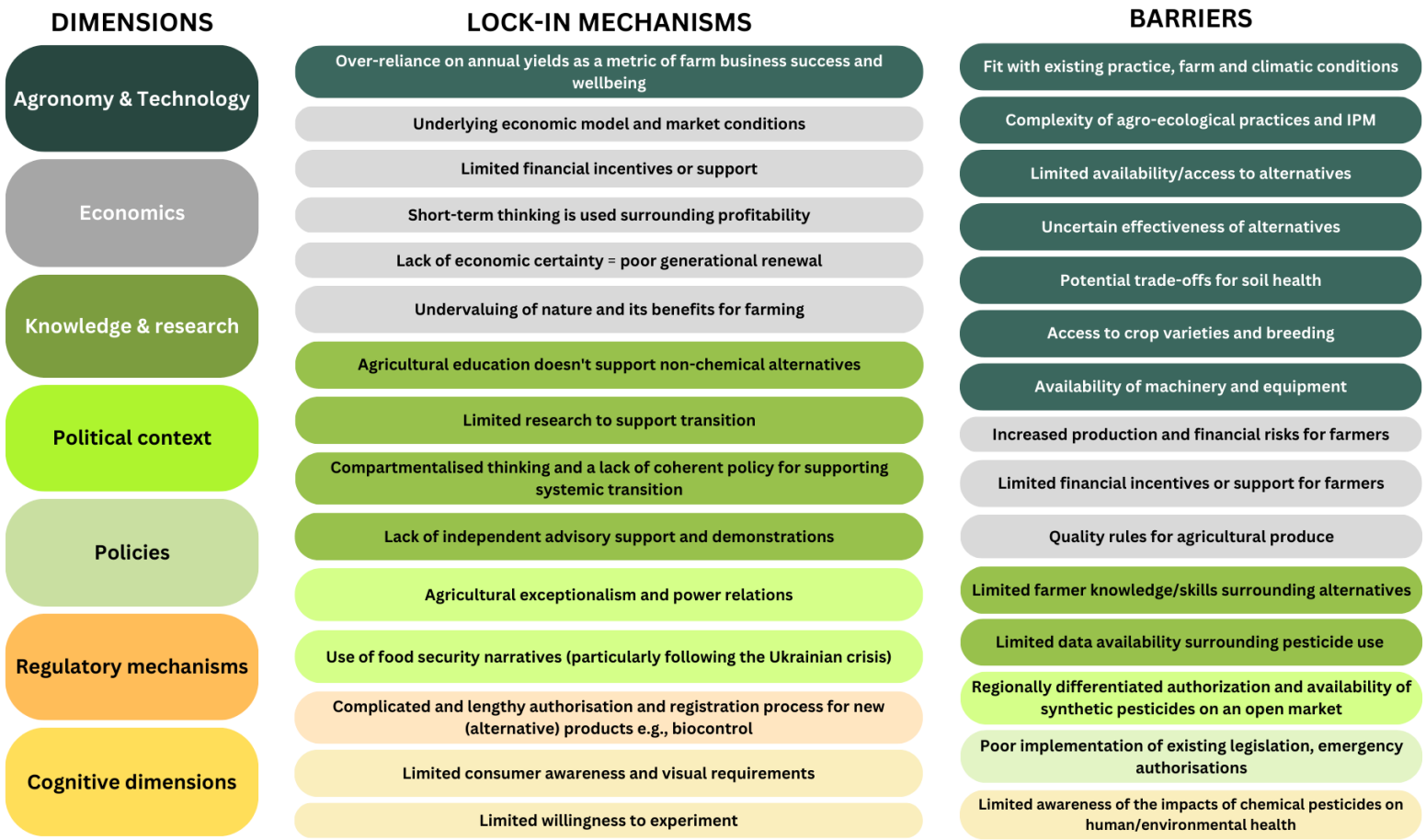

Figure 6 overview of lock-in mechanisms and barriers that hinder transition to reduced reliance on chemical pesticides

The underlying lock-in mechanisms are relevant across the different farming systems in SPRINT case study sites. Although the specific expressions of barriers can vary, most barriers also apply across SPRINT case study sites. There are also some differences and specificities. For example, there are no biological alternatives for herbicides, so that access to machinery and different trade-offs from machinery use are particularly strong in arable / cereal systems; excessive visual requirements from retailers and consumers are a key barrier for fruit growers, and there is also a higher financial risk with transitioning away from chemical pesticides with cash crops, such as fruit, vegetables, and viticulture.

How the lock-in mechanisms and barriers interact and reinforce each other creates for a very complex picture. For example, in a situation where no biocontrol is available or the cost of it is very high, there is limited openness to non-chemical alternatives and willingness to experiment, and at the same time farmers have already invested capital, time and knowledge resources to rely on mechanisations for pesticide applications, authorities rely on emergency authorisations and do not consider the possibility of substantial change, such as shift to growing other crops, or the redesign of farming systems because the cost and effort associated with these is very high and the possibilities beyond immediate emergency authorisations simply are not considered or imagined.

In the next steps of the SPRINT project, we will explore together with stakeholders what possibilities and opportunities there are for breaking the pesticide lock-in situation, by identifying different pathways to better support the emergence and diffusion of alternatives to chemical pesticides. This report clearly shows that such pathways need to take a systemic approach, addressing multiple lock-in mechanisms and barriers at the same time.

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7. Appendices

Appendix A EU-policy interview script: semi-structured interviews with EU level stakeholders

Date of interview:
Stakeholder Name & Organisation:
Contact:
Type of stakeholder:
Form (online, in person) and duration of interview:

A. Consent

Do you have any questions regarding our research or the interview?

Refer to data protection **- Are you happy for the interview to be recorded?**

B. Understanding and vision of sustainable plant protection

1. **Can you tell us a little but about what you work on in your current role in relation to pesticides / sustainable plant protection?**

2. **The Farm to Fork Strategy sets out the goal for 50% reduction in use and risk of pesticides by 2030, setting out the general direction of travel for sustainable plant protection. It emphasizes the role of IPM, organic farming, biocontrol, also other non-chemical solutions for plant protection, reducing the use of most toxic pesticides. It remains still somewhat general with limited clarity on actions needed to achieve the transition. Does this goal for 2030 align with your vision for sustainable plant protection? What does sustainable plant protection in 2030 look like in your view?**

3. **Can you point us to specific success stories – examples, where you think this understanding of sustainable plant protection is already reflected?**

4. **In your view, which are the most promising currently available alternatives to chemical pesticides? Do you know how effective these are? Are there any other alternatives or innovations that you can envision?**

5. **Are the targets set out in the Farm to Fork strategy (pesticide use/risk, organic farming, landscape features, microbial) helpful for measuring progress?**

C. Key dimensions for transition to sustainable plant protection in 2030

6. **What areas do you think are the most important to address to facilitate the transition towards the 2030 vision?**

D. Barriers, opportunities, and actions to be taken to facilitate the transition

7. **Where do you see the main obstacles or barriers which would prevent achieving the vision of sustainable plant protection in 2030?**

8. **What do you think are developments (societal, political, economic developments) that would increase the likelihood of achieving these targets / changes in moving towards achieving the 2030 goal of sustainable plant protection?**

9. **Are there certain new developments that could strongly hinder achieving these targets?**

10. **What concrete actions should be taken by 2030 to address the obstacles and respond to opportunities? Which policy instruments / regulation aspects are key in this process?**

11. **Are there specific windows of opportunity in policy processes or more broadly in society that you think are especially important?**

12. **What actions should be taken from 2030 onwards?**

Appendix B Questionnaire for farmers

Views on pesticide application and communication preferences

Levels of pesticide application

1a) How would you rank the levels of pesticide application on your farm?

Please choose on a scale from 1 to 7, with 1 very low and 7 very high.

1-very low 7-very high

1	2	3	4	5	6	7

1b) How would you rank the levels of pesticide application on your neighbouring farms?

Please choose on a scale from 1 to 7, with 1 very low and 7 very high.

1-very low 7-very high

1	2	3	4	5	6	7

Please feel free to provide any additional comments you have on pesticide application on your farm or on your neighbouring farms:

2) What are the main reasons for the current levels of pesticide application on your farm?

Please rank the following themes from 1 to 7 according to your personal preferences

(1 being the most important reason, you can use the same ranking for multiple answers).

	Ranking place
Risk of yield losses	
Lack of available alternatives	
Lack of knowledge about alternatives	
Concern about impacts on the environment and/or human health	
Regulatory restrictions	
Funding to support use of alternatives	
Other – please specify	
Other – please specify	
Other – please specify	

Please feel free to provide any additional comments here:

3) In your view, what would enable a reduction in pesticide applications in farming in general?

Please name and briefly explain the top 3 solutions that you think would enable a reduction in pesticide applications in farming in general. The answers, for example, could relate to farm economics in general, availability and demonstration of alternatives, knowledge and advice, regulation, specific funding support etc.

	Solution and brief explanation
1	
2	
3	

4) How would you like to receive information about SPRINT project progress during the lifetime of the project?

Please rank the proposed tools from 1 to 7 according to your personal preferences (1 being your preferred option, you can give equal rankings if required)

Tool	Ranking place
Newsletters	
Social media – state preference Twitter/Facebook/Instagram/LinkedIn	

SPRINT website – in your local language	
Project meetings/workshops	
Email	
Individual phone calls/visits	
Other – please specify	

5) There are many ways in which information about new farming practices can be communicated. Please indicate how you would like to learn about new approaches for sustainable pesticide use from SPRINT.

Please rank the proposed tools from 1 to 7 according to your personal preferences (1 being your preferred option, you can give equal rankings if preferred)

Tool	Ranking place
On-site demonstrations	
Agricultural magazines, newspapers	
Videos	
Paper forms e.g. fact sheets (on practices, success stories)	
Meeting presentations	
On-line farming forum/website	
Others – please state	

6) How would you normally find out about new farming practices?

7) What are the 3 main questions you need answered when deciding whether to take up a new practice on your farm and why?

For example, you can consider technical aspects, economics, time requirements, skill requirements, likelihood it will make a different, goodness of fit, regulatory requirements etc.

	Questions to be answered	Why this question
1		
2		
3		

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Appendix C Stakeholder workshop collaboration board