Impact Assessment of EC 2030 Green Deal Targets for Sustainable Crop Protection in potato production

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Dit rapport presenteert een effectbeoordeling van de twee doelstellingen van de Farm to Fork-strategie met betrekking tot vermindering van het gebruik en risico van gewasbeschermingsmiddelen voor de aardappelteelt en -verwerkende industrie. Aan de hand van zes cases in Noordwest-Europa zijn de agronomische en bedrijfseconomische gevolgen verkend van drie scenario's op bedrijfsniveau. Aan de hand van de resultaten van deze scenario's zijn de economische gevolgen verkend voor de teelt en de verwerkende industrie. Vervolgens is nagegaan welke duurzame alternatieve gewasbeschermingsmethoden perspectief hebben om de negatieve gevolgen te verminderen. Op basis van de analyses worden aanbevelingen gegeven voor alle betrokken stakeholders.

In this report, an impact assessment is given of the two objectives of the Farm to Fork strategy with regard to reducing the use and risk of pesticides for the potato growing and processing industry. Based on six cases in Northwestern Europe, the agronomic and economic consequences of three scenarios at farm level were explored. Based on the results of these scenarios, the economic consequences for cultivation and the processing industry have been elaborated. Then it is examined which sustainable alternative crop protection methods have prospects for reducing the negative consequences. Based on the analyses, recommendations are given for all stakeholders involved.

Key words: impact assessment, sustainability, crop protection, potato, climate change, weed control, farm level analysis, economic analysis, future pathways

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Preface

Sustainable crop production is increasingly the focus of European policy. The Farm to Fork and Biodiversity strategies are at the heart of the European Green Deal Roadmap aiming to make food systems fair, healthy and environmentally-friendly. Both strategies contain clear new targets to be met by 2030 which should contribute to a sustainable food system. These targets create challenges for all relevant public and private stakeholders.

The European Potato Processors' Association (EUPPA) requested Wageningen Research to execute an ex-ante impact assessment, in which we explore the consequences at farm and macro level of achieving the targets for crop protection. This impact assessment has been executed by a team from Wageningen Research with support from experts in research institutes located in the case study countries. The research team thanks all experts who have contributed to the execution of the case studies. Furthermore, we thank the colleagues from both outside and inside Wageningen UR for reviewing the results.

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Summary

S.1 Introduction

As part of its Green Deal Roadmap, the European Commission has launched the Farm to Fork (F2F) and Biodiversity (BD) strategies to cope with the environmental and climate challenges. Currently it is uncertain what the implications of the proposed targets could be for EU agriculture and the food system. Explorations into the consequences are vital for both policymakers and stakeholders to have an informed debate on the future food production in the EU.

EUPPA commissioned this study to assess the potential impacts for primary production of two targets of the F2F strategy for crop protection. The study focuses on the impacts on (processing) potato production, taking into account the present knowledge of farmers and available technologies. Furthermore, it explores pathways of promising alternative sustainable crop protection methods to reduce the negative consequences of the limitation to pesticide use.

In the study three scenarios have been developed, and compared with a reference situation, in which the following objectives of the Farm to Fork strategy are combined:

- Scenario 1: 50% reduction in the overall use and risks (HRI) of pesticides and a 50% reduction in the use of more hazardous pesticides (candidates for substitution).
- Scenario 2: 50% reduction in the overall use and risks (HRI)of pesticides and a 75% reduction in the use of more hazardous pesticides (candidates for substitution).
- Scenario 3: 50% reduction in the overall use and risks (HRI) of pesticides and a 100% reduction in the use of more hazardous pesticides (candidates for substitution).

S.2 Main results

The study has been carried out in context of the current potato market, with current land-use and technologies. Market development, innovation and other context altering developments have not been researched. The main results considering the above mentioned context can be summarized as follows:

1. Implementation of the F2F strategy objectives for crop protection can lead to a reduction in yield of potato production ranging from 0% to 20% in Scenario 1 with an average of 9%, depending on the context (region, farmer, availability of alternatives).
   If pesticides lose their registration up to 2030, the yield loss can be doubled. Scenario 2 and 3 reflect these developments and have an average yield loss of 16 and 21% respectively. The effects on yield reduction will partly be strengthened by consequences of climate change.
   Note: The reduction will be lower if we take into account the progress already made in realisation of the objectives since the reference period 2015-2017.
2. The costs for crop protection will increase due to additional labour input and investments in mechanical weeding, precision agriculture and Decision Support Systems. Reduced yield and higher costs result in higher per-unit costs of potatoes.
3. The yield reduction induces a reduction of total potato production, although this decline in production is expected to be less then proportional, since we expect an extension of the area on which potatoes will be cultivated.
4. The decline in production will induce an increase in potato prices, which will partly counteract the production decline since the increased prices are likely to induce some behavioural response of potato growers (e.g., induce them to allocate some more land to potatoes). However, the availability of additional land for potato production is limited.

5. The more variable yields and increased price will have a negative impact on potato users, including potato processors. The higher potato prices increase their sourcing costs and ceteris paribus reduce their profitability. Consequently, European potato processors lose competitiveness compared to non-European processors.
6. Reduction of the yield level in the entire EU will lead to sharp price increases. The production will slightly shift to countries which have the lowest yield reduction when complying to the F2F strategy objectives on crop protection, provided that additional land is available.
7. Both technological and ecological options and breeding can contribute to mitigating negative consequences. Mechanical weeding is an obvious example, as well as the application of decision-support systems. Other precision agriculture techniques require more development and the advantage can be scale dependent. It is likely that the costs for crop protection per ha will stay at a higher level compared to the existing costs per ha.
8. Both biocontrol and diversified systems will also contribute as they already do, although the efficacy can be lower, and the costs higher. Breeding can significantly contribute, but reduction in lead time of new varieties cannot be expected as long as new breeding techniques are not allowed.

S.3 Recommendations

- Farmers should invest in both technological (application of decision support systems, mechanical weeding) and ecological pathways (application of biocontrol agents and diversified systems). These investments also require investments in knowledge and elaboration of a careful crop protection strategy. Differentiation in application of techniques is recommended for the mid and long term. For the mid-term until 2030 we recommend to apply decision support systems, mechanical weeding, precision agriculture, a wider rotation and flower strips. In the long run we recommend to invest in using resistant varieties, application of biocontrol embedded in a resilient growing system.
- The potato processing industry should cooperate with farmers by assisting them in making decisions about reduction in pesticide use and risk and integrated pest management and sharing risks in line with the previous recommendation.
- The potato processing industry should focus on risk management in the mid-term until 2030 and on intensified cooperation with value chain partners to differentiate the product supply on the basis of the sustainability performance.
- The European Commission should adjust the regulations to allow New Breeding Techniques for resistance breeding.
- Breeders should develop potato varieties resistant against pests and diseases that currently require significant use of pesticides and/or pesticides belonging to HRI I risk group 3, such as *Phytophthora infestans*.
- The whole supply chain (from farmer to processor, retailer and regulators) should accept new, resistant varieties.
- The entire processed potato value chain should communicate about the sustainability of the products, and to elaborate minimum sustainability standards that growers must meet in order to supply.
- Research institutes should continue research in both technological and ecological pathways. For the long term to work on resilient cultivation systems less vulnerable for pests, weeds and diseases, and less dependent from plant protection products.

S.4 Research methods

The study consisted of three phases. In the first phase of the study, the potential consequences of each of the scenarios at farm level were investigated. For this 6 countries have been selected: Belgium, France, Germany, the Netherlands, Poland and the UK. Each case study has been executed by local experts filling in a detailed questionnaire capturing the responses of farmers to cope with the proposed reduction targets. This implies that in the scenarios the spraying schemes have been adjusted in such a way that the farmer complies with the objectives reducing the negative impacts as much as possible, making use of available technologies and knowledge. The impacts at farm level for each of the three scenarios have been assessed for a specific farm (which can differ from an average farm) in the region and have been measured relative to a baseline situation. The main parameters assessed are the level of yield and quality loss of the products. The experts have been provided by the authors with the necessary background information about the policy scenarios and reported their results with accompanying information to better understand the optimised farmer responses to the policy shocks.

In the second phase of the study, the results of the case studies have been used to explore the consequences at macro level, by extrapolating the results from the case studies to European level.

For this purpose, a crop-specific tailormade model has been developed relying on the equilibrium displacement modelling (EDM) methodology to calculate the market impacts (e.g. new balance in produced volume for each of the case crops, the corresponding adjusted price level, and the net effects on trade). However, since the six cases are not a sufficient basis for a representative study, the model has been used to identify the underlying mechanisms that determine the effects of reduced yields on the economics of potatoes.

In the last phase, alternative sustainable crop protection techniques have been elaborated based on literature review and expert judgements.

1 Introduction

Policy context

The *European Green Deal* was launched by the European Commission in December 2019, its main goal being to make Europe the first climate-neutral continent by 2050. It maps a new, sustainable and inclusive growth strategy to boost the economy, improve people's health and quality of life, care for nature, and leave no one behind. At the heart of the Green Deal is the Farm to Fork (F2F) strategy, which was launched by the European Commission in May 2020 in order to achieve a fair, healthy and environmentally-friendly food system by 2030. According to the F2F strategy, there is a need to reduce dependency on pesticides and antimicrobials, reduce excess fertilisation, increase organic area under farming, improve animal welfare and reverse biodiversity loss. The Commission will ensure that the strategy is implemented in close coherence with the other elements of the Green Deal, amongst others the Biodiversity (BD) for 2030, launched simultaneously with the F2F strategy. Many targets in the BD strategy overlap with the F2F strategy.

In June 2022, a proposal of the Sustainable Use of pesticides Regulation (Regulation (EU) 2021/2115, (SUR)) has been presented by the European Commission. This Regulation is the successor of the SUD, but serves also as the legal instrument to implement the targets of the Farm to Fork Strategy. The SUR contains binding prescriptions for Member States. Under conditions, Member States can deviate from the prescribed reduction of 50%, but at EU level, the 50% reduction must be realised. Therefore, the European Commission has proposed reduction percentages for each Member States. The percentages have been based on the average weight of active ingredients applied per ha and the average reduction realised in the period 2011-2017. In the first half of 2023, the European Commission has conducted an impact assessment of the proposed SUR. The European Commission concluded a well-managed reduction in pesticide use and risk will not lead to yield reductions.[1]

As outlined in the F2F strategy, the Commission will table a legislative proposal for a framework for a sustainable food system by the end of 2023 to accelerate and facilitate this transition and ensure that all foods placed on the EU market become increasingly sustainable. This will promote policy coherence at EU and national levels, mainstream sustainability in all food-related policies and strengthen the resilience of food systems. Following a broad consultation and impact assessment, the Commission will work on common definitions and general principles and requirements for sustainable food systems and foods.

As part of the EU policy use of chemical pesticides should be reduced. The use of *chemical pesticides* in agriculture may contribute to soil, water and air pollution, biodiversity loss and can harm non-target plants, insects, birds, mammals and amphibians. The Commission has already established two Harmonised Risk Indicators (HRI) to quantify the progress in reducing the use and risks linked to pesticides.[2] The latest Commission publication, according to HRI 1, demonstrates a 21% decrease in the use and risks from pesticides since the reference period 2011-2013 (Eurostat, 2022). The Commission will take additional action to reduce the overall use and risk of chemical pesticides[3] by 50% and the use of more hazardous pesticides[4] by 50% by 2030. The reference period is 2015-2017.

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1 https://food.ec.europa.eu/system/files/2023-07/pesticides_sup_comm-response_2022-2572_en.pdf

2 HRI are defined in the Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides (the Sustainable Use Directive). These indicators are needed to measure progress in the reduction of risks from pesticide use for human health and the environment. The European Commission calculates them for the EU, and MSs should calculate the HRI at a national level. The data to be used for the calculations shall be statistical data collected in accordance with Union legislation concerning statistics on plant protection products, i.e., Regulation (EC) No 1185/2009 on pesticide statistics, and other relevant data.

3 Chemical pesticides have a synthetic origin. However, in organic farming, pesticides from natural origin such as copper-based active ingredients are applied. Since these active ingredients are subject to the same regulation, we will use the term pesticides from now on.

4 These are PPPs containing active substances that meet the cut-off criteria as set out in points 3.6.2. to 3.6.5 and 3.8.2 of Annex II to Regulation (EC) No 1107/2009 or are identified as CFS in accordance with the criteria in point 4 of that Annex.

EUPPA has requested to execute an ex-ante impact assessment of the Plant Protection Products (PPPs) reduction targets from the Farm to Fork Strategy on potato production and processing. The focus will be on the primary production of potatoes, the raw material availability for the processing industry and solution pathways that can be applied to meet the targets of the F2F strategy. With this EUPPA wants to be able to identify the long-term effects of potential bottlenecks and to identify paths towards more sustainable potato production while meeting the EU policy targets and measures.

Objective

The objective of this study is to execute an economic impact assessment of the PPP reduction targets in the F2F strategy on potato production and processing in Europe. We will distinguish three types of analyses:

- Impact on potato production:
  - Farm level: the effects on potato production in six focus regions (cost, quality and yield)
  - EU level: change in produced volume and value of potatoes, pricing and trade (net export/import).
- Impact on potato processing sector: procurement (EU supply, need to source from other regions in and outside of Europe, prices, quality of materials)
- Pathways to meet the targets.

Focus

The primary focus of the research is the translation of the PPP reduction targets towards yield and quality effects on the primary production of ware potatoes, the effect on raw material (potato) availability and consequences of these effects on the potato processing industry. Potato production is defined as ware potatoes. For potato processing the focus will be on frozen potato products as much as possible.

In terms of project scope of the economic assessment, we will:

- Consider the following targets (ceteris paribus):
  - 50% reduction in the use and risk of pesticides by 2030
  - 50% reduction in the use of hazardous pesticides by 2030.
- Focus on the following regions: Germany, France, Poland, the Netherlands, Belgium (using EU targets) and the UK, with an extrapolation to EU averages
- Set the baseline year for conducting the impact assessment using the last years (2021) of available data, and potential impacts up to 2030
- Focus on producing quantifiable results for the economic impact on potato production, based on expert indications on changes at farm level, public data & research, and impact models at national and European level
- Generate results both quantitative and qualitative for the impact on potato processing
- Consider changes in raw material supply for the potato processing industry
- Include three solution pathways for the primary potato production, with qualitative descriptions (based on expert judgments and literature). This will include the following components: current state of solution/level of adoption, potential impact (e.g., % reduction of pesticides), indicative cost-benefits, key barriers for wide-scale adoption.

In addition to the main focus there will be two subjects that will be explored in expert meetings and interviews:

- Climate effects on crop protection
- Expectations about developments in regulation at EU level.

The results will provide input for the discussion needed in the EU, identify and address upcoming challenges and possible solution pathways whilst showing great progress in potato production on a voluntary basis.

Structure of the report

This report is structured as follows. Chapter 2 describes the research methods applied at both farm and macro levels. Chapter 3 presents the analyses and results at farm level, whereas Chapter 4 elaborates on the economic impact at EU level. Chapter 5 explores the pathways for meeting the F2F strategy crop protection targets, while mitigating the negative consequences. The report is concluded in Chapter 6 by providing further discussion, conclusions and policy recommendations.

2 Research methods

2.1 Impact Assessment (IA) Framework

The effects of achieving the targets of the F2F and Biodiversity (BD) strategies have been assessed into different elements of the agri-value chains. The general mechanism underlying the analysis of the impacts derived from both strategies is presented in Figure 2.1.

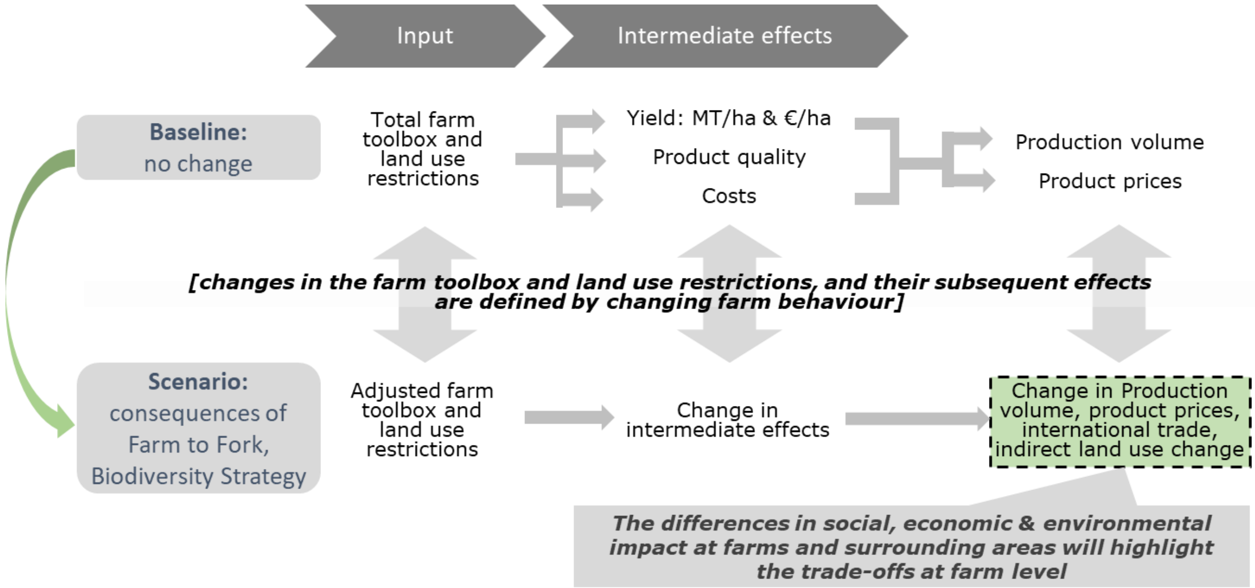

Figure 2.1 *Conceptual model for analysing impacts of the F2F strategy and Biodiversity strategy*
Source: Authors.

The Impact Assessment (IA) framework contains two basic dimensions:

- The horizontal dimension addresses the basic steps regarding how the applied cultivation measures are linked by intermediate effects to the final social, economic and environmental impacts.
- The vertical dimension includes the alternative scenarios and corresponding adjustments in the applied cultivation measures covering the objectives derived from the F2F and BD strategies subject to the impact assessment.

A crucial element of this impact assessment is the application of the proposed objectives at farm level. This application implies that we adjust the crop protection toolbox according to the targets derived from the F2F and BD strategies. These adjustments and consequences at farm level have also served as a basis for the estimates at EU level. The different changes, intermediate effects and impacts are summarised in Figure 2.1. The economic effects focus on the changes in yield, quality and production costs. The differences between the baseline (no change) and the scenarios (see Section 2.2 for the application of objectives from F2F and BD strategies) are the impacts and trade-offs at farm, sector, national and EU level.

2.2 Two objectives translated into three scenarios

Defining the scenarios

The effects of achieving the two objectives proposed in the F2F and BD strategies have been assessed in three scenarios both at farm level and macro level:

- Scenario *1* contains the following objectives:
  - 50% reduction of the overall use and risk of pesticides
  - 50% reduction of the use of more hazardous pesticides.
- *In Scenario 2* we increase the target for the reduction of the use of more hazardous pesticides to 75%:
  - 50% reduction of the overall use and risk of pesticides
  - 75% reduction of the use of more hazardous pesticides.
- *Scenario 3* changes the target for the reduction of the use of more hazardous pesticides to a total ban:
  - 50% reduction of the overall use and risk of pesticides
  - 100% reduction of the use of more hazardous pesticides.

The scenarios differ from each other with respect to the objective of the F2F strategy to reduce the use of Candidates for Substitution (CFS) (more hazardous pesticides). Scenario 1 contains the objectives of the F2F strategy for crop protection. The objectives for the reduction of the more hazardous pesticides have been adjusted in Scenario 2 and 3 because of the likelihood that a number of pesticides, especially CFS will lose their registration in the period until 2030. Since we do not know which pesticides will lose their registration, and a solid basis for anticipation is lacking, we have modelled this scenario by a reduction of 75% and 100% in Scenario 2 and 3 respectively.

EUPPA has requested to explore the consequences of climate change on crop protection. Although elaborated climate change scenarios are available, we have not included climate change in the definition of the scenarios. The reason is that climate change scenarios cover a period of at least 30 years, and the period to 2030 covers only eight years, which is too little for differentiation in the climate conditions assumed across the different scenarios.

Measuring progress – applied indicators

In terms of monitoring, the following indicators have been selected by the European Union to assess the progress in the realisation of the selected objectives (European Commission, 2020):

1. 50% reduction of use and risk of pesticides: Harmonized Risk Indicator I (HRI I) (Eurostat, 2021). HRI are defined in the Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides (the Sustainable Use Directive). These indicators are needed to measure progress in the reduction of the use and risk of pesticides for human health and the environment. The European Commission calculates these statistics for the EU, while Member States (MS) are expected to calculate the HRI at national level. The data to be used for the calculations shall be statistical data collected in accordance with Union legislation concerning statistics on plant protection products, i.e. Regulation (EC) No 1185/2009 on pesticide statistics, and other relevant data. The HRI I divides pesticides into the following four categories:
   a. Group 1
      Low-risk active substances which are approved or deemed to be approved under Article 22 of Regulation (EC) No 1107/2009, and which are listed in part D of the Annex to Regulation (EU) No 540/2011. Pesticides in this category have a weighting factor of 1.
   b. Group 2
      Active substances which are approved or deemed to be approved under Regulation (EC) No 1107/2009, and not falling in other categories and which are listed in part A and B of the Annex to Regulation (EU) No 540/2011. Pesticides in this category have a weighting factor of 8.
   c. Group 3
      Active substances which are approved or deemed to be approved under Article 24 of Regulation (EC) No 1107/2009, which are CFS and which are listed in part E of the Annex to Regulation (EU) No 540/2011. Pesticides in this category have a weighting factor of 16.

   d. Group 4
      Active substances which are not approved under Regulation (EC) No 1107/2009, and therefore are not listed in the Annex to Regulation (EU) No 540/2011. Pesticides in this category have a weighting factor of 64.

   The value of the HRI I can be calculated by summing up the weighted volume in kg of the active substances of the pesticides placed on the market. This means that for each active substance the volume is multiplied by the weighting factor. The outcomes are summed up for all active substances.

2. 50% reduction of the use of more hazardous pesticides: the volume summed up of all applied pesticides with active substances in group 3 (CFS).

For the purpose of this study the HRI I is calculated at crop level. However, it must be noted that in the rotation scheme potatoes are a crop with a relative high pesticide use per ha. Therefore the HRI I score per ha for potato will most likely be higher than the national averages. This HRI I score can be 'compensated' with a low HRI I score in other less intensive crops within the rotation.

2.3 Case studies at farm level

Selection of case crops and countries
This impact assessment started with the selection of case studies. Six MSs have been selected for the case studies, covering the most important countries where potatoes for the processing industry are produced: France, Belgium, the Netherlands, Germany, Poland and the United Kingdom. Each case is from a different country.

Data collection in the case studies
To collect the data, the project team applied the following methodology. We have developed a questionnaire in Excel, including the following sheets:
1. General instructions on how to fill in the questionnaire
2. Description of the specific farm situation with conventional production of potatoes for the processing industry for which the impacts of each scenario are assessed
3. Explanation of the three scenarios, how to apply the objectives in the scenarios and the corresponding indicators measuring the realisation of the objectives
4. Elaboration and assessment of the reference scenario and the three scenarios covering the objectives of the F2F and BD strategies
5. Overview of the available active substances and group.

Instructions
The Excel sheet 'Instructions' contained generic guidelines on how to fill in the questionnaire: which sheets need to be filled in, which cells in each sheet, the links between the scenarios, how to deal with the time horizon to 2030, as well as anticipated technological developments.

Description of case farms
The project team made the choice to analyse the consequences of the objectives for a case farm and not for an average farm. A case farm represents a large production region, and a farm type that is representative for that region. This contributes, on the one hand, to a consistent farm structure (rotation, machinery, crop protection management, level of technification etc.). On the other hand, it creates variety in farm types between the case studies, such as difference in farm size, level of technification and, normal yield level. In the sheet 'Generic questions', respondents were asked to describe the region, the farm size, the rotation, the soil type etc. More specifically, respondents were asked about the labour input, the machinery, the soil tillage and fertilisation, an overview of the main pests, diseases and weeds and the crop protection strategy, and the social importance of the crop for the region where it is produced. Case farms can greatly differ between regions within a country in terms of firm size, level of technification etc.

Explanation of the three scenarios
In the sheet 'Explanation of scenarios' a short overview presents the targets per scenario, the indicators that have been applied in accordance with the indicators used by the European Commission to monitor the progress of the realisation of the targets by MSs, and the way the objectives should be applied in the assessment.

Elaboration and assessment of the scenarios
In the sheet 'Elaboration of scenarios', the reference scenario (base line), representing the existing situation on the case farm, had to be defined, and the impact of implementing the targets of the F2F and BD strategies for Scenarios 1, 2 and 3.

In each scenario, the following aspects have been considered:
1. The spraying scheme
2. Additional non-chemical measures applied in the scenarios compared to the reference scenario
3. Measures applied to prevent emission and improve soil fertility and resilience against pests and diseases
4. The estimated yield
5. The relation between the scenarios and the product yield and quality
6. The occurrence of specific aspects that reduce the quality
7. The impact that potential extreme conditions due to climate change can have on yield or quality
8. Overview of differences with reference scenario
9. Impact of scenario on costs and revenues
10. Other possible effects of the scenario.

The formal reference period in the F2F strategy for measuring whether the reduction targets for pesticide use and risks are realised is 2015-2017. However, since quite a long time has passed since the reference period and crop protection practices have changed, it is not feasible to reconstruct spraying schemes for this period. Therefore, we have asked the experts to use the last season for elaboration of the reference scenario. Since the analyses have been executed in the course of 2022, the reference year is 2021. Because we know at MS level the progress made in reduction of pesticide use and risk measured with the HRI I, we can discuss the consequences of our approach in terms of overestimation and underestimations, see Chapter 6.

Overview of the available active substances
The sheet 'Pesticides' presents all active substances including the group to which they belong. The relevant active substances can be selected by a drop-down menu provided in the 'Elaboration of scenarios' sheet.

The questionnaire has been included in Appendix 1.

Execution of the impact assessment
The case studies have been executed by local experts with specific expertise on the cultivation of the crop who work at research organisations or universities. The members of the project team have recruited them making use of their international network. The experts needed to have expertise on crop protection, cultivation systems and a basic understanding of farm economics. The case studies were executed by small teams of two experts in Belgium, France and the UK and by single experts in Germany, Poland and the Netherlands. In all cases external advisors have been contacted by the experts for additional information. In Poland multiple farmers have been involved in the assessment.

The experts were given instructions how to fill in the questionnaire in Excel by a team member in an online meeting. The experts were requested to elaborate the reference scenario and to fill in the scenarios in such a way that the objectives of the scenario are met, while the negative economic consequences are reduced as much as possible. For Scenario 1, this implied that the application scheme had to be adjusted in such a way that the volume of the active substances from group 3 (CFS) had to be reduced by at least 50%. Furthermore, the overall use and risk of pesticides had to be reduced in such a way that the calculated value of the HRI I was reduced by at least 50%. This could be implemented by reducing the volume of the applied pesticides (the use of pesticides) and/or by replacing pesticides of a high-risk weighting factor by pesticides with a lower risk weighting factor. The assumption has been for Scenario 1 that the classification of the pesticides in the groups remains unchanged until 2030. In Scenario 2 and 3, the reduction in the availability of pesticides has been modelled by reduction in the use of more hazardous pesticides of 75% in Scenario 2 and 100% in Scenario 3. Furthermore, alternative non-chemical techniques that are available to farmers such as mechanical weed control, mating disruption, biocontrol agents etc. could be applied and separately listed. However, it should be noted that these alternative measures can differ from the replaced measures in terms of efficacy, costs and effect on the environment e.g., non-chemical measures such as mechanical weed control can have effects on soil life and contribute to erosion. Furthermore, it was emphasised that the assessment had to be executed considering the *expected* behaviour of the farmer. This means that the expert had to assess how they would expect the farmer or farm to respond when they would be requested to apply the selected objectives at farm level, making use of the alternative options that are available for them. The assessment, therefore, reflects what is technically and behaviourally feasible for the specific farmer.

After submission of the completed questionnaire to the responsible team member, the project team reviewed the results. Next, an additional meeting took place with the experts, in which the approach and results were discussed, and the assumptions were checked. Finally, some additional questions were asked regarding which technologies and innovations will be necessary to improve the feasibility of the objectives of the F2F and BD strategies. In some cases, the answers were adjusted.

Workshop with experts

After receipt of the first revision a workshop has been organised to discuss the results. The main objective of the workshop was to share and compare the results and to discuss the differences. A main point of attention were the starting points. During the workshop differences in starting points have been identified and a decision has been prepared which starting points have to be applied in order to make them mutually comparable. Examples are the period of weed control and the application of sprout inhibition. Furthermore, obvious differences in results have been discussed in order to have a good understanding in differences between cultivation practices and farm performances. After the meeting the conclusions have been summarised and shared with the experts.

Furthermore, this workshop has also been used to investigate future pathways. Which options does the potato processing industry have to mitigate negative consequences, if the F2F-Strategy objectives become reality and the availability of chemical pesticides decline? We have explored technical options, ecological options, organisational options and economic options.

3 Results at farm level

3.1 Introduction

In this chapter we present and discuss the results of the six case studies that have been completed. We start with a description of the case farms as defined by the expert, which is a specific farm type in a large production region. The results reflect the decision that a potato farmer would make when implementing the F2F strategy reduction targets for pesticide use and risk, according to the opinion of the expert. As described in Section 2.3, the case studies have been executed for case farms. Afterwards, we present the results of each scenario per case. At the end of this chapter we discuss the interpretation of the results and draw conclusions.

The specific cases have been anonymised to prevent the misinterpretation of the results, because the results for the specific cases do not represent the country as a whole.

3.2 The cultivation of potatoes

Potato is an important crop produced in large parts of the world. It contributes significantly to the provision of basic food. With respect to the cultivation, a distinction is made between seed potatoes, ware potatoes and starch potatoes. Seed potatoes are the tubers that are planted for producing ware or starch potatoes. Ware potatoes can be consumed fresh (table potatoes) or processed (industry potatoes). The varieties for both destinations differ. Potatoes for the processing industry need to fulfil specific quality requirements such as size, starch content, dry matter percentages etc., depending on the product they are used for. The case studies have been executed for potatoes grown for the processing industry. A more elaborated overview of the potato supply chain is presented in the recent study of Janssens et al. (2021) about the EU frozen potato product sector: a policy impact assessment for four key producing Member States.[5]

In terms of quality demands, potatoes are comparable to fruits and vegetables rather than to other arable crops. In comparison to other annual crops, potatoes are relatively vulnerable for pests and diseases, in particular soil diseases and Potato late blight (*Phytophthora infestans*). This requires a careful crop protection strategy. One of the most important and common measures is to cultivate them in rotation with other crops, such as cereals, maize, sugar beet and oilseeds.

3.3 Specific farms

Table 3.1 presents an overview of the farms that are selected for the case studies. This overview shows that the case farms in most cases are quite comparable in terms of acreage and rotation. With respect to the area, only Case 5 deviates with an average farm size of 20 ha. The other case farms have an area around 100 ha, including leased land. With respect the soil type, it is either silty clay or sandy loam. Potatoes are grown in rotation with other annual crops, predominantly cereals, maize, sugar beet and oilseeds. The share of potato cultivation varies between the cases from 12,5 to 33%.[6] In Table 3.1, the estimates of yield made by the experts are also listed for each specific case farm. For cases 1, 2, 3 and 6 this estimate is around 45 tonnes per ha, whereas the Case 4 and 5 experts reported estimated yield levels of 52 and 60 tonnes per ha for their case farms. To put the cases in context the national average yield of potato is also shown.

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5 https://edepot.wur.nl/553612
6 Including leased land.

Table 3.1 Overview of case farms

Cases	Soil-type	Farm size (ha)	Rotation	Case Yield (tonnes per ha)	Country average yield of potato (FAOstat 2019-2021)
Case 1	Sandy loam	80	Potato (25%), sugar beet (25%), wheat (25%), maize (25%)	47	42
Case 2	Silty clay	91	Potato (20%), wheat (40%), green beans (10%), sugar beet (10%), maize (5%), pastures (15%)	45	42
Case 3	Sandy loam	120	Potato (15%), winter wheat (30%), maize (25%), winter barley (15%), winter rye (15%)	43	42
Case 4	Sandy loam	90	Potato (33%),[7] sugar beet (17%), cereals (17%), onion (17%), maize (17%)	52	42
Case 5	?	15-25	Potato (25%), rapeseed (25%), wheat (25%), maize (25%)	60	29
Case 6	Sandy loam and silty clay	121	Potato (12,5%), winter wheat (50%), sugar beet (12,5%), oilseed rape (12,5%), winter barley (12,5%)	45	38

Source: Authors.

Case 1
A conventional farm with its own plough, spraying machine, and manure spreader. Farm size is 80 ha of which 20 ha potato. GPS is available for automated steering and planting while harvesting is undertaken by contract workers. Ploughing takes place once a year. It’s a rather standard conventional farm that tries to prevent as many pests and diseases as possible by eliminating volunteer potatoes, covering dump piles, and using variety choice. Monitoring and anti-resistance strategies are also applied. No other methods are used as of yet.

Case 2
A conventional farm with an acreage of 91 ha, and with a short rotation of which 20% consists of potato production. The farm has a plough, soil decompactor, disc stubble, conventional spray and GPS equipped fertiliser spreader. Ploughing is undertaken twice in the rotation and the farmer is increasingly moving towards no-till to save time and fuel, favouring shallow tillage. A cornerstone of the crop protection strategy is the use of a Decision Support System (DSS). Potato tops are shredded mechanically.

Case 3
A conventional farm with a rather high crop diversity, including some livestock. The acreage is 120 ha and potatoes are cultivated on 15% of the land. Potatoes are often sold through direct marketing. The farm has several ploughs, a grubber, a rotary harrow and a tractor driver sprayer. Seeding is undertaken by contract workers. Tillage is done by two stubble tillage’s and one primary tillage in autumn of spring. No IPM is applied.

Case 4
A highly specialised farm of 90 ha with a large share of potatoes through leasing land (30 ha). The farm possesses a plough, rotary cultivators, goosefoot cultivator, stubble cultivator, sprayer, hoe, fertiliser spreader and GPS. Deep cultivation is done once or twice per rotation. A DSS is used for potatoes.

Case 5
A mixed farm with crop production and livestock. This is a rather small farm with an area of approximately 20 ha, of which 5 ha consists of potato production. The farm has a cultivator, plough, sprayer, harrow, hoe, fertiliser and manure spreader and GPS guidance. Tractor operations and storage are undertaken by contract workers. Ploughing is done every other year. The trend is moving towards less ploughing. For spraying, advise of commercial companies and independent companies is followed. Mechanical weeding is applied before seeding.

[7] Including leased land.

Case 6
A conventional farm of 121 ha where harvesting is done by contract workers. Potato production takes 12,5% of the acreage. The farm has a power harrow, plough bed former, mechanical weeder, tractor driven spraying machine and a fertiliser spreader. Mechanical weeding (interrow) is undertaken once per season when the crop is 50cm high. GPS is available and used for planting and forming beds.

3.4 Reference scenario – Status quo

In order to analyse the scenarios, we have to compare the reference scenarios, which have the year 2021 as a basis. In Appendix 3 we have provided an overview of the spraying schemes for potato for all scenarios and cases. For all six cases the crop protection scheme is made for the reference scenario. This has been done for a season with normal growing conditions as interpreted by the expert.

A specific year was used (2021), and not the last 3 years, to prevent outliers. This provides a more comparable crop protection scheme for the case farms, as differences in weather conditions do not affect one case more than others. However variable weather conditions are a reality and will affect countries differently from year to year.

In the reference scenario a series of non-chemical measures is applied in addition to chemical measures. Some are basic agronomy, like rotation. Others are more innovative and technology-dependent, like cultivars with specific resistance. In Table 3.2 the non-chemical measures taken by specific cases are shown.

In Case 1, no integrated pest management strategy is applied, but measures are applied to limit the use of pesticides. Examples are the application of a DSS, preventive measures such as variety choice and eliminating volunteer potatoes. In Case 2 a DSS has been applied to reduce the number of applications of fungicides against late blight. Furthermore, shallow tillage is applied to control weeds mechanically. In the Case 4 as well as in Case 5, a DSS is applied to control late blight. Furthermore in Cases 2, 3, 5 and 6 mechanical weeding such as interrow weeding and addition ridging is applied. The measures taken in the reference scenario are shown in Table 3.2.

Table 3.2 *Non-chemical crop protection measures in ware potato production as indicated by the expert per farm in the reference scenario*

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Buffer zones	+	+		+		+
Drift reduction	+			+		+
DSS for potatoes		+	+	+		
Cultivar with resistance against late blight				+		
Break crops						+
A form of mechanical weed control		+	+		+	+
Mechanical haulm killing		+				

When we compare the reference scenarios elaborated the case studies, we observe large differences in the use and risk of the applied spraying schemes as measured by the Harmonized Risk Indicator I. As presented in Table 3.3 especially in Case 6 and Case 1 the HRI I scores are high. This high level of HRI I score is mainly caused by the intensive use of the active substance Mancozeb to control fungi. As a CFS Mancozeb has a high HRI I score and this will result in a high overall HRI I score. For the EU Mancozeb has lost its registration in 2021 and is no longer allowed. However, for the reference year this was not yet the case. In the UK, Mancozeb is authorised until 31 January 2024. All experts were told that the use of Mancozeb in the reference scenario was allowed. Five experts have included Mancozeb in the reference scheme. Only the Case 4 expert has not included Mancozeb in the reference scenario because in that specific case an alternative active substance was applied The objective to reach the 50% reduction in overall use and risk of pesticides and 50% reduction in the use of more hazardous pesticides Scenario 1 has been achieved in all cases (see Table 3.3), since all values of Scenario 1, 2 and 3 are equal to or less than 50% of the values in the reference scenario. The additional required reductions in the use of more hazardous pesticides in scenarios 2 and 3 has in most cases led to additional reduction in the HRI I score. Especially in Scenario 3 some experts had to change the strategy significantly, resulting in a HRI I that is lower than the target. One of the experts explained ‘when I had to change my strategy there came a point where I had to make fundamental changes to meet the targets, in this new situation I had some room left in the HRI I but adding additional pesticides made no sense in that strategy’. In most cases the HRI I scores reduced further due to banning the use of CFS. In Case 2, the strategic change resulted in a significant reduction, whereas in Case 3, the use of CFS has fully been substituted by active ingredients from risk group 2, resulting in a HRI I score at the same level.

Table 3.3 *Values of HRI I in the scenarios (per ha potato, between brackets the value as percentage of reference value)*

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Average
Reference	**227**	**122**	**110**	**137**	**137**	**229**	**160**
Scenario 1	112 (49%)	60 (49%)	55 (50%)	68 (50%)	52 (38%)	109 (48%)	76 (48%)
Scenario 2	104 (46%)	57 (47%)	55 (50%)	68 (50%)	49 (36%)	93 (41%)	71 (44%)
Scenario 3	103 (45%)	32 (32%)	55 (50%)	59 (43%)	43 (31%)	88 (38%)	63 (39%)

The yields are comparable (see Table 3.4), but Case 5 stands out with a high yield in the reference scenario. The experts assures that this is a common yield level in that region on the small 15-25 ha farms, which a high intensity in the production.

Table 3.4 *Estimated yield (tonnes per ha) per farm in the reference scenario and estimated percentage yield change in Scenario 1, 2 and 3 compared to the reference scenario*

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Average
Reference	**47**	**45**	**43**	**52**	**60**	**45**	**46**
Scenario 1	0%	-11%	-7%	-2.5%	-20%	-9%	-9%
Scenario 2	0%	-20%	-7%	-2.5%	-35%	-18%	-16%
Scenario 3	-4%	-44%[8]	-7%	-5%	-42%[9]	-22%	-21%

3.5 Scenario 1 – 50% Reduction of pesticide use and risk and a 50% reduction of CFS

In this section we describe the results per case taking into account the realisation of the objectives in Scenario 1: 50% reduction in the overall use and risk of pesticides and 50% reduction in the use of more hazardous pesticides measured by the HRI I. An overview of the HRI I scores in the reference scenario and Scenario 1 in Table 3.5 and the values of estimated yield losses in Scenario 1 is presented in Table 3.6.

With the new crop protection schemes all cases at least halved their risk indicator and halved the use of Risk Category 3 pesticides (CFS), as is shown in the Table 3.3.

In Table 3.5 the additional non-chemical measures taken to manage the crop protection are shown.

8 Switched to biological production.
9 A resulting from the relatively high production (almost double) compared to the regional average.

Table 3.5 *Additional non-chemical measures for potato in Scenario 1 compared to the reference scenario*

	Intended effect	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
DSS	Improving timing and preventing unnecessary application of crop protection	+	+	+	+		
Additional field inspections	Improving timing and preventing unnecessary application of crop protection			+			
Widening the rotation	Reducing disease pressure		+			+	
Cultivar with resistance	Increasing plant resilience against disease (like phytophthora)			+	+	+	
Break crops	Reducing weed and nematode pressure						+
Interrow weeding	Mechanically reducing weeds						+
Additional ridging	Reducing weed pressure by burying weeds under soil			+			
Harrowing early season	Mechanically reducing weeds			+			
Substantial mechanical weeding	Mechanically reducing weeds		+	+	++	++	+
Storage cooling	Reducing active ingredient use by reducing spouting and disease in storage with low temperature			+			
Mechanical haulm killing	Reducing active ingredient use by killing the haulm mechanically		+			+	
Strict field selection	Selecting fields with low pests, disease and nematode problems						+

+applied, ++ applied more extensively.

In the chemical protection in most cases (all except Case 6) Mancozeb, a CFS, is phased out. It is replaced by lower risk category 2 products. For weed management there is reduction of herbicide use and more application of mechanical weeding and additional ridging. In Cases 4 and 5 weed management is undertaken without chemical intervention. The CFS that are used are fungicides. With the reduction of pesticides in many cases there is need for more field inspections. Another measure taken in some cases is the use of a DSS for protection against fungi. In four cases there is a change in cultivar, more resistant cultivars are chosen to coop with the reduction of pesticides.

For Case 5, part of the solution to reduce the pesticide use and risk will be realised by a broader rotation. For Case 6 the loss is expected as a result from higher potato cyst nematode (PCN) pressure, resulting in stricter field selection.

In this first scenario with 50% reduction in the overall use and risk of pesticides and 50% reduction in the use of more hazardous pesticides, the yield reduces between 0% and 20% (Table 3.4). The differences between the cases are substantial. Where Case 1 and Case 4 expect no yield loss or little yield loss, the expert of Case 5 expects 20% and of Case 6 expects 9% yield loss. In Section 3.9, we discuss how these differences can be interpreted.

The differences in HRI I score and yield indicate a difference in reliance on pesticides. Where Case 5 has the highest reference yield, it is also very reliant on pesticides to achieve that level of yield. Case 1 has a very high HRI score reference, resulting in more availability in the first scenario. As can be seen the reference scenario for Case 3 scores a lower HRI I score than the first scenario of 50% reduction in Case 1.

It should be noted that changes in cultivation practices may lead to cost increase, as well as increased labour input together with more vulnerability to variable weather conditions. With respect to costs, most cases (2, 3, 4 and 6) report more labour input, mostly as a consequence of mechanical weeding. In some cases (4 and 6) also higher costs for machinery are reported. In Case 1 and 5 no higher costs are mentioned, and in Case 5 even reduced costs. With respect to quality, Case 5 and 6 report quality reduction of the potato tuber due to damage caused by mechanical weeding and potato cyst nematode (PCN) respectively.

3.6 Scenario 2 – 50% Reduction of pesticide use and risk and a 75% reduction of CFS

In this section we describe the results per case taking into account the realisation of the objectives in Scenario 2: 50% reduction in the overall use and risk of pesticides and 75% reduction in the use of more hazardous pesticides. An overview of the scores of the HRI I in the reference scenario and Scenario 2 are presented in Table 3.3 and estimated yield losses in Scenario 2 is presented in Table 3.4.

In Scenario 2 the CFS need to be reduced further to meet the 75% reduction target for the more harmful pesticides. Mancozeb is now no longer used. Other fungicide CFS are phased out as well. Difenoconazole and Fluopicolide are no longer used in most cases, but not fully phased out. Aclonifen and Metribuzin are removed from the spraying scheme in more cases.

In addition to the measures from Scenario 1, several additional measures to cope with the new scenario are used (if not used already). For weed management additional ridging, pre-emergence weed management and post emergence hoeing. More resistant cultivar selection, crop rotation prolonging and earlier seeding dates are measures used (also shown in Table 3.6).

Table 3.6 *Non-chemical measure in potato crop in Scenario 2*

	Intended effect	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
DSS	Improving timing of and preventing unnecessary application of crop protection	+	+	+	+		
Additional field inspections	Improving timing of and preventing unnecessary application of crop protection			+			
Further widening the rotation	Reducing disease pressure					+	
Cultivar with resistance	Increasing plant resilience against disease (like phytophthora)		+	+	+	+	
Break crops	Reducing weed and nematode pressure						+
Interrow weeding	Mechanically reducing weeds						+
Additional ridging	Reducing weed pressure by burying weeds under soil			+	+		
Harrowing early season	Removing weeds		+	+			
Mechanical weeding	Mechanically reducing weeds		++	+	++	++	+
Storage cooling	Reducing active ingredient use by reducing spouting and disease in storage with low temperature			+			
Mechanical haulm killing	Reducing active ingredient use by killing the haulm mechanically		+			+	
Strict field selection	Selecting fields with low pests, disease and nematode problems						+
Post emergence hoeing	Mechanically reducing weeds				+		
Bio fungicide	Biological control as substitute for active ingredients		+			+	

The non-chemical measures are not substantially different from Scenario 1. The main difference in this scenario is the switch from risk category 3 active ingredients to risk category 2 active ingredients. As expected, the HRI scores in Scenario 2 are very similar to Scenario 1 (see Table 3.3). In both cases there needs to be a reduction of the HRI I score of 50% compared to the reference scenario.

In Scenario 2 the average yield loss compared to the reference scenario lies between 0% and 35%, again large differences between cases. As seen in Table 3.4, Cases 1 and 5 stand out again, but in Scenario 2 also

Case 6 expects substantial yield reduction. Mainly weed management in addition to problems caused by PCN are mentioned as challenges in Case 6.

The increased efforts in weed management lead to increase of labour costs in Cases 3 and 6 compared to Scenario 1. Furthermore, more problems with the quality of the potato tuber are expected in Case 2 (due to Mildew) and Case 6 (reduced tuber size due to competition by weeds).

3.7 Scenario 3 – 50% Reduction of pesticide use and risk and a 100% volume reduction of CFS

In this section we describe the results per case taking into account the realisation of the objectives in Scenario 1: 50% reduction in the overall use and risk of pesticides and 100% reduction in the use of more hazardous pesticides (CFS). An overview of the scores of the HRI I in the reference scenario and Scenario 3 is presented in Table 3.3 and estimated yield losses in Scenario 3 is presented in Table 3.4.

The non-chemical measures taken in the cases are not that different from Scenario 2 (See Table 3.7). Only in this scenario Case 6 also starts using a resistant cultivar.

The experts mentioned more challenges, pointing out that potato cultivation becomes very difficult in Scenario 3. The availability of resistant cultivars was indicated to be vital in Case 5. PCN will become a challenge especially in Case 6 and overall weed management will be difficult. In Case 2 the expert indicates that at this level of pesticide reduction the farmers might switch to a biological system. The interaction with the total rotation and weed management is very important; several experts mentioned the weed seed bank build-up as a potential challenge.

Table 3.7 *Non-chemical measures taken in potato in Scenario 3*

	Intended effect	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
DSS	Improving timing of and preventing unnecessary application of crop protection	+	+	+	+		
Additional field inspections	Improving timing of and preventing unnecessary application of crop protection			+			
Further widening the rotation	Reducing disease pressure					+	
Cultivar with resistance	Increasing plant resilience against disease (like phytophthora)		+	+	+	+	+
Break crops	Reducing weed and nematode pressure						+
Interrow weeding	Mechanically reducing weeds						+
Additional ridging	Reducing weed pressure by burying weeds under soil			+	+		
Harrowing early season	Removing weeds		+	+			
Mechanical weeding	Mechanically reducing weeds		++	+	++	++	+
Storage cooling	Reducing active ingredient use by reducing spouting and disease in storage with low temperature			+			
Mechanical haulm killing	Reducing active ingredient use by killing the haulm mechanically		+			+	
Strict field selection	Selecting fields with low pests, disease and nematode problems						+
Post emergence hoeing	Mechanically reducing weeds				+		
Bio fungicide	Biological control as substitute for active ingredients		+			+	

The non-chemical measures are not substantially different from Scenario 1 and 2. The main difference in this scenario is the switch from last remaining Cat 3 active ingredients to Cat 2 active ingredients. The HRI I scores in Scenario 3 are very similar to Scenario 1 and 2 (see Table 3.3).

The yield reduction lies between 4% and 42%. In this scenario every case expects yield loss. With Case 5 (42%), Case 6 (22%) and Case 2 (20%) at very high yield reductions.

With respect to the costs, we see further increase of labour costs in the Cases 3 and 6 due to intensified mechanical weeding. The same applies for the expected quality loss in Cases 2 (due to mildew) and 6 (reduced tuber size due to competition by weeds). Case 1 also expects reduced tuber size in Scenario 3.

3.8 Barriers for non-chemical measures

The non-chemical measures taken in the adapted strategies do come at a cost and are not universally applicable. Some require knowledge that might not (yet) be present, some require further innovation and some require more time than is available due to farm size, labour or machine availability. For instance when the weather is suitable for mechanical weeding, it might need to be suitable long enough to apply weeding to all the hectares of a large farm. Furthermore, the applicability of mechanical weeding is weather dependent. During wet periods, mechanical weeding is not effective. With respect to resistant varieties, the lack of a EU regulatory framework for the use of new breeding techniques results in higher costs and longer periods of breeding resistant varieties. The generation of resistant varieties requires more efforts than generating non-resistant varieties, because the selection includes more properties of the species. By consequence the costs to produce a new resistant variety are higher than of non-resistant varieties.

In Table 3.8 the cost, knowledge intensity, time intensity and availability of non-chemical measures are shown using data from a study about the cost of crop protection measures done for the panel for the future of science and technology (STOA, 2021). Supplemented with expert judgment.

Table 3.8 *Non-chemical measures implications*

Measure	Cost	Knowledge intensity	Time intensity	Availability
DSS	€600/year	/	-	+++
Additional field inspections	/	+	+	+++
Widening the rotation	€10,000/year	+	/	+
Cultivar with resistance	+	/	-	/
Break crops	+	+	+	+++
Interrow weeding	€4,000 (GPS cost)	++	+++	+++
Additional ridging	+	/	++	+++
Harrowing early season	+	/	++	+++
Mechanical weeding	(€15,000 investment for a simple weeder) (€50,000 investment for a precision weeder)	++	+++	+++
Storage cooling	++	+	/	+++
Mechanical haulm killing	+	++	++	+++
Strict field selection	+	+	/	+++
Post emergence hoeing	+	+	++	+++
Bio fungicide	++	++	/	+

Legenda

-=reduced, /= close to none, += low, ++= medium, +++= high.

3.9 Observations

Case 1
In this case the expert expects to comply with objectives of the F2F strategy for crop protection up to Scenario 2 by changing between available active ingredients without losing yield. In Scenario 3 this is no longer possible and the increased weed pressure will start to cause reduced yield and reduced size, according to the expert. The only mitigating effect is the use of a DSS. This aims to reduce the use of active ingredients by reducing the concentration and preventing unnecessary passes by advise about best timing.

Case 2
The expert expects a reduction in yield in the first two scenarios. The local experiments indicate that a 50% reduction in treatments, with minor mitigating measures, result in an average 10% loss of yield. Mainly weed competition is expected to reduce the yield. The mitigating measures taken are the use of a DSS and mechanical shredding. In Scenario 1 passes are reduced from 24 to 22 and herbicides and anti-germination products are reduced to ¾ or even ½. Anti-germination is partly replaced with biocontrol like essential oils. In Scenario 2 the passes are reduced to 20 and mechanical passed are increased to control weeds. In scenario two a mildew resistant variety is used. The yield loss in scenario three is expected to be more substantial. The experts indicate that Scenario 3 is also the point where a farm considers switches to organic farming.

Case 3
The expert expects a yield reduction in all scenarios, reduced herbicide efficacy increases the competition with weeds. This is partly mitigated with increased ridging to supress weeds, use of a DSS for fungicides and a resistant cultivar. Scenario 3 will make weed management even more difficult because all candidates for substitution are prohibited to use, including in other crops, making it more difficult to keep some specific weeds under control in the whole cropping plan.

Case 4
The expert expects a minor reduction in yield in the first two scenarios and a higher reduction in Scenario three. The candidates for substitution are used in weed control and Early blight control. The expert states that fungicides for Early blight control are more important than herbicides. Weeds are controlled with mechanical methods. The impact is mitigated with mechanical weeding, cultivar with tolerance towards diseases and stimulating early development for reduced competition with weeds. Scenario 3 has a more substantial reduction as weed management and seedbank build-up become more challenging.

Case 5
The expert indicates a major loss in yield, increasing with each scenario. The major measures to mitigate the effects are reducing the frequency of potatoes in the rotation, mechanical weeding and using a cultivar with resistance. It is expected that these measures do not mitigate the effects substantially as in the reference scenario the high yield was very dependent on the use of active ingredients.

Case 6
The expert expects a significant loss increasing with each scenario. Reduction in use of pesticides to control PCN is a major factor in this reduced yield. Dosages are reduced and products are replaced with lower impact products. Mechanical weeding is implemented to keep weeds under control, low PCN sites are selected and break crops are used. The tuber size and damage will be affected according to the expert. Resistance to active ingredient is becoming a larger risk. The increasingly strong restrictions on candidates for substitution make weed and PCN management increasingly difficult resulting in increased yield losses.

Overall
An important result is the large differences between cases in the HRI I scores that we observe in the reference scenarios. When Case 1 would be able to raise the crop using the Case 3 crop protection scheme they would already comply to the 50% reduction target. Whether these differences are justified by the difference in climate and disease pressure is unclear. For this study this has not been studied. Besides the climatic differences there could also be a difference in the perceived risk and expertise level of the farmers. However, large differences in farm performance are normal practice, as can be observed in results of farms

in the Farm Accountancy Data Network (FADN).[10] This is also the case with the use of pesticides.[11] Therefore, the cases 1 to 6 do not only represent specific farm types, but also specific farmers with their skills and management practices. These differences regard also the farmer ability to adjust the crop protection strategy according to the objectives elaborated in Scenario 1, 2 and 3. Some have a conservative strategy and are able to mitigate negative consequences, while other farmers already act on the edge of their ability.

Storage of potatoes up to February is the principle for all scenarios. Reduction in sprout inhibitors used for storage seems to be difficult. In almost all cases there is no reduction in Maleic Hydrazide (MH) and 1,4-Dimethylnaphthalene (1-4-DMN). The use of MH, Pyraflufen-ethyl, Carfentrazone-ethyl and 1,4-DMN already account for around 55 HRI score in Case 1. More specifically, the basis for sprout inhibition is the use of MH, all countries agreed a use of 3 kg/ha is a standard approach. This accounts for 20 point in the HRI score. An option to reduce the impact is the use of better storage facilities with mechanical cooling and dormant varieties. This will not fully eliminate the need for these sprout inhibitors, but could significantly reduce it. While storing up to February is not considered difficult, storing for longer periods will be more challenging. For longer periods cooling will be more relevant. However storing for longer periods seems to be a challenge under all scenarios.

The effects on potato cultivation are linked with other crops in the system. Experts mention that when for instance weed management in other crops becomes more difficult as well, this will also have an effect on potatoes. This seems to be the largest obstacle.

In Case 3 the expert indicates that climate change (e.g., heat, drought) is likely to have more impact than the effect of the reduction in the use and risk of pesticides, which are expected to be minor.

Risk of resistance (e.g. of Late blight) is mentioned by experts, especially in Scenario 3. The fewer options to alternate active ingredients used there are left, the more difficult it is to alternate with different active ingredients to prevent resistance in pests and diseases.

The three scenarios require increasing amounts of expertise. A farmer has to be on point on every aspect of the farm, such as covering dump piles, eliminating volunteer potatoes, extra field inspections, field selection, using a DSS and mechanical weeding. This is all knowledge intensive and requires a high level of expertise from the farmer. The labour input is expected to increase, in most cases, resulting in high costs. The cost for pesticides is difficult to assess. Three cases report slightly lower costs per ha, 1 case no change and 2 cases slightly higher costs per ha. Saving pesticides reduces costs whereas substitution of pesticides increases costs. Low risk pesticides are often more expensive than the higher risk versions, since the costs of developing low risk pesticides are higher than of other pesticides. Low risk pesticides have to comply with more strict approval criteria than other pesticides. The risk will become higher and the possibilities to intervene become smaller. This will raise the cost and complexity for farmers. On the long term there will be a new balance where the increased risk, cost and complexity will be an integral part of European farming.

3.10 Conclusions

All scenarios seem to be technically possible, with impact on yield and necessary mitigation measures taken. However this results in larger labour demand and costs to mitigate the effects as much as possible. The ability to mitigate the effects of complying with the targets differs per case, becoming increasingly visible with subsequent scenarios.

In Scenario 1 the average yield reduction is 9%, although there is much difference between cases. This is the result after mitigating effects. The mitigating measures, besides the shift towards lower impact active ingredients, are mechanical weeding, DSS and some cultivar with resistance. These measures increase labour demand, cost and risk. Most high impact active ingredients still in use are fungicides.

[10] Agrimatie.nl.
[11] https://www.cbs.nl/nl-nl/onze-diensten/methoden/onderzoeksomschrijvingen/korte-onderzoeksomschrijvingen/bestrijdingsmiddelengebruik-in-de-landbouw

The reliance on and the overconsumption of pesticides is already visible in the first scenario. Where especially Case 1 has no reduction in yield, which indicates overconsumption. Case 5 with a large decline in yield, indicating the reliance on the pesticides to sustain a high yield.

In Scenario 2 more mechanical weed control is applied to mitigate the effects. Resulting in even more labour, cost and risk. Even with the additional mitigation measure the yield decreases further in some cases and the difference between cases becomes larger. On average the yield reduction is 16%.

Scenario 3 is technically possible but increases the expected average yield reduction to 21%. Economic viability depends on the price paid for potatoes, costs and available labour. In addition not all mitigation measures are available in practice yet. There is especially uncertainty about the availability, acceptance by industry and suitability for industry of potatoes with resistance (to for instance late blight).

Compliance to the scenario requirements also has consequences for the costs. Especially more labour input is required due to application of mechanical weeding and more investments have to be made.

Quality is expected to be affected as well. However the extend of this effect is very uncertain and therefore not included.

4 Potential economic impacts: an exploration

The results obtained from the case studies do not allow for a market impact assessment as they are not necessarily representative for what will happen in the EU market. However, some general comments can be made on the kind of market impacts that may be expected (see Annex C for the framework of reasoning that has been applied). The general impact pattern works as follows:

- The yield reduction induces a reduction of total potato production.
- The decline in production will induce an increase in potato prices, which will partly counteract the yield decline since the increased price are likely to induce some behavioural response of potato growers (e.g. induce them to allocate some more land to potatoes).
- A new market equilibrium will be reached at which the price level is expected to be higher than before and the volume of production and the demand will be lower than before.
- The increased price will have a negative impact on potato users, including potato processors. The higher potato prices increase their sourcing costs and ceteris paribus reduce their profitability.

The magnitude of the impacts will ultimately depend on the so-called supply and demand elasticities, which characterise the responsiveness of potato growers, potato processors and the end users of potato products. From a literature assessment it appeared that there is only limited information available with respect to these elasticities (see Appendix 4 for further details). However, the general picture is that demand and supply elasticities are inelastic, indicating that demand and supply only to a limited extent respond to changes in prices, especially in the short run. This means that for instance a 10% increase of the price will not increase the supply with 10% but by a lower (less than proportional) percentage. This also works the other way around: prices will increase more than proportionally on changes in supply. This is characteristic for essential goods like potatoes with inelastic demand and supply responses. Moreover, the timing of production and demand decisions is different as there is a growing season in between these decision choices. It is this phenomenon which gives rise to the so-called pig (or potato) cycle, and the associated price volatility (which is also confirmed from empirical price information).

The reductions in supply are likely to have a significant impact on the self-sufficiency rate of the EU and on its trade. In the reference situation the EU is estimated to be a net exporter of about 740 thousand tons ware potatoes. When the yields declines, followed by a subsequent supply decline, also this export is likely to decline. Here it should be noted that the percentage decline in trade figures is often much stronger than the percentage changes in yield and supply, as trade has often a kind of 'residual character' (with EU net exports being the difference between domestic supply and domestic demand).

There will most likely be a shift between countries as well. A country that is able to mitigate the effects and minimise the yield reduction will possibly increase its relative share in EU potato production. Alternatively, a member state which is less able to mitigate the effects is likely to face a stronger decline in production and may lose relative market share. The principles elaborated in the Equilibrium Displacement Modelling (Appendix 4), which also apply at member state level, helps to understand this mechanism.

The most probably differentiated impacts at EU member state level are derived from what happens at farm level. Country responses reflect the capabilities and options of farmers mitigating the effects of the policy measures on their production. The data from the six cases show that there is a large variance in the capacity of farmers to respond to the requirements following form the policy scenarios.

Another related dimension to explore when assessing the impacts of alternative targets of reduction in the use of pesticides, is the Indirect land use change (ILUC). As defined by the Council of the European Union (2018), 'Indirect land-use change occurs when the cultivation of crops for biofuels, bioliquids and biomass fuels displaces traditional production of crops for food and feed purposes. This additional demand may increase the pressure on land and can lead to the extension of agricultural land into areas with high carbon stock such as forests, wetlands and peat land causing additional greenhouse gas emissions'.[12] Here, it is recognised that not only changes in imports, but also in exports can lead to indirect land use change. More broadly speaking, indirect land use change can be also defined as 'land whose ultimate purpose is essentially changed from its previous use'. In this context, 'indirect land use change' is defined as opposed to 'direct land use change' which reflects 'a situation in which a field was being converted from corn-for-ethanol to switchgrass production, as in both cases the land would ultimately be used to grow crops for biofuel production'.[13]

Keeping in mind this definitions and leaving aside the specific biofuel purpose, in the context of this report a broad definition of ILUC is adopted using this term to reflect: (i) the changes in land use that occur outside the EU due to the substitution of local (EU) production with imported (non-EU) production (this is the so-called 'ILUC1') which is eventually consumed within the EU; and (ii) the changes in land use that occur outside the EU to produce additional commodities that compensate the 'loss' of EU production that is not exported to the EU (this is the so-called 'ILUC2'). The notion of 'use' that is behind the 'ILUC' definition used in this report goes beyond 'bioenergy/biomass production' and considers use as a broad 'EU demand' regardless it being domestic demand (i.e., local consumption) or foreign (non-EU) demand (i.e., exports). Since the EU is a net exporter of potatoes in the reference situation, we can anticipate that only ILUC2 would be relevant. The expected reduction in exports will introduce a land requirement abroad, which could potentially amount several thousand hectares.

Summarising, the general economic and market impacts expected are declines in yield and production, which will lead to an increase in potato prices. The price increase will lead to a reduction in domestic demand for processing. However, since the demand elasticities are low (suggesting an inelastic price response), there will be not only an impact on the domestic processing, but also on trade. Most likely the various scenarios will lead to a reduction in the current EU's net export. However, also the net trade positions of individual EU member states are likely to be affected and potentially to different degrees and in different ways. However, without knowing more details about the characterisation of the potato sectors at member state level it is difficult to make an estimate of the impacts.

[12] This information has been retrieved from: https://www.iscc-system.org/how-to-deal-with-indirect-land-use-change/
[13] Further discussion and full definition are available at: https://farm-energy.extension.org/what-is-direct-land-use-or-direct-land-use-change/

5 Pathways to mitigate negative consequences

Farmers have different options to mitigate consequences. The objectives of the case studies is to adjust the spraying scheme while minimising the farm-economic consequences as much as possible. As such the first pathway regards the application of integrated pest management (IPM) tools, or make advancements in the application of IPM. In this chapter we will elaborate the pathways that can be applied separately or together. The first pathway regards the advanced application of IPM principles, in line with the choices made in the case studies. We make a distinction between technical pathways, ecological pathways and breeding, and will pay attention to the level of adoption, potential impact, expected costs and benefits, and barriers and drivers for adoption. The second pathway regards differentiation of the supply based on the sustainability performance of the production, that is rewarded in the supply chain. The third pathway regards the application of risk sharing in the contracts between farmers and the potato processing industry.

5.1 Application of IPM

The application of IPM implies that the farmer applies sustainable crop protection techniques as much as possible and applies chemical pesticides as a last resort. When we look more carefully to the crop protection applied on the case farms we can look at the categories of harmful organisms that threaten the potato production. The selection of alternative options will be determined by the following aspects:

1. The relative contribution to environmental impact of the groups of pesticides (fungicides, insecticides, herbicides etc.). In these groups we have to include the active ingredients applied for sprout inhibition
2. The availability of alternative measures
3. The efficacy of these alternative
4. The costs of these alternatives, taking into account scale dependency
5. The level of knowledge that is necessary to apply alternatives, and the associated risks that need to be managed.

When we look at the distribution of pesticides applied, we see herbicides, fungicides and sprout inhibitors as main categories. The application of nematicides and insecticides is of minor importance in the production of ware potatoes (contrary to the production of seed potatoes). In areas with sandy soils, also nematicides are important. Furthermore, alternatives are available for weed control, such as mechanical weed control, although the costs are higher than of the application of herbicides, and results may be more variable as the methods are more weather-dependant. Furthermore, there is a higher risk on damage to young plants, and a higher use of post-harvest herbicide We propose the following three pathways to consider for future development:

1. Technical solutions: mechanical weeding and precision agriculture
2. Ecological solutions: biocontrol and diversification
3. Breeding, for resistance and resilience.

The pathways do not exclude each other but have to be applied in combination.

5.1.1 Technical pathways

The technical solutions regard (1) physical methods such as mechanical weeding and (2) precision agriculture, which are data-driven and based on digital solutions. Mechanical weeding is an obvious example of a technical solution that can be applied, since these techniques are already on the market and are applied by some of the potato farmers, especially before the growing season starts. The application of herbicides is a relative large part in the application of pesticides and part of them belong to risk category 3. In terms of costs, the disadvantage of mechanical weeding is that investment in machinery has to take place (12,000 to 15,000 euros for a machine and 50,000 euros for a camera-guided precision machine). Furthermore mechanical weeding must be executed at a higher frequency than herbicide use, so the labour input and other costs significant higher than herbicide use. In addition, the efficacy of mechanical weeding is more weather dependent. The effectiveness reduces significantly in wet weather conditions. Further research takes place to develop technology with less harm to young plants.

Precision agriculture (PA) is a modern farm management concept using digital techniques to monitor and optimise agricultural protection processes. The most well-known application of precision agriculture regards the DSS to control late blight, based on data about weather conditions, weather forecast and disease pressure. In this way the volume of fungicides that will be applied to control late blight can be reduced significantly. This DSS is applied in most cases. The level of adoption is rather high. The license costs for DSS are limited (order of size) and can be compensated by saving on pesticide use. Also GPS controlled tractor steering can be classified as precision agriculture because it may help to control weed populations by correct alignment of cultivation passes.

More advanced techniques that will be applied regard the early detection of diseases, e.g., using drones, reducing the application rate by automatic boom height control, automatic GPS nozzle control to eliminate overlap and to treat only affected spots. These techniques contribute to reduction in the use of pesticides and reduction of emissions. An example of precision agriculture in potato production regards the spot specific application of soil herbicides. The spot specific application makes the dose dependent on the level of organic matter in the soil.

However, the application of more advanced PA techniques requires high investments, while the volume of pesticides that can be saved depends on the scale on which it is applied. By consequence the application of precision agriculture that require expensive equipment is scale dependent. Therefore, for most of these advanced PA techniques, the level of adoption is rather low. An option to reduce the costs is the involvement of contract workers, who can invest in PA equipment and use it on multiple farms. Joint efforts between suppliers of PA techniques, farmers and contract workers are needed to implement these technologies at a larger scale. The current adoption rate of those advanced techniques is rather low, since they have been recently developed. Based on the existing technological readiness level it can be expected that some of these techniques will be available for application in practice in the period until 2030. An example is the autonomous flying drone for monitoring pests and diseases.[14] Barriers for adoption are the skills necessary to apply, availability of independent data about costs and benefits, interoperability, standardisation, smart use of sensor data (Kempenaar, 2018).

5.1.2 Ecological pathway

Ecological pathways regard techniques that make use of the natural environment to reduce disease pressure and crop protection mechanisms derived from nature. The following categories can be distinguished:
1. Biocontrol
2. Ecologically diverse systems.

Biocontrol: micro-organisms or beneficial insects that can be applied to control diseases and pests, and diversified systems (Riemens et al., 2021).

The number of introductions of biocontrol agents has exceeded the number of introductions of chemical pesticides. Despite the growth, less than 5% of the plant protection products are biocontrol agents (Buckwell, 2020). Contrary to crops grown in greenhouses, only few biocontrol agents can be applied in arable crops such as potato. An example is *Bacillus thuringiensis*, a bacterium that is applied to control insects in Poland, where insects cause larger problems than in countries with a maritime climate. For farmers, the main limitation to apply biocontrol is the perceived limited effectiveness of biocontrol agents in comparison with the currently available alternatives and this directly relates to higher cost as it impact upon yield. Since most farmers are risk averse, they require the same level of effectiveness as the pesticide they are intended to be a substitute for. Furthermore, gaining experience and increase of knowledge are necessary for increasing the trust in biocontrol agents. The adoption of biocontrol agents by potato growers is limited (Lamichhane et al., 2017), since only a few efficacious biocontrol agents are available to control pests and diseases.

[14] https://www.proeftuinprecisielandbouw.nl/autonome-drone-voor-gewaswaarneming-bij-van-den-borne

Ecologically diverse systems have been developed to include more genetic variety in the cropping system that makes the crop more resilient. Three dimensions can be distinguished:

1. Temporal diversity: rotation, including cover crops that provide green manure;
2. Spatial diversity: extending and improving semi-natural habitats such as hedgerows, flower strips along the fields etc.;
3. Genetic diversity: mixing crops such as strip cropping.

All types of diverse systems have the objective to make the cultivation system more resilient against pests and diseases. As such, it contributes to some reduction of pesticide use. However, in most cases, application of those principles results in higher costs, or reduced revenues (Riemens et al., 2021). E.g., if the rotation scheme will be extended, the relative share of potato will reduce. Farmers may want to keep the share of potato high because it is the may be the most valuable crop in the rotation scheme and because of the high investment in storage facilities.

To a certain extent, diversified systems are applied in the entire EU. Potatoes can only be grown in rotation with other crops such as wheat, maize, sugar beet, oil seed rape and sunflowers. The application of spatial diversity can be extended, but will have minor effects on the reduction of pesticide use, which is currently the case in some of the case countries, e.g., the Netherlands. The application of more genetic diversity has more consequences and is still subject of research.

5.1.3 Resistant cultivars

An option is to apply resistant cultivars, especially against late blight. However, resistant cultivars that comply with the requirements of the potato processing industry are hardly available. Breeding is necessary to produce new resistant varieties. This option is complicated for the following reasons. First of all, the current practice of conventional breeding is a long-lasting process which takes around ten years. This period can significantly be shortened by the application of new breeding techniques (NBTs), e.g., CRISPR-CAS, but these techniques are not permitted in the EU for application under the existing EU regulation for genetic modification (GMO). Furthermore, the combination of multiple goals such as resistance against late blight and nematodes, while maintaining the properties required by the processing industry complicates the breeding process. Therefore, the perspective of this pathway remains limited as long as NBTs are not allowed to apply and the machinery is unable to process less favourable varieties. Furthermore, after selection of the new variety, a few years is necessary to multiply the new variety to produce the volume necessary for market introduction.

Furthermore, organic farming is suggested as a solution by the EU in general, given the objective to have at least 25% of the agricultural area under organic production in 2030. The share in the market for processed organic potato products is minimal. The product requirements for processing the potatoes such as the required size of the potatoes cannot be easily fulfilled by organic production. However, experiences in organic potato production can be used for assessing the feasibility in an IPM approach.

5.2 Differentiation of product supply on the basis of sustainability

A long lasting complaint about the transition towards a sustainable agriculture is that the consumer does not want to pay for it voluntarily, while the costs are higher than for current production. As a consequence, it took a long time to differentiate the supply of products on the basis of sustainability. However, within the EU, successful examples exist about sustainable product differentiation in the supermarket. Examples are differences in supply of eggs and meat, with associated different prices. This principle can also be applied in product differentiation of sustainable plant products, although it is likely that this principle needs to start to be applied on fresh products, followed, not accompanied, by processed products. It is important that the product requirements are not unilaterally imposed by retailers.

In Switzerland a successful example exists of differentiation of the product supply on the basis of sustainability criteria, that are composed by the supplying farmers. The drawback is that this solution currently only functions in a small, closed market situation, and would be difficult to apply the open market of the EU.

However, a concept that is positioned between conventional and biological agriculture seems promising and is something that is already applied in other sectors. Currently regenerative agriculture (RegAg) seems to be a concept that might be suitable for this purpose. RegAg does not have a strict definition. Based on the gathered insights, Schreefel et al. (2020) propose a provisional definition defining RegAg as:

> ‘an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production’ (Schreefel et al., 2020).

The lack of a strict definition can be a weakness, but also allows for more easy adoption of sustainable measures by farmers, such as pesticide reduction.

5.3 Risk management

One of the expected consequences of the F2F strategy objectives is the likelihood that the fluctuation in yield and quality amplified by climate change will increase. More extreme weather conditions on the one hand, and reduced options to control pests and diseases on the other hand can lead to yield and/or quality reduction in years with extreme drought or heavy rainfall, as we have experienced in the last decades. This will have consequences for the processing industry, with an increased risk on supply shortage, dependent on irrigation possibilities. This situation requires a strategy to anticipate potential shortages in the supply. We see the following options:

1. Improvement of the storability of potatoes, without the additional use of chemical pesticides. This requires research in cooling techniques, that keep the potatoes in good conditions for the long term. This technique enables farmers and processors to increase the volume of potatoes kept in stock longer than a year. In this way processors will be less dependent on the yield level of a single growing season. This option requires more investment in storability capacity with higher costs (electricity use). The storability can also be supported by selection of more dormant varieties.
2. Inclusion of risk in the contract. Farmers and processors can make agreements how to share the risk in the case a farmer is not able to deliver the contracted volume with the required quality level. Possible contracts and the spot market are presented in Janssens et al. (2021). The risk can be borne by the processor, or by the farmer. In the last case the processor needs to pay a risk premium to the farmer. An alternative is to reduce the contracted volume in relation to the produced volume. In this case, the processor needs to contract more farmers. This means for the farmer that more potatoes need to be sold after harvest, with a high risk on low prices. The processor needs to pay higher prices. However, this solution does not work for potatoes traded on the spot market.

5.4 Conclusion about the pathways

The pathways presented in the Sections 5.1, 5.2 and 5.3 do not exclude each other, but need to be combined in order to realise the best combination of measures in terms of efficacy, contribution to pesticide use and risk reduction, costs and risk. Furthermore, we have to consider the timeline: measures that can be applied until 2030 and measures that can only be applied afterwards.

Until 2030
Techniques that are recommended to be applied until 2030 are DSSs as far as they are not applied, since the level of adoption is already considerable. Furthermore, we recommend to apply mechanical weeding and PA techniques, especially drones for monitoring and early detection and equipment to reduce the application rate. The last techniques can be applied by large farms or contract workers. Furthermore, ecological principles such as a wider rotation and the use of flower strips and hedgerows are applicable. Finally *Bacillus thuringiensis*, a biocontrol agent can be applied to control caterpillars. Farmers have to develop their strategy in such a way that the measure are as complementary as possible, contribute to reduction of fluctuations in yield, take profit of scale dependency, have the lowest costs and risks and require not more investment than necessary.

After 2030
The development of resilient cultivation systems with application of measures such as biostimulants takes more time. The same applies for breeding resistant varieties which is promising after 2030 and the continuous search for biocontrol agents.

Differentiation of product supply on the basis of sustainability techniques need collective efforts of growers, processors and retailers to develop sustainability standards and how the products can be placed in the market differentiated on the basis of compliance to these sustainability standards. This can be a task for EUPPA in cooperation with other branch organisations representing the interest of farmers and value chain partners in the production and sale of food.

6 Discussion, conclusions and recommendations

6.1 Discussion

Comparison with Impact Assessment study commissioned by Croplife EU and Croplife International

The approach of this research has largely been based on the study executed in 2021, commissioned by Croplife Europe and Croplife International (Bremmer et al., 2022). A number of methodological and political issues discussed in Chapter 5 of that report are still relevant for this study but will not be repeated. This study deviates in the following aspects to this study:

1. The focus is on a single crop: potatoes produced for the processing industry;
2. The geographical area is limited to northern and north-western Europe;
3. The assessed objectives of the F2F strategy have been limited to crop protection aspects;
4. Attention has been paid to the availability of pesticides, by inclusion of additional limitation to the use of more hazardous pesticides;
5. In this study more attention has been paid to alternative solutions to cope with the F2F objectives.

When we compare the results at crop level for potato with the crops analysed in the above-mentioned study, we conclude that they are in line with other annual crops such as wheat, rapeseed and sugar beet. In the Case 3, the expected consequences of climate change are even more severe than of the F2F strategy objectives for crop protection. Furthermore, we see that the limitation of the use of more hazardous pesticides will lead to additional farm economic consequences by additional yield reduction or additional costs.

Availability of pesticides

Although the registration of active ingredients is not part of the F2F strategy, there is a link. It is likely that a number of active ingredients will lose their registrations by 2030; either because the registration holder decides not to apply for re-registration, or the active ingredient does not comply with the existing criteria anymore. In a study regarding the consequences of the European crop protection policy for greenhouse horticulture in the Netherlands, we have calculated that more than 70% of the chemical active substances currently registered will pass their expiration dates within 4 years (Bremmer et al., 2023). 32% of the chemical pesticides that passed the expiration date between 2018 and 2022 has been renewed. Taking into account the expected renewals for microbial active ingredients and active ingredients with the status ‘pending’, we expect that the number of active ingredients will decrease by 25 to 30% in the next four years.

The decrease in the availability of pesticides will contribute to realisation of the targets for crop protection of the F2F strategy. If active ingredients change from (HRI I)risk category due to reassessment, the weighting factor will change not only after the reassessment but also retrospectively to 2011. Especially the high weighting factor of 64 for active ingredients that will lose registration will contribute to realisation of the targets. Therefore, we expect that the reassessment of active ingredients will be more important in realising the targets for crop protection policy of the F2F strategy than the proposed Sustainable Use of Pesticides Regulation.

Furthermore, MS can have their own policy, additional to the F2F strategy. In the Dutch Parliament, an amendment has been accepted to reduce the use of more hazardous pesticides by 50% in 2025 and by 95% in 2030. Active ingredients that lose their registration will move to risk category 4, and in retrospect are labelled a weighting factor of 64.

Variation in results

The assessment by the experts of the consequences of Scenario 1 (50% reduction in use and risk of pesticides and 50% reduction in the use of more hazardous pesticides) show significant differences between the case studies. Results vary from 0% reduction in one case farm up to 20% reduction in another. This raises the question how to interpret these differences. The following aspects need to be considered:

1. We have decided to execute the assessment for a specific farm, and not for an average farm. A specific farm can deviate from the average farm. An example is Case 5 where the specific farm, is rather small, but with a high yield per ha.
2. When we compare the performance of comparable farms in a region, we observe large differences in farm performance such as yield level and pesticide use. This can be the consequence of farm structure (e.g., soil type, health and fertility), farmers skills and risk attitude. Therefore the assessment not only takes place for a specific farm, but also for a specific farmer.
3. Differences between countries can play a role, such as availability of pesticides, dependency of pesticides, pest and disease pressure, the support and services are organised etc.
4. Finally, also differences between the experts assessing the impacts can play a role. Especially the risk perceptions could play a role in assessing the yield reduction.

Therefore, the variation shown in the results is not unexpected, and in line with the results of the impact assessment study of the F2F strategy for different crops in the EU (Bremmer et al., 2022). The interpretation of the results points toward variances in results in practice. Some farmers will have no difficulties to realise the objectives, but others will experience significant consequences. Furthermore, the figures of each case-study cannot be considered as fully representative for the case countries separately, but it has added value for the entire region where potatoes are produced for the processing industry. This has also consequences for the interpretation of the results at macro-level. The message however is that reduction of the yield level in the entire EU will lead to sharp price increases. The production will slightly shift to countries which have the lowest yield reduction when complying to the F2F strategy objectives on crop protection, as far as additional land is available for potato production.

Costs

In the questionnaire we have asked the experts to indicate changes in costs, especially labour and machinery costs. Administrative burden has not been taken into account. Most experts reported higher labour and machinery costs due to application of mechanical weed control as has been elaborated in Chapter 3. In Case 1 farm no change in costs have been reported and in Case 2 farm a reduction in costs. However, the reduction can be explained by the extension of the rotation scheme with a reduction of the share of potatoes in the scheme. In general, shifting from the use of pesticides to sustainable alternatives will lead to higher costs. However, in comparison to the yield reduction, the change in costs is less important.

Policy objectives and development

The F2F and BD strategies include clear targets for crop producers to meet in 2030. In June 2022, the Sustainable Use Regulation (SUR) has been presented as a successor of the criticised Sustainable Use Directive (SUD). Since too little result in sustainable pesticide use has been obtained under the SUD according to the European Commission assessment, the SUR will get a more binding character. The SUR will act as a mean to implement the F2F strategy objectives for crop protection. The European Commission has decided that the MS can deviate from the 50% reduction targets, but that these targets need to be achieved for the entire EU. Therefore, criteria for differentiation have been developed as a basis for negotiation:

- The average use of pesticides measured in kg. a.i. per ha
- The reduction in pesticide use and risk measured by the HRI I in the period 2011 to 2017. The reference period for the measurement of reduction targets is 2015 to 2017. The progress is measured relative to the average of the period 2011 – 2013 HRI value (index number = 100).

In Table 6.1 we have listed the index numbers for the case countries except the UK, which is no longer a MS of the EU. This table needs to be read as follows: The first column (2015-2017) contains the relative reduction in use and risk of pesticides use measured by the HRI I of the period 2015-2017 compared to the period 2011-2013. The second column contains the reduction in 2019 compared the period 2011-2013. The last column contains the comparison of the same figure compared to 2015-2017. The figures show that Belgium and the Netherlands have made the largest reduction in the period before the reference period

2015-2017. Belgium and France have made the largest progress in 2019. Especially the figures in France show a significant reduction. For Belgium and France figures for 2020 lack. It should be noted that these figures reflect total pesticide use, and not only pesticide use in potato cultivation.

Table 6.1 *Progress in reduction of pesticide use and risk (%). for the case countries measured by HRI I*

Case country	2015-2017 compared to 2011-2013	2019 compared to 2011-2013	2019 compared to 2015 - 2017
Belgium	87	66	76
France	96	63	66
Germany	97	85	87
The Netherlands	83	68	82
Poland	95	81	85

We can observe that France has made the largest progress already (two-thirds of the reduction target (Table 6.1). In contrast, Germany, the Netherlands and Poland have made less progress. All three countries report a slight increase of the pesticide use and risk in 2020 compared to 2019.[15] Since all countries have made progress in the realisation of the F2F objectives for crop protection, the assessment of yield reduction in Scenario 1 (Table 3.4) based on the reference year 2021 for all case studies can be considered as an overestimation. However, this scenario assumes the availability of all pesticides until 2030. Since we expect a significant reduction in the availability of pesticides (see description earlier in this section), the assumptions under Scenario 2 and 3 are more realistic, but the assessment of these scenarios also contain overestimation like Scenario 1.

Policy expectations
The negotiations with the Member States about the implementation of the SUR are ongoing. These negotiations are not public. However, at Member State level, national parliaments are frequently informed about ongoing discussions in EU council working groups, consisting of policy officers of the Member States. These discussions regard the issues regarding the implementation of the SUR, and do not contain information about the likelihood of adoption in the EU.

With respect to the legislation about new breeding techniques, the European Commission published a legislative proposal in July 2023 containing less restricting conditions to apply New Genomic Techniques in Plant Breeding. This opens the perspective to apply techniques such as CRISPR-CAS in breeding, reducing the lead times and the costs of producing new varieties with resistance against pests and diseases such as late blight. This opens the way for introducing resistant varieties that have been bred by application of the new breeding techniques.

Implementation in practice
In this study we have focused on a single crop, and the options farmers have to mitigate negative consequences in the production of this crop. However, potatoes are always produced in rotation with other crops. Since it is the most important crop in the rotation scheme generating the highest margin, farmers will tend to reduce the pesticide use and risks in other crops within the rotation scheme, although the pesticide use can be lower than in potato. This will especially be the case if prices for potatoes will increase due to reduction in the production volume.

Interaction between climate change and crop protection
Climate change can have direct effects on yield and quality levels of potato production, and indirect effects. Direct effects regard higher temperatures, more periods of severe drought and early start of the growing season with a higher probability on frost damage. Indirect effects regard the introduction of new pests and diseases which survive under the changed climatic conditions, a higher disease pressure due to higher humidity, but also a lower disease pressure and a higher pest pressure in periods with severe droughts. Crop protection measures will be necessary to control these pests and diseases.

[15] These figures have not been presented in Table 6.1, since they were not available for France and Belgium.

The experts consulted in the case studies have been asked to comment on listed potential consequences of climate change and the interaction with pest and disease pressure. They expect that severe drought, heat waves, increased air humidity and early start of the growing season will have consequences for yield and/ or quality. On the contrary, seasons with heavy rainfall can lead to increased disease pressure with consequences for the yield level. Effects such as more hail damage and salinisation of the soil are of minor importance.

Climate change and the timeframe of the effects (seven years up to 2030) was found to be too complicated for quantitative assessment of the impacts.

Consequences for the potato processing industry
The potato processing industry has to cope with the consequences of the F2F strategy, expected reduction in the availability of pesticides and the impact of climate change. The consequences of the F2F strategy on potato production are yield loss (on average 9% in Scenario 1, see Table 3.4), quality loss and increased costs, due to increased labour input and additional investments in equipment and machinery, such as mechanical weeding. Furthermore, these consequences are not equally distributed over the farmers. Some farmers will have severe problems to meet the targets and experience severe losses, while other farmers will be able to meet the targets without losses. However, meeting the targets is not an obligation at individual level but at Member State level. The expected reduction in the availability of pesticides will enlarge the consequences. On the one hand, it contributes to the realisation of the targets, on the other hand it reduces the availability of alternative options to mitigate negative consequences. The results of Scenario 2 and 3 will be more likely, but need to be corrected for the overestimation due to the fact that Member States have already made progress in realisation of the F2F strategy targets for crop protection (see Table 6.1), and therefore more in line with the results of Scenario 1. For the processing industry this would mean that the supply might reduce and shift between regions.

The reduced yield, partly compensated by expansion of the area, and the increased costs will face the potato processors with higher costs to source potatoes. Furthermore, climate change and reduced effective options to manage pests and diseases will face the producers with higher fluctuations in the yield level. This requires a careful adjustment of the sourcing strategy of the processing industry. In the short term the focus should be on reduction of fluctuations and risk management. This implies intensified cooperation with their supplying farmers, encouraging them to apply the measures until 2030 outlined in Section 5.4 in combination with measures to reduce risk as outlined in Section 5.3. In the long run the focus should be on transition towards fully sustainable potato production and processing, in line with the measures after 2030 presented in Section 5.4 and the cooperation with value chain partners to differentiate the product supply in the retail on the basis of the sustainability performance as presented in Section 5.2. Furthermore, the focus has to be on reduction of fluctuations in the yield level, and making the production systems less vulnerable for weather conditions. The focus for the long run does not mean that the efforts can be made after 2030, but need to be started in parallel to the actions with the focus until 2030.

6.2 Conclusions

Our conclusions are as follows:

1. Implementation of the F2F strategy objectives for crop protection can lead to a reduction in yield of potato production ranges from 0% to 20% in Scenario 1 with an average of 9%, depending on the context (region, farmer, availability of alternatives).
   If pesticides lose their registration up to 2030, the yield loss can be doubled. Scenario 2 and 3 reflect these developments and have an average yield loss of 16 and 21% respectively. The effects on yield reduction will partly be strengthened by consequences of climate change.
   Note: The reduction will be lower if we take into account the progress already made in realisation of the objectives since the reference period 2015-2017.
2. The costs for crop protection will increase due to additional labour input and investments in mechanical weeding, precision agriculture and Decision Support Systems. Reduced yield and higher costs results in a higher per unit costs of potatoes.

3. The yield reduction induces a reduction of total potato production, although this decline in production is expected to be less then proportional, since we expect an extension of the area on which potatoes will be cultivated;
4. The decline in production will induce an increase in potato prices, which will partly counteract the production decline since the increased price are likely to induce some behavioural response of potato growers (e.g. induce them to allocate some more land to potatoes). However, the availability of additional land for potato production is limited.
5. The more variable yields and increased price will have a negative impact on potato users, including potato processors. The higher potato prices increase their sourcing costs and ceteris paribus reduce their profitability. Consequently, European potato processors loose competitiveness compared to non-European processors.
6. Reduction of the yield level in the entire EU will lead to sharp price increases. The production will slightly shift to countries which have the lowest yield reduction when complying to the F2F strategy objectives on crop protection, provided that additional land is available.
7. Both technological and ecological options and breeding can contribute to mitigating negative consequences. Mechanical weeding is an obvious example, as well as the application of decision support systems. Other precision agriculture techniques require more development and the advantage can be scale dependent. It is likely that the costs for crop protection per ha will stay at a higher level compared to the existing costs per ha.
8. Both biocontrol and diversified systems will also contribute as they already do, although the efficacy can be lower, and the costs higher. Breeding can significantly contribute, but reduction in lead time of new varieties cannot be expected as long as new breeding techniques are not allowed.

6.3 Recommendations

- Farmers should invest in both technological (application of decision support systems, mechanical weeding) and ecological pathways (application of biocontrol agents and diversified systems. These investments also require investments in knowledge and elaboration of a careful crop protection strategy; Differentiation in application of techniques is recommended for the mid and long term. For the midterm until 2030 we recommend to apply decision supports systems, mechanical weeding, precision agriculture a wider rotation and flower strips. In the long run we recommend to invest in using resistant varieties, application of biocontrol embedded in a resilient growing system.
- The potato processing industry should cooperate with farmers by assisting them in making decisions about reduction in pesticide use and risk and integrated pest management and sharing risks in line with the previous recommendation.
- The potato processing industry should focus on risk management in the midterm until 2030 and on intensified cooperation with value chain partners to differentiate the product supply on the basis of the sustainability performance.
- The European Commission should adjust the regulations to allow New Breeding Techniques for resistance breeding.
- Breeders should develop potato varieties resistant against pests and diseases that currently require significant use of pesticides and/or pesticides belonging to HRI I risk group 3, such as *Phytophthora infestans.*
- The whole supply chain (from farmer to processor, retailer and regulators) should accept new, resistant varieties.
- The entire processed potato value chain should communicate about the sustainability of the products, and to elaborate minimum sustainability standards that growers must meet in order to supply.
- Research institutes should continue research in both technological and ecological pathways. For the long term to work on resilient cultivation systems less vulnerable for pests, weeds and diseases, and less dependent from plant protection products.

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Appendix 1 Questionnaire

Sheet Instructions

1	Fill in the sheets 'Generic questions' (description of farm, cultivation) and 'Elaboration of scenarios'. In the sheet 'Explanation of scenarios' the objectives of each scenario are explained
2	Fill in only the white coloured cells with cell borders
3	Scenario 4 contains the combination of Scenario 1 and 2. By consequence, the pesticides applied in Scenario 1 and the nutrients applied in Scenario 2 are copied.
	Scenario 4 contains the 10% set aside objective additionally, which need to be incorporated in the assessment of the consequences
4	The objectives have the time horizon of 2030. This means that the autonomous technical developments in the coming 10 years need to be included in the analysis!
5	In case of questions, don't hesitate to contact the involved project team member!

Sheet generic questions

Description of the specific farm that serves as an example for the analysis of the scenarios
Provide justification to explain why this is farm is 'specific' for the selected crop and country:
Question
Case crop
What is the case crop?
What is the region where this type of farms are common?
Normal sowing and planting time?
Normal harvesting time?
Description of the specific farm, crop and field:
Which crops are grown at the farm in a specific rotation scheme?
What is the time period of this rotation scheme
Specify the relative share per crop summing up to 100% over the whole rotation period
Describe the complete rotation cycle
What is a specific farm size measured in ha?
What is the soil type?
What is the percentage of content of organic matter in the soil?
What is the level of acidity (pH)
Labour input
Family hours per year
Paid labour hours per year (contract work excluded)
Which machinery is present for:
Tillage?
Crop protection?
Mechanical weed control?
Fertilisation (manure, artificial fertilisers)?
precision agriculture?
Which cultivation operations are executed by a contract worker?
Soil tillage and fertilisation
Which types of soil tillage is applied
What is the frequency of soil tillage?

Description of the specific farm that serves as an example for the analysis of the scenarios
Explain the answer, if necessary
Description of crop protection for the case crop:
List the main pests in the crop
List the main diseases in the crop
List the main weeds
What is the main crop protection strategy:
IPM-strategies? Please describe
chemical
non-chemical measures: list machinery used, frequency, crop stage
application of buffer strips?
Other methods? Please describe

Sheet Explanation of the scenarios

	Reference scenario	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
	Common Agricultural Practice	**Reduction of use and risks of pesticides**	**Reduction of use and emissions of nutrients**	**Organic agriculture and set aside**	**combination of Scenario 1, 2 and 10% set aside**
Generic Targets		50% reduction in use and risks of pesticides	50% reduction in nutrient losses, ensuring no deterioration of soil fertility	25% of land under organic agriculture	Targets of Scenario 1 and 2
		50% reduction in use of hazardous pesticides	20% reduction in use of fertilisers		10% set aside of agricultural area.
Explanation and indicator		Use of pesticides: kg active ingredients per ha Risk of pesticides: risk calculated with HRI I of EC Hazardous pesticides: plant protection products containing active substances that meet the cut-off criteria as set out in points 3.6.2. to 3.6.5 and 3.8.2 of Annex II to Regulation (EC) No 1107/2009 or are identified as CFS in accordance with the criteria in point 4 of that Annex.	Nutrient losses: total nutrient inputs minus total nutrient outputs measured in kg per ha Soil fertility: no reduction of organic matter content in the soil Use of fertilisers: Mineral fertilisers, animal manure, other organic fertilisers	Organic production according Regulation (EU) 2018/848.	Set asides include inter alia, buffer strips, rotational or non-rotational fallow land, hedges, non-productive trees, terrace walls and ponds.
How to apply in scenario?		Adjust crop protection, meeting the targets while limiting economic consequences as far as possible	Adjust nutrient management meeting the targets while limiting economic consequences as far as possible	Adjust the cultivation practice to 100% organic production.	Adjust the crop protection, nutrient management according to Scenario 1 and 2, add 10% set aside target.

Sheet elaboration of the scenarios

Which non-chemical measures are applied in this scenario in addition to the reference scenario?
Which measures are applied to prevent emission to soil, air and water?
Which measures are applied to increase soil fertility?
Which measures are applied to increase resilience against pests and diseases?
What is the estimated yield in this scenario?
How do the scenarios affect the yield
How do the scenarios affect the quality of the product
Indicate whether the following aspects contribute to quality reduction:
Deviating submerged weight
Changed size (sorting)
low dry matter percentage
Which effects does the expected climate change by 2030 have on the yield and quality?
Increased likelihood on heat waves
Increased air humidity
Longer periods with drought
Early start growing season with increased risk on frost damage
higher risk on salinisation due to drought
Increased risk on damage by hail
List differences (pesticides used, adjusted doses, adjusted frequencies, alternative measures applied) compared with reference scenario
Socio-economic questions:
Employment for farmer
Employment for employees or contract workers
Change in costs
Labour
Machinery (energy, depreciation, maintenance)
Pesticides
Yield
Price
Which other effects can be mentioned?

Appendix 2 Overview of institutes and experts involved in case studies

Country	Institutes
Belgium	PCA: Ilse Eeckhout en Pieter Vanhaverbeke
France	Junia: Maud Roblin and Marie Stankowiak
Germany	Julius Kühn Institute (JKI): Arnd Verschwele
The Netherlands	Wageningen Plant Research: Hilfred Huiting
Poland	Kuyavian-Pomeranian Agricultural Advisory Centre: Josip Zubac
United Kingdom	Adas: Tim Boor

Appendix 3 Spraying schemes ware potato

Reference scenario

Fungicide | Herbicide | Insecticide | Nematicide | Haulm killing | sprout inhibition storage | Sprout inhibition in field

	Case 1		Case 2	97	Case 3		Case 4		Case 5		Case 6	
AMETOCTRADIN	AMETOCTRADIN		AMETOCTRADIN	0,465	AMETOCTRADIN		AMETOCTRADIN		AMETOCTRADIN		AMETOCTRADIN	
AMISULBROM	AMISULBROM	0,06	AMISULBROM		AMISULBROM		AMISULBROM		AMISULBROM		AMISULBROM	
AZOXYSTROBIN	AZOXYSTROBIN		AZOXYSTROBIN		AZOXYSTROBIN		AZOXYSTROBIN		AZOXYSTROBIN		AZOXYSTROBIN	
BENTHIAVALICARB-ISOPROPYL	BENTHIAVALICARB-ISOPROPYL		BENTHIAVALICARB-ISOPROPYL		BENTHIAVALICARB-ISOPROPYL		BENTHIAVALICARB-ISOPROPYL	0,084	BENTHIAVALICARB-ISOPROPYL		BENTHIAVALICARB-ISOPROPYL	
COPPER OXYCHLORIDE	COPPER OXYCHLORIDE		COPPER OXYCHLORIDE		COPPER OXYCHLORIDE		COPPER OXYCHLORIDE		COPPER OXYCHLORIDE	1,1	COPPER OXYCHLORIDE	
CYAZOFAMID	CYAZOFAMID	0,24	CYAZOFAMID	0,32	CYAZOFAMID		CYAZOFAMID	0,24	CYAZOFAMID		CYAZOFAMID	0,24
CYMOXANIL	CYMOXANIL	0,27	CYMOXANIL	0,27	CYMOXANIL		CYMOXANIL	0,12	CYMOXANIL	0,31	CYMOXANIL	0,60
DIFENOCONAZOLE	DIFENOCONAZOLE	0,25	DIFENOCONAZOLE		DIFENOCONAZOLE	0,45	DIFENOCONAZOLE	1,5	DIFENOCONAZOLE		DIFENOCONAZOLE	
DIMETHOMORPH	DIMETHOMORPH		DIMETHOMORPH	0,34875	DIMETHOMORPH		DIMETHOMORPH		DIMETHOMORPH		DIMETHOMORPH	
FLUAZINAM	FLUAZINAM		FLUAZINAM	0,885	FLUAZINAM		FLUAZINAM		FLUAZINAM		FLUAZINAM	
FLUOPICOLIDE	FLUOPICOLIDE	0,3	FLUOPICOLIDE		FLUOPICOLIDE		FLUOPICOLIDE	0,15	FLUOPICOLIDE	0,02	FLUOPICOLIDE	0,20
FLUTOLANIL	FLUTOLANIL	0,24	FLUTOLANIL		FLUTOLANIL		FLUTOLANIL		FLUTOLANIL		FLUTOLANIL	0,05
MANCOZEB	MANCOZEB	8,88	MANCOZEB	5,13	MANCOZEB	0,45	MANCOZEB		MANCOZEB	5,13	MANCOZEB	12,80
MANDIPROPAMID	MANDIPROPAMID	0,3	MANDIPROPAMID	0,3	MANDIPROPAMID		MANDIPROPAMID	1,6	MANDIPROPAMID		MANDIPROPAMID	0,35
METIRAM	METIRAM		METIRAM		METIRAM	3,15	METIRAM		METIRAM	1,26	METIRAM	
OXATHIAPIPROLIN	OXATHIAPIPROLIN	0,02	OXATHIAPIPROLIN		OXATHIAPIPROLIN		OXATHIAPIPROLIN	0,036	OXATHIAPIPROLIN		OXATHIAPIPROLIN	0,03
PENFLUFEN	PENFLUFEN		PENFLUFEN		PENFLUFEN		PENFLUFEN	0,03	PENFLUFEN		PENFLUFEN	
PROPAMOCARB	PROPAMOCARB	3	PROPAMOCARB		PROPAMOCARB		PROPAMOCARB	1,5	PROPAMOCARB		PROPAMOCARB	2,00
PROTHIOCONAZOLE	PROTHIOCONAZOLE		PROTHIOCONAZOLE		PROTHIOCONAZOLE		PROTHIOCONAZOLE	0,0054	PROTHIOCONAZOLE		PROTHIOCONAZOLE	
ZOXAMIDE	ZOXAMIDE	0,6	ZOXAMIDE		ZOXAMIDE		ZOXAMIDE		ZOXAMIDE		ZOXAMIDE	
ACLONIFEN	ACLONIFEN	1,2	ACLONIFEN	1	ACLONIFEN	2,00	ACLONIFEN	0,9	ACLONIFEN		ACLONIFEN	1,05
CLETHODIM	CLETHODIM		CLETHODIM		CLETHODIM	0,18	CLETHODIM		CLETHODIM		CLETHODIM	
CLOMAZONE	CLOMAZONE	0,072	CLOMAZONE	0,06	CLOMAZONE		CLOMAZONE		CLOMAZONE		CLOMAZONE	
FLUFENACET	FLUFENACET	0,48	FLUFENACET		FLUFENACET	0,48	FLUFENACET		FLUFENACET		FLUFENACET	0,48
GLYPHOSATE	GLYPHOSATE	1,44	GLYPHOSATE		GLYPHOSATE		GLYPHOSATE	0,72	GLYPHOSATE		GLYPHOSATE	1,35
METOBROMURON	METOBROMURON	1	METOBROMURON		METOBROMURON		METOBROMURON	1,5	METOBROMURON		METOBROMURON	
METRIBUZIN	METRIBUZIN	0,35	METRIBUZIN	0,2	METRIBUZIN	0,35	METRIBUZIN		METRIBUZIN	2,4	METRIBUZIN	0,69
PROSULFOCARB	PROSULFOCARB		PROSULFOCARB	2	PROSULFOCARB		PROSULFOCARB	1,6	PROSULFOCARB		PROSULFOCARB	
RIMSULFURON	RIMSULFURON		RIMSULFURON		RIMSULFURON	0,013	RIMSULFURON		RIMSULFURON		RIMSULFURON	0,05
ACETAMIPRID	ACETAMIPRID		ACETAMIPRID		ACETAMIPRID	0,10	ACETAMIPRID	0,25	ACETAMIPRID		ACETAMIPRID	0,10
BACILLUS THURINGIENSIS SUBSP. TENEBRIONIS (NB 1	BACILLUS THURINGIENSIS SUBSP. TENEBRION		BACILLUS THURINGIENSIS SUBSP. TENE		BACILLUS THURINGIENSIS SUBSP. TENEBR		BACILLUS THURINGIENSIS SUBSP. TENEBRIONIS (		BACILLUS THURINGIE	0,5	BACILLUS THURINGIENSIS SUBSP. TENEBR	
Chlorantraniliprole	Chlorantraniliprole	0,01	Chlorantraniliprole		Chlorantraniliprole		Chlorantraniliprole		Chlorantraniliprole	0,07	Chlorantraniliprole	
CHLORPYRIFOS	CHLORPYRIFOS		CHLORPYRIFOS		CHLORPYRIFOS		CHLORPYRIFOS		CHLORPYRIFOS	0,4	CHLORPYRIFOS	
CLOTHIANIDIN	CLOTHIANIDIN		CLOTHIANIDIN		CLOTHIANIDIN		CLOTHIANIDIN		CLOTHIANIDIN	2	CLOTHIANIDIN	
CYPERMETHRIN	CYPERMETHRIN		CYPERMETHRIN		CYPERMETHRIN	0,06	CYPERMETHRIN		CYPERMETHRIN		CYPERMETHRIN	
FERRIC PHOSPHATE	FERRIC PHOSPHATE		FERRIC PHOSPHATE		FERRIC PHOSPHATE		FERRIC PHOSPHATE		FERRIC PHOSPHATE		FERRIC PHOSPHATE	0,83
FLONICAMID	FLONICAMID		FLONICAMID		FLONICAMID	0,16	FLONICAMID		FLONICAMID	0,16	FLONICAMID	
LAMBDA-CYHALOTHRIN	LAMBDA-CYHALOTHRIN		LAMBDA-CYHALOTHRIN		LAMBDA-CYHALOTHRIN		LAMBDA-CYHALOTHRIN		LAMBDA-CYHALOTHR	0,16	LAMBDA-CYHALOTHRIN	
THIAMETHOXAM	THIAMETHOXAM		THIAMETHOXAM	0,0125	THIAMETHOXAM		THIAMETHOXAM		THIAMETHOXAM	0,01	THIAMETHOXAM	
FOSTHIAZATE	FOSTHIAZATE		FOSTHIAZATE		FOSTHIAZATE		FOSTHIAZATE		FOSTHIAZATE		FOSTHIAZATE	3,00
FLUOPYRAM	FLUOPYRAM		FLUOPYRAM		FLUOPYRAM		FLUOPYRAM	0,1	FLUOPYRAM		FLUOPYRAM	
CARFENTRAZONE-ETHYL	CARFENTRAZONE-ETHYL	0,06	CARFENTRAZONE-ETHYL		CARFENTRAZONE-ETHYL	0,05	CARFENTRAZONE-ETHYL		CARFENTRAZONE-ETHYL	0,06	CARFENTRAZONE-ETHYL	0,12
PYRAFLUFEN-ETHYL	PYRAFLUFEN-ETHYL	0,0212	PYRAFLUFEN-ETHYL		PYRAFLUFEN-ETHYL	0,05	PYRAFLUFEN-ETHYL	0,0212	PYRAFLUFEN-ETHYL		PYRAFLUFEN-ETHYL	0,03
1,4-DIMETHYLNAPHTHALENE	1,4-DIMETHYLNAPHTHALENE	3,976	1,4-DIMETHYLNAPHTHALENE		1,4-DIMETHYLNAPHTHALENE		1,4-DIMETHYLNAPHTHALENE	1,18	1,4-DIMETHYLNAPHTHALENE		1,4-DIMETHYLNAPHTHALENE	
MALEIC HYDRAZIDE	MALEIC HYDRAZIDE	3	MALEIC HYDRAZIDE	3	MALEIC HYDRAZIDE	3	MALEIC HYDRAZIDE	3	MALEIC HYDRAZIDE	3	MALEIC HYDRAZIDE	3,00
Total active ingredients per hectare		25,7692		14,05125		10,49		14,5326		13,26		26,9686
Total active ingredients per hectare in risk group 3		2,58		1,2		3,28		2,55		3,68		2,42
Value Harmonized Risk Indicator		226,79		122,01		110,16		136,6608		135,48		229,2918

Scenario 1

Case 1		Diff	Case 2		Diff	Case 3		Diff	Case 4		Diff	Case 5		Diff	Case 6		Diff
AMETOCTRADIN		-	AMETOCTRADIN	0,465	-	AMETOCTRADIN		-	AMETOCTRADIN		-	AMETOCTRADIN		-	AMETOCTRADIN		-
AMISULBROM		-0,06	AMISULBROM			AMISULBROM		-	AMISULBROM		-	AMISULBROM		-	AMISULBROM		-
AZOXYSTROBIN		-	AZOXYSTROBIN		-	AZOXYSTROBIN		-	AZOXYSTROBIN	0,23	0,23	AZOXYSTROBIN		-	AZOXYSTROBIN		-
BENTHIAVALICARB-ISOPROPYL	0,112	0,11	BENTHIAVALICARB-ISOPROPYL		-	BENTHIAVALICARB-ISOPROPYL	0,025	0,03	BENTHIAVALICARB-ISOPROPYL	0,08	-	BENTHIAVALICARB-ISOPROPYL		-	BENTHIAVALICARB-ISOPROPYL		-
COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE		-5,13	COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE	0,25	-0,85	COPPER OXYCHLORIDE		-
CYAZOFAMID	0,16	-0,08	CYAZOFAMID	0,48	0,18	CYAZOFAMID		-	CYAZOFAMID	0,16	-0,08	CYAZOFAMID		-	CYAZOFAMID	0,32	0,08
CYMOXANIL	0,45	0,18	CYMOXANIL	0,19	0,19	CYMOXANIL		-	CYMOXANIL	0,12	-	CYMOXANIL	0,31	-	CYMOXANIL	0,6	-
DIFENOCONAZOLE	0,125	-0,13	DIFENOCONAZOLE		-	DIFENOCONAZOLE	0,3	-0,15	DIFENOCONAZOLE	0,5	-1,00	DIFENOCONAZOLE		-	DIFENOCONAZOLE		-
DIMETHOMORPH		-	DIMETHOMORPH	0,34875	0,35	DIMETHOMORPH		-	DIMETHOMORPH		-	DIMETHOMORPH		-	DIMETHOMORPH		-
FLUAZINAM	0,376	0,38	FLUAZINAM	0,89	0,89	FLUAZINAM		-	FLUAZINAM	0,56	0,56	FLUAZINAM		-	FLUAZINAM		-
FLUOPICOLIDE		-0,30	FLUOPICOLIDE		-	FLUOPICOLIDE		-	FLUOPICOLIDE		-0,15	FLUOPICOLIDE	0,02	-	FLUOPICOLIDE	0,2	-
FLUTOLANIL	0,184	-0,06	FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL	0,05	-
MANCOZEB		-8,88	MANCOZEB		-1,00	MANCOZEB		-0,45	MANCOZEB		-	MANCOZEB		-5,13	MANCOZEB	3,2	-9,60
MANDIPROPAMID	0,45	0,15	MANDIPROPAMID	0,6	0,60	MANDIPROPAMID	0,3	0,30	MANDIPROPAMID	1,6	-	MANDIPROPAMID		-	MANDIPROPAMID	0,3	-0,05
METIRAM		-	METIRAM		-0,06	METIRAM	1,3	-1,85	METIRAM		-	METIRAM	0,68	-0,58	METIRAM		-
OXATHIAPIPROLIN	0,06	0,04	OXATHIAPIPROLIN		-	OXATHIAPIPROLIN	0,012	0,01	OXATHIAPIPROLIN	0,04	-	OXATHIAPIPROLIN		-	OXATHIAPIPROLIN	0,03	-
PENFLUFEN		-	PENFLUFEN		-	PENFLUFEN		-	PENFLUFEN	0,03	-	PENFLUFEN		-	PENFLUFEN		-
PROPAMOCARB	1,6	-1,40	PROPAMOCARB		-	PROPAMOCARB		-	PROPAMOCARB		-1,50	PROPAMOCARB	0,94	0,94	PROPAMOCARB	2	-
PROTHIOCONAZOLE	0,0563	0,06	PROTHIOCONAZOLE		-0,20	PROTHIOCONAZOLE		-	PROTHIOCONAZOLE	0,01	-	PROTHIOCONAZOLE		-	PROTHIOCONAZOLE		-
ZOXAMIDE		-0,60	ZOXAMIDE		-2,00	ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE		-
ACLONIFEN	1	-0,20	ACLONIFEN	0,5	0,50	ACLONIFEN		-2,00	ACLONIFEN		-0,90	ACLONIFEN		-	ACLONIFEN		-1,05
CLETHODIM		-	CLETHODIM		-	CLETHODIM	0,18	-	CLETHODIM		-	CLETHODIM		-	CLETHODIM		-
CLOMAZONE	0,0648	-0,01	CLOMAZONE	0,03	0,03	CLOMAZONE		-	CLOMAZONE		-	CLOMAZONE		-	CLOMAZONE		-
FLUFENACET		-0,48	FLUFENACET		-	FLUFENACET	0,24	-0,24	FLUFENACET		-	FLUFENACET		-	FLUFENACET		-0,48
GLYPHOSATE	1,08	-0,36	GLYPHOSATE		-	GLYPHOSATE		-	GLYPHOSATE		-0,72	GLYPHOSATE		-	GLYPHOSATE	1,35	-
METOBROMURON	1	-	METOBROMURON		-	METOBROMURON	0,2	0,20	METOBROMURON		-1,50	METOBROMURON		-	METOBROMURON		-
METRIBUZIN		-0,35	METRIBUZIN	0,15	0,15	METRIBUZIN	0,175	-0,18	METRIBUZIN		-	METRIBUZIN		-2,40	METRIBUZIN	0,31	-0,38
PROSULFOCARB		-	PROSULFOCARB	1,5	1,50	PROSULFOCARB		-	PROSULFOCARB		-1,60	PROSULFOCARB		-	PROSULFOCARB	0,0636	0,06
RIMSULFURON		-	RIMSULFURON		-	RIMSULFURON	0,013	-0,00	RIMSULFURON		-	RIMSULFURON		-	RIMSULFURON	0,05	-
ACETAMIPRID		-	ACETAMIPRID		-	ACETAMIPRID	0,1	-	ACETAMIPRID	0,25	-	ACETAMIPRID		-	ACETAMIPRID	0,096	-
BACILLUS THURINGIENSIS SUBSP. TENEBRIONIS (NE		-	BACILLUS THURINGIENSIS SUBSP. TEN		-0,01	BACILLUS THURINGIENSIS SUBSP. TENEB		-	BACILLUS THURINGIENSIS SUBSP.		-	BACILLUS THURINGIENSIS S	0,45	-0,05	BACILLUS THURINGIENSIS SUBSP. TENEBRION		-
Chlorantraniliprole	0,01	-	Chlorantraniliprole		-	Chlorantraniliprole		-	Chlorantraniliprole		-	Chlorantraniliprole		-0,07	Chlorantraniliprole		-
CHLORPYRIFOS		-	CHLORPYRIFOS		-	CHLORPYRIFOS		-	CHLORPYRIFOS		-	CHLORPYRIFOS	0,2	-0,20	CHLORPYRIFOS		-
CLOTHIANIDIN		-	CLOTHIANIDIN		-	CLOTHIANIDIN		-	CLOTHIANIDIN		-	CLOTHIANIDIN	1,5	-0,50	CLOTHIANIDIN		-
CYPERMETHRIN		-	CYPERMETHRIN		-	CYPERMETHRIN	0,06	-	CYPERMETHRIN		-	CYPERMETHRIN		-	CYPERMETHRIN		-
FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE	0,831	-
FLONICAMID		-	FLONICAMID		-3,00	FLONICAMID	0,16	-	FLONICAMID		-	FLONICAMID	0,16	-	FLONICAMID		-
LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		####	LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN	0,08	-0,08	LAMBDA-CYHALOTHRIN		-
THIAMETHOXAM		-	THIAMETHOXAM		-1,20	THIAMETHOXAM		-	THIAMETHOXAM		-	THIAMETHOXAM		-0,01	THIAMETHOXAM		-
FOSTHIAZATE		-	FOSTHIAZATE		####	FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-3,00
FLUOPYRAM	0,0563	0,06	FLUOPYRAM		-	FLUOPYRAM		-	FLUOPYRAM	0,1	-	FLUOPYRAM		-	FLUOPYRAM	0,25	0,25
CARFENTRAZONE-ETHYL	0,06	-	CARFENTRAZONE-ETHYL		-	CARFENTRAZONE-ETHYL	0,05	-	CARFENTRAZONE-ETHYL		-	CARFENTRAZONE-ETHYL		-0,06	CARFENTRAZONE-ETHYL	0,12	-
PYRAFLUFEN-ETHYL	0,0212	-	PYRAFLUFEN-ETHYL		-	PYRAFLUFEN-ETHYL	0,05	-0,00	PYRAFLUFEN-ETHYL	0,02	-	PYRAFLUFEN-ETHYL		-	PYRAFLUFEN-ETHYL		-0,03
1,4-DIMETHYLNAPHTHALENE	2,982	-0,99	1,4-DIMETHYLNAPHTHALENE		-	1,4-DIMETHYLNAPHTHALENE		-	1,4-DIMETHYLNAPHTHALEN	1,15	-0,03	1,4-DIMETHYLNAPHTHALENE		-	1,4-DIMETHYLNAPHTHALENE		-
MALEIC HYDRAZIDE	3	-	MALEIC HYDRAZIDE	2	2,00	MALEIC HYDRAZIDE	3	-	MALEIC HYDRAZIDE	3	-	MALEIC HYDRAZIDE	1,5	-1,50	MALEIC HYDRAZIDE	3	-
12,8475			7			6,1595			7,9407			6,09			12,7706		
1,125			0,5			0,715			0,5			0,35			0,51		
111,78			59,99			54,996			67,5256			51,52			108,4658		

Scenario 2

Case 1		Diff	Case 2		Diff	Case 3		Diff	Case 4		Diff	Case 5		Diff	Case 6		Diff
AMETOCTRADIN		-	AMETOCTRADIN	0,47	-	AMETOCTRADIN		-	AMETOCTRADIN		-	AMETOCTRADIN		-	AMETOCTRADIN		-
AMISULBROM		-	AMISULBROM		-	AMISULBROM		-	AMISULBROM		-	AMISULBROM		-	AMISULBROM		-
AZOXYSTROBIN		-	AZOXYSTROBIN		-	AZOXYSTROBIN		-	AZOXYSTROBIN	0,225	#####	AZOXYSTROBIN		-	AZOXYSTROBIN		-
BENTHIAVALICARB-ISOPROPYL	0,112	-	BENTHIAVALICARB-ISOPROPYL		-	BENTHIAVALICARB-ISOPROPYL	0,03	-	BENTHIAVALICARB-ISOPROPYL	0,084	-	BENTHIAVALICARB-ISOPROPYL		-	BENTHIAVALICARB-ISOPROPYL		-
COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE	0,25	-	COPPER OXYCHLORIDE		-
CYAZOFAMID	0,16	-	CYAZOFAMID	0,48	-	CYAZOFAMID		-	CYAZOFAMID	0,16	-	CYAZOFAMID		-	CYAZOFAMID	0,32	-
CYMOXANIL	0,45	-	CYMOXANIL	0,19	-	CYMOXANIL		-	CYMOXANIL	0,12	-	CYMOXANIL	0,31	-	CYMOXANIL	0,89	0,29
DIFENOCONAZOLE		-0,13	DIFENOCONAZOLE		-	DIFENOCONAZOLE	0,3	-	DIFENOCONAZOLE	0,5	-	DIFENOCONAZOLE		-	DIFENOCONAZOLE		-
DIMETHOMORPH		-	DIMETHOMORPH	0,35	-	DIMETHOMORPH		-	DIMETHOMORPH		-	DIMETHOMORPH		-	DIMETHOMORPH		-
FLUAZINAM	0,376	-	FLUAZINAM	0,89	-	FLUAZINAM		-	FLUAZINAM	0,5625	0,00	FLUAZINAM		-	FLUAZINAM		-
FLUOPICOLIDE		-	FLUOPICOLIDE		-	FLUOPICOLIDE		-	FLUOPICOLIDE		-	FLUOPICOLIDE	0,02	-	FLUOPICOLIDE		-0,20
FLUTOLANIL		-0,18	FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL	0,05	-
MANCOZEB		-	MANCOZEB		-	MANCOZEB		-	MANCOZEB		-	MANCOZEB		-	MANCOZEB		-3,20
MANDIPROPAMID	0,45	-0,00	MANDIPROPAMID	0,6	-	MANDIPROPAMID	0,3	-	MANDIPROPAMID	1,6	-	MANDIPROPAMID		-	MANDIPROPAMID	0,6	0,30
METIRAM		-	METIRAM		-	METIRAM	1,3	-	METIRAM		-	METIRAM	0,68	-	METIRAM		-
OXATHIAPIPROLIN	0,06	-	OXATHIAPIPROLIN		-	OXATHIAPIPROLIN	0,01	-	OXATHIAPIPROLIN	0,036	-	OXATHIAPIPROLIN		-	OXATHIAPIPROLIN	0,03	-
PENFLUFEN	0,04	0,04	PENFLUFEN		-	PENFLUFEN		-	PENFLUFEN	0,03	-	PENFLUFEN		-	PENFLUFEN		-
PROPAMOCARB	1,6	-	PROPAMOCARB		-	PROPAMOCARB		-	PROPAMOCARB		-	PROPAMOCARB	0,94	-	PROPAMOCARB		-2,00
PROTHIOCONAZOLE	0,056	-0,00	PROTHIOCONAZOLE		-	PROTHIOCONAZOLE		-	PROTHIOCONAZOLE	0,1054	0,10	PROTHIOCONAZOLE		-	PROTHIOCONAZOLE	0,06	0,06
ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE	0,6	0,60
ACLONIFEN	0,6	-0,40	ACLONIFEN	0,29	-0,21	ACLONIFEN		-	ACLONIFEN		-	ACLONIFEN		-	ACLONIFEN		-
CLETHODIM		-	CLETHODIM		-	CLETHODIM	0,18	-	CLETHODIM		-	CLETHODIM		-	CLETHODIM		-
CLOMAZONE	0,09	0,03	CLOMAZONE	0,03	-	CLOMAZONE		-	CLOMAZONE		-	CLOMAZONE		-	CLOMAZONE		-
FLUFENACET		-	FLUFENACET		-	FLUFENACET	0,24	-	FLUFENACET		-	FLUFENACET		-	FLUFENACET		-
GLYPHOSATE	1,08	-	GLYPHOSATE		-	GLYPHOSATE		-	GLYPHOSATE		-	GLYPHOSATE		-	GLYPHOSATE	0,9	-0,45
METOBROMURON	1,2	0,20	METOBROMURON		-	METOBROMURON	0,2	-	METOBROMURON		-	METOBROMURON		-	METOBROMURON	0,75	0,75
METRIBUZIN		-	METRIBUZIN	0,15	-	METRIBUZIN	0,18	-	METRIBUZIN		-	METRIBUZIN		-	METRIBUZIN	0,31	-
PROSULFOCARB		-	PROSULFOCARB	1,5	-	PROSULFOCARB		-	PROSULFOCARB		-	PROSULFOCARB		-	PROSULFOCARB	3,2	3,14
RIMSULFURON		-	RIMSULFURON		-	RIMSULFURON	0,01	-	RIMSULFURON		-	RIMSULFURON		-	RIMSULFURON	0,05	-
ACETAMIPRID		-	ACETAMIPRID		-	ACETAMIPRID	0,1	-	ACETAMIPRID	0,25	-	ACETAMIPRID		-	ACETAMIPRID	0,1	-
BACILLUS THURINGIENSIS SUBSP. TENEBRIONIS (NB 176)		-	BACILLUS THURINGIENSIS SUBSP. TENEBRIONIS (NB 176)		-	BACILLUS THURINGIENSIS SUBSP. TENEBRIONIS (NB 176)		-	BACILLUS THURINGIENSIS SUBSP. TENEBRIONIS (NB 176)		-	BACILLUS THURINGIENSIS SUBSP. TENEBRIONIS (NB 176)	0,45	-	BACILLUS THURINGIENSIS SUBSP. TENEBRIONIS (NB 176)		-
Chlorantraniliprole	0,01	-	Chlorantraniliprole		-	Chlorantraniliprole		-	Chlorantraniliprole		-	Chlorantraniliprole		-	Chlorantraniliprole		-
CHLORPYRIFOS		-	CHLORPYRIFOS		-	CHLORPYRIFOS		-	CHLORPYRIFOS		-	CHLORPYRIFOS	0,2	-	CHLORPYRIFOS		-
CLOTHIANIDIN		-	CLOTHIANIDIN		-	CLOTHIANIDIN		-	CLOTHIANIDIN		-	CLOTHIANIDIN	1,5	-	CLOTHIANIDIN		-
CYPERMETHRIN		-	CYPERMETHRIN		-	CYPERMETHRIN	0,06	-	CYPERMETHRIN		-	CYPERMETHRIN		-	CYPERMETHRIN		-
FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE	0,83	-
FLONICAMID		-	FLONICAMID		-	FLONICAMID	0,16	-	FLONICAMID		-	FLONICAMID		-0,16	FLONICAMID		-
LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-0,08	LAMBDA-CYHALOTHRIN		-
THIAMETHOXAM		-	THIAMETHOXAM		-	THIAMETHOXAM		-	THIAMETHOXAM		-	THIAMETHOXAM		-	THIAMETHOXAM		-
FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-
FLUOPYRAM	0,056	-0,00	FLUOPYRAM		-	FLUOPYRAM		-	FLUOPYRAM	0,1	-	FLUOPYRAM		-	FLUOPYRAM	0,25	-
CARFENTRAZONE-ETHYL	0,06	-	CARFENTRAZONE-ETHYL		-	CARFENTRAZONE-ETHYL	0,05	-	CARFENTRAZONE-ETHYL		-	CARFENTRAZONE-ETHYL		-	CARFENTRAZONE-ETHYL	0,12	-
PYRAFLUFEN-ETHYL	0,021	-	PYRAFLUFEN-ETHYL		-	PYRAFLUFEN-ETHYL	0,05	-	PYRAFLUFEN-ETHYL	0,0212	-	PYRAFLUFEN-ETHYL		-	PYRAFLUFEN-ETHYL		-
1,4-DIMETHYLNAPHTHALENE	2,982	-	1,4-DIMETHYLNAPHTHALENE		-	1,4-DIMETHYLNAPHTHALENE		-	1,4-DIMETHYLNAPHTHALENE	1,15	-	1,4-DIMETHYLNAPHTHALENE		-	1,4-DIMETHYLNAPHTHALENE		-
MALEIC HYDRAZIDE	3	-	MALEIC HYDRAZIDE	2	-	MALEIC HYDRAZIDE	3	-	MALEIC HYDRAZIDE	3	-	MALEIC HYDRAZIDE	1,5	-	MALEIC HYDRAZIDE	3	-
12,4032 0,6 104,03			6,79 0,29 56,63			6,1595 0,715 54,996			7,9407 0,5 67,5256			5,85 0,27 48,96			12,0576 0,31 93,1238		

Scenario 3

Case 1		diff	Case 2		diff	Case 3		diff	Case 4		diff	Case 5		diff	Case 6		diff
AMETOCTRADIN		-	AMETOCTRADIN	0,465	-	AMETOCTRADIN		-	AMETOCTRADIN	0,25	0,25	AMETOCTRADIN		-	AMETOCTRADIN		-
AMISULBROM		-	AMISULBROM		-	AMISULBROM		-	AMISULBROM		-	AMISULBROM		-	AMISULBROM		-
AZOXYSTROBIN		-	AZOXYSTROBIN		-	AZOXYSTROBIN		-	AZOXYSTROBIN	0,225	-	AZOXYSTROBIN		-	AZOXYSTROBIN		-
BENTHIAVALICARB-ISOPROPYL	0,112	-	BENTHIAVALICARB-ISOPROPYL		-	BENTHIAVALICARB-ISOPROPYL	0,05	0,03	BENTHIAVALICARB-ISOP	0,084	-	BENTHIAVALICARB-ISOPROPYL		-	BENTHIAVALICARB-ISOPROPYL		-
COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE		-	COPPER OXYCHLORIDE		-0,25	COPPER OXYCHLORIDE		-
CYAZOFAMID	0,16	-	CYAZOFAMID	0,24	-0,24	CYAZOFAMID	0,34	0,34	CYAZOFAMID	0,16	-	CYAZOFAMID		-	CYAZOFAMID	0,32	-
CYMOXANIL	0,45	-	CYMOXANIL	0,13	-0,06	CYMOXANIL		-	CYMOXANIL	0,12	-	CYMOXANIL	0,31	-	CYMOXANIL	0,887	-
DIFENOCONAZOLE		-	DIFENOCONAZOLE		-	DIFENOCONAZOLE		-0,30	DIFENOCONAZOLE		-0,50	DIFENOCONAZOLE		-	DIFENOCONAZOLE		-
DIMETHOMORPH		-	DIMETHOMORPH	0,34875	-	DIMETHOMORPH		-	DIMETHOMORPH		-	DIMETHOMORPH		-	DIMETHOMORPH		-
FLUAZINAM	0,376	-	FLUAZINAM	0,49	-0,40	FLUAZINAM		-	FLUAZINAM	0,5625	-	FLUAZINAM		-	FLUAZINAM		-
FLUOPICOLIDE		-	FLUOPICOLIDE		-	FLUOPICOLIDE		-	FLUOPICOLIDE		-	FLUOPICOLIDE		-0,02	FLUOPICOLIDE		-
FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL		-	FLUTOLANIL	0,05	-
MANCOZEB		-	MANCOZEB		-	MANCOZEB		-	MANCOZEB		-	MANCOZEB		-	MANCOZEB		-
MANDIPROPAMID	0,45	0,00	MANDIPROPAMID	0,29	-0,31	MANDIPROPAMID		-0,30	MANDIPROPAMID	1,6	-	MANDIPROPAMID		-	MANDIPROPAMID	0,6	-
METIRAM		-	METIRAM		-	METIRAM		-1,30	METIRAM		-	METIRAM	0,68	-	METIRAM		-
OXATHIAPIPROLIN	0,06	-	OXATHIAPIPROLIN		-	OXATHIAPIPROLIN	0,02	0,01	OXATHIAPIPROLIN	0,036	-	OXATHIAPIPROLIN		-	OXATHIAPIPROLIN	0,03	-
PENFLUFEN	0,04	-	PENFLUFEN		-	PENFLUFEN		-	PENFLUFEN	0,03	-	PENFLUFEN		-	PENFLUFEN		-
PROPAMOCARB	1,6	-	PROPAMOCARB		-	PROPAMOCARB		-	PROPAMOCARB		-	PROPAMOCARB	0,94	-	PROPAMOCARB		-
PROTHIOCONAZOLE	0,056	-	PROTHIOCONAZOLE		-	PROTHIOCONAZOLE		-	PROTHIOCONAZOLE	0,1054	-	PROTHIOCONAZOLE		-	PROTHIOCONAZOLE		-0,06
ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE		-	ZOXAMIDE	0,6	-
ACLONIFEN		-0,60	ACLONIFEN		-0,29	ACLONIFEN		-	ACLONIFEN		-	ACLONIFEN		-	ACLONIFEN		-
CLETHODIM		-	CLETHODIM		-	CLETHODIM		-0,18	CLETHODIM		-	CLETHODIM		-	CLETHODIM		-
CLOMAZONE	0,09	-	CLOMAZONE		-0,03	CLOMAZONE	0,07	0,07	CLOMAZONE		-	CLOMAZONE		-	CLOMAZONE		-
FLUFENACET		-	FLUFENACET		-	FLUFENACET		-0,24	FLUFENACET		-	FLUFENACET		-	FLUFENACET		-
GLYPHOSATE	0,72	-0,36	GLYPHOSATE		-	GLYPHOSATE		-	GLYPHOSATE		-	GLYPHOSATE		-	GLYPHOSATE	0,9	-
METOBROMURON	1	-0,20	METOBROMURON		-	METOBROMURON		-0,20	METOBROMURON		-	METOBROMURON		-	METOBROMURON	0,75	-
METRIBUZIN		-	METRIBUZIN		-0,15	METRIBUZIN		-0,18	METRIBUZIN		-	METRIBUZIN		-	METRIBUZIN		-0,31
PROSULFOCARB	1,6	1,60	PROSULFOCARB		-1,50	PROSULFOCARB	1,8	1,80	PROSULFOCARB		-	PROSULFOCARB		-	PROSULFOCARB	3,2	-
RIMSULFURON		-	RIMSULFURON		-	RIMSULFURON	0,01	-	RIMSULFURON		-	RIMSULFURON		-	RIMSULFURON	0,05	-
ACETAMIPRID		-	ACETAMIPRID		-	ACETAMIPRID	0,1	-	ACETAMIPRID		-0,25	ACETAMIPRID		-	ACETAMIPRID	0,096	-
BACILLUS THURINGIENSIS SUBSP. TENEBRION		-	BACILLUS THURINGIENSIS SUBSP. TENE		-	BACILLUS THURINGIENSIS SUBSP. TENEB		-	BACILLUS THURINGIENSIS SUBSP. T		-	BACILLUS THURINGIENSIS S	0,45	-	BACILLUS THURINGIENSIS SUBSP. TENE		-
Chlorantraniliprole	0,01	-	Chlorantraniliprole		-	Chlorantraniliprole		-	Chlorantraniliprole		-	Chlorantraniliprole		-	Chlorantraniliprole		-
CHLORPYRIFOS		-	CHLORPYRIFOS		-	CHLORPYRIFOS		-	CHLORPYRIFOS		-	CHLORPYRIFOS		-0,20	CHLORPYRIFOS		-
CLOTHIANIDIN		-	CLOTHIANIDIN		-	CLOTHIANIDIN		-	CLOTHIANIDIN		-	CLOTHIANIDIN	1,5	-	CLOTHIANIDIN		-
CYPERMETHRIN		-	CYPERMETHRIN		-	CYPERMETHRIN	0,06	-	CYPERMETHRIN		-	CYPERMETHRIN		-	CYPERMETHRIN		-
FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE		-	FERRIC PHOSPHATE	0,831	-
FLONICAMID		-	FLONICAMID		-	FLONICAMID	0,16	-	FLONICAMID		-	FLONICAMID		-	FLONICAMID		-
LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-	LAMBDA-CYHALOTHRIN		-
THIAMETHOXAM		-	THIAMETHOXAM		-	THIAMETHOXAM		-	THIAMETHOXAM		-	THIAMETHOXAM		-	THIAMETHOXAM		-
FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-	FOSTHIAZATE		-
FLUOPYRAM	0,056	-	FLUOPYRAM		-	FLUOPYRAM		-	FLUOPYRAM	0,1	-	FLUOPYRAM		-	FLUOPYRAM	0,25	-
CARFENTRAZONE-ETHYL	0,06	-	CARFENTRAZONE-ETHYL		-	CARFENTRAZONE-ETHYL	0,05	-	CARFENTRAZONE-ETHYL		-	CARFENTRAZONE-ETHYL		-	CARFENTRAZONE-ETHYL	0,14	0,02
PYRAFLUFEN-ETHYL	0,0424	0,02	PYRAFLUFEN-ETHYL		-	PYRAFLUFEN-ETHYL	0,05	-	PYRAFLUFEN-ETHYL	0,0212	-	PYRAFLUFEN-ETHYL		-	PYRAFLUFEN-ETHYL	0,0636	0,06
1,4-DIMETHYLNAPHTHALENE	2,982	-	1,4-DIMETHYLNAPHTHALENE		-	1,4-DIMETHYLNAPHTHALENE		-	1,4-DIMETHYLNAPHTHAL	1,12	-0,03	1,4-DIMETHYLNAPHTHALENE		-	1,4-DIMETHYLNAPHTHALENE		-
MALEIC HYDRAZIDE	3	-	MALEIC HYDRAZIDE	2	-	MALEIC HYDRAZIDE	3	-	MALEIC HYDRAZIDE	3	-	MALEIC HYDRAZIDE	1,5	-	MALEIC HYDRAZIDE	3	-
12,8644			3,96375			6,9135			11,7676			5,38			11,7676		
0			0			0			0				0		0		
102,92			31,71			55,308			59,29				43,04		88,3238		

Appendix 4 Methodology for exploration of potential economic impacts

Equilibrium displacement modelling (EDM)

To enrich the qualitative analysis on the potential implications of reducing the risk of crop protection applications at EU level (Chapter 3) an economic framework has been developed to assess the most likely effects. This analytical framework, or 'tailor-made' tool relies on the EDM methodology – its general methodology closely followed the methodological approach used by Bremmer et al. (2021). Nevertheless, in this case a quantitative modelling exercise is not possible since the case studies have not delivered sufficient data to translate farm specific insights into representative shocks at macro level.

Coming back to the methodological approach, EDMs are partial-equilibrium models that provide a simplified and (very) stylised representation of a sectoral (related) market-setting.[16] The economic theory behind the EDM assumes a competitive structure of the market under consideration (Pathiraja et al., 2017). In the EDM context, elements such as changes of government policies, climate change and other regulations are considered exogenous shocks and provoke movements of the supply/demand curve. EDMs date back to the work of Muth in the 1960s (Piggot, 1992) and have since found many applications in international literature (e.g., Wohlgenant, 1993, 2011; and Lusk et al., 2011).

Focusing on the conceptual framework, an EDM provides an economic framework or is a modelling 'tool' that provides a representation of the current market situation (equilibrium), which is defined by the supply and demand functions of a particular commodity (potatoes in this specific case).[17] See Figure A4.1 for a graphical illustration of the general structure of a EDM which covers the market of a commodity (*x*). The left panel of the graph represents the EU market by both EU demand and supply functions. In the figure they are presented in an aggregate way, but in the EDMs that are used EU MS (key producers) or regions (Rest of EU-27) are often distinguished, which together represented EU total supply and demand. The interaction with non-EU countries (aggregated as the Rest of the World, [RoW]) has to be taken into account also, and is via trade. As the right panel shows there are two curves which characterise the RoW-market. The first one is the EU's excess supply, which simply follows from a horizontal aggregation of the EUs supply and demand curves (where ES = S-D). The second curve is the other side of the market, which captures the RoW's excess demand. The interaction of both curves determines the world price, which in turn also fixes the price in the EU. As is indicated in Figure A4.1, the EU is a net exporter while the RoW is a net importer based on the initial world market equilibrium being E_0, with a price p_0). Due to EU declines in crop yields resulting from the implementation of the F2F and BD strategies, an inward shift of the supply curve of the EU is observed in the EDM (e.g. from S_0 to S_1). As a result, EU's excess supply curve also shows an inward shift (from ES_0 to ES_1). As a consequence of this shift, a new (world) market equilibrium will emerge (E_1), and market prices in the RoW and the EU will increase. As observed in the graph, the EU remains a net exporter to RoW, but its exports will have declined.[18] EU producers (farmers) produce less volume but receive a higher price. Due to these counteracting forces, the impact on farmer revenues may be ambiguous and will depend on the market specificities (in Figure A4.1 these are reflected in the slopes and curvature of the supply and demand curves) as well as the magnitude of the (yield)[19] shock.[20]

[16] The EDM tool used for the purpose of this project only represents the potato market since cross-price elasticities to capture the possible substitution between potatoes and other crops were not available in the existing literature.

[17] As any other methodology, EDMs are not exempt from limitations. The reader is referred to Harrington and Dubman (2008) which elaborates on the assumptions and limitations of this approach.

[18] The EDM tool that was developed for this study provides a net trade indicator for the RoW region. A detailed modelling of the supply and demand of potatoes in this region has not been included in the tool since no supply and demand shocks in the RoW were analysed in this case.

[19] Also other types of shocks can be taken into account in this framework. An important one which has been considered in this study is a negative price shock (to producers) due to a deterioration on product quality. This is modelled as a (negative) price wedge for the product grown in the EU relative to that grown outside the EU (where the F2F and BD strategies do not apply and quality has been assumed to be unchanged). This type of impact is not shown in the graph, but has been included in the EDMs.

[20] Note that the mechanism how markets will adjust to F2F and BD shocks, as represented here for an EDM, is similar to what happens in the AGMEMOD model, with the main difference being that the AGMEMOD model is more refined and detailed.

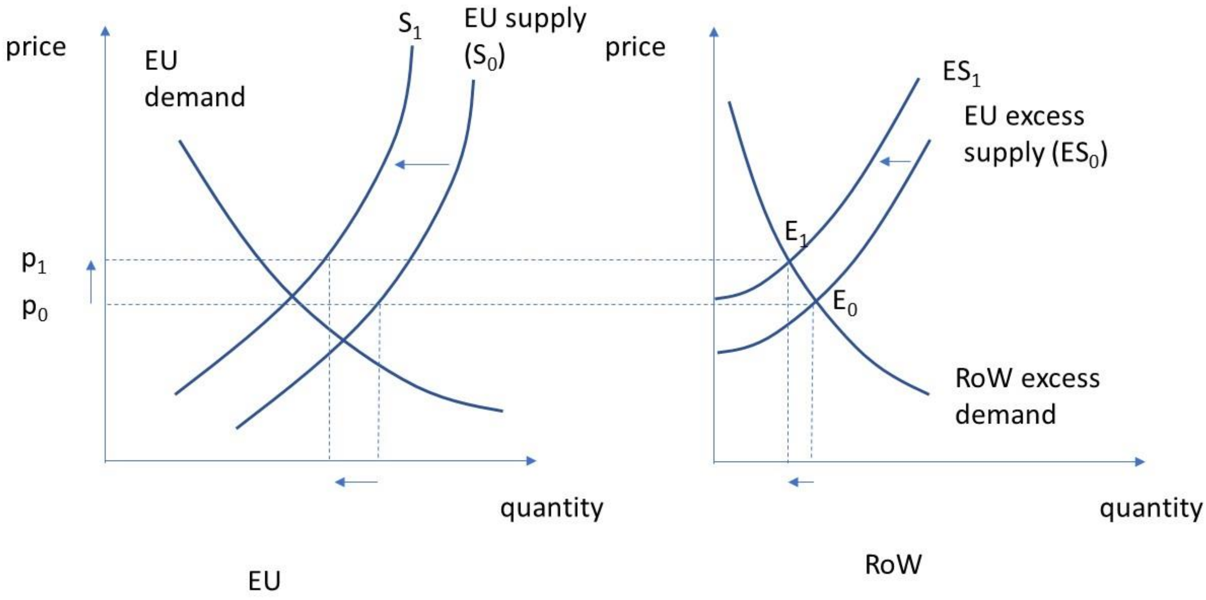

Figure A4.1 *Generic example of an EDM for one commodity (x) and two regions (EU, RoW) and its use to assess potential supply shocks*
Source: Authors.

EDMs use demand and supply elasticities to describe the relationship between changes in the quantity demanded or quantity supplied and the price of a commodity (e.g., supply elasticity, own-price elasticity of demand, cross-price elasticities of demand). Table A4.1 provides and overview of the elasticities as they have been used in the EDM model. Overall, the elasticities used to calibrate the equations of an EDM tool are taken from the existing literature or based on expert knowledge (see, Table A4.1. for an overview of the elasticities chosen). Alternatively, the relevant elasticities could be econometrically estimated if data allows for that. In this specific case, the findings from the literature review were not sufficient and did not provide supply and demand elasticities for all the regions included in the model. The remaining gaps were filled in by means of expert information. An overview of the different elasticities used for the EDM tool is provided in Table A4.1. Note that in general, EU demand and supply elasticities are (own) price inelastic. This is quite a general characteristic for agricultural and food products. By consequence, changes in demand and supply of agricultural and food products will result in more than proportional price changes. In contrast, the excess demand or supply elasticities of the RoW (see most right column of the table) are elastic, which reflects the depth of the world market, the responsiveness of world demand and supply, and the EU’s share in world supply and demand. Note that due to the ‘approximate nature’ of these elasticities, the reasoning based on these estimates should be seen as indicative and be interpreted with caution.

Table A4.1 *Price elasticities as they have been applied in the EDMs used for the F2F and BD assessment*

	Price elasticities used in EDMs		
Crop	**Regional Demand**	**Regional Supply**	**RoW (excess demand (-) or excess supply (+) elasticity**
Potatoes	-0.2 - -0.1	0.02 - 0.26	-5.0

Source: Authors.

Note: A supply elasticity equal to 0.26 means that for every one percent increase in price, the quantity supplied will increase by 0.26%.

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