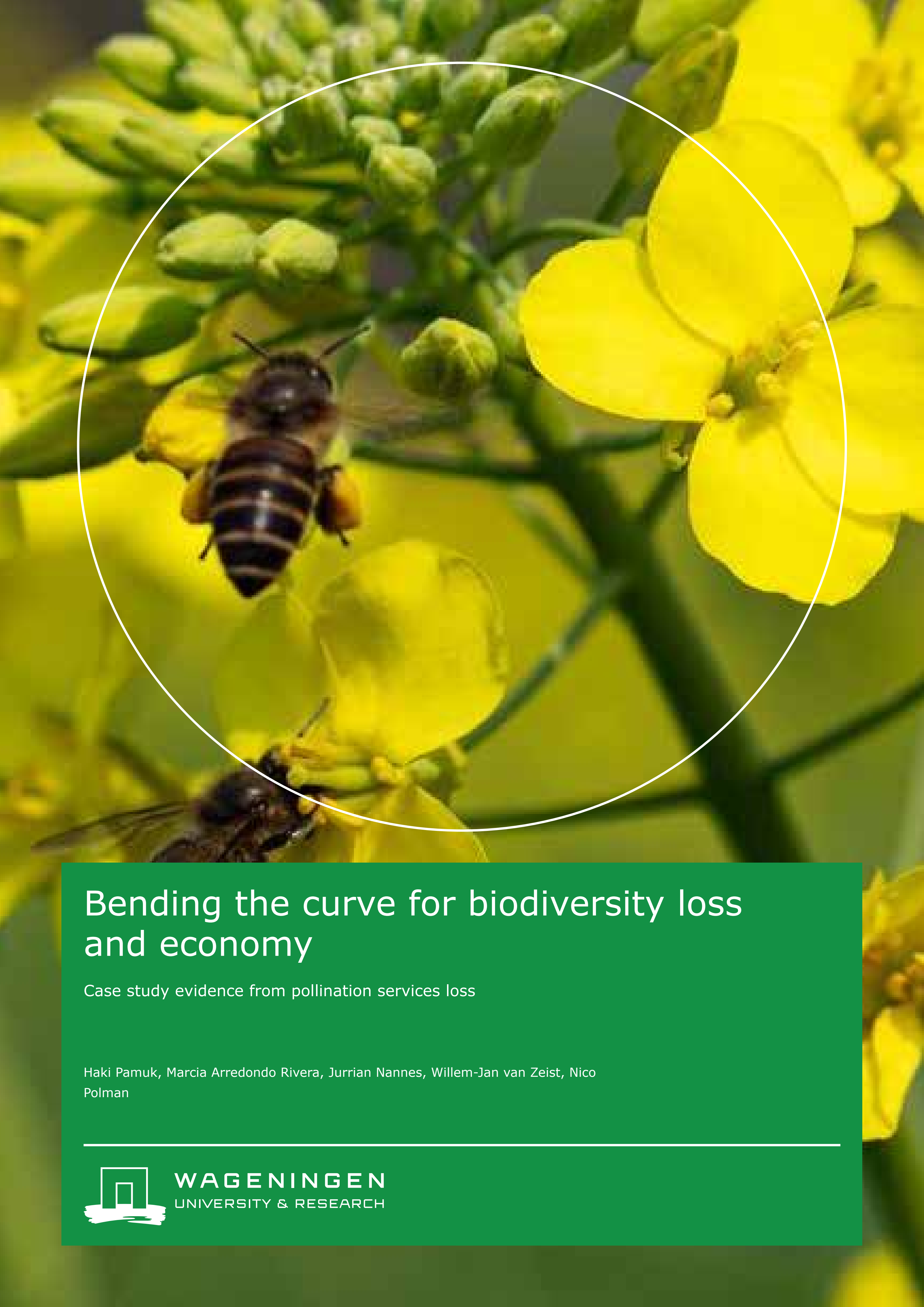

Bending the curve for biodiversity loss and economy

Case study evidence from pollination services loss

Haki Pamuk, Marcia Arredondo Rivera, Jurrian Nannes, Willem-Jan van Zeist, Nico Polman

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This report highlights the challenges in addressing biodiversity-loss related issues and contributes to the economic valuation of biodiversity and its relationship with the financial sector. Through a case study on pollination services loss, we analyse the economic consequences of such losses in Western Europe and North America. We estimate the direct and indirect monetary costs associated with pollination service loss and find that it reduces agricultural output and indirectly affects non-agricultural sectors reliant on agriculture. We also find that implementing proposed measures to reduce such losses may not be financially worthwhile when considering only their pollution-reduction potential. Additional research is needed to assess the cost effectiveness of these measures.

Key words: biodiversity, pollination loss, general equilibrium model, financial risks, economy, agriculture

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Preface

We would like to express our gratitude to Allianz SE for funding this research study, with special thanks to Markus Zimmer and Arne Holzhausen for guiding our research team and sharing valuable insights during the project. We also extend our appreciation to the experts from Allianz who participated in our interviews and shared their sector knowledge to help us identify the right research. Stijn Reinhard and Judith Jacobs from WUR provided the study with valuable comments to improve the report. Vince van ‘t Hoff and Mieke Siebers from the Foundation for Sustainable Development shared their insights on the Ecosystem Services Evaluation Database. We could not have completed this report without the expert knowledge of Bert Smit, Johan Bremmer, Mark Manshanden, Wijnand Sukkel, Pieter de Wolf, Bas Janssens, and Coen van Ruiten on the costs of farm management practices.

Ir. O. (Olaf) Hietbrink
Business Unit Manager Wageningen Economic Research
Wageningen University & Research

Summary

Allianz SE and WUR are collaborating to answer three important questions about the impact of financial investments on biodiversity and the necessary investments to achieve a zero-biodiversity loss economy.

- How do financial investments impact biodiversity?
- How can biodiversity loss influence financial sector companies' insurance and investment portfolio?
- How much private and public investment should be invested in biodiversity measures to reach a zero-biodiversity loss economy?

This study, a product of this collaboration, has two objectives. First, it identifies progress and challenges faced in answering three research questions by conducting interviews and using existing knowledge. Second, it provides evidence of the economic effects of loss of biodiversity and the costs of mitigating those losses at a country-sector level through a case study pollination services loss (PSL). The study assesses the impact of the loss of pollination services on sectoral economic activities in France, Germany, Italy, the Netherlands, the United Kingdom, and the United States and estimates the cost of agricultural measures to mitigate pollination services in these markets. It compares those costs with their economic benefits through abating pollination services loss.

Interviews generated important insights related to measuring the impact of biodiversity in the financial sector. First, measuring the impact of investment portfolios on biodiversity is difficult due to a lack of specific indicators, local factors, and supply chain risks. Sectors such agri-food, hospitality, and tourism are particularly vulnerable. There is limited knowledge of the costs and benefits of restoring biodiversity and investment opportunities for finance.

We have identified two research areas from the interviews to improve the assessments of the economic risks and opportunities associated with the loss of biodiversity and ecosystem services. The first is to identify the economic impact of biodiversity loss on financial sector portfolios at the country and sector levels. The second is to develop a list of biodiversity restoration measures and estimate the cost-effectiveness of those measures at the country and sector level.

This study contributes to addressing the two areas of research mentioned above. We examine the economic impact of various PSL shock scenarios in Western Europe and the US. We use pollination dependence ratios (PDR) to estimate how different levels of PSL would affect agricultural production in each country. To estimate the impact of PSL on the wider economy, we use the MAGNET general equilibrium model to analyse the effects on economic activity in different sectors and countries. The study then looks at the cost-effectiveness of farm management measures in abating PSL. Farmers can enhance pollination by creating habitats for pollinators using various farming measures. The cost of reducing these effects was estimated using literature, open databases, and expert opinion by adapting three widely known farm management methods, no-tillage, and wider use of crop rotation in France, the UK, Germany, Italy, and the Netherlands. We then compared the costs with same measures' economic benefits through abating PSL.

PSL's country sector affects various depending on those sector and country economies' dependence on pollination services and the agriculture sector. PSL negatively affects economies' agricultural output, with varying severity depending on crop pollination reliance. This hits industries relying on agriculture like processed food and meat, and PSL's impact on a country's economy depends on agricultural 's importance in the same country. For instance, PSL would impact Germany's and the Netherlands' GDP by USD 3.2bn and USD 2bn, respectively, while the US would lose almost USD 28bn annually. Eliminating pollination in Germany and Netherlands would particularly reduce agricultural output by 3% and 4%, resulting in annual losses of USD 2bn and USD 1.6bn in the sector.

The cost of crop protection measures varies by country and cropland size. We studied the cost of implementing computer-assisted decision support systems, precision spraying, sensor-based systems,

nematode application, organic fungicide, wider crop rotations, no-tillage, green manures in France, Germany, Italy, the Netherlands, the UK. For example, computer-assisted decision support systems in Germany cost around USD 45m, while nematode application costs over USD 3.5bn. Meanwhile, using organic fungicide can cost anywhere from USD 135m in the Netherlands to USD 2.4bn in France.

Implementing farm management practices for reducing PSL may be economically feasible in some countries. Wider crop rotation can reduce 11.5% of PSL, no-tillage can reduce 6.9%, and green manure can reduce 5.75% in five European countries. We find that, only in the Netherlands, wider crop rotation and green manure are economically viable to implement when only economic benefits through abating PSL are considered. No-tillage is feasible in Italy and the Netherlands but not in France, Germany, or the UK.

The results show that a decline in biodiversity may harm the financial industry and create opportunities for financial investment. Our study found that in the case of PSL, biodiversity loss has significant adverse economic impacts on economies. Yet there are opportunities to mitigate those effects by investing in farm management measures at some countries to restore biodiversity.

To advance our understanding of the consequences of pollinator declines and identify effective solutions, future research can pursue the following lines of inquiry:

- Generating realistic scenarios for global or local pollination loss: While we lack reliable predictions of how pollinator populations will change at specific locations in the coming years, combining land-use changes with biophysical models can help estimate the effects of pollinator declines on crop yields.
- Studying the ripple effects of pollinator declines on ecosystems: We must recognise that damaged ecosystems have broad environmental and economic impacts beyond their effects on crop growth. Therefore, future research should investigate how pollinator declines affect other ecosystem services and functions.
- Examining the co-benefits of conservation measures: Many conservation measures can have positive effects beyond pollination, such as improving water quality and soil health. Future research should develop methods to quantify the economic benefits of these additional positive effects.
- Estimating the effectiveness and costs of pollination measures: We need more evidence on how much different measures can abate or restore pollination services at regional and national levels. This knowledge is crucial to estimating the costs and benefits of pollinator conservation.
- Assessing the impact of economic growth on biodiversity and ecosystem services: Our study did not examine how economic changes affect the pressures on biodiversity-related ecosystem services. Future research should investigate this relationship to inform sustainable development policies.

1 Introduction

1.1 Background

The effects of biodiversity (BD), ecosystem services (ESs) and natural capital assets (NCAs) losses on the economy are comparable to climate change's impacts. Biodiversity is defined as the variety of living organisms from all ecosystems, including terrestrial, marine and other aquatic systems.[1] While ESs are services provided by nature that benefit humans in various ways (see Box 1 for details), there has been considerable BD loss - reduction of species in an ecosystem over time - over the past decades due to land and sea use change, exploitation of resources, pollution, invasive alien species, etc. Compared to baseline estimates, IPBES's global indicators of natural ecosystem conditions show a decline of 47% on average and 25% of assessed plant and animal species under are threat (Ngo et al., 2019), and 20% of countries globally are at risk of ecosystem collapse due to a decline in biodiversity (Swiss Re Institute, 2020). If the world economy functions as usual and continues losing essential ecosystem services that biodiversity provides, it will also lose 0.67% of global GDP per year (equivalent to about USD 479bn per year) until 2050 (Johnson et al., 2021). To address this, several strategies have been developed on the route to living in harmony with nature by 2050. For example, to transform society's relationships with biodiversity, the Convention on Biological Diversity set ambitious targets such as: 'ensure at least 30% globally of land areas and of sea areas, […], are conserved through effectively and equitably managed, ecologically represented and well-connected systems of protected areas', or 'increase financial resources from all sources to at least US $200 billion per year […]' (CBD, 2021, July 6).

Box 1. Ecosystem services and Natural Capital Assets

The set of renewable and non-renewable resources that benefit people are understood as natural capital assets (NCAs), and they support ecosystem services that our economic activities rely upon (Guerry et al., 2015; Leach et al., 2019). Ecosystem services (ES) are widely defined as services that nature provides to humans, these services can be varied, and some economic activities such as agriculture, livestock and forestry benefit from them. They are usually categorised as either provisioning, regulating, supporting, or cultural services. Some examples include water and food, pollination, habitat for species, recreation, and mental and physical health (FAO, 2022). An ecosystem needs to be functioning properly so that it is able to provide such services. A delicate balance of interacting species among each other and with their natural environment will allow an adequate ecosystem functioning and thus, enable the provision of ecosystem services (Vos et al., 2014). Causes of disruption of ecosystem services are varied, for instance, climate change, eutrophication, and biodiversity loss. The latter is evidenced whenever species are reduced in an ecosystem. This loss can negatively influence the balance in that ecosystem and disrupt or impede the provision of the ecosystem's services. For example, loss of pollinators, such as species of bees or moths, affects the ecosystem service of pollination (pollination services from here onwards). At the same time, this can affect the production of several crops and bring economic loss (Potts et al., 2016).

The strategies to protect and restore biodiversity bring new business opportunities for the financial system. The biodiversity financing gap to restore biodiversity until 2030 is estimated to be USD 711bn per year, whereas, as of 2019, USD 143bn (16% of the total need) was invested in biodiversity.[2] The majority (55%) of that finance was domestic budget spending and tax policies. And only 5% of it was green financial products, nature-based solutions, and carbon market products that the financial sector can provide. While

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[1] The variety of organisms is observed in 'genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems'. IPBES Biodiversity.

[2] This section is mainly based on findings from Deutz et al. (2020) and based on the loss of biological ecosystem services.

cutting harmful agricultural, forestry, and fishery subsidies, USD 542bn in total, could cover 76% of the gap,[3] the financial sector could contribute to financing the rest through new investment and insurance products.

Biodiversity loss is also a risk to the financial system. Fifty-five per cent of the global economy depends on well-functioning biodiversity and ecosystem services (Swiss Re Institute, 2020), yet investments that increase the economy may adversely affect biodiversity. Financial institutions may face financial, market, reputational and legal risks when they invest in economic activities with adverse effects on biodiversity or are highly dependent on natural capital.

This phenomenon of the economy being dependent on biodiversity and simultaneously impacting biodiversity is called dual materiality (Figure 1.1). Understanding the details of this phenomenon and obtaining insights into risks is vital for financial sectors' performance and essential with the new Corporate Sustainability Reporting Directive (CSRD) of the European Union.

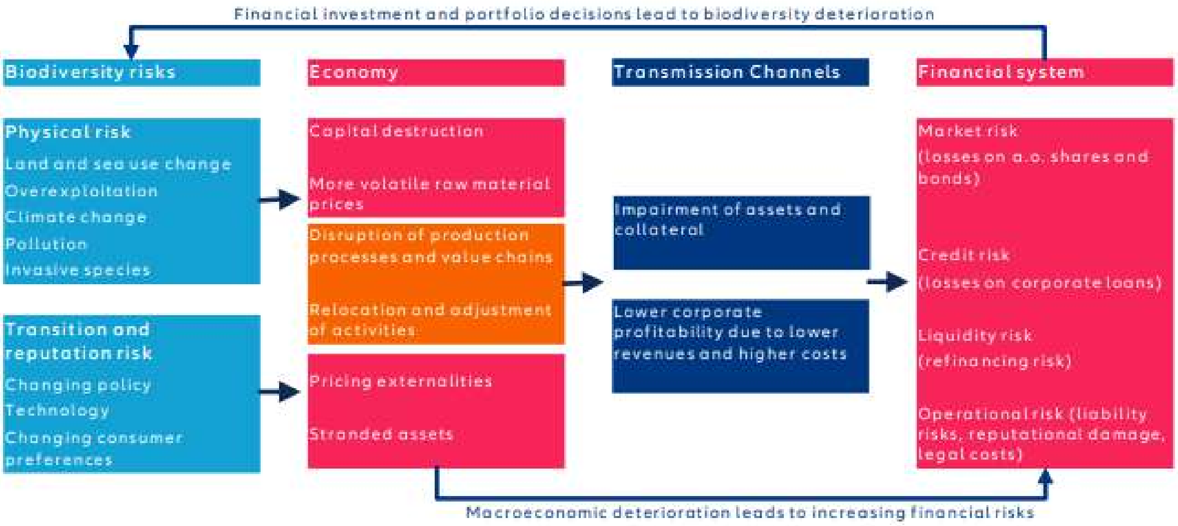

Figure 1.1 *Biodiversity risks to financial risks*
Source: Zimmer et al. (2023) based on DNB (2020).

Three main research questions should be answered to identify those biodiversity-related risks and investment opportunities for the financial sector:

1. How do financial investments impact biodiversity?
2. How can biodiversity loss influence financial sector companies' insurance and investment portfolio?
3. How much private and public investment should be invested in biodiversity measures to reach a zero-biodiversity loss economy?

WUR has collaborated with Allianz SE in an effort to address certain questions. Allianz SE is a global financial services provider that offers insurance and asset management solutions worldwide. By seeking answers to biodiversity-related questions, the company aims to make informed decisions regarding their financial portfolio. The study conducted by WUR will provide valuable insights to Allianz SE on this topic.

1.2 Objective and plan of the study

The objective of this report is two-fold. The first objective is to identify the progress in research and the challenges to answer the above mentioned three research questions. For this purpose, it uses in-depth interviews with Allianz and Wageningen University and Research (WUR) experts and information from the

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[3] For instance, according to the estimates from Deutz et al. (2020), USD 30.9bn to USD 92.5bn green finance could be used to finance biodiversity from 2020 to 2030.

internal biodiversity and finance workshop organised at WUR. WUR, supplemented by existing knowledge and data from the scientific and grey literature. Using those findings, it proposes a research agenda to improve the capacity of financial sector organisations to assess biodiversity-related risks and opportunities.

The second objective is to provide case study evidence on the potential economic effects of BD loss and the costs of abating those losses at country-sector level. Around 75% of cultivated crop types such as fruits, nuts, and highly valued commodities like coffee and cocoa, depend on pollinators (Potts et al., 2016). The global economic value added of pollination services is estimated to be between 235 and 577 billion (in 2015 US dollars)[4] (IPBES, 2016). Declines in pollinators have been documented mostly at regional or national levels, and a global study found that the number of bee species was 25% lower from 2006 to 2015 than before 1990 (Zattara and Aizen, 2021). While pollinators continue to decline, for example, at the European level, around 40% of bees and butterfly species are highly threatened, with national numbers in European countries reaching 50% of highly threatened species (IPBES, 2016). Trends in species abundance and diversity in European agricultural landscapes (hereafter: agrobiodiversity) are worrisome as a consequence of agricultural intensification, a limited number of cultivated species as well as land abandonment (EEA, 2021; Lécuyer et al., 2021; Mupepele et al., 2021). The loss of pollinators is expected to limit crop yield and production, harming agricultural production and related sectors (Johnson et al., 2021). This study uses general macroeconomic equilibrium modelling to assess the impact of the loss of pollination services on sectoral economic activities in France, Germany, Italy UK, the Netherlands, and the USA, critical markets for the financial sector. Then it combines information from experts, public databases, and existing literature to estimate the cost of agricultural measures to abate pollination services in those markets.

This report is structured as follows. The second section introduces the challenges and opportunities in evaluating the risks and opportunities related to the zero-biodiversity loss economy from the financial sector perspective. The third section presents the conceptual framework and methodology to assess the economic effects of BD loss and the cost of abatement measures for BD. The fourth section summarises the findings on the impact of pollination services loss (PSL) on sectoral economic activity and the cost of implementing farming measures to abate pollination loss in selected countries. The fifth section concludes with a summary and implications of the findings for the financial sector and next steps for research.

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[4] This is the market value of production directly attributable to pollination.

2 Challenges and opportunities in evaluating the risks and opportunities related to the zero biodiversity loss economy

Global biodiversity strategies have been in place for a few decades, but specific indicators to measure progress need further development. Unlike greenhouse gas emissions, biodiversity faces the challenge of being a complex topic regarding its relation to ecosystems, biomes, and their inherent local nature; therefore, setting specific numerical targets is complicated. The Convention on Biological Diversity has developed Strategic plans for biodiversity, setting the AICHI biodiversity targets from 2011-2022 and later being replaced by the post-2020 global biodiversity framework (GBF). Because these previous targets were considered to have low measurability and to be unrealistic, the updated version presented by the post-2020 GBF includes specific indicators to measure the progress of each target.[5]

There are several indicators and methods for biodiversity measurement, but there is no consensus on those methods and indicators. The most commonly used biodiversity indicators to calculate the pressure on biodiversity is the Potential Disappearing Fraction of Species (PDF), the Local Biodiversity Intactness Index (LBII), and the Mean Species Abundance (MSA) (Marques et al., 2021). PDF measures the number of species lost in a given land area or water volume over a given period following land transformation and occupation, toxic emissions, climate change, etc. (Crenna et al., 2019). LBII is defined as 'the average abundance of a large and diverse range of organisms in a given geographic area, relative to their reference populations,' where the reference condition is approximated by current conditions at minimally degraded sites, given the lack of sufficiently accurate historical baseline data (De Palma et al., 2021). While the MSA is defined as the population size of species in a site ecosystem relative to their population size in an undisturbed situation. Several biodiversity methods provide data and models to link biodiversity pressures to potential impacts on biodiversity. The most common ones are LCA-based methods (e.g. ReCiPe, LC-IMPACT, Impactworld+) applicable at different scales (from global to product) (Chouchane et al., 2022)[6].There is no international consensus in business about which methods and indicators should be used to measure and evaluate biodiversity. We note that more and more researchers and enterprises use MSA to measure biodiversity.

An early-stage tool for the financial sector to assess and report on the effects of investment portfolio's impact on biodiversity. ENCORE (Exploring Natural Capital Opportunities, Risks, and Exposure) is an early-stage tool to report on the likely results of investments on biodiversity loss, determining the potential impact of portfolios using the Mean Species Abundance indicator[7] (please see a detailed explanation Of ENCORE in Box 2). When combined with data from Integrated Biodiversity Assessment Tool (IABT) data that provides geographic information on existing biodiversity, it is possible to develop reports showing the proximity of invested companies' assets to areas vulnerable to biodiversity loss and assess the potential effects of existing invested company assets on biodiversity.

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[5] For example, Target 14: Mainstreaming biodiversity, includes 'integration of biodiversity into national accounting and reporting systems, defined as implementation of the System of Environmental-Economic Accounting" One-pagers on the Goals and Targets in the First Draft of the Post-2020 Global Biodiversity Framework | Convention on Biological Diversity (cbd.int).

[6] This section is work by a research group within Wageningen Economic Research, the publication under review is the following: Chouchane et al. (2022).

[7] Please see ENCORE Guide to Biodiversity Module for detailed information.

Box 2. ENCORE knowledge base description

ENCORE (Exploring Natural Capital opportunities, risks and exposure) is an assessment and visualisation tool to help users better understand and visualise the impact of environmental change on the economy. Focusing on the goods and services that nature provides to enable economic production guides users in understanding how businesses across all sectors of the economy potentially depend on and impact nature, and how these potential dependencies and impacts might present a business risk (ENCORE (naturalcapital.finance).

The tool was jointly developed by the Natural Capital Finance Alliance in partnership with UNEP-WCMC and was financed by the Swiss State Secretariat for Economic Affairs (SECO) and the MAYA Foundation.

ENCORE defines natural capital assets (NCA) as components of natural capital that provide ecosystem services. They categorise them into habitats, species, soils and sediments. The platform shows, for instance, that pollination services are dependent on the natural capital assets' species', 'water', and 'atmosphere',[8] the latter also including 'change in precipitation seasonality' or 'change in wind speed' *(Biodiversity Impact and Ecosystem Service Dependencies Integration of Dependencies Using the BFFI and ENCORE,* n.d.; ENCORE, 2022).

Box 3. The Heterogeneity in ecosystem services valuation in Germany, France, Italy, Great Britain, and the Netherlands

Ecosystem Services Valuation Database is a public database including standardised monetary values of ecosystem services in a specific geographic area, based on 900 peer-reviewed studies evaluating the value of ecosystem services for different regions in different years. We used that database to analyse the variation in the monetary values of the services in Germany, France, Italy, the UK, and the Netherlands, some critical European financial markets for which many studies are available. In our analysis, we only included monetary valuations for non- and semi-protected areas, as valuating fully protected areas would not be relevant financial sector investments.

The table shows each country's minimum, median, average, and maximum value of ecosystem services in 2020 US dollars per hectare per year. It shows that the economic value of ecosystem services may differ within and between countries. While the average value of ecosystem services is about USD 120 thousand per hectare in Italy and USD 21 thousand per hectare in France, it is no more than USD 4 thousand in Germany and the Netherlands. The variations among the monetary values of ecosystem services for different geographic zones are much wider within the countries. For instance, the value of ecosystem services can range between USD 0.21 to USD 545 thousand per hectare within France and reach more than USD 2m per hectare in Italy. The high numbers for Italy might be because sectors like tourism highly benefits from the ecosystem services than other European countries. For instance Italy the Bergeggi area the ecosystem services worth around 72 euros per m^2 in 2013.

Table B3 *Monetary value of ecosystem services in 2020 US dollars per hectare per year.*

Method	Min.	Mean	Max
France	0.21	21,465	545,709
Germany	124.43	3,109	9,504
Italy	2.82	121,638	2,301,802
Great Britain	0.02	3,738	100,391
The Netherlands	5.15	8,394	70,998

Own calculations from ESVD database.

The local nature of biodiversity creates challenges when estimating an investment portfolio's impact on biodiversity. Risk reporting based on ENCORE posed some challenges due local nature of biodiversity due to biome, geography and environmental stressors exposure to the ecosystem. Multinational companies invested by financial institutions have premises in different regions for different business activities, countries, and continents with other ecological characteristics and are used for different purposes (manufacturing, storing, office space etc.), creating various risks for biodiversity. Existing tools and databases like ENCORE provide information on the dangers at the high level of sectoral aggregation, not at the activity level, making it challenging to identify the potential effect of each premise at a specific location. Moreover, the biodiversity-related impact of investments will be geographically heterogeneous. For instance, we see a wide range of variation between the economic values for ecosystem services in non-protected areas in Germany, France, Italy, the UK, and the Netherlands that we estimated using the Ecosystem Services Valuation Database

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[8] Please note that water and atmosphere is also defined as abiotic ecosystem services in other sources.

ranges widely, depending on the region (please see Box 3 for details). All this implies that ecological harm stemming from a specific business activity in one area differs from the environmental damage it would create in another region. It depends on the activity, the presence of the type of ecosystem services, and the values of those services.

Measuring the biodiversity risks created by supply chain linkages is challenging. It is difficult to pinpoint where an investment's ecological risk starts and ends, as indicated in our interviews. For instance, the financial sector cannot assess the biodiversity-related risk an agri-food company's linkages with global supply chains (e.g., coffee, cocoa, sugar procurement globally) creates. However, such risks should be evaluated according to the CSRD regulations if investments lead to significant physical or transition risks.

Agri-food, hospitality and tourism sectors are highly dependent on natural capital and are at risk due to biodiversity loss. The decision-makers state that they need to know the businesses most dependent on ecosystem services provided by biodiversity and the most exposed biodiversity loss risk to optimise portfolio choices. Recent scoping studies shed some light on the high-risk sectors, providing a qualitative ranking among them by their qualitative exposure to biodiversity-related risks. For instance, the (Swiss Re Institute, 2020) shows that agriculture, forestry, fishing, manufacturing, accommodation, and food services have the highest dependency on ecosystem services. Furthermore, six industries – chemicals and materials; aviation, travel and tourism; real estate; mining and metals; supply chain and transport; retail, consumer goods, and lifestyle have low direct dependencies on ecosystem services; however, they are highly dependent on them through their supply chains (World Economic Forum, 2020). In Sustainable Insurance Forum (2022), Allianz Global Corporate and Specialty presents their sectoral biodiversity risk assessment[9] reaching a similar conclusion to the latter. They find that agri-food and tourism, travel, and hospitality industries have very high, and manufacturing, mining, quarrying, real estate, transportation, and storage industries are exposed to increased physical risks due to biodiversity loss.

There is limited evidence on the direct effects and supply chain effects of biodiversity loss at the country-sector level in monetary terms, but some new frameworks and methods exist to assess those monetary effects. Our interviews indicate that financial sector decision-makers seek economic risk assessment to optimise their portfolio decisions. Although qualitative studies show how different sectors are exposed to biodiversity-related risk, we have not detected such a scoping study on the monetary value of those risks but have seen new emerging methods to evaluate the economic risks on a case study basis. For instance, a new framework to assess biodiversity risks is the LEAP framework by TNFD,[10] which can be combined with TNFD's data to determine a business's entire value chain biodiversity-related risks. The Foundation for Sustainable Development (FSD) used the LEAP framework and Ecosystem Valuation Data to propose a method for assessing ASN Bank's biodiversity-related risks of their investments and insurance. Also, FSD provides several cases in which financial comparisons are made between baseline economic activity and a favourable ecosystem change scenario (e.g., reforestation), resulting in an increase in the monetary value of the case areas by 22% and 127% (van 't Hoff et al., 2022). For instance, general macroeconomic equilibrium models can assess outcomes of ecological biodiversity shocks covering effects along entire value chains. This report will use the Magnet general equilibrium model to estimate the total economic loss in the vegetables, fruits, pulses, vegetable oils and fats, and food industries due to pollination services loss caused by invasive alien species (Please see Section 4 for details).

Limited knowledge about the costs and benefits of measures to restore biodiversity for understanding investment opportunities for the financial sector. Adapting and building resilience to achieve biodiversity goals will require investments in several biodiversity measures related to stopping deforestation, reforestation, coastal restoration, sustainable fishing and biodiversity-friendly agricultural practices, sustainable food production and value chain systems, restoration of wetlands, building green and blue spaces in urban areas etc. including several measures to abate and restore biodiversity that private sector should also implement.[11] To restore and protect biodiversity, the conservation of croplands needs about USD 315bn, and preservation of protected areas requires USD 149bn, and protection from invasive species needs

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[9] This assessment is based on ENCORE database and determined by mapping the potential level of dependency to ecosystem services for each sector and the level natural capital loss.

[10] LEAP is the risk and opportunity assessment approach of TNFD (Taskforce on Nature-related Financial Disclosures).

[11] Please the first draft of the post-2020 global biodiversity framework Convention on Biologic Diversity (2021) and Table 1 at Shin et al. (2022) for the list of biodiversity measures.

USD 36bn (Deutz et al., 2020). At this stage, a complete list of investments necessary is unavailable to the decision-makers. Also, the costs of implementing and the biodiversity benefits of those measures, commonly used biodiversity indicators are not well known.

The financial sector has three research areas to assess the economic risks and opportunities that biodiversity and ecosystem services loss create.

First of all, there is a need for a location-specific data to improve risk assessments and biodiversity risk assessments for companies' value chains. Decision-makers, including those participated in our interviews, need location-specific information on insured or invested companies. They can use that information to estimate the biodiversity-related risks an investment might create or the risks that biodiversity loss creates in the investment portfolios of the institutions. For this purpose, key data providers should be identified, and companies should share their location-specific business activities, including their value chain linkages, in more detail through a framework shared by the financial sector companies. If necessary, third parties can be invited to assess the risks in the value chains of companies that financial sector institutions invest in.

Second, research should identify the monetary effects of biodiversity loss on financial sector portfolios at country and sector level. New methods to evaluate the economic value of ecosystem services (e.g., general equilibrium models) will show the monetary loss the insurance businesses and banks might incur due to biodiversity loss. Such research will help financial sector agents optimise financial strategies, re-aligning insurance and investment portfolios according to the risks' monetary value and trigger new insurance product development to adapt to the risks.

Third, research should provide a list of measures to adapt and restore biodiversity and cost-effectiveness estimates of those measures at the country-sector level. Learning the capital investment required to adopt measures to abate biodiversity loss and the contributions of those investments to the restoration of biodiversity loss will help the financial sector prioritise the investment projects with the highest potential to restore biodiversity.

This study contributes to second and third areas of research needed to assess the economic risks and opportunities that biodiversity loss may create for the financial sector. The study contributes to the second area of research, providing an assessment of the economic effect of biodiversity at the country-sector level and estimating the economic impact for the case of pollination services loss using a macroeconomic general equilibrium model. The financial sector can use those economic effects estimates to assess their portfolios' biodiversity-related risk exposure. The sector can weigh the estimated sector-country level economic losses due to the losses by the share of financial assets in those sectors and countries. It contributes to the third area of research, providing an example of abatement cost estimation for measures from arable agriculture contributing to the restoration of pollination services. The financial sector can use those cost estimates to predict the investment required to restore pollination services and credit demand to finance those investments.

3 Method to evaluate the economic effects and financial costs of abatement measures

3.1 Relationship between ecosystem services, natural capital assets and business activities

Business activities depend on ecosystem services (ESs) supplied by natural capital assets (NCAs), but they can also affect NCAs adversely (Figure 3.1). Biodiversity - the variety of species and habitats - is part of diverse NCAs[12] that provide ESs[13] such as water, soil quality, dilution, pollination, pest control, and flood protection. The economy comprises several businesses utilising those services (e.g., hydropower production, agriculture through pollination), which the financial sector may have also invested or insured. A decline in biodiversity and loss of habitats and species causes a reduction in the ability of NCAs to provide ESs essential for the economy and decreases the productivity of businesses (measured by the value of output obtained with one unit of economic input) dependent on ecosystem services. Business activities and natural disturbances are 'impact' drivers that change the environment and lead to (quantitative) changes in NCAs. For instance, in the case of business activities impact, drivers are man-made pressures on NCAs such as GHG emissions, water pollutants, terrestrial ecosystem use, etc. In case of natural disturbances, they are natural events such as storms, and vulcanos, which can also drive Environmental Change.

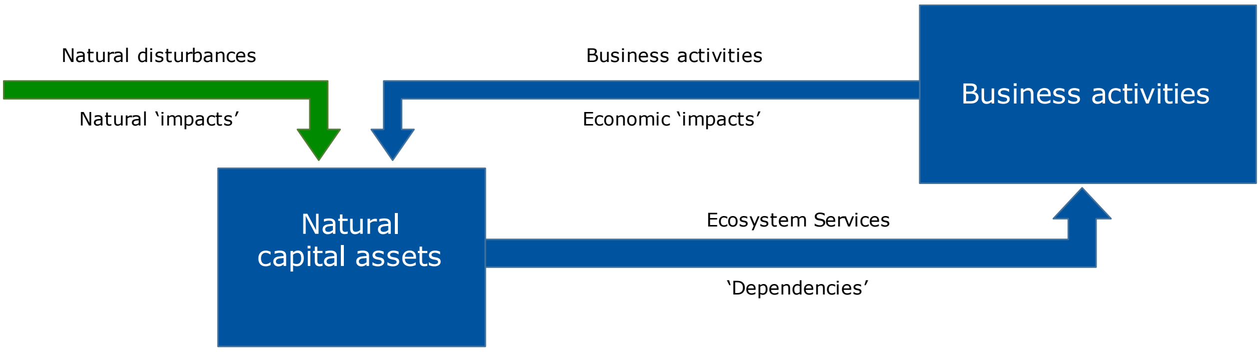

Figure 3.1 *Relationship between natural capital assets, ecosystem services, and business sectors*
Source: Generated by WUR researchers using ENCORE framework.

Several steps should be completed to estimate the economic effects of ES loss on business activities and the financial costs of abating those ES losses. We can start estimating the economic effect of ES loss on business activity by developing alternative shock scenarios on the changes in the NCAs based on the expected developments in impact drivers, natural disturbances and business activities. After identifying the NCAs changing in the scenarios, we can determine the list of ESs influenced by those. As a next step, we can focus on an ES to estimate the economic effects on business activities and determine the NCAs that are impacted by the scenarios. Concentrating on one ES category is helpful in the estimation because there is a variation in the economic effect of ES loss between sectors. For instance, the construction sector is directly dependent on the availability of soil but not pollination services, while the agriculture sector is dependent on both and identifies the NCAs providing those ecosystem services. The sectors that will directly experience production losses due to ES loss can be determined, and we can estimate the amount of production loss that they will experience per loss of NCA under selected ES. As a final step, we can estimate the direct effect of production loss in the economic activity of selected sectors due to those NCAs and evaluate the indirect, second-tier

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[12] Classified according to UNEP-WCMC and explained in Leach et al. (2019).
[13] Classified according to CICES: Structure of CICES |.

economic effect of ES on other related sectors, using a relevant economic model (e.g., general macroeconomic equilibrium model).

To estimate the costs of abating ES loss on economic activity, we should first determine the applicable measures that will prevent or reduce the identified adverse effects of natural disturbances and financial activities on selected NCAs. The next step is to identify the extent (e.g., number of) of economic actors for which it is relevant to implement those measures and their likelihood of adopting them, using microeconomic models, evidence from the literature, or expert opinion. We can find the cost of adopting those measures per measure and economic agent using evidence from the literature or expert opinion. Then we can estimate the total costs of implementing those measures by combining information on the adoption rate, the extent of economic actors for the measures are relevant for and their predicted adoption rate, cost per measure and economic agent.

3.2 Estimating the economic effect of pollination services loss

To demonstrate how someone can estimate the economic effects of ES loss and the financial costs of abatement measures, we focus on pollination services loss (PSL) in Western Europe and the North America[14] as a case study.

3.2.1 Estimating the effects of pollination loss on economic activity

PSL affects overall business activity in the agriculture sector, where pollination is essential (Figure 3.2). Pollination is necessary for food production and human nutrition. Most of the producing plants of nuts, fruits and seeds in the human diet depend on pollinators to reproduce. Pollinators, such as diverse species of bees, moths, butterflies and other insects, play a key role in flowering plant reproduction, mobilising pollen from one plant to another, enabling fruit production. In this sense, pollination services are essential for crop, horticultural and orchard production (FAO, n.d.; Potts et al., 2016). PSL can directly and adversely affect agricultural production activities through decreases crop production yields and production, which also impact other sectors dependent on agricultural inputs.

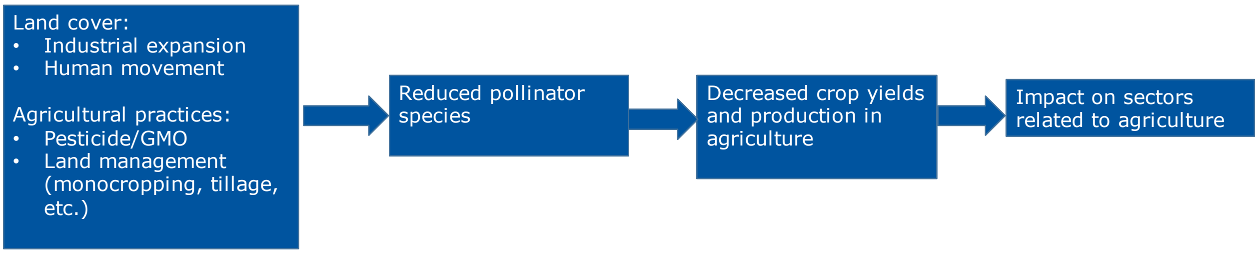

Figure 3.2 *Impact pathway of pollination loss*

In this study, we estimate the economic effects of different PSL shock scenarios in Western Europe and North America. In total, we study ten PSL shocks, 100% (complete pollination loss), 90%, 80%, ... to 10% pollination loss. The main results are presented for the complete PSL (100% pollination loss) scenario, which is a common scenario in other studies in the literature[15] to show the importance of pollination services for economic activity, and for the 20% PSL scenario to demonstrate how the estimated effect changes by the level of the loss. We use estimates from the other eight scenarios to illustrate the nonlinearity in effects and compare the calculated economic loss estimates with the costs of abatement measures. Our shock scenarios are similar to those of previous studies.[16] We skip the step of producing pollinator loss scenarios through biophysical models as utilised

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[14] We estimated crop production losses due to PSL loss in Belgium, France, Germany, Great Britain, Italy, Portugal, Spain, the US and the Netherlands.

[15] Such as the *Economic case for nature* report (Johnson et al., 2021) that considers 90% loss of pollinators, or see also Bauer & Wing, (2016) that present a total loss of pollination services.

[16] See the JRC Economic Accounting report (Vallecillo Rodriguez et al., 2018), WWF's Global Futures report (Roxburgh et al., 2020) and the World Bank report (Johnson et al., 2021).

in WWF's Global Futures report (Roxburgh et al., 2020) and the World Bank report (Johnson et al., 2021) as those models are not available to us at this stage (Please see Box 4 summarising the method used in those studies). WUR researchers are currently developing projects to use the GLOBIO biodiversity model.

Box 4. Summary of the model used in WWF's Global Futures report

Roxburgh et al., 2020 and Johnson et al., 2021 use biophysical models to use foresight scenarios (Box 1 in the Figure below) (e.g., change in socio-economic structure, technologies, population) to predict land use change at the geospatial levels (Box 2 in the Figure). and estimate the effect of land use change on pollinator losses (Box 3.in the Figure), and finally estimate the effect of pollinator losses on economy (Box 4 in the Figure) For instance in WWF's Global Futures report (Roxburgh et al., 2020), pollinator services changes are derived from an ecological model, InVEST. Similarly, the World Bank (Johnson et al., 2021) first links the GTAP – Agro-Ecological Zone (GTAP-AEZ) model to SEALS model to predict land use change and use predicted land use change in InVEST model to predict pollinator losses at the geospatial level. Then their model use those predicted pollinator losses to estimate GDP loss due to pollination services under different foresighted scenarios. In our study, we take a shortcut around steps 1,2 and 3 in the Figure as SEALS and InVEST models are not available to us.

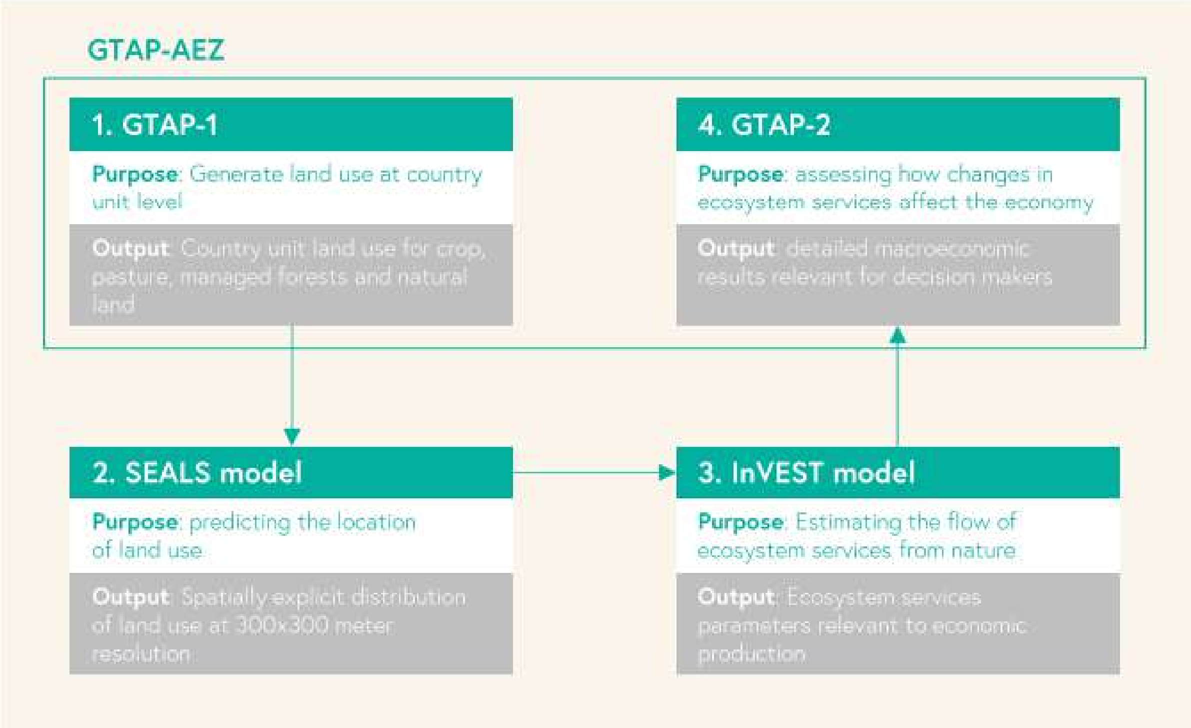

Figure B4 *Building blocks of the integrated ecosystem-economy model (Johnson et al., 2021, p.19)*

We use pollination dependence ratios (PDRs) to estimate the effect of different PSL shock scenarios on agricultural production at the country level. Like the economic losses calculation methods of Bauer and Wing (2016) and La Notte et al. (2020), we assume that PSL decreases crop yields by their PDRs. Using those ratios for various crops from the ecology literature[17] and FAOSTAT data on historic agricultural production,[18] we estimate the decrease in crop production in Western Europe and North America for different rates of hypothetical PSL.[19] For instance, a 100% PSL is equivalent to a crop production loss by the size of the crop's PDR, and a 20% PSL is equal to a production decrease of the crop's PDR multiplied by 0.2. As some countries produce more pollinator-dependent crops than others, these steps result in variation in the PSL shocks amongst countries. Please see Table A3 in the Appendix for PDRs by countries and crops.

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[17] Crop PDRs are derived from studies by Aizen et al. (2019) and Klein et al. (2007).

[18] We used agricultural production of the year 2020.

[19] When necessary we aggregated FAOSTAT production volumes per crop type according to commodity types in MAGNET model. This implies that for every relevant MAGNET commodity (fruit, vegetables, nuts, etc.), a weighted average production loss for the considered country is calculated.

We use the MAGNET general equilibrium model to estimate the effect of pollination loss scenarios on economic activity at the sector-country level (Please see the MAGNET model description in Box 5). The crop production losses estimated for different scenarios are used as input in the MAGNET model to generate production effects for various economic sectors in different countries and regions trading each other. We estimate results for eight countries and ten regions if relevant Belgium, France, Germany, Italy, Netherlands, Portugal, Spain, United Kingdom, the rest of EU, the rest of Europe (non-EU), Africa, Northern America, Latin America, Central America, Asia, the rest of the World. In addition to primary agriculture, the model estimates the indirect effect of PSL on sectors such as consumer staples, processed & packaged foods and meats, brewers, distillers and wine producers, food services, and indirectly affected sectors such as industrial products and fertiliser sector. The GICS sectoral classification used in this study and its match with Magnet modelling sectors is presented in Table A2 of the Appendix. Please also note that due to agricultural production shocks, production factors (e.g., land, labour, capital etc.) will be reallocated from agriculture-related sectors that are affected from PLS to non-agriculture-related industries that are less affected. Due to this reallocation of resources, MAGNET can estimate that those non-agriculture-related sectors might increase their production, and those non-affected sectors might increase their output after PLS.

Box 5. Magnet model

MAGNET (Modular Applied GeNeral Equilibrium Tool) is a multi-regional, multi-sectoral applied computable general equilibrium (CGE) model, which builds on GTAP datasets (Woltjer et al., 2014). CGE models combine economic theory with data to derive effects of economic shocks or policy change. In MAGNET, perfect competition is assumed and actors choose the cheapest combination of production factors labour, land, capital and natural resources. Contrary to partial agri-food models, MAGNET includes income feedback loops between primary and industrial sectors in order to cover the full (bio)economy (MAGNEt-model.eu, n.d.). MAGNET will be linked to land use models related to ecological data – such as IMAGE and GLOBIO – to include ecological details.

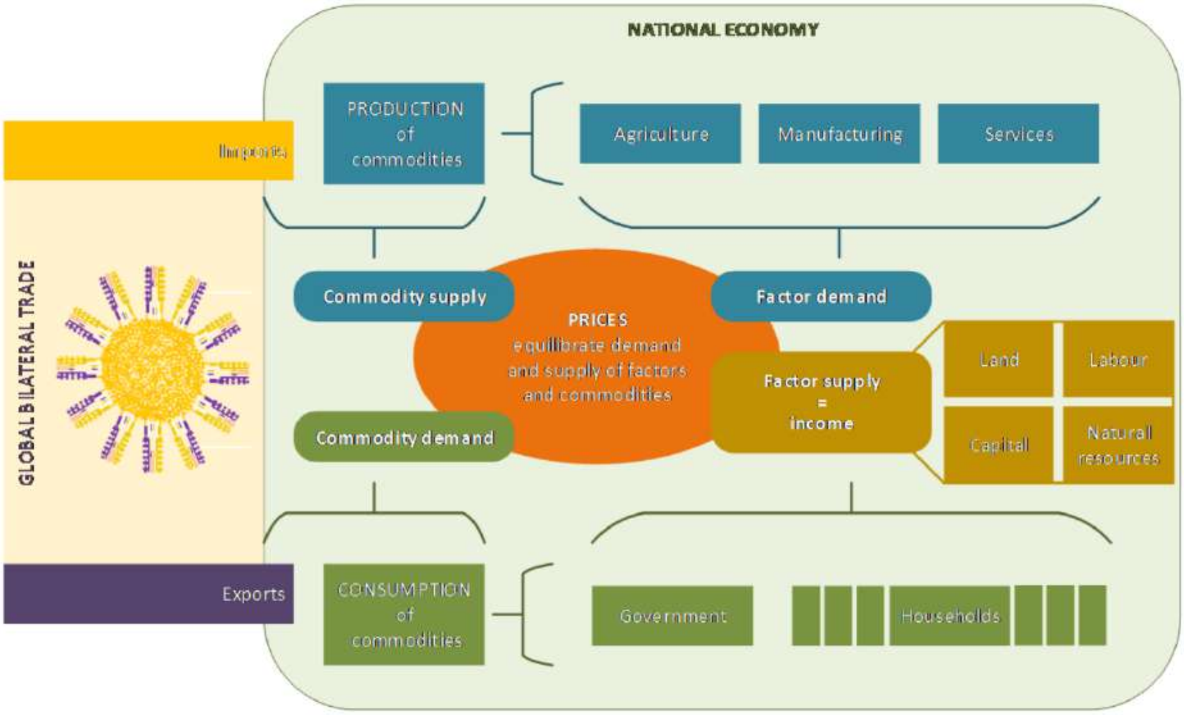

Figure B5 *Building blocks Magnet model*

Estimating economic loss due to PSL by following this method has some limitations. First we simulate or assume a 20% and 100% PSL and demonstrate what the consequences might be.[20] Using actual estimations of future PSL might provide a more realistic economic impact prediction. Second, related to the first limitation lies the assumption that a 100% PSL causes a decrease in agricultural output of the size of the

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[20] We do not estimate the magnitude of global or local PSL, like Roxburgh et al. (2020) and Johnson et al. (2021).

dependence ratio of the crop and that a 20% PSL is a linear 20% part of that decrease. It should be clear that the pressure on wild pollinators and its effects on crop production is not a linear relationship but a complex system highly dependent on many contextual aspects of a specific area. Third, for estimating the crop pollinator dependence ratios, we used estimations of dependence rations provided by Klein et al. (2007) and Aizen et al. (2019), which are estimated very roughly for some crops. For some crops, Klein et al. (2007) and Aizen et al. (2019) estimated the dependence ratios between 40% and 90% for which we took the average of 65%.

3.2.2 Measuring costs and effectiveness of abatement measures for PSL

Human activities such as intensive agriculture and land use change lead to the loss of pollinators (Figure 3.2). Two NCAs, (pollinator) species (insects, birds, mammals) and atmosphere (i.e. wind and favourable seasonal activity patterns for species) are sources of pollination services. Economic activities, such as intensive agriculture, industrial activities affect pollinator habitats and colonies. Especially land management, changes in land cover, and pesticide use are the main drivers of pollinator species decline, next to climate change, genetically modified crops and invasive species (Dicks et al., 2021). For instance, changes in land use and intensive agriculture (large homogenous fields, agrochemical inputs and tillage) reduce the supply of pollen, nectar and nesting resources, leading to insect malnutrition, pollinator colony stress and increased vulnerability to pests and diseases (Potts et al., 2016). The reduced pollinator habitats and species decrease the agricultural yields of the crops that depend on pollinators, adversely affecting the agriculture-related sectors.

This study estimated the cost of abating pollination services for agricultural measures that protect pollinators. We select measures to restore pollination services based on a review of academic and grey literature and consultation with agriculture, plant science, and agricultural experts. Practices that positively affect biodiversity and pollinators, such as improving NCAs such as general habitat quality that will foster a greater biodiversity, are selected. Arable farming to grow crops can be an intervention area to introduce sustainable farming practices to reduce PSL limiting the extensive use of chemicals. There are methods available to farmers for reducing pesticide use and support pollination services. Table 3.1 lists those farming practices to prevent the loss and restore pollination services and costs of implementing those in the Netherlands. In this study we do not attribute the share of the cost to protecting pollinators or other benefits (e.g., abating greenhouse gas emissions) from these measures.

Table 3.1 *Abatement measures for PSL and their implementation costs for the Netherlands. Implementation costs represents costs in 2022*[21]

Type	Measure	Cost adjusted to 2022
Precision agriculture	Computer-assisted decision support systems for optimal timing of input (e.g., fungicide use)	€625 per farm-year
	Precision spraying	Around €10.413 per farm (one time)
	Sensor-based identification, quantification of diseases and high-resolution spraying with cameras and sensors	Minimum of €104.130 per farm (one time)
	Controlled traffic farming	€937 per hectare (one time)
Biocontrol	Nematode application	€625 per ha-year
	Organic fungicide (trianum)	€274 per ha-year
Ecological principles	Wider crop rotations	€10.413 per farm-year
	No-tillage	€52 per hectare-year
	Use of green manures (organic material to improve soil fertility)	€182 per hectare-year

Notes: # The sources of costs estimates are as follows: computer assisted decision support systems, (Dacom,n.y.); precision spraying and sensor based identification, NPPL (2020); controlled farming, (DAW, n.y.); nematode application and organic fungicide, Smit et al., (2021); no tillage, De Wolf et al. (2019), wider crop rotations and green manures, KWIN AGV (2018).

* Estimates can include the costs of yield reduction and the investment required to implement the method.

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[21] These indicative costs were adjusted for inflation using the growth rate of GDP deflator January 2021 compared to GDP deflator January 2022 of the European Union (European Union GDP Deflator - 2022 Data - 2023 Forecast - 1995-2021 Historical - Chart (tradingeconomics.com)).

Management practices that provide habitat for pollinators are beneficial for pollination services, however, estimating the exact increase of pollination services resulting from each measure is difficult. Among the selected measures presented here, some ensure that pollinators face less artificial inputs e.g., precision farming, while others provide resources and habitat for pollinators to thrive, e.g., biocontrol and ecological principles. These practices offer wider benefits to biodiversity and ecosystems supporting agricultural production (Riemens et al., 2021), and are thus recognised by the EU Common Agricultural Policy to support wild pollinators in farmed land (Cole et al., 2020). The exact number of pollinators benefiting from the measures and the increased service in pollination that they can offer is very difficult to estimate. This is because any effects following the implementation of any of these practices will be context dependent. They will depend on local environment, ecosystem conditions of the farm and its surroundings. When analysing specific cases, for instance, implementing measures to reduce pesticide use (e.g., precision spraying, computer-based systems) results are reported as increased amount of pollinator visits to flowers of a particular crop which correlates with pollinator conservation and with increased pollination services and yields (Pecenka et al., 2021).

This study estimates the rough abatement cost[22] of PSL per measures in France, the UK, Germany, Italy and the Netherlands, using the following formulation and implementation costs of measures, based on the costs for the Netherlands (Table 3.1).

$$\Delta AC_{pc} = AR_c \times C_p \times \Delta AD_p \tag{1}$$

p indicates the practices and c show the country. ΔAC_{pc} indicates the change in the country level abatement cost of a practice f,rom 2023 to 2035, AR_c is the area (in hectares) of crops land or number of farms, C_p is the cost of implementing the practice per hectare (or per farm) from Table 3.1, and ΔAD_p the expected change in the adoption rate of the practices from 2023 to 2035. Due to budget and time limitations to perform the analysis, these adoption rates are not crop specific. Future studies could explore adoption rates of each measure for different crops and countries.

Existing literature, open databases such as EUROSTAT and FAOSTAT, and expert opinion are used to estimate the costs. Data for cost of implementing measures (C_p) is from the literature and presented in Table 3.1. To estimate the costs, we use data for both total cropland and the number of cropland farms of soy, oilseeds, as well as fruit and nut trees dependent on animal pollination (Klein et al., 2007). The data on area of cropland (AR_c) is from the FAO,[23] taking into account crops growing on 'arable land' as well as areas covered with 'permanent crops'. Aligned with this, the data on the number of farms is from EUROSTAT under the category of 'crop specialists',[24] including data for the same crops with FAO. This data was available for all countries except for Great Britain. The data on the number of farms for Great Britain is from the Department for Environment Food and Rural affairs.[25] To estimate the cost of adopting these measures, someone should also predict the fraction of additional area or farms for adopting these practices. We use WUR expert opinion to predict the expected change in the adoption rates of those practices from 2023 to 2035 (AD_p). In their predictions, experts considered the current adoption rate and potential upcoming regulations concerning those measures, as well as the suitability of farms to adopt those measures. As input for the abatement cost calculation, the difference between the present and future adoption rates for each measure and country were calculated. The change then on adoption rates represents a maximum for each measure and country, and they are presented in Table A4 in the Appendix. To check the robustness of the predictions, experts have separately been consulted.

Limitations to the calculations are associated to the methodology followed and its assumptions. First, the indicative implementation costs of crop protection measures are mostly from the Netherlands and the Dutch context. The consulted experts agreed that these indicative costs could be extrapolated for the other countries in the set due to similarities in the chosen countries. Second, adoption rates of crop protection measures were provided by the consulted experts. These are approximate values and future studies will need

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[22] Abatement cost understood as costs of implementing crop protection measures that are expected to improve pollination services.

[23] Food and Agriculture Organization of the United Nations. FAOSTAT, Land Use data. Link.

[24] Farms and farmland in the European Union- statistics. EUROSTAT Link.

[25] Agriculture in the UK Evidence Pack. Department for Environment Food and Rural Affairs, 2022. Link.

to perform empirical studies considering, for example, the feasibility of adoption, willingness to adopt, age of farmers, farm size, and crops grown, among others.

Other measures outside of agricultural land use can positively contribute to improving natural habitats and boosting biodiversity and pollinator populations. However, we do not focus on those due to data limitations. Some of these are forestry, the development of landscape elements, such as flower margins, hedges, as well as green roofs in a more urban setting (Passaseo et al., 2021). A rough cost estimation based on the new EU Forest Strategy for 2030[26] and EUs pledge to plant 3 billion trees in the EU by 2030 would indicate that implementing forestry as a measure to restore pollination services would cost around 2,7 billion euros in total for EU. However, we do not report costs estimations for forestry in this report, as we do not have access to information to estimate those costs at the country level.

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[26] EU Forest Policy. European Commission Link.

4 Results

4.1 Economic effects of pollination services loss (PSL)

PSL decreases agriculture output. The level of the loss of the production varies by the extent of countries' dependency on pollination services (e.g., type of crops) and the level of PSL. Figure 4.1 shows the impact (in percentage and absolute levels) of 20% and 100% PSL shock scenarios (compared to the current pollination services level) on the agricultural production of countries we introduced the shocks. A complete loss of pollination services (100% PSL loss) decreases the agricultural output by 1.98% in Great Britain to 7.87% in Belgium. In monetary value, the production loss is between USD 0.6bn in Portugal to USD 26bn in the USA. The production losses are small (between 0.45% and 1.92%) when the shock is 20% pollinator loss when compared to the current level of pollination. Compared to pre-shock agricultural production levels, farm production decreases more in countries like Belgium, Italy, Portugal, Spain, and the US, specialising in high pollination-dependent crops such as apples, pears and nuts. Please also note that, for our study, we have introduced a localised PSL shock to only Western European and North American countries, which experience direct decreases in crop yields in our shock scenarios. As a result, agricultural production increases in other countries not experiencing PSL shock and gaining a competitive advantage in agricultural trade over countries experiencing the shock (Please see Figure A1 in the Appendix).

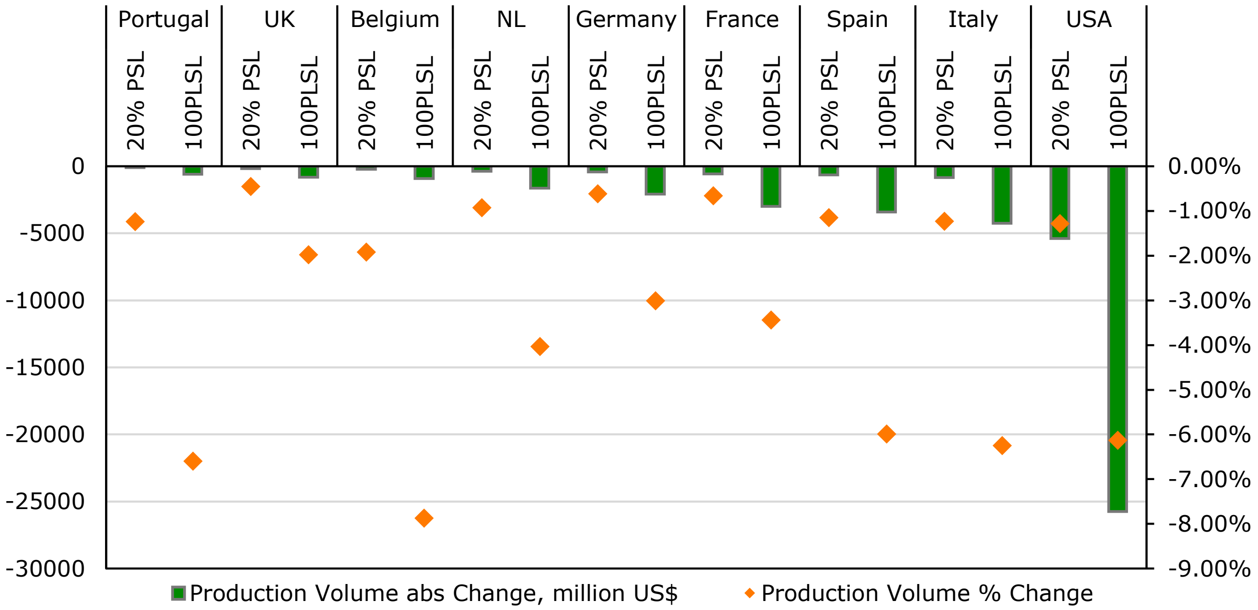


Figure 4.1 *PSL effect on agricultural production in countries experiencing hypothetical PSL shock, 100% and 20% PSL scenarios, absolute change million US$ on the left and % change on the right y-axis*

The level of the agricultural production loss due to PSL and the importance of agriculture and agriculture-related sectors in country economies determine the extent of total macroeconomic losses due to PSL (Figure 4.2). Our model shows that when the indirect effect of decreased crop yields due to PLS, a complete PSL in Western Europe and North America is estimated to reduce the annual gross domestic product (GDP) by 0.04% (Great Britain) to 0.4% (Portugal), in absolute levels between USD 1bn (Portugal) and USD 28bn (US) annually. Compared to pre-PSL GDP levels, this loss is highest in Portugal, Italy, Spain, and the Netherlands, where PSL directly affected agricultural production and agriculture and agriculture-related sectors such as food processing have a high share in total macroeconomic output. For instance, the relative of PSL on the GDP level in Belgium is less compared to pre-PSL shock levels, because agriculture and agriculture-related sectors' role in Belgium's economy is small compared to other industries in the same country.

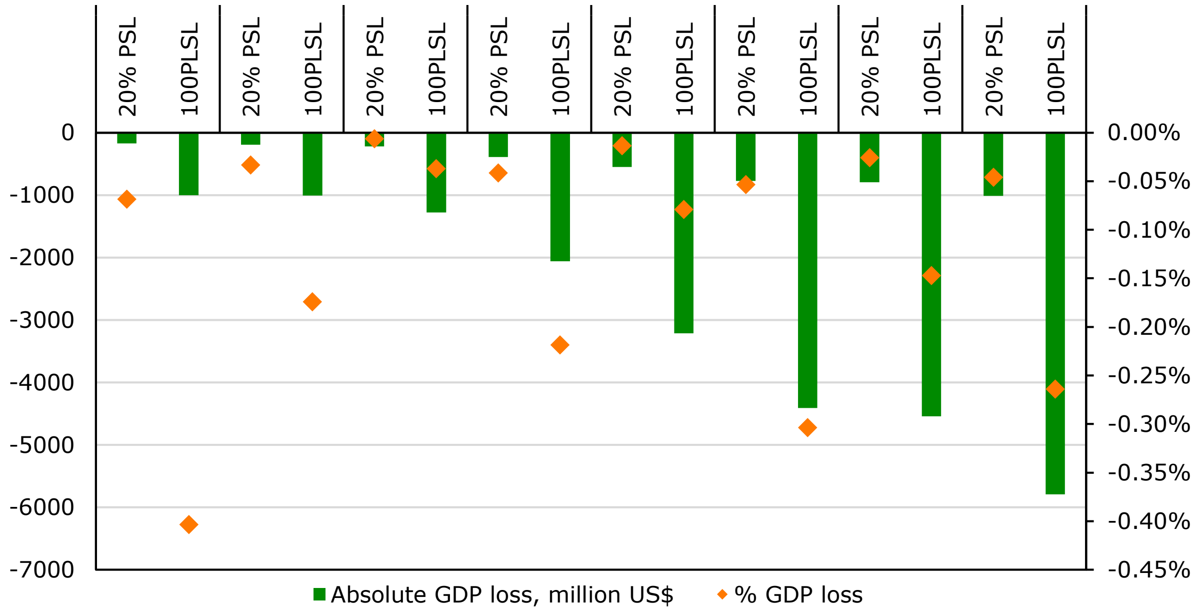
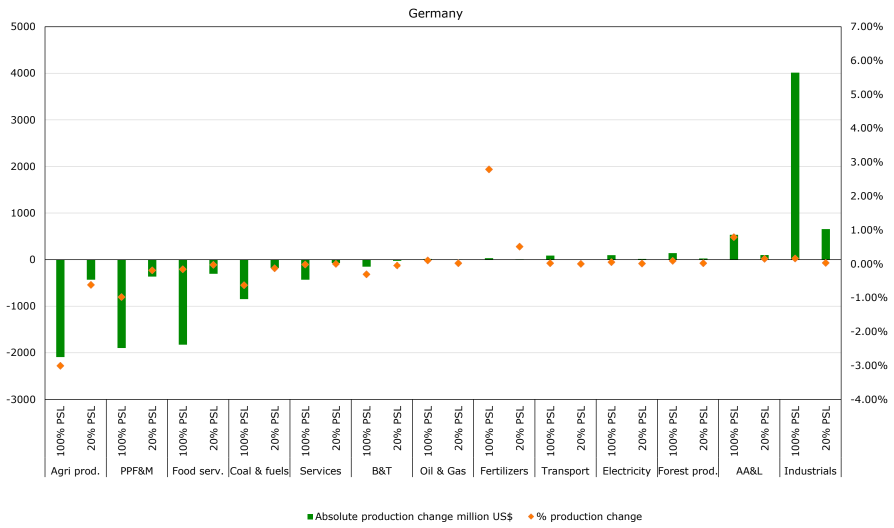


Figure 4.2 *PSL effect on Gross Domestic Product (GDP) of countries experiencing hypothetical PSL shocks, 20% and 100% PSL scenarios, % change and absolute change in million US$*

PSL may adversely affect non-agriculture sectors such as processed packaged food and meats, food services, coal and consumable fuels (e.g., biofuels), beverages and tobacco sectors, which depend more on agricultural inputs than other sectors depend (Figure 4.3). For instance, in case Western Europe and North America experience a complete (100%) PSL, the production loss of the processed packaged food and meats industry in Italy is estimated to be about USD 4bn per year, and the same sector's losses in Germany is estimated to be about USD 2bn, close to the level of agriculture sector's losses in the same countries after the PSL. Similarly, the food services sector, directly dependent on agricultural products, is contracting in all countries after PSL. This is mainly because the prices of agriculture products, the inputs for these sectors, increase and at the same time, the countries hit by PSL shock import more crops dependent on pollination services. The price increase in those agricultural products increases the costs and prices in sectors such as food processing and food services dependent on agricultural inputs, decreasing their profitability and resources allocated to these sectors.

PSL is also estimated to increase the production of sectors that benefit from land, capital, and labour released by the contracting agricultural sector. The model predicts that production in almost all countries in the industrials and services sectors will increase after PSL. In the estimations, our model reallocates agricultural labour, land and capital from agriculture to other sectors unrelated to agriculture and with a relatively higher rate of return than agriculture due to reduced returns to crop production after PSL. The wide variety of sub-sectors under Industrials and Services, such as 'biochemicals, pharmaceuticals, manufacturing' and 'construction', and public and private services are less dependent on agricultural inputs. The positive effect of reallocating resources from agriculture to the Industrial and Services sector compensates for the negative of the increased agricultural input prices in those sectors. The model estimates also show that the food processing and meat industry will have a higher production volume after PSL, particularly in Great Britain and the Netherlands. In those countries, the positive effect of substituting arable land from crop production to livestock production is higher than the negative effect of increased animal feed prices due to PSL.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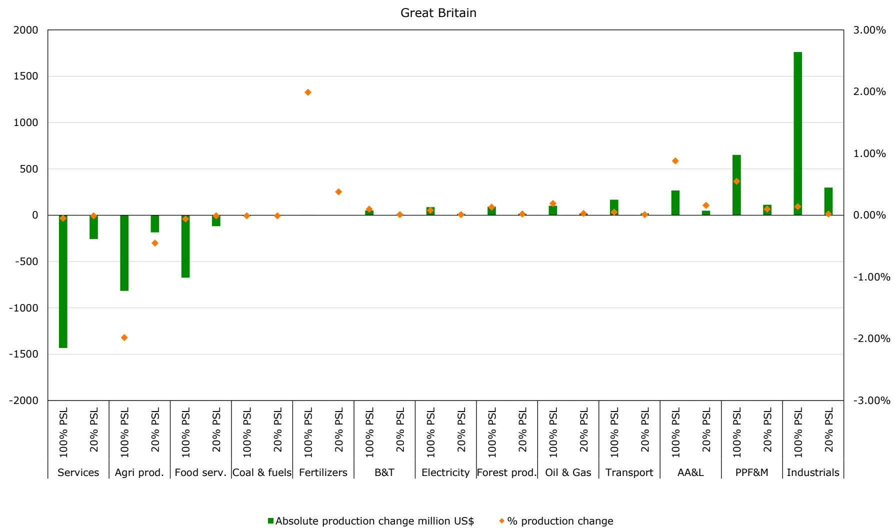
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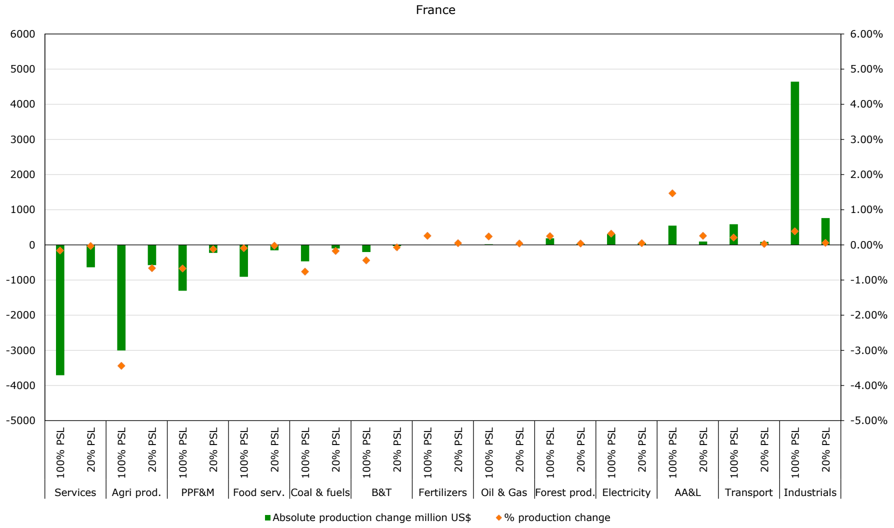
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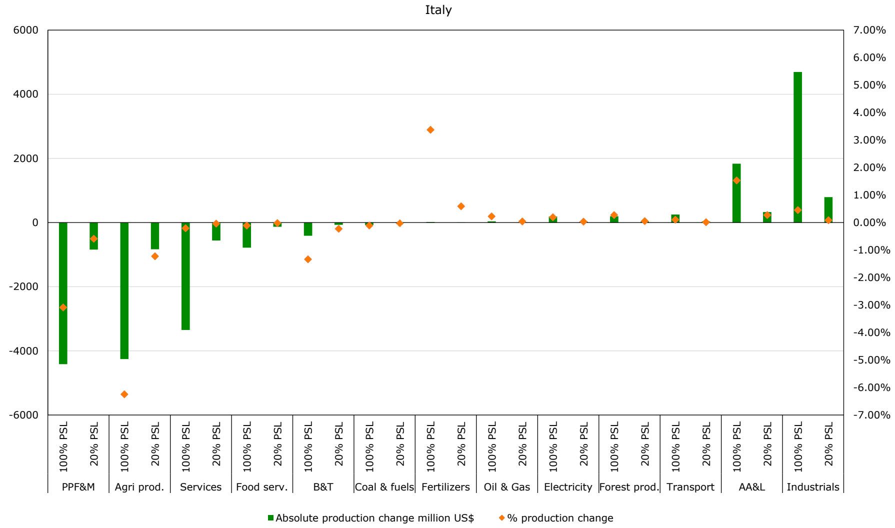
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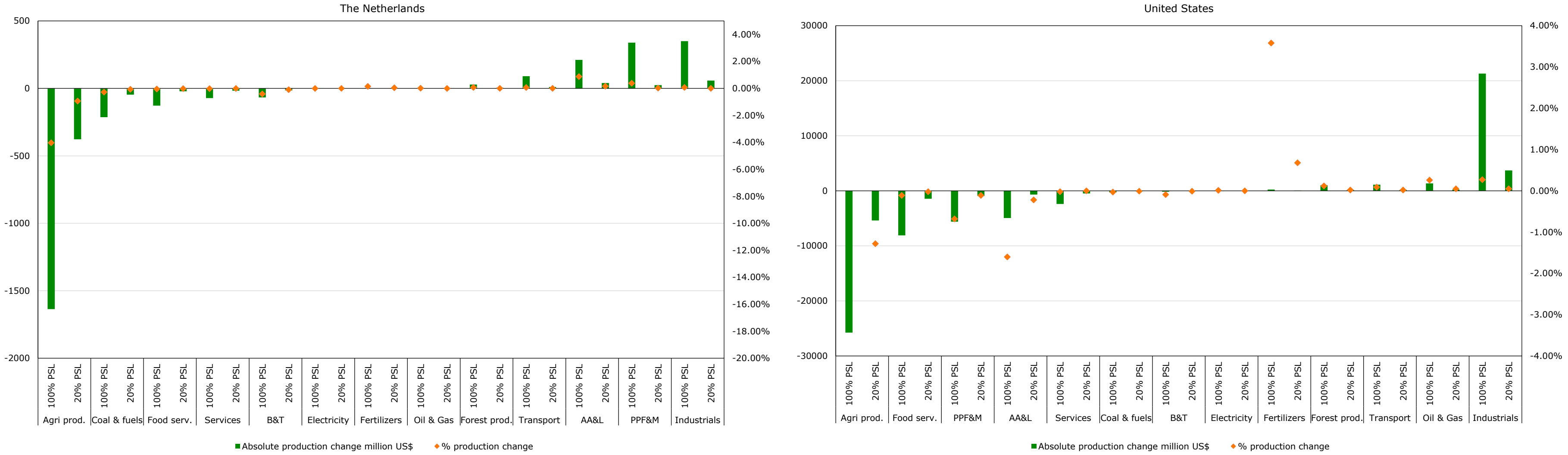

Figure 4.3 *Sectoral effects of PSL in selected countries, million USD, 100% and 20% PSL scenarios*
Notes: The Figures show results for Agricultural production (Agri prod.): Food Services (Food serv.), Packaged and process food and meat (PPF &M:), Apparal, Accesories and luxury goods (AA&L) Services, Beverages and Tobacco (B&T), Electricity, Fertilizers, Forest products (Forest prod.), Transport, Oil and Gas, and Industrials.

4.2 Costs of abatement measures

This section focuses on the costs of implementing PS abatement measures in France, Germany, Italy, the Netherlands, and the UK. We first present the estimated costs of implementing the measures in each country. Second, we present what would be the cost of implementing these measures covering additional cropland in all countries combined. This is assuming that all measures have already been implemented to a certain extent in each country (please see Methods on adoption rates in Section 3.2.2 and Table A4 in the Appendix). Finally, we provide some analysis regarding the economic viability of the measures according to the economic value of PS derived from the results of Section 4.1.

Country level implementation costs of measures vary by cropland size in a country and ranges between USD 4.6m (Netherlands-Computer-assisted decision support systems) to USD 5.6bn (France-nematode application). Table 4.1 presents the estimated costs of implementing a selection of crop protection measures in Germany, the Netherlands, United Kingdom, Italy, and France using formula (1) in Section 3.2.2. All figures in the table show annual cost of implementing the measures except of sensor-based systems and precision spraying, requiring a one-time investment. At country level, for instance, costs for measures in Germany range from USD 45m for computer-assisted decision support systems to over USD 3.5bn for nematode application. Whereas for one measure, use of organic fungicide for example, costs range from USD 135m in the Netherlands to USD 2.4bn in France. In line with formula (1) to calculate country-measure level implementation costs,[27] the implementation costs grow by country land size and are high in countries with large cropland areas (like Germany, Italy and Germany).[28]

Table 4.1 *Estimated cost of implementing farm management measures to abate PSL by countries, million USD (2022)*

Measure	Cost-type	Germany	Netherlands	United Kingdom	Italy	France
Computer-assisted decision support systems	Per year	45.51	4.62	25.61	317.95	76.87
Precision spraying	Per year	344.80	109.99	193.99	2,408.70	582.32
Sensor-based systems	One time	3,448.01	1,099.88	1,939.87	24,087.04	5,823.23
Nematode application	Per year	3,506.85	308.07	1,780.80	2,737.60	5,608.40
Organic fungicide	Per year	1,537.17	135.04	780.58	1,199.98	2,458.35
Wider crop rotations	Per year	689.60	109.99	387.97	4,817.41	1,164.65
No-tillage	Per year	194.82	17.11	98.93	152.09	311.58
Use of green manures	Per year	568.24	49.92	288.56	443.59	908.77

Costs of implementing PS abatement measures in all countries combined. Figure 4.4 aggregates additional land each pollination protection measure can cover in five European countries (France, Germany, Italy, the Netherlands and UK) combined from 2023 to 2035, and those measures' corresponding annual implementation cost per land use. The area of each bar thereby shows the total cost of implementing those measures from 2023 till 2035. The chosen time period only indicates when these measures could be implemented and was used as a guiding point for discussions on adoption rates with our group of experts (please see Section 3.2.2). The Y-axis indicates the costs per hectare per year for each measure. The X-axis indicates the total additional area of cropland on which adoption of the measure is plausible. It is assumed that for each measure, the implementation costs per hectare per year are equal for each considered country. Note that the bars along the X-axis are not showing cumulative results, but individual results. This means that, for example, computer-assisted decision support systems for optimal timing of input (e.g., fungicide use) (CADDS, most left bar in Figure 4.4) has a larger potential land area for implementation than no tillage (NT, second most left bar in Figure 4.4), even though CADDS is located left of NT. The estimation of the

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[27] As Section 3.2.2 describes, we used a three factor formula to estimate costs of each measure. These were: 1. farm size or number of hectares where the measure will be implemented, 2. indication of cost per measure, 3. expected adoption rate of the measure.

[28] Our expert group was uncertain about adoption rates of controlled traffic farming, therefore we do not estimate costs of implementation for this measure.

additional cropland is based on each measure's additional adoption rates estimated by the expert panel and corrected for the (average) percentage of cropland on which the measure is already implemented. A country's additional covered cropland is calculated by multiplying each measure's additional adoption rate by the total arable farmland of a country. In the figure, each country's potential additional areas are added together, meaning that each bar represents the potential adoption for five countries combined. We use estimated EU average additional adoption rates for France, Germany, Italy and UK, and different additional adoption rates for the Netherlands, as the expert's panel expertise in Dutch agriculture allows us to use more precise estimates in the Dutch agricultural context. Note that the figure does not incorporate the fact that using multiple measures on the same hectare could be unnecessary or inefficient. Adoption rates are provided individually and independent from other adoption rates.

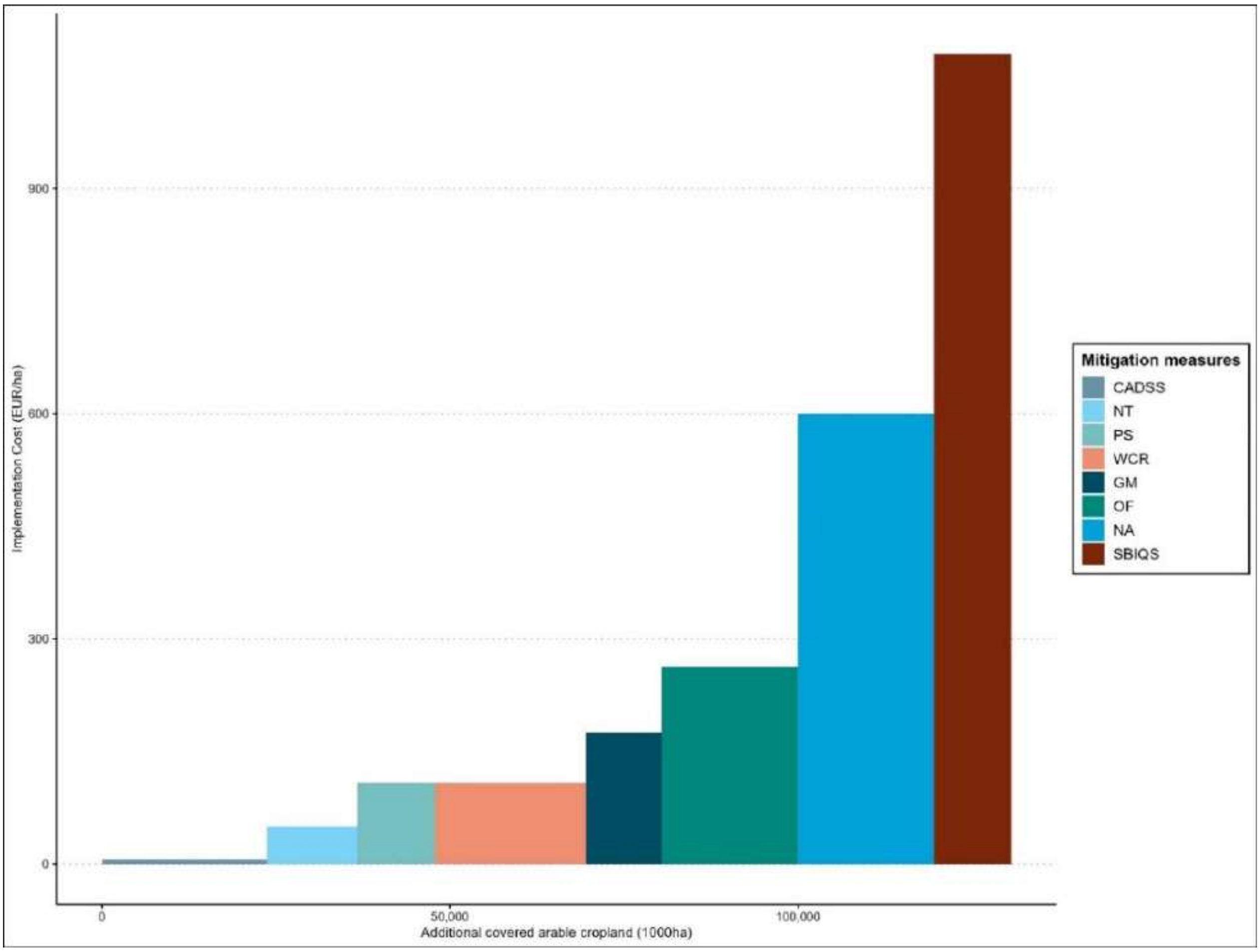

Figure 4.4 *Pollination protection measure implementation cost for covering additional cropland, France, Germany, Italy, the Netherlands and the UK combined*
Note: The Figure shows results for CADSS: Computer-assisted decision support systems for optimal timing of input (e.g., fungicide use), NT: No-tillage, PS: Precision spraying, WCR: Wider crop rotations, GM: Use of green manures (organic material to improve soil fertility), OF: Organic fungicide, NA: Nematode application, SBIQS: Sensor-based identification, quantification of diseases and high-resolution spraying with cameras and sensors.

The total land these practices cover in five countries changes by their implementation costs. Figure 4.4 shows that the cheapest measure to implement (CADDS) can cover the largest land area while the most expensive measure (GM) can cover the smallest. The applicability of the measures does not only depend on their costs. For instance, WCR can cover a large area although the implementation of it is as least as costly as PS and NT. The estimated area where the measure can be implemented depends on the size of crop cultivation and the willingness of farmers to adopt new practices. The expert panel considers all these factors when estimating adoption rates.

How does the cost of farm management measures compare to the economic value of pollinations services? We answer this question by comparing the economic value of PSL estimates from the Magnet model and cost figures from Table 4.1. Figures 4.6 to 4.10 present those economic loss and costs for Germany, Great Britain, the Netherlands, France, and Italy. The blue lines in the Figures show the economic value of pollination services in Germany as estimated using Magnet model, by the corresponding % of pollination services (e.g., 10% of PS, 20% of PS, 30% of PS.... 100% of PS) available in the country.[29] For example, with the 100% PSL scenario, economic losses in Germany would amount to about USD 3.2bn as estimated by the Magnet model, and thus, the economic value of 100% pollination services was assumed the same. The orange dots indicate the cost of country-level implementation of the measures from Table 4.1 (x-axis) and the corresponding % of PSL that would lead to an economic loss equivalent to the cost of the measure.[30] In Germany, UK, France there are two farm management practices (NA: Nematode application, SBIQS: Sensor-based identification, quantification of diseases and high-resolution spraying with cameras and sensors), and in Italy there is one farm management practice (SBIQS) with implementation costs more than the economic value of complete 100% PSL in those countries.[31] In the Netherlands, the figures show that, for 7 out of 8 measures in the Netherlands, cost of implementation is less than the economic value of 10% PSL. This is for 3 in Italy, 2 in Germany, Great Britain and France, showing the relative importance PSL and low cost of implementing measures in Dutch economy.

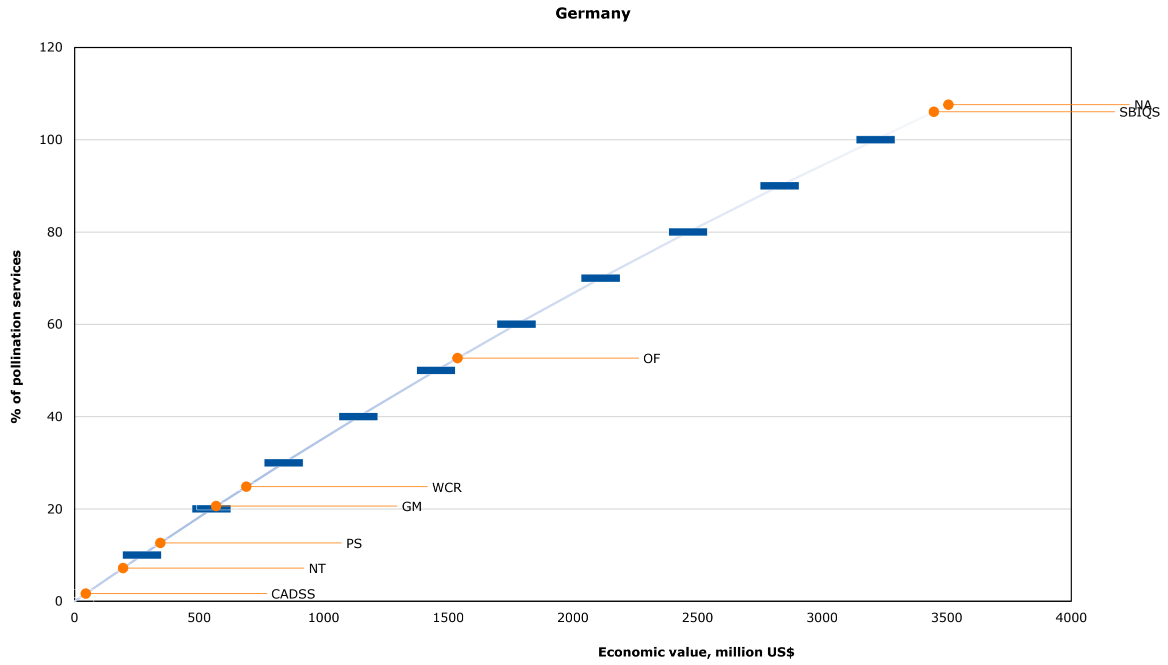

Figure 4.5 *Economic value/cost of country-level implementation of abatement measures and % of pollination services loss leading to an economic loss equivalent to the cost of the measure, Germany*
Notes: Figure shows results for CADSS: Computer-assisted decision support systems for optimal timing of input (e.g., fungicide use), NT: No-tillage, PS: Precision spraying, WCR: Wider crop rotations, GM: Use of green manures (organic material to improve soil fertility), OF: Organic fungicide, NA: Nematode application, SBIQS: Sensor-based identification, quantification of diseases and high-resolution spraying with cameras and sensors.

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[29] The economic value of pollination services presented here was derived from the economic loss that each PSL scenario would cause.

[30] To find the corresponding % of pollination services loss of which would lead an economic loss equivalent to the cost of a measure, we assume that the relationship between within 0-10%, 10%-20%,..., 90%-100% pollination services loss intervals and economic value of pollination services are linear.

[31] In Italy SBIQS: Sensor-based identification, quantification of diseases and high-resolution spraying with cameras and sensors have higher implementation.

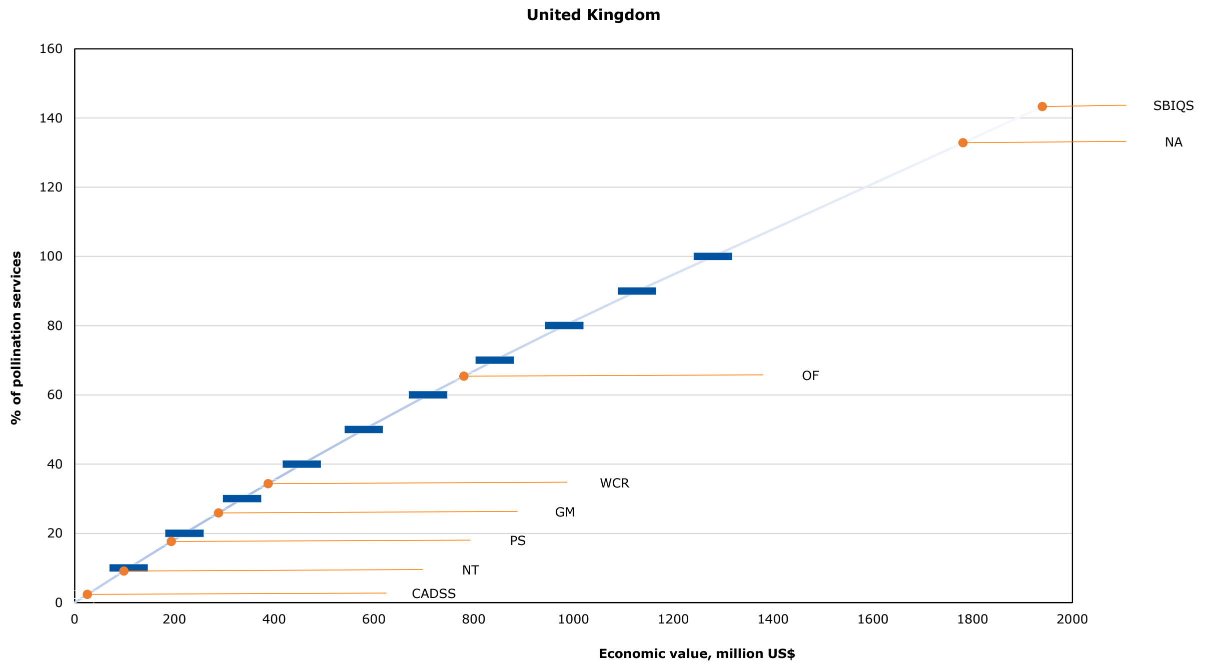

Figure 4.6 *Economic value/cost of country-level implementation of abatement measures and % of pollination services loss leading to an economic loss equivalent to the cost of the measure, United Kingdom Notes: Figure shows results for CADSS: Computer-assisted decision support systems for optimal timing of input (e.g., fungicide use), NT: No-tillage, PS: Precision spraying, WCR: Wider crop rotations, GM: Use of green manures (organic material to improve soil fertility), OF: Organic fungicide, NA: Nematode application, SBIQS: Sensor-based identification, quantification of diseases and high-resolution spraying with cameras and sensors.*

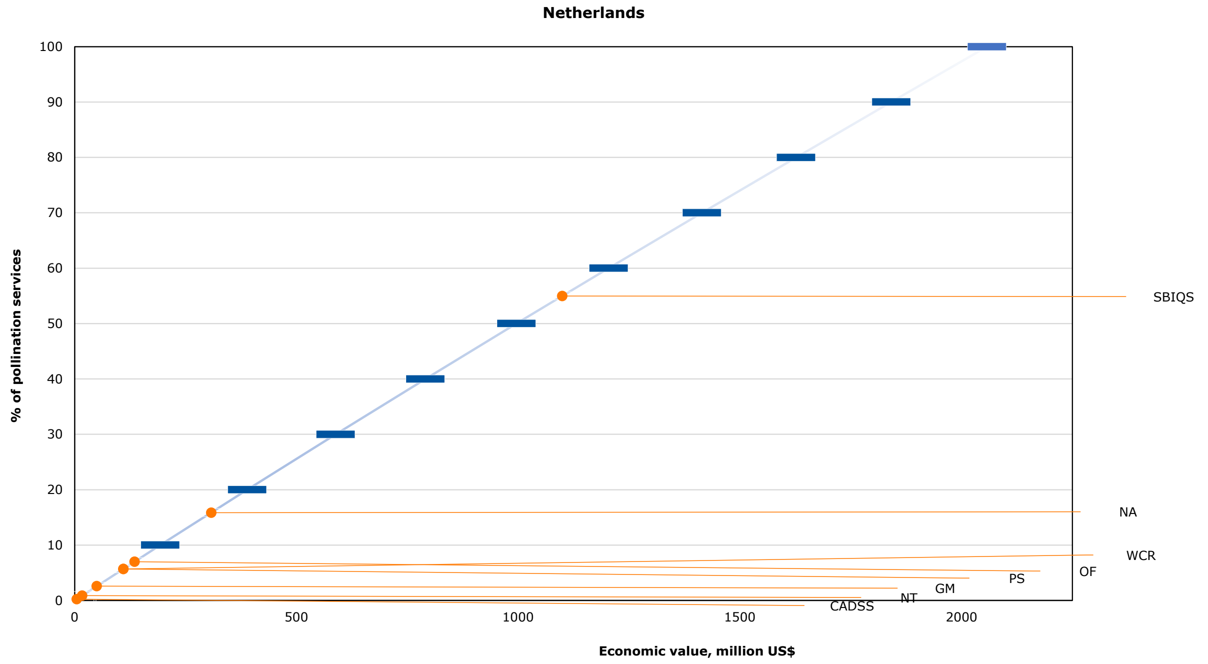

Figure 4.7 *Economic value/cost of country-level implementation of abatement measures and % of pollination services loss leading to an economic loss equivalent to the cost of the measure, the Netherlands Notes: Figure shows results for CADSS: Computer-assisted decision support systems for optimal timing of input (e.g., fungicide use), NT: No-tillage, PS: Precision spraying, WCR: Wider crop rotations, GM: Use of green manures (organic material to improve soil fertility), OF: Organic fungicide, NA: Nematode application, SBIQS: Sensor-based identification, quantification of diseases and high-resolution spraying with cameras and sensors.*

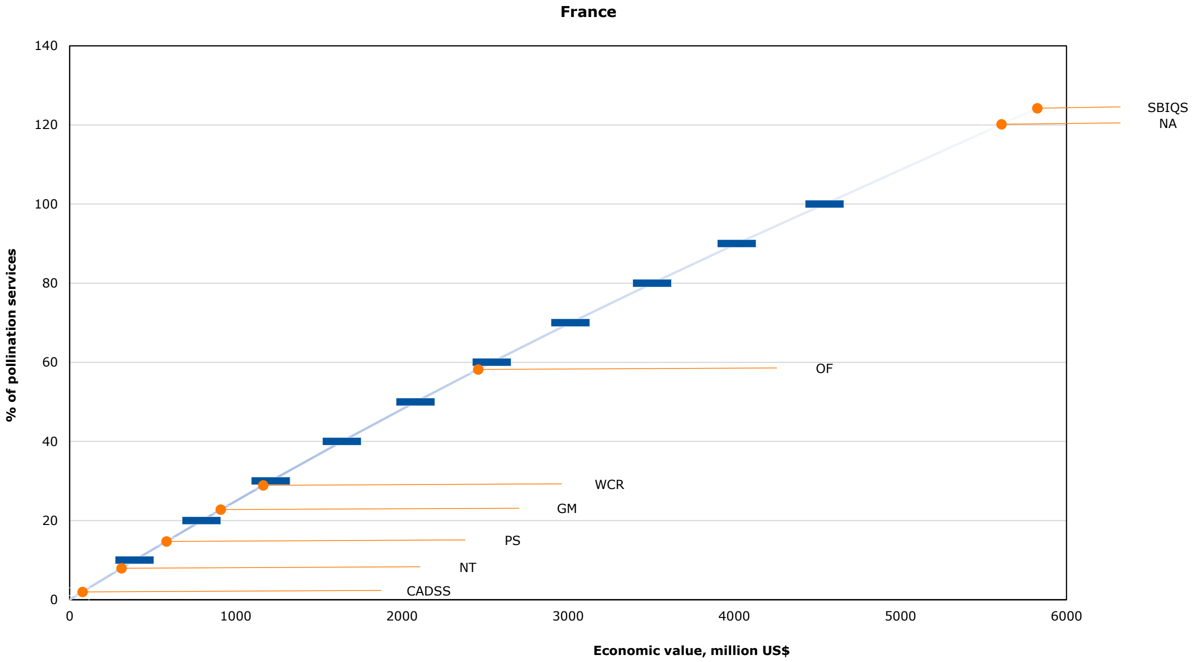

Figure 4.8 *Economic value/cost of country-level implementation of abatement measures and % of pollination services loss leading to an economic loss equivalent to the cost of the measure, France*
Notes: The measures presented in the Figure are computer-assisted decision support systems: Comp. ass. sys.; precision spraying: precision spr.; sensor-based identification, quantification of diseases and high-resolution spraying: sensor bas. ide.; nematode application: Nematode App.; organic fungicide: organic fun.; wider crop rotations: wider cro. rot.; no-tillage: no till.; use of green manure; green man.

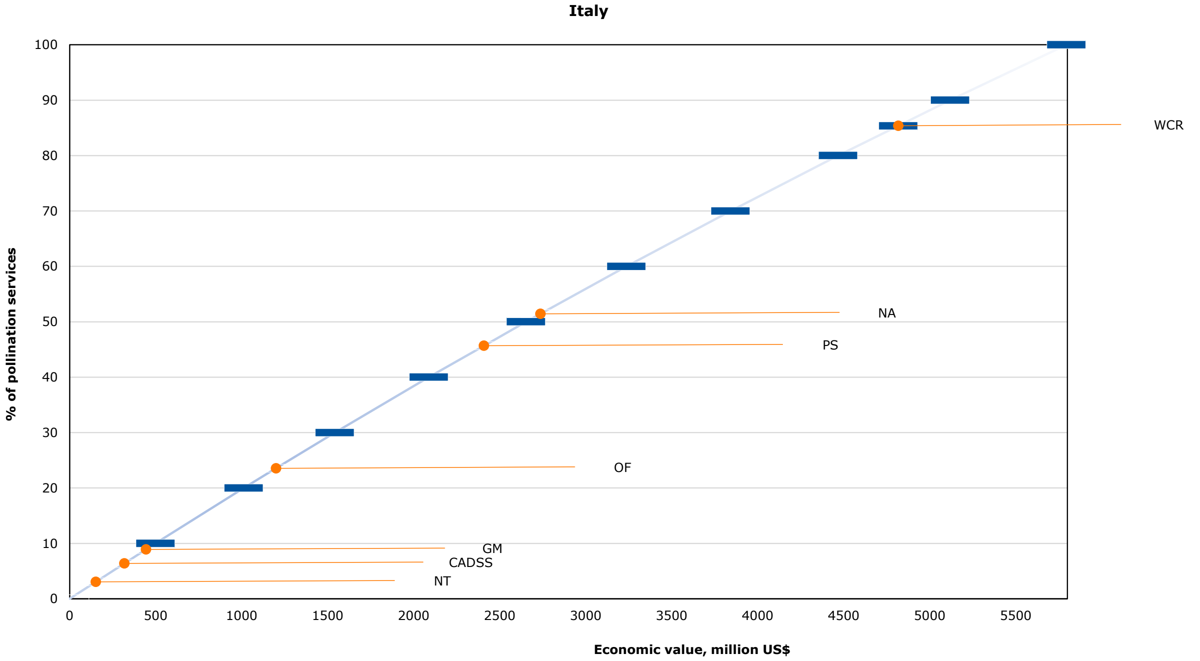

Figure 4.9 *Economic value/cost of country-level implementation of abatement measures and % of pollination services loss leading to an economic loss equivalent to the cost of the measure,Italy*
Notes: Figure shows results for CADSS: Computer-assisted decision support systems for optimal timing of input (e.g., fungicide use) NT: No-tillage, PS: Precision spraying, WCR: Wider crop rotations, GM: Use of green manures (organic material to improve soil fertility), OF: Organic fungicide, NA: Nematode application,

Our preliminary analysis shows that implementing farm management practices may not be economically feasible to implement in many countries except the Netherlands when one only considers their economic benefits through their potential to abate PSL. Are the selected measures economically viable to implement with only an objective of abating PSL? We provide a preliminary answer to this question through a back of the envelope calculation.[32] The calculation shows that wider crop rotation can abate 11.5% of PS, and no-tillage can abate 6.9%, and use of green manures will abate 5.75% in five European countries in our study (see Table 4.2 for details).

Table 4.2 *Expected pollination services (PS) improvement for measures based on ecological principles in France, Germany, Great Britain, Italy and the Netherlands, by ecological measures*

		Wider crop rotation	**No-tillage**	**Use of green manure**
(1)	PS improvement value from case studies (%)	23	23	23
(2)	Expected increase in adoption rates in the countries (%)	50	30	25
(3)	Expected PS improvement at the country level (%) row (3) = row (1) X row (2)	11.5	6.9	5.75

In Figure 4.10, the cost of implementing different technologies in each country is compared to the economic value of abating 11.5% of PSL through wider crop rotation, 6.9% of PSL through no-tillage, and 5.75% PSL through the use of green manure in each country.[33] Realisation of local measures that fall on the left side of the green line can be considered 'no regret' as already are considered economically feasible because the cost of implementing the technology is lower than the pure local economic value of abating PSL without accounting for further co-benefits or positive spill overs. The analysis shows that wider crop rotation and green manure are only economically viable in the Netherlands, not in other countries. No tillage is economically viable in Italy and the Netherlands, but not in France, Germany, or the UK.

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[32] We provide a preliminary estimate for the potential to abate PSL based on some assumptions and using evidence from the literature and comparing it with the results from our economic viability analysis. The details are as follows. Our study shows that country-level adoption rate of ecological principles such as wider crop rotations, no-tillage, and use of green manures are expected to increase by 50%, 30% and 25% respectively. Academic literature suggests that ecological arable farming measures such as hedgerows or intercropping increase PS on average by 23% (Morandin et al., 2016; Pecenka et al., 2021). To find the potential to abate PSL, we assume that on average, all ecological principles have similar potential to abate PSL (23%) and multiply increase in adoption rate for each ecological technology with potential to abate PSL.

[33] To find the corresponding economic of 11.5%, 6.9%, and 5.75% PSL, we assume that the economic value within of PSL within 0-10%, 10%-20% PSL intervals are linearly increasing.

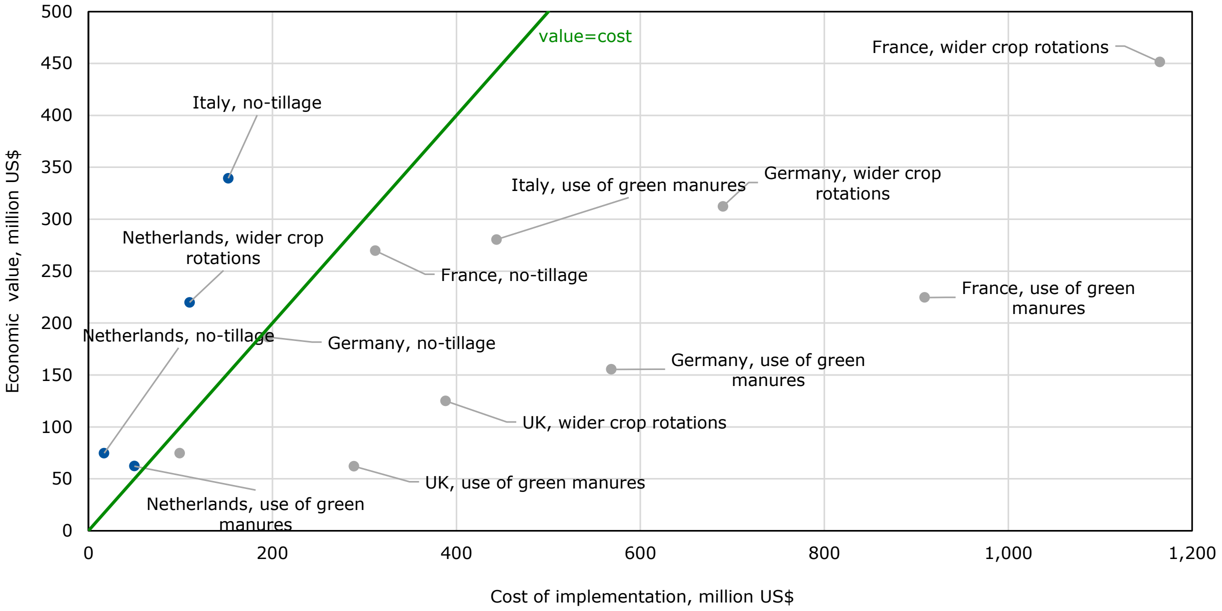

Figure 4.10 *Comparison of cost and economic benefit of farm management measures in terms of PSL*

Estimates from this economic viability analysis should be used with caution. Given that we do not estimate the actual benefit of the measures to restore PS, the implementation costs of such measures may exceed the economic benefits offered by the abated PS. We also note that we do not consider the co-benefits of those measures, spill overs, or economies of scale that could develop following the joint implementation of measures.

More research is needed to measure the economic viability of these measures and their potential to abate as these analyses far from perfect, therefore, one should use these results with caution due to methodological limitations. First, the improvement of PS observed in the case studies in the literature can be extrapolated to other measures following ecological principles at least to a certain extent. Second, we assume that the effects of these measures based on the literature will be the same in other geographical contexts, e.g., growing different crops, and different pollinator habitat conditions, and can therefore apply to countrywide calculations. Third, these results are also under the assumptions and opinions of experts informing our adoption rate numbers. Fourth, our analysis does not take any co-benefit of those measures, positive effects on other ecosystem services, greenhouse gas emission, or societal effects into account.

5 Conclusion

5.1 Summary of main findings

Our interviews with professionals from Allianz and sector experts indicated that although global biodiversity strategies have been in place for several decades, measuring the impact of investment portfolios on biodiversity is still challenging for several reasons. First, there is a lack of specific indicators to measure biodiversity progress. Second, many local factors affect biodiversity. Additionally, it's difficult to measure the biodiversity risks posed by supply chain linkages. Sectors such as agri-food, hospitality, and tourism are particularly vulnerable to biodiversity loss because their heavy reliance on natural resources. While some new frameworks and methodologies exist to assess the monetary impact of biodiversity loss, there is limited knowledge about the costs and benefits of measures to restore biodiversity and understanding of investment opportunities for the financial sector.

We have identified two areas to improve the assessments of the economic risks and opportunities associated with the loss of biodiversity and ecosystem services. The first is to identify the economic impact of biodiversity loss on financial sector portfolios at the country and sector levels. The second is to develop a list of biodiversity restoration measures and estimate the cost-effectiveness of those measures at the country and sector level.

This study contributes to addressing the areas of research mentioned above. We examine the economic impact of various PSL shock scenarios in Western Europe and the US. We use pollination dependence ratios (PDR) to estimate how different levels of PSL would affect agricultural production in each country. To estimate the impact of PSL on the wider economy, we use the MAGNET general equilibrium model to analyse the effects on economic activity in different sectors and countries.

The study then looks at the cost of reducing the adverse effects on pollination services resulting from farming practices that harm pollinators. By providing habitats for pollinators through the implementation of specific farming practices, farmers can increase pollination services. Estimating how much of an increase each measure will provide is a difficult task and will depend on the current level of pollination services. We estimate the approximate cost of reducing the negative impact on pollination services for various measures in France, the UK, Germany, Italy, and the Netherlands. The estimates are based on existing literature, open databases such as EUROSTAT and FAOSTAT, and expert opinion. It's important to note that other measures other than those related to agricultural land use can also help improve natural habitats and increase biodiversity and pollinator populations. However, the study does not focus on these measures due to data limitations.

We find that PSL reduces agricultural output, and the extent of this reduction depends on factors such as a country's dependence on pollination services (which varies by crop) and the severity of the PSL. PSL's impact on agriculture has wider economic consequences, affecting not only agricultural sectors but also non-agricultural sectors that rely heavily on agricultural inputs, such as processed food, meat, beverages, and tobacco. This can result in macroeconomic losses that vary depending on the importance of agriculture in a country's economy. For instance, a total elimination of pollination would reduce agricultural output in equilibrium by 3% in Germany and 4% in the Netherlands. We estimate this reduction in absolute terms in around USD 2bn, and USD 1.6bn annually for Germany and the Netherlands respectively. Following MAGNET's output, we also note that PSL can have a 'positive' impact on other sectors, as it can free up land, capital, and labour previously used in agriculture for other industries. In France and Germany, for example, the increased output in the industrials sector could exceed USD 4bn per year.[34] Altogether, we estimate that

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[34] It should be emphasised that the loss of pollinators in western Europe or in the US would have dramatic consequences of which the local and global impacts are unprecedented and unpredictable by any general equilibrium model.

PSL impacts Germany’s and the Netherlands’ GDP by USD 3.2bn and USD 2bn per year respectively, while for the US, the annual loss would amount to almost USD 28bn.

The cost of implementing measures to reduce pollination services loss at the country level depends on the amount of land covered and technology-specific costs of implementation. For example, the use computer-assisted decision support systems in the Netherlands costs about USD 4.6m, while applying nematodes in France costs about USD 5.6bn. However, our initial analysis of wider crop rotation, no tillage, and green manure application practices suggests that those measures may not be financially worthwhile to implement in some countries if we only consider the economic benefits of abating pollination services. However, we note that further research is needed to accurately determine their economic viability and effectiveness in restoring pollination services. Due to the limitations of the analysis, those estimates should be used by caution.

5.2 Implication for the financial sector

Based on our pollination case study, we have found that the loss of biodiversity can negatively impact various sectors. However, it can also create new opportunities for the financial sector by requiring a high level of investment to restore and protect biodiversity. In our pollination case study, we found that implementing abatement measures may not be financially feasible for some countries if they consider the economic benefits that come from pollination services. To address this, the financial sector needs innovative financial instruments, such as blended finance, to fund the implementation of these practices.

Our case study offers preliminary findings for a sole ecosystem service connected to biodiversity. To enhance our understanding of the associated risks and opportunities, the financial sector requires information on:

- Quantitative impacts of biodiversity loss and ecosystem services on sectors and countries: Our study on the loss of pollination services demonstrated the substantial impact of biodiversity shocks, which varied by country and sector. To effectively prepare for future financial and market risks and opportunities, the sector can analyse the economic effects of biodiversity loss (e.g., pollination services loss) on investment and insurance portfolios at both the country and sector levels using our estimates. The sector can reduce PSL related or biodiversity loss related risks to their portfolios by stimulating investments in the cost-effective farm management practices.
- Development of a list of potential biodiversity restoration measures and estimating their cost-effectiveness and capital requirements at country and sector level: To achieve a zero loss in biodiversity, we need to transform our economic activities and implement various nature-based solutions. However, this requires significant capital investment. Providing a list of cost-effective measures to restore biodiversity and their investment estimates will help the financial sector identify related business opportunities. The list of measures to abate PSL is a first step for this.
- Private sector effects on biodiversity. The case study does not explore how private sector investments in the financial industry impact biodiversity levels, potentially leading to litigation and liability risks. It is important for the industry to have a better understanding of these risks.

5.3 Limitations and future research

Our estimates of economic losses due to PSL and abatement costs for different farm management measures have several limitations. First, we need to define better current level of PSL at the regional level and how effective the practices to restore pollination services loss. Second, we do not use local PSL data to estimate the economic impact of PSL. Instead, we report on potential PSL scenarios. Using actual estimates of future PSL will provide a more realistic estimate of economic impact of losses. Third, we assume that the relationship between pollinator loss and crop production is linear, whereas this relationship is complex and highly dependent on many contextual aspects of a particular area. Fourth, the dependency ratios we use in our economic impact estimates are rough estimates for some crops. Our abatement cost estimates are also far from perfect. We had limited access to data on the cost and adoption rate of specific measures and we do not have any data on the abatement effect of each measure. These estimates should be used with caution, and future research should address these concerns. Finally, our economic impact estimates are estimated using a static model that does not take into account the future effects of economic contraction due the loss of pollination services.

Future research can focus on the following:

- Developing realistic (global or local) scenarios for the loss of pollination services: Scientific forecasts on site-specific pollinator declines in the coming years are currently lacking or unspecific. However, combining land-use alteration scenarios with biophysical modelling has been an accepted method to provide pollinator decline effects on crop yields.
- Investigating how pollinator decline affects other ecosystem changes: The environmental and economic impacts of damaged ecosystems should not be isolated, but recognised as harmed parts of a wider system that affects much more than, in this case, crop growth.
- Consider the co-benefits of measures: The measures in our analysis can have positive effects beyond pollination, for example, on other ecosystem services and functions, such as water quality and improved soil health. Future research should develop methodologies that also include the economic benefits derived from these additional positive effects (co-benefits).
- Estimating the abatement effects of pollination measures: There is limited evidence in the literature on how much different measures can abate or restore pollination services at the regional and country level. Scientific research should provide this evidence in order to estimate reasonable abatement costs.
- Examining the impact of economic expansion on biodiversity and ecosystem services: Our study does not examine what happens to the pressures on biodiversity-related ecosystem services when economies contract or expand. Future research should investigate this.

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Appendix

Table A1 *List of interviewees*

Organisation	Position or areas of expertise of the itnerviewess
Allianz Global Investors, Allianz Investment Management, Allianz SE	Sustainability Methodologies & Analytics, Sustainability Research, ESG, Sustainable Investments Analyst, International Accounting & Sustainability Reporting, Climate Integration, Ecosystem Valuation/
Wageningen Economic Research	Researcher Entrepreneurship, CAP, Arable farming
Wageningen Economic Research	Senior Researcher Plant health and Market Intelligence
Wageningen Economic Research	DLO researcher, agricultural research service
Wageningen Plant Research	Senior researcher AgroEcology
Wageningen Plant Research	Senior applied researcher and project leader in sustainable farming
Wageningen Economic Research	Senior researcher biobased economy, agricultural economics
Wageningen Economic Research	Senior researcher

Table A2 *Sectoral classification used in modelling*

MAGNET commodity	MAGNET Aggregation	GICS sector
Paddy and processed rice	Primary agri food	Agricultural products
Wheat	Primary agri food	
Cereal grains nec	Primary agri food	
Vegetables	Primary agri food	
Fruit	Primary agri food	
Nuts	Primary agri food	
Roots and tubers	Primary agri food	
Pulses	Primary agri food	
Oil seeds	Primary agri food	
Sugar cane, sugar beet	Primary agri food	
Other agriculture	Non-food commodities	
Crops	Primary agri food	
Other cattle	Primary agri food	
cattle	Primary agri food	
Pig Poultry	Primary agri food	
Poultry	Primary agri food	
Milk	Primary agri food	
Wool	Non-food commodities	
Wild Fish	Primary agri food	
Aquaculture	Primary agri food	
Electricity	Non-food commodities	Electricity
electricity from coal	Non-food commodities	
electricity from gas	Non-food commodities	
electricity from nuclear	Non-food commodities	
electricity from hydro	Non-food commodities	
electricity from wind and solar	Non-food commodities	
bioelectricity 2nd gen	Non-food commodities	
Heat	Non-food commodities	
bioheat	Non-food commodities	
Textiles	Non-food commodities	Apparel, accessories & luxury goods
Nitrogen fertilizer	Non-food commodities	Fertilizer
Phosphorus fertilizer	Non-food commodities	
Potassium fertilizer	Non-food commodities	
Food services	Food services	Food service
Animal feed	Non-food commodities	Industrials
residue sector	Non-food commodities	
Chemical products	Non-food commodities	
Basic pharmaceutical products	Non-food commodities	
Rubber and plastic products	Non-food commodities	
biochemicals	Non-food commodities	
biopharmaceuticals	Non-food commodities	
bioplastics	Non-food commodities	
Manufacturing	Non-food commodities	
Mineral products nec	Non-food commodities	
Manufactures nec	Non-food commodities	
Construction	Non-food commodities	
residue pdr	Non-food commodities	
residue gro	Non-food commodities	
residue osd	Non-food commodities	
residue frs	Non-food commodities	
Services	Non-food commodities	Service
Education	Food services	

Table A3 *Pollinator dependence ratio per country-commodity*

Crop	Italy	France	Germany	UK	US	Netherlands	Belgium	Spain	Portugal
Panel A: 100% pollinator loss scenario									
Fruits	0.21	0.20	0.39	0.53	0.24	0.37	0.48	0.21	0.21
Nuts	0.30	0.12	0.00	0.00	0.26	0.00	0.06	0.21	0.21
Pulses	0.21	0.16	0.21	0.25	0.23	0.06	0.21	0.19	0.19
Oil seeds	0.25	0.22	0.25	0.24	0.24	0.14	0.31	0.24	0.24
Vegetables	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Other crops	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00
Panel B: 20% pollinator loss scenario									
Fruits	0.04	0.04	0.08	0.11	0.05	0.07	0.10	0.04	0.04
Nuts	0.06	0.02	0.00	0.00	0.05	0.00	0.01	0.04	0.04
Pulses	0.04	0.03	0.04	0.05	0.05	0.01	0.04	0.04	0.04
Oil seeds	0.05	0.04	0.05	0.05	0.05	0.03	0.06	0.05	0.05
Vegetables	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Other crops	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00

Table A4 *Expected increase in the adoption rates of measures to restore pollination services in Europe and the Netherlands from 2023 to 2035*

Measures	Adoption rate The Netherlands (%)	Adoption rate Europe (%)
Computer-assisted decision support systems	35	55
Precision spraying	50	25
Sensor-based systems	50	25
Controlled traffic farming	0	-
Nematode application	45	45
Organic fungicide	45	45
Wider crop rotations	50	50
No-tillage	30	30
Use of green manures	25	25

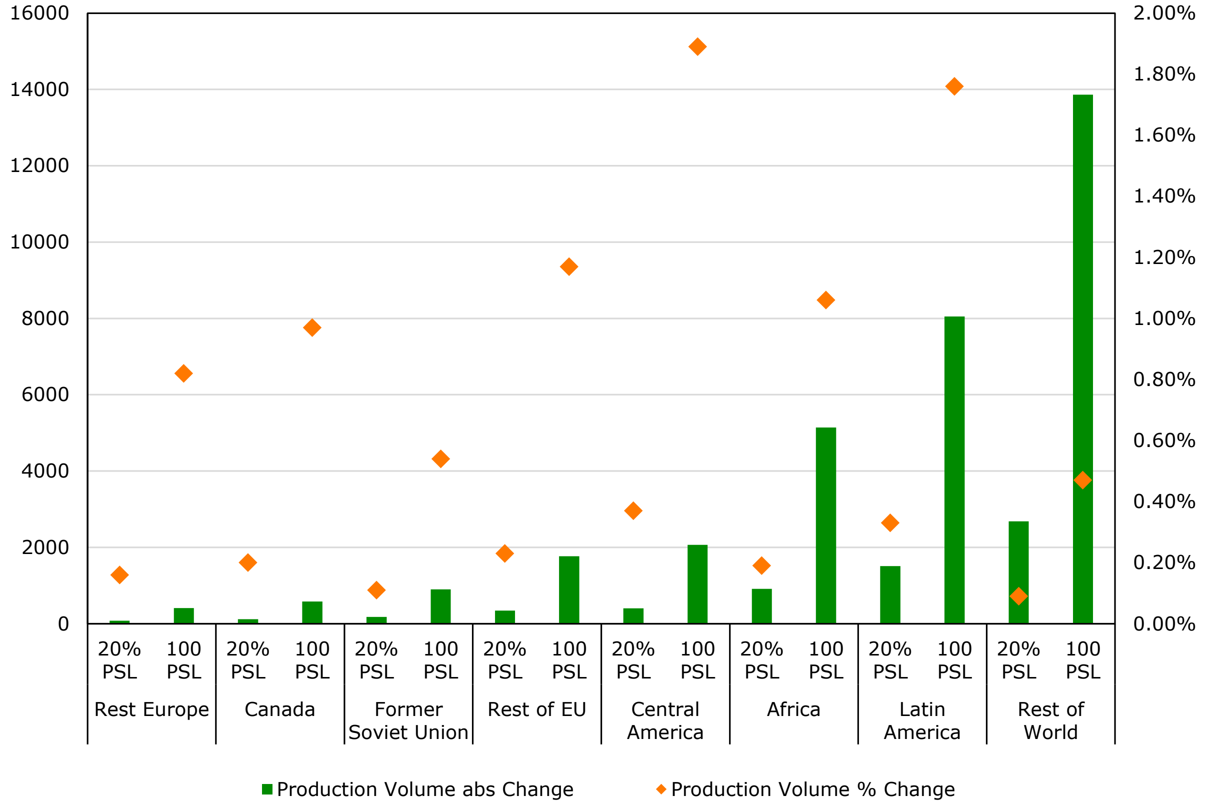

Figure A1 *Agricultural production changes non shocked countries, absolute and percentage changes*

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The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,200 employees (6,400 fte) and 13,200 students and over 150,000 participants to WUR’s Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.