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M. Paulin (author), RIVM
T. de Nijs (author), RIVM
R. Koopman (author), RIVM
J. Otte (author), RIVM
M. Rutgers (author), RIVM

Contact:
Michiel Rutgers
Centre for Sustainability, Environment and Health (DMG)
michiel.rutgers@rivm.nl

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Synopsis

Social cost-benefit analysis of field margins in the Hoeksche Waard, the Netherlands

Field margins are strips of land with grass or flowers on which no crops are grown. They are located between fields or between a field and a ditch. When designed for this purpose, field margins support natural pest control. As a result, there are fewer pests, less crop protection products need to be used, and less of these products end up in ditches. Field margins support the natural control of pests by insects. As a result, fewer pests. The field margins also increase biodiversity and pollination. They also limit the nitrogen and phosphate run off into the ditch. In addition, a more attractive landscape for recreation is created.

The European Union wants to encourage the creation of field margins. RIVM has therefore calculated whether the benefits of field margins outweigh the costs over the course of 30 years (2025-2055). This so-called social cost-benefit analysis (SCBA) was done for the Hoeksche Waard because of its large amount field margins. In this SCBA, the effects on eight themes have been calculated. These include crop production, pollination, pest control, water quality, climate, recreation and biodiversity.

The benefits of field margins for people, nature and the environment appear to be about the same as the costs. Basically, a more attractive landscape and lower costs for the water board to purify surface water outweigh a smaller cropping area and the costs for farmers to create the margins. Two 'benefits' that cannot be expressed in monetary terms and have therefore been assessed ecologically are also greater with field margins. It concerns biodiversity and the self-cleaning capacity of water and soil.

Twelve variants have been calculated for this study in order to be able to take uncertainties into account. Seven of the twelve variants showed higher benefits than costs, such as the effects on health and less crop protection products in ditches, could not be included in this SCBA. If it had, the calculated benefits would probably have been greater. An additional advantage is that field margins along ditches help to achieve the goals of the Water Framework Directive for plant protection products.

The costs now lie mainly with farmers and co-financing government bodies. RIVM sees opportunities to create new revenue models in which the costs and benefits are distributed more fairly among the various parties involved. This can make it more attractive for farmers to build field margins. This SCBA can be used for this.

Keywords: SCBA, social cost benefit analysis, field margins, functional agrobiodiversity, FAB, sustainable agriculture, Hoeksche Waard.

Publiekssamenvatting

Maatschappelijke kosten-batenanalyse van akkerranden in de Hoeksche Waard, Nederland

Akkerranden zijn stroken land met gras of bloemen waarop geen gewassen worden verbouwd. Ze liggen tussen akkers of tussen een akker en een sloot. Akkerranden ondersteunen de natuurlijke bestrijding van plagen door insecten. Hierdoor zijn er minder plagen, worden minder gewasbeschermingsmiddelen gebruikt en komen deze middelen minder in sloten terecht. Ook vergroten de akkerranden de biodiversiteit en de bestuiving. Verder zorgen ze ervoor dat er minder stikstof en fosfaat naar het oppervlaktewater wegspoelt. Daarnaast ontstaat er een aantrekkelijker landschap om te recreëren.

De Europese Unie wil de aanleg van akkerranden stimuleren. Het RIVM heeft daarom berekend of de baten van akkerranden opwegen tegen de kosten in de loop van 30 jaar (2025-2055). Deze zogeheten maatschappelijke kosten-batenanalyse (MKBA) is gedaan in de Hoeksche Waard omdat daar veel akkerranden liggen. In deze MKBA zijn de effecten op acht thema’s berekend. Dat zijn onder andere gewasproductie, bestuiving, plaagbestrijding, waterkwaliteit, klimaat, recreatie en biodiversiteit.

Op basis van de aspecten die in deze studie konden worden doorgerekend, blijkt dat de baten van akkerranden voor mens, natuur en milieu ongeveer even groot zijn als de kosten. Zo wegen een aantrekkelijker landschap en lagere kosten voor het waterschap om oppervlaktewater te zuiveren op tegen een lagere opbrengst en de kosten voor boeren om de randen aan te leggen. Twee baten die niet in geld kunnen worden uitgedrukt en daarom ecologisch zijn beoordeeld, zijn ook groter in de akkers met randen. Het gaat om biodiversiteit en het zelfreinigend vermogen van water en bodem. Daarnaast konden belangrijke baten, zoals de effecten op de gezondheid en minder gewasbeschermingsmiddelen in sloten, in deze MKBA niet worden meegenomen. Als dat wel was gedaan, waren de baten waarschijnlijk groter. Een bijkomend voordeel is dat de akkerranden langs de sloten helpen om de doelen van de Kaderrichtlijn Water voor gewasbeschermingsmiddelen te halen.

Voor dit onderzoek zijn twaalf varianten doorgerekend om rekening te kunnen houden met onzekerheden. De uitkomsten van zeven van de twaalf varianten zijn positief.

De kosten liggen nu vooral bij boeren en meebetalende bestuursorganen. Het RIVM ziet mogelijkheden om nieuwe verdienmodellen te maken waarbij de kosten en baten evenredig verrekend worden over betrokken partijen. Daarmee kan het voor boeren aantrekkelijker worden om akkerranden aan te leggen. Deze MKBA kan hiervoor worden gebruikt.

Kernwoorden: MKBA, maatschappelijke kosten-baten analyse, akkerranden, functionele agrobiodiversiteit, FAB, duurzame landbouw, Hoeksche Waard.

Contents

Summary

Over the past five decades, the EU's Common Agricultural Policy (CAP) has encouraged farmers to modernise and intensify production, fostering a resource-intensive agricultural sector that relies heavily on external inputs and natural resources, and leading to environmental pollution and a reduction in farmland biodiversity. One potential solution to these issues is functional agrobiodiversity (FAB), representing the elements of the agricultural landscape that support biodiversity, providing important ecosystem services that support sustainable agricultural production and deliver benefits to society as a whole.

Ecosystem services are the benefits that ecosystems provide to society. For instance, ecosystems in the agricultural landscape can contribute to good soil quality, crop pollination and biological pest control. They also provide important ecosystem services that support society, such as water quality regulation for human safety, water storage for flood protection, carbon sequestration to combat climate change, and an attractive landscape that stimulates recreation.

Since the year 2000, one FAB solution has been widely applied in the Hoeksche Waard, namely field margins. Field margins are strips of land located between agricultural fields or between fields and surface water. In these margins, management (e.g. use of pesticides and fertilisers, vegetation type) differs from that of adjacent fields. The main aim of these field margins was to buffer runoff and drift of fertilizers and pesticides across surface water. This aim has been combined with the aim of improving ecological functions, such as pollination, natural pest control, supporting farm land birds and aesthetic or landscape values.

Over the years, promising results have been seen on farms that have introduced field margins, including enhanced biodiversity, a reduction in pests feeding on crops and reduced pesticide use. Despite these benefits, the costs farmers incur in adopting field margins often cannot be offset by the benefits they receive as compensation. That is why local farmers are looking for economically sound business models that support both environmental quality and business operations in the short and long term.

As part of the EU Interreg FABulous Farmers project and commissioned by the University of Amsterdam (UvA), this study aims to assess whether field margins are societally desirable from an economic perspective. A social cost-benefit analysis (SCBA) was carried out for this purpose. An SCBA is a structural approach to assessing whether the benefits of taking measures outweigh the costs, making them desirable from a societal and economic perspective. In this SCBA, one measure was evaluated, namely the introduction of field margins in the Hoeksche Waard. The welfare effect of field margins was measured as the net present value (NPV), or the sum of all monetary costs and benefits over a period of thirty years (2025-2055). A positive NPV implies that the societal benefits outweigh the costs.

The results of this SCBA show that over a period of thirty years the NPV of field margin implementation is slightly positive (€ 0.1 million), suggesting that the benefits of field margins in the Hoeksche Waard outweigh the costs. The additional costs associated with 550 km field margins relative to the costs that would otherwise be incurred for cultivating crops, were estimated at a value of € 3.3 million. Despite this increase in costs associated with field margins, the creation of field margins also yields additional societal benefits. The highest estimated benefits in the Hoeksche Waard consist of the contributions to recreation and health, water quality, carbon sequestration and biological pest control. The lowest, negative, benefit was associated with the reduction in crop production of € -2.1 million, as space is made available for the creation of field margins where crop production would otherwise take place.

Two benefits, biodiversity and natural attenuation capacity, were only quantified in ecological units due to lacking models for monetarization. Biodiversity was quantified from four populations, i.e. field birds, insects, aquatic invertebrates and a set of soil organisms (bacteria, nematodes, enchytraeids, micro-arthropods and earthworms). The biodiversity capacity ratio was 1.3 meaning that biodiversity was 30% higher in the Field Margin Alternative in comparison to the baseline. The natural attenuation capacity was quantified from bacterial diversity, bacterial biomass, aquatic invertebrate diversity, N and C mineralization rate, soil organic matter content, pH and nutrients (N and P). The natural attenuation capacity ratio was 1.8 meaning that this parameter was 80% higher in the Field Margin Alternative. Consequently both parameters of the soil and water system confirm a positive effect on the delivery of ecosystem services that were not quantified in monetary values.

The uncertainties of the SCBA were quantitatively analysed by adjusting reference values used in various calculations that together constitute the NPV. Altered assumptions include the evaluation period (i.e. fifty years, hundred years) and the discount rate, as well as assumptions underlying the calculation of field margin benefits (i.e. carbon sequestration, water quality regulation, recreation and health benefits).

The calculated NPV was also positive in seven out of twelve scenarios when adjustments were made to reference values underlying the calculation of the NPV. In the uncertainty analysis, the Net Present Value ranged from € -0.53 million to € 1.23 million

One benefit that made a substantial positive contribution to the NPV was the effect of field margins on recreational activities (i.e. hiking) and resulting health benefits. The estimation of this benefit also carries a high degree of uncertainty, which could possibly lead to the NPV ranging from € -0.53 million to € 0.72 million.

The NPV is also strongly dependent on the CO_2 price. Changing the CO_2 price between the low WLO scenario and the 2 °C WLO scenario would result in an NPV of € -0.22 million and € 1.2 million respectively. Although, in this study, we assumed a CO_2 price according to the high WLO scenario, according to the IPCC, an even higher price is needed, as current pledges would eventually cause the world to warm 2.7°C. In that case, the NPV would be much higher.

The application of field margins along surface water contributes to reducing leaching and run-off of plant protection products and other compounds, such as nutrients. This supports achieving of the objectives of the WFD. This emission reduction towards surface water by farm fields could not be included in this SCBA given knowledge and time constraints. Including these benefits in the analysis would likely lead to a higher NPV. Also the potential risks, especially for arable farming and flower bulb cultivation, and the associated costs of not achieving the targets for plant protection products of the WFD could not be assessed. Furthermore, the potential risks of the application of plant protection products to human health (Alzheimer's, Parkinson's) are currently being investigated. There are indications that, in particular, farmers who use these products have an increased health risk (RIVM, 2021). Since there is too little information about these potential effects, these effects could not be included in this analysis.

A stakeholder analysis showed that the costs and benefits of introducing field margins are not shared equally among the various stakeholder groups. Farmers bear the costs of constructing and managing field margins (€ 3.3 million) as well as the loss of crop production (€ 2.1 million). On the other hand farmers (as a whole, not necessarily the same farmers) also share the benefits from the biological pest control (€ 1.4 million) and pollination (€ 0.3 million). If you add up these costs and benefits, the field margins will cost the farmers in the Hoeksche Waard € 4 million over a period of 30 years.
The water boards benefit from the construction of field margins: the benefits from nutrient reduction in water bodies is estimated to be € 1.2 million. The benefits of € 2.5 million for recreation and health and the increase in biodiversity and natural attenuation will be shared by society as a whole.

Farmers in the Hoeksche Waard have shown an intrinsic interest in adopting FAB measures and see them as a promising contribution to the necessary transition to sustainable agricultural systems. Revenue models that attract funding options need to be devised in order to make this transition economically feasible for farmers, while allowing both farmers and society as a whole to get the most out of these measures. Currently, several legislations are in force or under development to provide funding opportunities for FAB practices. Some examples are the CAP, the Biodiversity Strategy for 2030, the Farm to Fork Strategy, the Soil Strategy for 2030 and the European Commission’s proposal for a Nature Restoration Law.

This SCBA only provides insight into the welfare effects of one FAB measure, namely field margins in the Hoeksche Waard, the Netherlands. Additional research is recommended into the benefits of field margins that we could not include in this study, such as the emission of plant protection products to surface water and the potential risks to human health, as well as potential additional FAB measures e.g. development or preservation of semi-natural landscape features, buffer strips[1], hedges, reduced tillage, solid manure, cover crops, etc.

[1] Alles over bufferstroken (rvo.nl)

1 Introduction

1.1 Background

In 2020, 38% of the land in the EU was used for agricultural production (Eurostat, 2023-02-08). Encouraged by the EU's Common Agricultural Policy (CAP), farmers have modernised and intensified production over the past five decades, enabling the supply of goods and services such as food, feed and fibre to society, as well as water retention and landscape values. Despite its benefits, this essentially 'linear' approach to production has also fostered a resource-intensive agricultural sector that is substantially dependent on external inputs (e.g. fertilisers, pesticides, machinery) and natural resources (e.g. soil, water, biodiversity) and that strives to maximise production. The consequence is environmental pollution and a reduction in biodiversity on agricultural lands, threatening the very ecosystems that make farming possible. Addressing this issue requires a transition to sustainable agroecosystems that use resources more efficiently, relying less on external inputs and conserving natural resources.

A promising approach to stimulating resilient and circular agroecosystems is Functional Agrobiodiversity (FAB, Visser et al., 2011, Van Rijn et al., 2019; Van Rossum et al., 2022). FAB refers to 'those elements of biodiversity on the scale of agricultural fields or landscapes, which provide ecosystem services that support sustainable agricultural production and can also deliver benefits to the regional and global environment and the public at large' (ELN-FAB, 2012). FAB knowledge offers a promising opportunity for developing and implementing science-based measures for achieving a sustainable and optimal delivery of ecosystem services (the benefits that ecosystems provide to society; MEA, 2005) in agroecosystems. FAB can contribute to the productivity of agricultural landscapes, for instance by stimulating the soil quality, crop pollination, biological pest control and the availability of genetic diversity (ELN-FAB, 2012). It can also contribute to other ecosystem services that are important in rural villages, such as water purification, infiltration and storage, erosion control, carbon sequestration, and to the attractiveness and recreational potential of the landscape (ELN-FAB, 2012).

FAB measures include a set of relatively simple practices that can be applied by themselves or in combination to support biodiversity and thereby improve the delivery of ecosystem services (ELN-FAB, 2012; https://vb.nweurope.eu/projects/project-search/fabulous-farmers/).
Examples include:

1. the development or conservation of semi-natural landscape features that act as habitats for pollinators;
2. the introduction of field margins to provide alternative food sources and overwintering sites for bees and natural enemies of pests (insects);
3. the use of small-sized fields to support foraging by bees and natural enemies of pests;
4. reduced tillage to increase the abundance and diversity of soil organisms and soil organic matter;

5. the use of green manures and cover crops for good soil structure, soil fertility and nutrient cycling;
6. Application of extended rotations for biological pest and disease control and increased soil fertility (ELN-FAB, 2012).

Over the years, promising results have been achieved on farms that applied FAB measures, including a marked reduction in pest pressure and, therefore, in pesticide use (ELN-FAB, 2012).

In the Hoeksche Waard, one FAB measure has been widely applied since its first implementation in 2000 (M. Klompe, personal communication, 7 February 2023), namely the creation of field margins. Field margins are strips of land located between agricultural fields and other fields or surface water, where the management (e.g. vegetation type, fertilisation, use of pesticides) differs from that of adjacent fields (H-WodKa, 2014). Field margins have been created in the Hoeksche Waard with the aim of reducing the use and emission of pesticides and stimulating biodiversity, pollination, landscape values, clean surface water and water storage (H-WodKa, 2014).

For years, many farmers in the Hoeksche Waard have made their farming practices more sustainable (e.g. focusing on local food production and healthy soil management, creating field margins, discontinuing the use of pig manure and discontinuing the frequent use of heavy machinery). However, the costs farmers incur in transitioning to more sustainable production models often cannot be offset by the benefits they receive in return. That is why local farmers are looking for a new revenue model that enables more sustainable business operations in the short and long term (M. Klompe, personal communication, 15 March 2018).

1.2 EU Interreg 'FABulous Farmers' project

Although much research has been done on FAB, knowledge about its effectiveness is still fragmented and economically sound business models supporting the implementation of FAB measures on farms are lacking. The EU Interreg 'FABulous Farmers' project aims to support the transition from a linear to a circular agroecosystem that is more impervious to disturbances, optimises the reuse of natural resources and is less dependent on exhaustible external inputs, while benefitting farmers, society and the environment. It does so by accelerating the adoption and implementation of FAB as a nature-based solution by farmers and land managers in Northwest Europe: i.e. Belgium, Netherlands, Luxembourg, United Kingdom, Germany and France. Twelve tailor-made collective FAB action plans have been jointly developed and are being tested and evaluated for ecological impact and economic return. These action plans have been implemented on 315 farms (25 000 hectares of agricultural land), which receive support to implement a set of ten customised FAB measures.

1.3 Aim of this study

As part of the EU Interreg FABulous Farmers project, this study aims to assess the societal costs and benefits of field margins in the Hoeksche Waard. A social cost benefit analysis (SCBA) was carried out for this purpose. An SCBA is a structural approach to assessing whether particular measures or sets of measures are societally desirable from a utilitarian perspective. Costs and benefits are systematically measured, where possible in a common unit of measurement (e.g. euros), to provide insight into the expected welfare effect of this FAB measure. In this SCBA, the welfare effect is measured as the net present value (NPV), the sum of all (monetary) costs and benefits associated with the creation of field margins. The NPV can be positive (i.e. the benefits outweigh the costs), neutral (i.e. the benefits are equal to the costs) or negative (i.e. the costs outweigh the benefits). All monetary costs and benefits to society are calculated over a period of thirty years (2025-2055) and then adjusted to the base year 2025. This SCBA only provides insight into the welfare effects of one FAB measure, namely field margin creation in the Hoeksche Waard, the Netherlands. In a follow-up study, the effects of other possible FAB measures can be assessed (e.g. development or preservation of semi-natural landscape features, development of smaller fields, less tillage).

1.4 Reading guide

Chapter 2 provides an overview of the methodology applied to carry out this SCBA, following the 'General guidelines for social cost-benefit analysis' (Romijn & Renes, 2013). The first step of the SCBA (Chapter 3) identifies the societal challenges for which a solution is sought. In Chapter 4, two alternative scenarios are defined for the Hoeksche Waard: one where field margins are present (Field Margins alternative) and one where they are not present (No Field Margins alternative). These alternative scenarios form the basis for assessing the additional costs and benefits of introducing field margins in the Hoeksche Waard compared to a situation where no field margins are present, over a period of thirty years (2025-2055). Chapter 5 examines the effects and benefits of implementing field margins in the Field Margins alternative, compared to the No Field Margins alternative. Effects are the changes (e.g. ecological, societal) that result from implementing measures, while benefits are the monetary value of effects. The methods used for quantifying these effects and benefits are also briefly described (see Appendices 3-10 for a detailed description of these methods). Chapter 6 provides insight into the methodology used to quantify the costs of creating, maintaining and managing field margins. The results of this SCBA are presented in Chapter 7, including an overview of all costs and benefits associated with field margins in the Hoeksche Waard. In this chapter, the NPV, or the sum of all benefits minus all costs, is calculated. An uncertainty analysis is also performed, showing how the assumptions for the most relevant parameters affect the results of the SCBA. The results are discussed in Chapter 8 and the main conclusions of this study are summarised in Chapter 9.

2 Method: social cost-benefit analysis (SCBA)

An SCBA is a useful instrument for estimating the societal costs and benefits of taking measures aimed at tackling specific societal challenges. This SCBA has been drawn up and implemented under the guidance of the General Guidelines for Social Cost-Benefit Analysis (Romijn & Renes, 2013). These guidelines, developed by PBL Netherlands Environmental Assessment Agency and CPB Netherlands Bureau for Economic Policy Analysis, describe eight steps for carrying out an SCBA. In this SCBA, these steps have been synthesised into six steps, which are described below.

2.1 Step 1: Identifying the problem (Chapter 3)

In the first step, the study area is introduced and the societal challenges for which a solution is sought are identified and described. In this SCBA, the societal challenges in the Hoeksche Waard that may have a connection with field margin implementation have been identified. Challenges may, for instance, relate to environmental and societal issues relevant to the area, as well as their alignment or disagreement with local policies. Societal challenges were identified by examining the available peer-reviewed and non-peer-reviewed literature (e.g. technical reports on field margins), particularly focusing on literature in the Netherlands and on the Hoeksche Waard. In addition, semi-structured interviews were conducted with experts (e.g. scientists, policy makers, farmers, nature and other conservation organisations) who were deemed to have valuable knowledge about field margin implementation or relevant interests, particularly in the Hoeksche Waard and the Netherlands.

2.2 Step 2: Defining alternatives (Chapter 4)

In the second step, alternative scenarios (possible futures) are formulated. In this SCBA, two alternatives have been assessed. The 'No Field Margins' alternative represents a future in which no field margins are present in the Hoeksche Waard. The 'Field Margins' alternative represents a future in which field margins are bordering on agricultural fields, according to the real situation in 2021. The No Field Margins alternative serves as a reference for assessing the additional costs and benefits of field margins in the Hoeksche Waard over a thirty-year period (2025-2055).

2.3 Step 3: Identifying and quantifying effects and benefits (Chapter 5)

This step identifies (1) negative and positive societal and environmental effects that result from the implementation of field margins, and (2) the resulting effects on societal welfare. To express the impact of implementing field margins on societal welfare, effects are expressed in monetary units wherever possible. Effects expressed in monetary units are referred to as 'benefits'. Quantifying effects in monetary units is referred to as 'valuation'. In this chapter, potential effects and benefits of introducing field margins in the Hoeksche Waard are identified, as well as methods for quantifying and valuing them. Effects and benefits were identified by experts (i.e. scientists) and selected on the basis of their relevance to the assessment (see Chapter 5 for details on how this was done).

2.4 Step 4: Identifying and quantifying costs (Chapter 6)

In this step, the additional costs of implementing field margins in the Field Margins alternative, compared to the No Field Margins alternative, are quantified. In this SCBA, the costs of field margins include the annual costs for the creation, management and maintenance of field margins. Changes in external (indirect) costs as a result of the creation of field margins (i.e. costs that are not directly related to the creation, maintenance and management of field margins), such as cost reductions due to reduced use of pesticides or lower water treatment costs, are included in the assessment of the benefits (positive or negative) of field margins in this SCBA.

2.5 Step 5: Results (Chapter 7)

In the results section, an overview table containing the main results is presented. The NPV is calculated to determine whether the Field Margins alternative is preferable to the No Field Margins alternative. The NPV of the Field Margins alternative is calculated as the sum of all future benefits minus the sum of all future costs. The present value of costs and benefits is obtained by converting the value of future costs and benefits to their value in in the reference year 2025, using a discount rate that has been adjusted for inflation (i.e. the change in the price level). The discount rate used in this assessment is 2.25%. A measure or set of measures benefits society from an economic perspective if the NPV is positive (Romijn & Renes, 2013). A positive NPV implies that the benefits of implementing particular measures are larger than the costs.

The NPV is a useful indicator for determining whether a measure or set of measures is desirable from an economic welfare perspective, but it does not provide an overall picture. One issue with the NPV is that not all costs and benefits can be quantified due to various limitations (e.g. time and data constraints), which may lead to their exclusion from the calculation of the NPV. Moreover, the NPV is a useful indicator for how society as a whole benefits from the implementation of measures in an alternative but does not provide information about the distribution of costs and benefits across various stakeholder groups in society. It is important that all these and other aspects that are not reflected in the NPV are clearly described in this part of the SCBA. On the basis of this information, decision makers can decide to implement measures from an alternative scenario even if the NPV is neutral or negative. For instance, a decision maker may decide that the benefits of implementing measures in an alternative are still desirable, but that adjustments (optimisations) must be made before a policy is formulated (Romijn & Renes, 2013).

An uncertainty analysis is also performed in this section. This SCBA examines the degree of uncertainty of the methods used to quantify and value monetary costs and benefits by calculating twelve uncertainty scenarios. In each scenario, assumptions made in the calculation of costs and benefits are adjusted to determine the consequences for the NPV and what this implies for the degree of certainty regarding the calculations made.

2.6 Step 6: Discussion (Chapter 8)

The results of this SCBA are discussed in Chapter 8. This chapter primarily focuses on the results for quantified and valued costs and effects, the NPV calculations and the analysed uncertainties, as well as what this means for the implementation of the FAB measure ‘field margins’ in the Hoeksche Waard and elsewhere.

3 Problem identification

3.1 Study area: Hoeksche Waard

The Hoeksche Waard is located in the southwest of the Netherlands, south of the cities of Rotterdam and Dordrecht. It is an area with a traditionally agricultural character, made possible by a long-term reclamation process that led to the creation of an island with approximately sixty polders (HW, 2019; Frazão et al., 2017; Heijting et al., 2011). Today, this area of approximately 324 km^2 consists of agricultural land (77%), forest and other nature (9%), built-up and paved areas (9%) and other built-up infrastructure (5%) (Figure 3.1). The agricultural sector on the island mainly focuses on the production of arable crops, such as sugar beets, potatoes and wheat, in rotation with various other crops (Frazão et al., 2017). Soils in the Hoeksche Waard can be classified as marine 'polder vague', ranging from hydromorphic calcareous sandy loam to clay formed in marine sediments (Frazão et al., 2017; Heijting et al., 2011). The average temperature on the island is 10.8 °C and the annual precipitation is about 883 mm (Frazão et al., 2017).

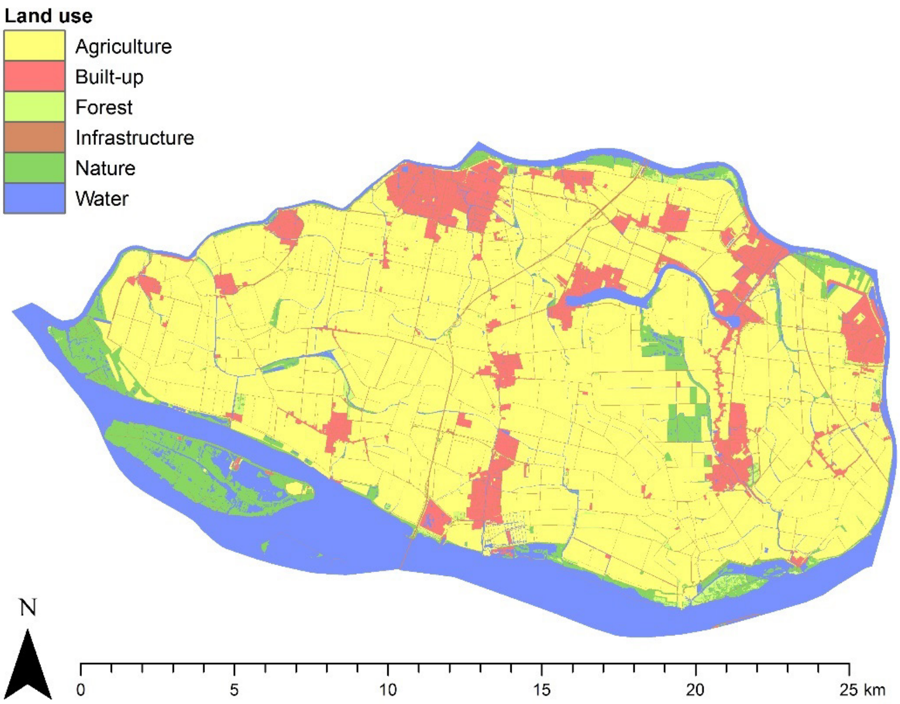

Figure 3.1 Land cover in the Hoeksche Waard (source of spatial data: BRP map; RVO, 2020)

For hundreds of years, the Hoeksche Waard consisted of small farming communities that were relatively isolated. Nature was abundant, so it was used indiscriminately. In recent decades, a decline in biodiversity (e.g. loss of the skylark, the partridge, various pollinator species, soil life) has been witnessed as a result of a variety of non-natural interventions, such as the use of chemical pesticides (Lerink & Klompe, 2016; Gieu-Arbaret, n.d.; HW, 2022). Climate change has also led to recurrent drought, forcing entrepreneurs to invest in freshwater supplies to maintain agricultural production. To address this challenge, the municipality of the Hoeksche Waard is striving for a circular economy, reducing CO_2 emissions and finding a balance between food production and nature in the short and long term (HW, 2020).

3.2 Field margins in the Hoeksche Waard

3.2.1 Origin

Field margins are crop-free strips of land adjacent to crop fields, which can provide various benefits to farmers and the rest of society (van Rijn, 2018). They were introduced in the Netherlands in 1989 with the aim of mitigating the effects of economies of scale and agricultural intensification (Bos & Musters, 2014). A structured approach to field margin management emerged in 1991 as a result of the Long-Term Crop Protection Plan (*Meerjarenplan Gewasbescherming*), which stated the ambition of reducing the emission of pesticides to surface water by 90% by 2000 (Bos & Musters, 2014). Subsequently, crop-free zones along waterways were introduced in 2000 in the Discharges Decree 2000 (*Lozingenbesluit 2000*). Since then, initiatives have been launched throughout the country to widen these zones in order to combine policy ambitions with other goals (Bos & Musters, 2014).

One of these initiatives is the introduction of so-called ‘FAB field margins’. The most important pilot for this form of field margin management was carried out in the Hoeksche Waard in the LTO-FAB project from 2005 to 2011 (Bos & Musters, 2014). Field margins and adjacent crop fields were closely monitored during five seasons on four arable farms (Bos & Musters, 2014). As a result of this pilot, a great deal of data was collected, new knowledge was developed, and a methodology was developed for Dutch field margin management (Bos & Musters, 2014). Farmers also reported spraying fewer insecticides against aphids thanks to the FAB advice (Bos & Musters, 2014). Since 2016, field margins have been a part of the Dutch system for Agri-environmental Management (*Agrarisch Natuur- en Landschapsbeheer*), which requires that the implementation and management of field margins is provided by agricultural collectives (WSHD, n.d.).

3.2.2 Types of field margins

The Hoeksche Waard contains approximately 164 ha of field margins, also referred to as ‘Hoeksche Randen’ (Figure 3.2). Unlike unmanaged margins, Hoeksche Randen are managed by the ‘Coöperatie Collectief Hoeksche Waard’ (CCHW) in a way that creates added value in the form of ecosystem services (HW, 2020; CCHW, 2017). CCHW distinguishes different types of field margins. These include annual flower margins (30 ha), perennial grass margins (26 ha), newly sown perennial grass-herb margins (aged one year or less) (15 ha), older perennial grass-herb margins (older than one year) (85 ha), perennial partridge margins (6 ha), annual winter bird margins (2 ha). The remaining margins consist of combinations of different margins. Annual margins mainly flower in the summer, while perennial margins mainly flower in the spring of the second and following year (van Rijn, 2018). Partridge and winter bird margins are sown on broader surfaces than the usual narrow herb and flower margins. They mainly serve as a habitat for partridge birds and as a winter habitat for farmland birds (van Rijn, 2018). All Hoeksche Randen except for grass margins are sown with herbs that produce flowers suitable for pollinators and/or natural enemies (P. van Rijn, personal communication, 2 February 2022).

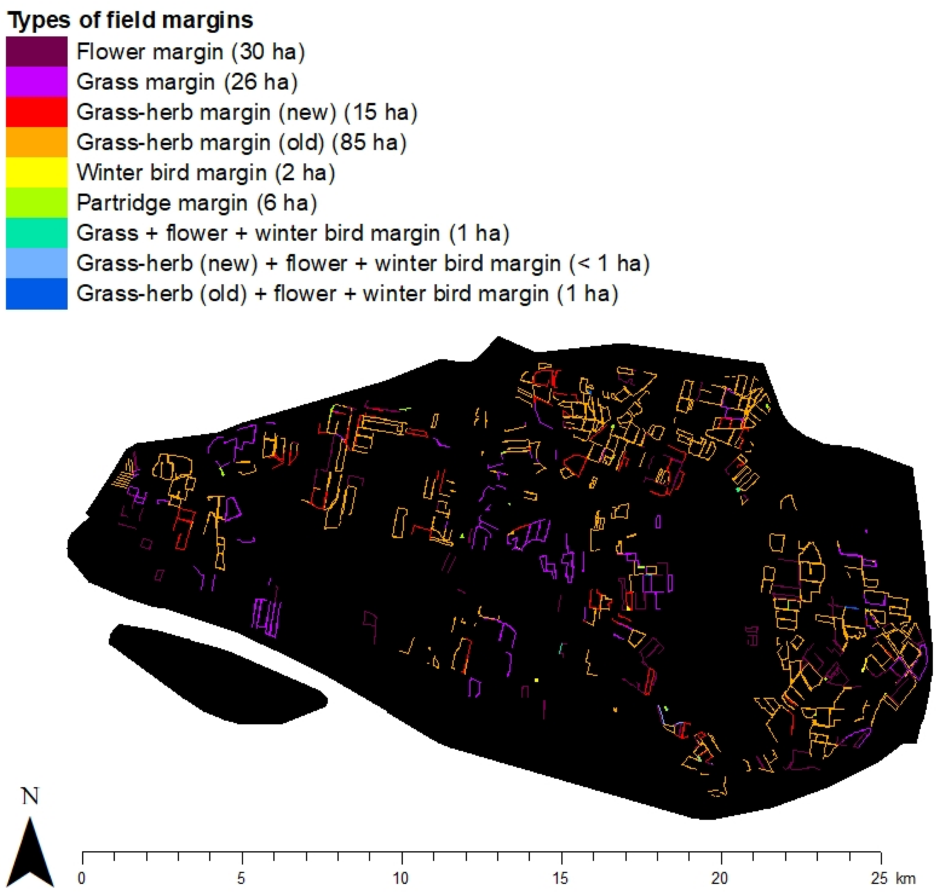

Figure 3.2 Field margins in the Hoeksche Waard (source of spatial data: Field Margins map; Lerink, 2021). Old = 2 or more years. New = less than two years.

3.2.3 *Financing*

In recent years, the implementation of field margins in the Hoeksche Waard has been subsidised by the EU, with contributions from various organisations and the local water board, *Waterschap Hollandse Delta* (WSHD, n.d.). Half the costs of agri-environmental management were financed by the EU. Of the remaining 50%, 1/3 was paid by the Province of South Holland, 1/3 by the water board and 1/3 by regional partners. The Hoeksche Randen received an annual compensation ranging from € 0.07 to € 0.24 per meter, provided certain preconditions were met. For instance, a margin should preferably be situated along a ditch, should have a width of no less than 3.5 m (with some exceptions) and cannot be used as a path for access to agricultural fields (CCHW, 2017). The use of chemical weed control is only permitted under specific circumstances to control problematic weeds patch-wise, and fertilisation and grazing are not permitted in the margins (CCHW, 2017). Farmers that introduced field margins sown with specific flower mixtures received additional financial support, as field margins containing specific flowers play an important role in supporting natural pest control and pollination (van Rijn, 2018). They do this by providing food (e.g. nectar and pollen) and habitat, resulting in increase in the abundance of natural enemies of pests (van Rijn, 2018).

3.3 Field margin effects and their interplay with local challenges

3.3.1 Water quality (nutrients)

Runoff water contains plant remains, soil particles and nutrients from fertilisers, such as phosphorus (P) and nitrogen (N) (Bos & Musters, 2014). The extent to which nutrients and sediments end up in surface water varies greatly and depends on numerous factors, such as soil type, natural attenuation capacity and drainage, as well as vegetation density and type, field margin width and precipitation (Bos & Musters, 2014). Runoff mainly occurs in agricultural areas on slopes (Bos & Musters, 2014). During heavy rainfall, runoff from flat fields can cause strong peak loads in surface water (Bos & Musters, 2014), but most of the precipitation surplus will be discharged to the nearest water body (ditch, watercourse) via leaching (STOWA, 2010). Leaching through shallow groundwater streams is particularly important for the transport of nitrogen compounds (Bos & Musters, 2014).

The Netherlands is a predominantly flat delta with deeply permeable soils and artificial ditches and canals (STOWA, 2010). Scientific literature has shown that, in the Netherlands, the influence of field margins on nutrient emissions from agricultural fields to surface water can vary greatly depending on their width (27-90% phosphorus reduction and 0-94% nitrogen reduction) (Magette et al., 1989; Furlan et al., 2012; Wratten et al., 2012). Wind erosion appears to have a minor impact on emissions and to be less affected by field margins, due to their relatively small area compared to the area of agricultural fields and other semi-natural features (e.g. hedges and rows of trees) (Bos & Musters, 2014).

Water quality in the Netherlands is currently at odds with the objectives of frameworks, agreements and visions that the country is pursuing. Some examples include the Nitrogen Reduction and Nature Conservation Act (*Wet Stikstofreductie en Natuurverbetering*; Tweede Kamer, 2020-2021), the National Water Plan (*Nationaal Waterplan 2016-2021*; IenM, 2015) based on Dutch legislation, as well as on the European Water Framework Directive (WFD) (EC, 2000) based on EU legislation. The local water board (WSHD), responsible for water management in the Hoeksche Waard, manages 41 larger water bodies to which the WFD guidelines apply. In 2027, these water bodies must have good water quality (WSHD, n.d.). Tackling the problem of agricultural emissions is important for accommodating these national goals, as well as the 'Hoeksche Works' (*Hoeksche Werken)*, which are the current societal challenges faced by the municipality of Hoeksche Waard (HW, 2019). These challenges include the pursuit of a more sustainable municipality with sufficient space and commitment to water quality and quantity, and the pursuit of an agricultural sector that is both sustainable and innovative (HW, 2019).

This SCBA quantifies and values the effect of field margins on the reduction of P and N loads to ditches (see section 5.1.4).

3.3.2 *Water quality (plant protection products and biocides)*

Pollution of surface water with nutrients (e.g. N and P), plant protection products and biocides can be harmful to aquatic life (Bos & Musters, 2014). In 2027, the water quality in the Netherlands will have to comply with the WFD for targets for nutrients, crop protection products and insecticides.

There are three main mechanisms by which pesticides accumulate in surface water: direct emissions, superficial runoff and leaching. Direct emissions are mainly caused by drift or spillage. Drift occurs when a large proportion of the pesticides used do not reach their intended target and end up in surface water (STOWA, 2010). The extent to which drift occurs is influenced by the application technique and weather conditions (STOWA, 2010). Superficial runoff consists of the part of the water that cannot infiltrate into surface water during rainfall, as well as of irrigation that cannot infiltrate into the soil and thus ends up in surface water. Leaching occurs when water-containing plant protection products penetrate groundwater or enter surface water via this route. Water-containing plant protection products and biocides can also enter surface water more quickly if a drainage system is present.

Field margins can form a reactive barrier between fields and surface water, reducing the amount of pesticides entering surface water. The size of the effect of field margins depends on their width, soil type and the vegetation type, as well as the concentration, chemical properties and application type of the substances used (e.g. equipment and spray nozzle) (STOWA, 2010; Bos & Musters, 2014). Research has shown that unsprayed field margins can form a barrier to the emission of pesticides to surface water. For instance, research conducted in the Netherlands revealed that field margins with a width of 3 meters can lead to a reduction of more than 95% in the amount of pesticide runoff ending up in surface water (De Snoo, 1999). Research conducted in the Hoeksche Waard revealed that field margins with a width of 3.5 meters result in a 75-95 % reduction in the amount of pesticide drift that ends up in surface water (Stoots & van der Vlies, 2007).

Various types of vegetation can be planted on field margins to serve as a habitat for insects that can act as natural enemies of crop pests (van Rijn, 2018). Boosting natural enemy populations reduces pest pressure on crops, leading to a reduction in the need to use pesticides to protect crops (van Rijn, 2018). Reducing the discharge of pesticides into the water in the Hoeksche Waard is necessary to meet the local demand for clean water for uses such as recreation, the supply of drinking and irrigation water, and to achieve local water quality goals (HW, 2019). It is also required for meeting EU targets such as those under the European Green Deal (EC, 2019), the Farm to Fork Strategy and the Biodiversity Strategy for 2030 (EC, 2020 a).

The impact of reducing pesticide and biocide emissions on water quality is an important benefit that can positively contribute to the NPV. In particular, improvements in water quality could lead to lower costs for society (e.g. avoided health costs from poor water quality). Despite these potential benefits, this effect has only been assessed qualitatively in this SCBA because of quantification issues, due to insufficient information on the amount of pesticides and biocides that farmers currently apply to agricultural fields in the Hoeksche Waard. The SCBA does, however, quantify the effect of field margins on pest control and what this means for cost savings associated with a reduction in the use of pesticides, since they are considered unnecessary on fields surrounded by field margins (see section 5.1.2). The effect of field margins on the natural attenuation capacity of the soil and water system is also quantified in a non-monetary fashion (see section 5.1.5).

3.3.3 Water quantity

Field margins can contribute to the water storage function (STOWA, 2010) and thus assist in reducing the risk of local flooding and drought (Crooijmans, 2020). They are especially effective for the water storage function, particularly in catchment areas where flooding poses a risk to society (STOWA, 2010). Most areas in the Hoeksche Waard are so low that they would quickly become submerged in the event of a dike breach (HW, n.d.). Field margins can mainly fulfil the function of water storage if they are designed as wet buffer strips (STOWA, 2010). Wet buffer strips are strips of land adjacent to waterways where the groundwater level is relatively high (STOWA, 2010). Part of the strip may even lie below surface water level (STOWA, 2010). Field margin management usually refers to the management of dry buffer strips, which are strips of land adjacent to watercourses and which are usually at the same level as the ground level of adjacent fields (Crooijmans, 2020). Practice shows that dry buffer strips have limited effectiveness in terms of water storage compared to wet buffer strips (STOWA, 2010). For this reason and because of the limited knowledge of the water storage function of field margins, this function has not been included in this SCBA.

3.3.4 Biodiversity

In the Netherlands, the need for a transition to sustainable agriculture is increasing due to the decrease in biodiversity on agricultural land (Delbaere et al., 2014). The Parties to the Convention on Biological Diversity define biodiversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems” (CBD, 1992). Biodiversity underpins fundamental ecosystem processes that benefit society. It is also an ecosystem service in its own right, as people value the cultural services it provides, such as its intrinsic value (e.g. the value people assign to it due to its inherent existence) and its educational and scientific value.

An important purpose of field margins in the Hoeksche Waard is to promote biodiversity (e.g. protecting vulnerable species and nurturing the populations of species that act as enemies for pests in the agricultural landscape) (CCHW, 2017). In the Hoeksche Waard, the use of insecticides on fields adjacent to field margins is no longer necessary due to increased pest control, although herbicide and fungicides are still applied to most fields. Perennial field margins serve as a breeding habitat for farmland birds, such as the skylark and western yellow wagtail and as a foraging area for their chicks. Field margins are also attractive habitats for mice that serve as food for predators, such as the marsh harrier, the common kestrel and short-eared owl. Margins containing flowers also benefit populations of bees and other nectarivores (CCHW, 2017).

By supporting a higher diversity of soil organisms, field margins also support the natural attenuation capacity (NAC) of the soil and water systems. The NAC of the soil and water systems is the capacity for self-maintenance and purification of the soil, the groundwater and the surface water without human intervention. A high NAC reduces the risks posed by contaminants and nutrients by reducing their mass, toxicity, mobility, volume and/or concentration in soil and groundwater (EPA, 1999).

This SCBA quantifies the effect of creating field margins on biodiversity (see section 5.1.4). It also measures the indirect effect of changes in biodiversity on:

1. The effective pollination rate of pollinator-dependent crops sown in fields adjacent to field margins, as a result of changes in pollinator biodiversity, as well as the subsequent effect on crop yield (see section 5.1.1);
2. The effectiveness of b Biological pest control via changes in the biodiversity of the natural enemies of pests (see section 5.1.2), as well as the effect on costs associated with insecticide use;
3. The NAC of the water and soil system (see section 5.1.5).

3.3.5 *Climate change mitigation*

Continuous cropping and tillage alters the carbon cycle and, consequently, the carbon sequestration. Carbon cycles in agroecosystems are largely influenced by crop management. Different types of vegetation, crop sequence, tillage techniques and fertilisation levels influence decomposition and regulate the amount of carbon sequestered by plants, exported by harvest and incorporated into the soil (D’Acunto et al., 2014). Sechi et al. (2017) revealed that, driven by the soil microbial community, field margin soils in the Hoeksche Waard store more carbon than soils in adjacent fields. As a result, the organic matter content in field margins, and thus the extractable carbon, was higher.

The contribution of field margins to carbon sequestration is in line with the climate goals and ambitions set nationally and internationally. At the Dutch level, the Climate Agreement (*Klimaatakkoord*; Rijksoverheid, 2019) and the Climate Act (*Klimaatwet*; Eerste Kamer, 2019-05-18) advocate a reduction of greenhouse gas emissions in the Netherlands by 95% compared to 1990 by 2050, and a 49% reduction by 2030. At the EU level, Member States are expected to reduce greenhouse gas emissions by at least 55% by 2030 and to make the EU climate neutral by 2050, under the European Climate Law (EC, 2021b). In addition, the European Commission’s (EC) proposal for the Nature Restoration Law suggests binding nature restoration measures that should be implemented on 20% of the EU's territory by 2030 in order to achieve, among other objectives, the Union's climate mitigation and adaptation objectives (EC, 2022a). Internationally, countries that have joined the Paris Agreement are expected to substantially reduce global greenhouse gas emissions to limit global temperature rise to 2 degrees Celsius in this century (UN, n.d.). Given the contribution of carbon sequestration by field margins to meeting these goals, this SCBA takes this effect into account (see chapter 5.1.7).

3.3.6 *Landscape quality, recreational opportunities, and health*

Field margins play an important role in improving the quality of the landscape and providing recreational opportunities in agricultural areas. Landscape quality is often defined in terms of the degree of naturalness or greenness of an area and is often associated with variation in the landscape (STOWA, 2010). Field margins improve the aesthetic value of the agricultural areas in which they are located, as they make the landscape more varied, consist of different types of vegetation (e.g. herbaceous floral mixtures), and attract birds and insects (Lovell & Sullivan 2006; Crooijmans, 2020). Increasing the aesthetic value of nature can generate opportunities for creating a leisure economy, for instance by offering recreational activities (e.g. mini-camping, accommodation, outdoor sport facilities) and by encouraging higher spending on tourism and recreation (Bos et al., 2008).

Field margins can contribute to the beauty of the landscape in an area, which can generate income from recreation by locals and non-locals visiting the area (e.g. holidaymakers or passers-by) (Bos & Musters, 2014). Some studies have shown that the appreciation of a landscape may depend on factors such as age, gender, education, knowledge and familiarity with the landscape (Strumse 1996; Junge et al. 2011). Moreover, farmers seem to value the landscape differently than other beneficiaries of natural capital (Angileri & Toccolini 1993; Lovell & Sullivan 2006; Junge et al. 2011). In general, farmers and urban dwellers seem to prefer neat and moderately managed landscapes (Lovell & Sullivan 2006; Paar et al. 2008), while non-farmers living in or visiting the countryside tend to find neatly managed landscapes monotonous and dull (Burton, 2012).

The Hoeksche Waard is conveniently located between the Biesbosch National Park and the cities of Rotterdam and Dordrecht (HW, 2019). Every day, about 12 500 people travel to the area for work, and the flow of tourists is expected to increase in the coming years (HW, 2019). This calls for an attractive living and working climate for residents and businesses (HW, 2019). The municipality of Hoeksche Waard, therefore, wants to increase the importance of the leisure economy, which is currently of limited value (HW, 2019). In general, it is essential to improve the recreational and landscape value of natural elements such as field margins independently of economic considerations, given their clear positive influence on the perception of the landscape and its contribution to the recreational potential (Paulin et al., 2020; Bos & Musters, 2014).

This SCBA quantifies the effect of field margins on the number of hikes by residents of the Hoeksche Waard (local recreationists) and the surrounding area (non-local recreationists). The benefits this generates for the recreational economy of the Hoeksche Waard are also valued in monetary terms. These benefits include the effects on the human health of recreationists, expenditures on food by local and non-local recreationists and expenditures on accommodation by non-local recreationists (see section 5.1.7). Field margins can also enhance the experience of cyclists. For instance, cycling tours take place in the Hoeksche Waard to view field margins. This benefit has not been included in this SCBA due to the lack of data needed to quantify it.

Finally, there are indications that persons with a history of working over a long period of time with chemical substances, such as farmers who work with plant protection products, are at greater risk of developing diseases that damage the nervous system (neurodegenerative diseases), such as Parkinson’s disease and Alzheimer’s disease. Since too little is currently known about the possible effects of plant protection products on human health, these effects have not yet been included in this SCBA (Heusinkveld et al., 2021).

4 Alternatives

This chapter describes the No Field Margins and the Field margins alternatives. Field margins are already present in the area, but their contribution to societal welfare has not yet been assessed.

The Field Margin alternative is in fact the current situation in the Hoeksche Waard, where field margins are present adjacent to the fields, as shown in Figure 3.2. We compare this Field Margin alternative with the situation in which there would no longer be any field margins in the Hoeksche Waard: the No Field Margins alternative.

The distribution in the Field Margins alternative shown in Figure 3.2 is based on their actual distribution (census 2021). The introduction of field margins entails costs for their creation, maintenance and management. It also leads to changes in the delivery of several ecosystem services for the Hoeksche Waard region and society as a whole. The affected ecosystem services considered in this SCBA include crop production, biodiversity, biological pest control, pollination, the NAC of the water and soil system, water quality regulation, recreation and climate change mitigation.

Where possible, all costs and benefits associated with the introduction of field margins have been quantified and valued. Costs and benefits that have not been assessed are qualitatively described in the results of the SCBA to reduce bias (section 7.4.8). Chapters 5 and 6 describe in detail how the costs and benefits of creating field margins have been quantified and valued.

4.1 Quantification approach

The costs and benefits of creating field margins have been quantified in a spatially explicit manner. Spatial datasets (maps) have served as inputs for the spatially explicit calculation of costs and benefits. These calculations result in output maps representing the distribution of costs and benefits. Output maps are useful for visualising the distribution of costs and benefits across the assessment area. They can, for instance, give an idea of where and to what extent field margins are most effective. However, creating output maps for costs and benefits is resource-intensive (i.e. time, knowledge, data). Given limited resources, the effect of field margins was measured in the form of spatial output maps for only three ecosystem services:

- crop production;
- biological pest control;
- pollination.

The costs and other effects quantified and valued in this SCBA were assessed using spatial data as input, but the results are not visualised as spatial output maps.

To quantify the costs and benefits of field margins, (spatial and non-spatial) data that is relevant per cost or effect/benefit item have been incorporated into the calculations. This means that for all calculations, spatial data, statistics and reference parameter values, obtained from the scientific literature and based on expert judgment, have been incorporated. Where necessary, spatial maps have been adjusted to reflect the situation in each alternative. Where possible, ecosystem services have been quantified as physical flows (e.g. biophysical, chemical, social indicators) and as economic flows (euros).

Non-spatial quantifications were performed in Excel. For spatial calculations, spatial data was pre-processed and, in some cases, analysed using the ArcMap (version 10.6.1) and QGIS (version 3.0.2) software. Where spatial modelling took place, algorithms were written in the Python programming language (https://www.python.org/) using the PCRaster library (http://pcraster.geo.uu.nl/). Algorithm-based spatial modelling was performed for the effects/benefits related to the ecosystem services pollination, biological pest control and crop production.

4.2 Spatial data

Two main spatial datasets have been used to calculate the changes in costs and effects/benefits associated with the realisation of field margins in the Hoeksche Waard. These include the vector maps with the distribution of field margins (Lerink, 2021) and maps of fields of *Agricultural crop parcels (Basisregistratie Gewaspercelen, BRP*; RVO, 2020).

4.2.1 Field margins maps

The Field Margins vector map (Lerink, 2021) is a spatial dataset that contains data on the distribution and type of field margins (Hoeksche Randen) in the Hoeksche Waard. The Field Margins vector map was used to develop the Field Margins raster map. This was done by first converting the Field Margins vector map to a raster map with a resolution of 2.5 m, where cells contain either a value of 1 (field margin present) or 0 (field margin not present). This raster map was then converted to a raster map with a resolution of 10 m, with cells containing a value between 0 and 16, since 16 cells with a resolution of 2.5 m fit in a cell with a resolution of 10 m. By dividing the cell value by 16 (e.g. 2/16 for a cell with a value of 2), the fraction of the 10 m cell that is covered by field margins (value between 0-1) can be estimated.

The Field Margins vector and raster maps were used to calculate the area and other characteristics of field margins in the Hoeksche Waard (Table 4.1). These reference values have been used to calculate the costs and benefits of field margins in this SCBA. In the No Field Margins alternative it is assumed that the field margins can be used entirely for crop production. The raster map has also served as input for developing agricultural field maps for each alternative (see section 4.2.2).

Table 4.1 Area and other physical characteristics of field margins in the Field Margins alternative . Based on statistics for the year 2021.

Area	Total	Source
Area of field margins	164 ha	CCHW (2022)
Area of field margins with only grass	23 ha	CCHW (2022)
Area of field margins with flowers	141 ha	CCHW (2022)
Length of field margins	550 km	Lerink (2021)
Average width of field margins	3 m	Calculation
Number of field margins units	736	CCHW (2022)

4.2.2 *Agricultural crop parcels and agricultural fields*

The BRP vector map (RVO, 2020) contains spatial data on the types of agricultural land use in the Netherlands and the corresponding codes. The map is updated annually in September for the reference date of May 15, which means that if there is more than one crop on a field, it is recorded which crop is growing on it on May 15. It is therefore assumed that only cultivation of one crop takes place on each field.

The BRP vector map served as input to calculate the costs and effects/benefits of the Field Margins and No Field Margins alternatives. Raster maps have been made for each alternative, showing the distribution of fields and specific crop types. This was done in ArcMap as described in Appendix 1. The BRP vector file and the raster files that were created for both alternatives served as input for the calculation of the area and other characteristics of agricultural fields in the Hoeksche Waard (Table 4.2, Figure 3.2).

Table 4.2 Area and other physical characteristics of agricultural fields in the No Field Margins and in the Field Margins alternatives, based on the BRP map (census 2020) (RVO, 2020) and the Field Margins map (census 2021) (Lerink, 2021).

Landscape element (LE)	Area (ha)	Units	Source
Agricultural fields (No Field Margins alternative)	12 064	4100	RVO (2020)
Agricultural fields (Field Margins alternative)	11 900	4100	RVO (2020)

4.3 Other aspects considered in the calculation of costs and effects/benefits

4.3.1 *Uncertainty analysis*

Estimates of the costs and benefits of implementing measures are uncertain. Uncertainties include, but are not limited to, data-related uncertainties (e.g. missing data, errors, spatial extrapolations), knowledge-related uncertainties (e.g. imperfect models, expert knowledge bias, uncertainty in reference parameter values obtained from regressions or statistics), policy/management-related uncertainties and uncertainties related to changes that will occur in the future (long-term). One way to deal with uncertainties is to develop alternatives to evaluate the costs and benefits of implementing a particular measure.

However, calculations of the costs and benefits of applying measures in the future carry their own degree of uncertainty. This is the case because the estimates used in cost-benefit calculations can vary within a certain bandwidth, which increases in proportion to the length of the assessment period (Romijn & Renes, 2013). In addition, in the absence of robust data and models, simplified calculations based on expert judgment and non-peer-reviewed data are sometimes used for calculations.

Chapter 7.4 provides a quantitative analysis of the uncertainty associated with the cost-benefit calculations in this SCBA. In particular, variations in the NPV are calculated on the basis of twelve uncertainty scenarios. For each scenario, reference parameter values, used in the calculations of different ecosystem services/benefits, are adjusted. The parameter values that are adjusted in each uncertainty scenario include the assessment period of the SCBA, the discount rate, the soil organic carbon content (SOC) in field margins and agricultural fields, the market price of CO_2 over time, the shadow prices of P and N and a factor that represents the relative number of hikes taken in the No Field Margins alternative compared to in the Field Margins alternative.

4.3.2 *WLO scenarios*

In the Netherlands, SCBA practice requires costs and benefits to be calculated under various future uncertainty scenarios (Werkgroep Discontovoet, 2020). This is often done on the basis of the WLO scenarios for the future outlook on welfare and the living environment (*Toekomstverkenning Welvaart en Leefomgeving*, WLO) scenarios (CPB & PBL, 2015). The WLO scenarios form the basis for a wide range of many policy decisions that relate to the environment in the Netherlands, taking into account climate policies abroad (Werkgroep Discontovoet, 2020).

A CO_2 emission budget and an emission reduction for the rest of the century have been determined for each WLO climate scenario. The low WLO scenario assumes a lower CO_2 emission reduction (30% in 2030 and 45% in 2050) than the high WLO scenario (40% in 2030 and 65% in 2050). In addition, a scenario has also been developed with the aim of achieving a 2 °C target (2 °C WLO scenario; Werkgroep Discontovoet, 2020).

This SCBA uses the WLO climate scenarios as a basis for determining the discount rate and the CO_2 price used in the calculation of costs and benefits (see section 5.1.7). On the basis of these scenarios, lower and upper bounds are also used to perform uncertainty analyses about possible variations in the discount rate and the future CO_2 price (see Chapter 7.4).

4.3.3 *Discount rate*

In an SCBA, all costs and benefits calculated for a future point in time are discounted to estimate their present value. Discounting refers to determining the present value of future costs and benefits. Discounting takes place by means of a discount rate. The main argument for applying a discount rate is that people would rather have a euro today than have a euro tomorrow. Based on this reasoning, a euro will theoretically be worth less tomorrow than a euro today. As such, future costs or benefits will have a lower value today.

In the Netherlands, the discount rate that is intended for use in SCBAs is set by the government on the basis of the advice of the Werkgroep Discontovoet (Werkgroep Discontovoet, 2020). Currently, the standard discount rate is set at 2.25%. The Discount Rate Working Group also proposes to use a discount rate of 2.65% for the high WLO scenario, and a discount rate of 1.85% for the low WLO scenario (Werkgroep Discontovoet, 2020). The latter two discount rates have been applied within the uncertainty analysis (Chapter 7.4). Appendix 2 describes the method used in this SCBA for applying discount rates when quantifying future costs and benefits.

5 Effects and benefits

5.1 Overview of effects

In this SCBA, the effects of field margins in the Hoeksche Waard are evaluated across the Field Margin and the No Field Margin alternatives. Part of the effects is expressed in terms of differences in ecosystem service values. Ecosystem services assessed in this SCBA were selected by a panel of experts (i.e. scientists) on the basis of their relevance to the assessment. An ecosystem service was considered relevant for this assessment (1) if its supply is affected by the presence or absence of field margins, (2) if the beneficiaries of the service could be clearly defined, and (3) if sufficient data and methodologies are available for their quantitative assessment. On the basis of these criteria, eight ecosystem services have been selected for inclusion in this SCBA (table 5.1). Sections 5.1.1-5.1.8 describe an outline how each effect was quantified and/or valued. A more detailed explanation of the quantification and valuation of each effect can be found in Appendices 3-10.

Table 5.1 Overview of effects

Ecosystem service	Description of effect item	Section
Pollination	Change in the biodiversity of wild pollinators that find shelter and alternative food sources in field margins, and in the effective pollination rate of pollination-dependent crops.	5.1.1
Crop production	Change in realised income from crop production due to changes in (1) the area of agricultural fields, and (2) the resulting reduction in crop production costs.	5.1.2
Biological pest control	Change in (1) the pest control rate by natural enemies of pest species that find shelter and alternative food sources in field margins, and (2) the resulting reduction in the application of insecticides.	5.1.3
Water quality regulation	Changes in nutrient emissions (P & N) to surface water due to changes in the area that is fertilised, and due to a reduction by field margins of emissions to surface water.	5.1.4
Biodiversity	Change in the biodiversity of birds, insects, soil organisms and aquatic invertebrates.	5.1.5
Natural attenuation capacity (NAC) of the soil and water systems	Change in the regulation of the chemical condition of soils and freshwaters by biological, biophysical and chemical processes.	5.1.6
Climate change mitigation	Change in soil’s contribution to carbon sequestration and its utilitarian (monetary) contribution to global climate change mitigation.	5.1.7
Recreation and health	Change in the numbers of recreational hikes due to the presence of field margins, as well as its economic effect on the leisure economy and its human health impact.	5.1.8

5.1.1 *Pollination*

In this SCBA, pollination services refer to the ecosystem contributions by wild pollinators to fertilisation of pollinator-dependent crops (i.e. crops whose yields benefit from pollination) (van Berkel et al., 2021). In the Hoeksche Waard, pollinator-dependent crops comprise 8% of cultivated land in the Field Margins alternative and 10% in the No Field Margins alternative. Pollinator visits have been associated with outcross pollen movement between individuals, increase in the total amount of pollen deposited on flower stigmas and an increased seed set. This, in turn, leads to an increase in the product quantity and quality of the pollinated crops. Today, many beekeepers place beehives for breeding the honeybee species *Apis mellifera* near crops that require pollination. However, honeybees are not always the most efficient pollinators. Many crops can be effectively pollinated by e.g. wild bees, bumblebees, butterflies and hoverflies, which can only partially be replaced by commercial beehives and make an important contribution to the quality of Dutch crops, such as pears (van Berkel et al., 2021).

The contribution of pollination by insects to the yield of pollinator-dependent crops (€) was quantified on the basis of the model developed by van Berkel et al. (2021). The model considers pollination by wild bees, bumblebees, butterflies and hoverflies and excludes pollination by honeybees. The contribution of pollination to crop production is supported by ecosystems in agricultural landscapes that are adjacent to agricultural fields. These ecosystems provide valuable resources needed by wild pollinators, such as nesting habitats and suitable floral sources for pollen and nectar (van Berkel et al., 2021). In this SCBA, field margins containing flowers act as sources of pollen and nectar, while other semi-natural landscape elements are considered as nesting habitats and, to a minor degree, as sources of pollen and nectar. The contribution of semi-natural elements to pollination was estimated for the No Field Margins and the Field Margins alternatives, as the effective pollination rate of pollinator-dependent crops by wild pollinators (%). The monetary benefit of changes in pollination was measured as the avoided loss in farmers' incomes resulting from the presence of semi-natural elements that contribute to pollination (€), including field margins. Farmers' incomes from crop production consists of the market value of the crop yield less the crop production costs incurred. In addition, the average subsidy value received per ha of cultivated land was also deducted from the calculation of farmers' incomes.

5.1.2 *Crop production*

Field margins also affect farmers' incomes by reducing the amount of space available for growing crops. The reduction in farmers' incomes related to crop production due to the introduction of field margins is calculated by multiplying the area of field margins (ha) by the average annual crop yield per ha in the Netherlands. To translate the reduction in crop yield to the reduction in crop-related income, the costs of crop production have been deducted from the crop yield value. Crop production costs include fertiliser, energy and maintenance costs for agricultural fields,. The estimates for the average crop yield, production costs and subsidies per ha of cultivated crop are based on data obtained from Wageningen University Research (WUR, 2022).

5.1.3 *Biological pest control*

Biological pest control occurs when an ecosystem element (e.g. field margins) prevents or reduces the effects of pests on crop production by providing shelter and alternative food sources for natural enemies of pest species (De Knegt, 2023). The effective pest control rate was measured as the relative visitation rate of crops by natural enemies of crop-feeding pests (0-100, where 100 marks the maximum visitation rate), on the basis of a model developed by De Knegt et al. (2023). The model assumes that arthropod natural enemies of aphid crop pests are present in semi-natural elements in the agricultural landscape and that they contribute to pest control in all arable crop farming, fruit and vegetable cultivation and open field horticulture. The model considers three groups of natural enemies with different dispersal abilities and forms of dependency on landscape elements (e.g. dependence on woody and herbaceous semi-natural habitats for nesting and floral sources for nectar/pollen). These natural enemy groups include ground-dwelling natural enemies (e.g. ground beetles and wolf spiders), flying natural enemies that depend on floral resources (e.g. predatory hoverflies and parasitoid wasps) and other flying natural enemies (e.g. ladybugs, flower bugs) (De Knegt et al., 2023).

The method by De Knegt et al. (2023) is useful for gaining insight into the influence semi-natural elements have on the effective control of pests in agricultural fields However, it does not provide information on the economic benefit of biological pest control to society. For instance, improved pest control can lead to fewer insecticides sprayed on fields to protect crops against pests. It can lead to a reduction of crop damage by pests and thus can have a positive effect on crop productivity. It can also lead to a reduction in the concentration of insecticides that end up in surface water via runoff, which has a positive effect on the water quality. In the Hoeksche Waard and other parts of the Netherlands, insecticides no longer need to be applied to fields once adjacent field margins have been formed. For this SCBA, a separate calculation was performed in order to take into account the avoided costs of insecticide use as a result of field margin formation (€). The cost of insecticides used for this calculation has been estimated at € 25 per ha of agricultural field per application (M. Klompe, personal communication, 3 October 2022; W. Dieleman, personal communication, 26 September 2022). On average, one application of insecticides is applied per year. Other benefits have been excluded due to insufficient resources (knowledge and time) required for their quantification and valuation, including the cost reduction associated with the application of insecticides (e.g. labour, machinery), the reduction in crop damage by pests and the effect of reducing insecticide use on water quality.

5.1.4 *Water quality regulation (nutrient reduction)*

Field margins affect the amount of nutrients that end up in surface water, which in turn affects the water quality. This effect was estimated by calculating the reduction in P and N emissions to ditches due to field margin formation, according to the method presented in STOWA (2010). In particular, the reduction in emissions from agricultural fields takes place through two main mechanisms: reduced transportation and reduced application. In the first mechanism, field margins lead to a reduction in the amount of P and N emissions reaching ditches due to the residence time and interception effects. In the residence time effect, N- and P-rich water from fields takes longer to reach ditches than the N- and P-poor water from the unfertilised field margins. This in turn has consequences for the short flow paths that originally have the highest concentrations (STOWA, 2010). In the interception effect, water flowing from fields at ground level, or via the topsoil to ditches, first flows through the field margin, allowing P and N to be removed from the water by plants and soil organisms. In a second mechanism, a reduction in the area of arable land due to the creation of field margins leads to a lower total emission of P and N due to a decrease in the area to be fertilised (equal to the total surface area of the field margins). It is expected that some farmers will apply the maximum fertilisation for the total area regardless of the presence of field margins, but this has not been included in the calculations since there is no estimate of the degree to which this occurs.

The environmental cost of emissions to ditches in each alternative was estimated by multiplying the total P and N emissions by their environmental prices. Environmental prices (*'milieuprijzen'*) are shadow prices that express the societal value of a pollutant in euros per kilogram (de Bruyn et al., 2023). Shadow prices are monetary estimates of the value of environmental substances, based on the costs that should be incurred to achieve environmental policy objectives (de Bruyn et al., 2023). Environmental prices reflect the welfare losses that would occur if an extra kilogram of a particular substance would end up in the environment (de Bruyn et al., 2023). Although there is no direct market price for nutrients and pollutants, their reduction improves environmental quality and in turn can have a positive effect on human health.

5.1.5 Biodiversity

The effect of field margin formation on the biodiversity in the Hoeksche Waard was estimated by calculating a Biodiversity Capacity (BC) index (Otte, 2022). The BC index measures the biodiversity in field margins compared to the biodiversity in agricultural fields. The calculation is based on a model developed by Rutgers et al. (2012) and uses measurement data in the Hoeksche Waard of soils in field margins and fields. Data used as input included data on the diversity of birds (Fokker, 2020), insects (van Rijn, 2018; Otte, 2022), soil organisms (Sechi et al., 2017) and aquatic invertebrates (Schuurmans, 2021). Soil biodiversity indicators were measured using data obtained by Rutgers et al. (2012) on the populations of earthworms, nematodes, microarthropods, enchytraeids and microbial communities (microbial biomass and functional microbial activity) as input. Several biodiversity parameters were quantified for each organism group, including the Shannon index, evenness, richness, abundance, biomass and density. Parameters were then combined into one overarching BC performance index. This was done by assigning weights to these parameters on the basis of expert judgement. The effect of field margin formation on biodiversity was not expressed in monetary values.

5.1.6 Natural attenuation capacity (NAC)

The ability of soils to provide the service of attenuating and detoxifying pollutants is called the natural attenuation capacity (NAC) of soils. The effect of field margin formation on the NAC of soils was estimated by calculating an NAC index, which measures the NAC performance of field margins relative to its performance in agricultural fields. This calculation follows the same kind of methodology applied to calculate the BC performance index. The calculation is based on a model developed by Rutgers et al. (2012) and uses data measured in the Hoeksche Waard as input. This includes data on soil characteristics (i.e. microbial biomass, functional microbial activity, soil pH, soil organic matter, potential N mineralisation, potential C mineralisation) (Sechi et al., 2017), aquatic invertebrates (Schuurmans, 2021) and plants (Bojacá et al., 2011; van Rijn, 2018). Parameters were combined into one overarching NAC performance index, by assigning weights to measured parameters on the basis of expert judgement.

5.1.7 *Climate change mitigation through carbon sequestration by soils*

Soils in field margins in the Hoeksche Waard have a higher carbon content than soils in adjacent fields (Sechi et al., 2017), contributing to climate change mitigation through carbon sequestration. To calculate the effect of the formation of field margins on the amount of carbon sequestered by soils in the Hoeksche Waard, the soil organic carbon content (SOC) in agricultural fields and field margins was calculated for each alternative. The SOC (tons CO_2) was calculated by performing calculations incorporating information about the total carbon content and the bulk density of soils in fields and field margins in the Hoeksche Waard, on the basis of data obtained from Sechi et al. (2017), as well as the molar mass of carbon. Although the bulk density measured in arable fields and field margins was approximately the same, the total carbon content differed (1.87 mol/kg in arable land and 2.91 mol/kg in field margins), and the difference was statistically significant. The monetary value of carbon sequestration was calculated by multiplying the annual carbon sequestration value in a given year (tons CO_2/year) by the price of carbon in that same year (€/ton CO_2 eq.), as defined by the Discount Rate Working Group (Werkgroep Discontovoet, 2020).

Information on the total carbon content and bulk density of soils in the Hoeksche Waard was obtained from Sechi et al. (2017), who measured various soil biotic and abiotic indicators within field margins and fields in the Hoeksche Waard. The values for the total carbon content in fields and field margins were significantly different. Including these values in the SOC calculations shows that the SOC content in field margins is 51-59% higher than in fields. The SOC content cannot increase indefinitely; therefore, this SCBA assumes that the SOC content estimated for field margins and fields using the data from Sechi et al. (2017), is the maximum achievable value. To account for the gradual increase in carbon sequestration in soils after their transformation from fields to field margins, the increase in carbon sequestration has been assumed to occur over a period of five years. Measurements by Sechi et al. (2017) were made in 2012, more than ten years after the introduction of the first field margins and less than five years after the first large-scale implementation of field margins in the Hoeksche Waard (M. Klompe, personal communication, 7 February 2023). It is unknown whether the soil carbon content will continue to increase in subsequent years, which would imply that the calculations performed in this SCBA underestimate the true carbon sequestration potential of field margins.

5.1.8 *Recreation and health*

This SCBA calculates the contribution of field margins to hiking in the Hoeksche Waard and the associated health benefits. Hiking through nature increases the experiential value, making people more involved in it (Antheunisse et al., 2008). Hiking trails connecting to and within the agricultural landscape can create hiking and recreational opportunities, enhance the landscape experience and generate benefits to human health. For instance, hiking can contribute to the leisure economy (e.g. by attracting tourism from nearby towns and cities). It can also lead to a reduction in the risk of stress, cardiovascular disease, cancer and obesity, and it is successful in the treatment of psychiatric patients. This in turn leads to lower healthcare costs and higher life expectancy (Bos et al., 2008). In the Netherlands, the demand for recreational hiking trails is highest in agricultural areas surrounded by large cities (Bos et al., 2008), such as the Hoeksche Waard, and is expected to increase in the future (Kroon & Kuhlman, 2004; Crooijmans, 2020).

To calculate the recreational benefits of field margins, this SCBA calculates the additional number of hikes that would be made in a situation with field margins compared to a situation without field margins, as well as the associated monetary benefits. The number of hikes in the No Field Margins alternative was calculated according to the method developed by Bos et al. (2008), who estimated the number of hikes in the Hoeksche Waard on the basis of the extent of hiking trails in the area. The additional number of hikes in the Field Margins alternative was calculated on the basis of expert judgement (i.e. scientists). In particular, it is assumed that in a situation without field margins, the number of hikes taken by locals and non-locals will be 10% lower than in a situation with field margins. The methodology developed by Bos et al. (2008) was also applied to calculate the monetary benefits of recreational hikes. These benefits were valued in terms of the contribution of hikes to the leisure economy in the Hoeksche Waard (e.g. expenditures on accommodation, food, recreation) and in terms of the benefits to human health. The health benefit of hiking was calculated as the difference in health care costs between active and inactive people, on the basis of the calculated number of hikes in each alternative.

6 Field margin costs

The additional costs associated with field margins were calculated as the remainder of the annual field margin costs less the annual costs associated with crop production during the assessment period (2025-2055). In this assessment, field margin costs include the costs associated with their creation, maintenance and management, which amount to approximately € 2604/ha/year (M. Klompe, personal communication, 3 October 2022). These costs are incurred by farmers, yet substantial contributions are made in the form of subsidies by the EU, the local water board, the Province of South Holland and regional partners (CCHW, 2017). The creation of field margins also leads to a reduction in land available for cultivation, which is in turn linked to a reduction in crop production and its associated costs. Crop production costs have been estimated at approximately € 1641/ha/year (WUR, 2022). Hence, the annual additional costs of field margins compared to the costs crop cultivation were estimated at approximately € 963 per ha of field margin per year.

7 Results

This chapter describes the results of this SCBA. First, an overview is given of the parameter values incorporated in calculations performed in the main analysis and in the uncertainty analysis. Subsequently, an overview is given of the direct costs and the direct and indirect benefits of developing field margins in the Hoeksche Waard for the 2025-2055 period. Finally, a stakeholder analysis is performed, as well as an uncertainty analysis that evaluates the effect of making alterations to some of the calculations by changing the values of key reference parameters included in calculations in the main analysis.

7.1 Overview of assumptions

A number of key assumptions have been made in the calculations performed for this SCBA. Table 7.1 summarises some of the assumptions made in the main analysis and the uncertainty analysis. In the uncertainty analysis, key parameter values included in calculations have been adjusted to determine the sensitivity of the results to changing these values.

Table 7.1 Key parameters incorporated in calculations in the main analysis and the uncertainty analysis, including the discount rate, evaluation period, CO_2 price (€/ton of CO_2-equivalent unit), SOC content in agricultural fields and field margins, the shadow prices of P and N, and a factor representing the relative number of hikes carried out in the No Field Margins alternative against the Field Margins alternative

Parameter	Main analysis	Uncertainty analysis		Source
		Scenario 1	Scenario 2	
Discount rate	2.25%	1.85%	2.65%	Werkgroep Discontovoet (2020)
Evaluation period	30 years	50 years	100 years	-
CO_2 price (2025)	68 €/ton (WLO-high)	17 €/ton (WLO-low)	254 €/ton (WLO-2 °C)	Werkgroep Discontovoet (2020)
CO_2 price (2035)	96 €/ton (WLO-high)	24 €/ton (WLO-low)	358 €/ton (WLO-2 °C)	Werkgroep Discontovoet (2020)
CO_2 price (2055)	190 €/ton (WLO-high)	48 €/ton (WLO-low)	713 €/ton (WLO-2 °C)	Werkgroep Discontovoet (2020)
SOC in field margins	2.91 mol/kg	2.52 mol/kg	3.31 mol/kg	Sechi et al. (2017)
SOC in agricultural fields	1.87 mol/kg	1.68 mol/kg	2.06 mol/kg	Sechi et al. (2017)
P shadow price	5.53 €/kg	2.56 €/kg	10.13 €/kg	CE-Delft (2023)
N shadow price	4.23 €/kg	2.27 €/kg	8.19 €/kg	CE-Delft (2023)

Parameter	Main analysis	Uncertainty analysis		Source
		Scenario 1	Scenario 2	
Factor (ratio) - Hikes in No Field Margins alternative / hikes in Field Margins alternative	0.900	0.925	0.875	Expert judgement

In the main analysis, costs and benefits are evaluated over a period of thirty years. To assess how cost and benefit flows would change over time, the uncertainty analysis additionally calculates the NPV over an evaluation period of fifty and a hundred years.

The discount rate values applied in the main analysis and uncertainty analysis have been determined by the Discount Rate Working Group (Werkgroep Discontovoet, 2020). Two scenarios were evaluated in the uncertainty analysis, one in which the discount rate used in the main analysis (2.25%) is replaced by a lower bound value (1.85%), and one in which it is replaced by an upper bound value (2.65%). The lower bound is linked to a higher welfare scenario and the upper bound is linked to a lower welfare scenario (Werkgroep Discontovoet, 2020).

The values for the CO_2 price in the main analysis and uncertainty analysis have also been determined by the Discount Rate Working Group (Werkgroep Discontovoet, 2020). The CO_2 price in the main analysis is related to a higher welfare scenario. In the uncertainty analysis, two scenarios are evaluated, one where the CO_2 price is linked to a future with lower welfare and one where it is linked to a more ambitious future where a 2 °C target is achieved. All CO_2 prices increase annually by 3.5% (Werkgroep Discontovoet, 2020).

The values of SOC content in crop fields and field margins used in the main analysis were obtained from Sechi et al. (2017). Values used in the uncertainty analysis were obtained from the same study and are based on the standard deviations of the SOC content values.

The price of P used in the main analysis and the uncertainty analysis has been determined in the Environmental Prices Handbook (CE-Delft, 2023). The price of P in the main analysis was determined on the basis of the damage cost of biodiversity loss due to P emissions. In the uncertainty analysis, two scenarios are evaluated, where the price of P is replaced by a lower bound value and an upper bound value. The lower bound value has been calculated on the basis of a pollution levy per kg P emission to water. The upper bound value has been calculated on the basis of a revealed preference study that defines a price for P emissions to soil (IEEP, 2021). This price for P was then translated into the amount of P that is leached into fresh water, on the basis of the ReCiPe method (CE-Delft, 2023).

The recreational benefits of implementing field margins were calculated by including in the calculations a factor representing the relative number of hikes performed in the No Field Margins alternative against the Field

Margins alternative. This factor was assigned a value of 0.900 by experts (i.e. scientists) for the main analysis, and values of 0.875 and 0.925 for the uncertainty analysis. In other words, the main analysis assumes a 10% reduction in the number of hikes carried out in the No Field Margins alternative relative to the Field Margins alternative. In the uncertainty analysis, this percentage is adjusted to a lower bound (8.75%) and an upper bound (9.25%).

7.2 Overview of costs and benefits

Table 7.2 provides an overview of the costs and benefits relating to field margins in the Hoeksche Waard, based on their current distribution. On the basis of these calculations, the NPV (benefits – costs) was slightly positive and was estimated at € 94 thousand. This value only amounts to approximately € 0.6 thousand per ha of field margins. This suggests that over the 2025-2055 period, the societal benefits of field margins in the Hoeksche Waard, based on their current distribution, will outweigh the costs.

The average benefit per hectare field margin per year amounts to € 684. Recreation, water quality regulation and avoided pesticide use constitute the major benefits. The loss of crop production amounts to € -429 per hectare field margin per year. The additional costs of field margins are about € 665 per hectare field margin per year. The NPV is slightly positive and has a value of € 19 per hectare field margin per year.

The following subsections describe the main results for the different cost and benefit categories calculated for this SCBA.

Table 7.2 Overview of costs and benefits in a situation with field margins (FM) compared to a situation without field margins. The second column shows the final benefit, the third column the average benefit per hectare field margin and the last column the average annual benefit per hectare field margin.

Benefit indicator	**Final benefit [k€]**	**Avg. benefit per ha FM [k€]**	**Avg. benefit per ha FM per year [€]**
Biological pest control	**1090**	**6.6**	**222**
Avoided insecticide use	1090	6.6	222
Pollination	**306**	**1.9**	**62**
Avoided loss in income (excl. subsidies) due to pollination	306	1.9	62
Crop production	**-2109**	**-12.9**	**-429**
Reduction in farmers' incomes (excl. subsidies) due to field margins	-2109	-12.9	-429
Water quality regulation	**1168**	**7.1**	**237**
Avoided P emission (tons)	31	0.2	6
Avoided N emission (tons)	369	2.2	75
Avoided P emission costs	114	0.7	23
Avoided N emission costs	1053	6.4	214
Carbon sequestration by soils	**415**	**2.5**	**84**
C-sequestration by soils	6000	36	1
Monetary value of C-sequestration by soils	415	2.5	84
Natural attenuation capacity (dimensionless)	**PM 1.8**	-	-
Biodiversity capacity (dimensionless)	**PM 1.3**	-	-
Recreation and health benefits	**2495**	**15.2**	**507**
Additional hikes by recreationists due to presence of field margins (hikes)	20 000	122	4
Additional expenditures made by daytime recreationists	544	3.3	111
Additional expenditures made by overnight recreationists	301	1.8	61
Avoided health costs due to increased physical activity	1.649	10.0	335
Total benefits	**3363**	**20.5**	**684**
Cost indicator	**Final cost**	**Avg. cost per ha FM**	**Avg. cost per ha FM per year**
Additional costs of field margins compared to crop production	3269	19.9	665
Total costs	**3269**	**19.9**	**665**
Net present value (NPV)	**94**	**0.6**	**19**

7.2.1 *Recreation, health and other cultural services*

The largest contribution to the positive NPV is attributed to the recreation and health benefits, which amount to € 2.5 million over a period of 30 years. This calculation was based on the assumption that the number of hikes carried out by local and non-local recreationists would decrease by 10% in the absence of field margins in the Hoeksche Waard. Field margins have a high recreational value in the area. Semi-structured interviews with local residents (farmers, recreationists) revealed that field margins are intrinsically valued in the area because of their contribution to the aesthetic character of the landscape (F. van Zijderveld, personal communication, 9 April 2018). Field margin formation is in line with local objectives aiming to make the Hoeksche Waard an attractive destination for external tourism, not just for day trips (e.g. hiking and cycling trips), but also for overnight stays (F. van Zijderveld, personal communication, 9 April 2018). This includes encouraging the development of activities and facilities that appeal to tourists (e.g. excursions to flower field margins, overnight accommodation).

7.2.2 *Biological pest control*

The creation of field margins in the Hoeksche Waard also seems to offer promising benefits with regard to pest control. Figures 7.1 and 7.2 illustrate the visitation rate of crops by natural enemies of crop-feeding pests (0-100, where 100 marks the maximum visitation rate) in the Hoeksche Waard in the No Field Margins and Field Margins alternatives respectively. The visitation rate in these maps captures the contribution made by semi-natural landscape features, including field margins, to the abundance of natural enemies. It is assumed that these arthropod natural enemies contribute to pest control in all crops. Areas are marked in shades between blue and light yellow, indicating a relatively lower or higher contribution to the visitation rate, respectively. The maps reveal that the introduction of field margins (Figure 7.1) would lead to an increase in the effectivity of pest control in various areas compared to a situation without field margins (Figure 7.2).

The improvement in pest control implies that fewer insecticides are required in arable fields adjacent to field margins (herbicides and fungicides are still required). The reduction in costs of insecticide use is estimated at approximately € 1.1 million over a 30-year period. A follow-up study should consider other financial benefits that result from improved biological pest control, such as the reduction in crop damage and what this means for farmers' incomes, as well as the cost reduction normally associated with water quality degradation due to pesticides that end up in the surface water and groundwater (for instance through runoff, leaching and drift).

7.2.3 *Water quality*

Field margins also act as buffers between fertilised fields and surface water. As a result, the formation of field margins leads to a reduction in the costs normally associated with water quality degradation due to nutrients entering the surface water (e.g. P and N). The avoided costs associated with the deterioration of water quality due to the emission of nutrients P and N to the surface water has been estimated at approximately € 1.2 million.

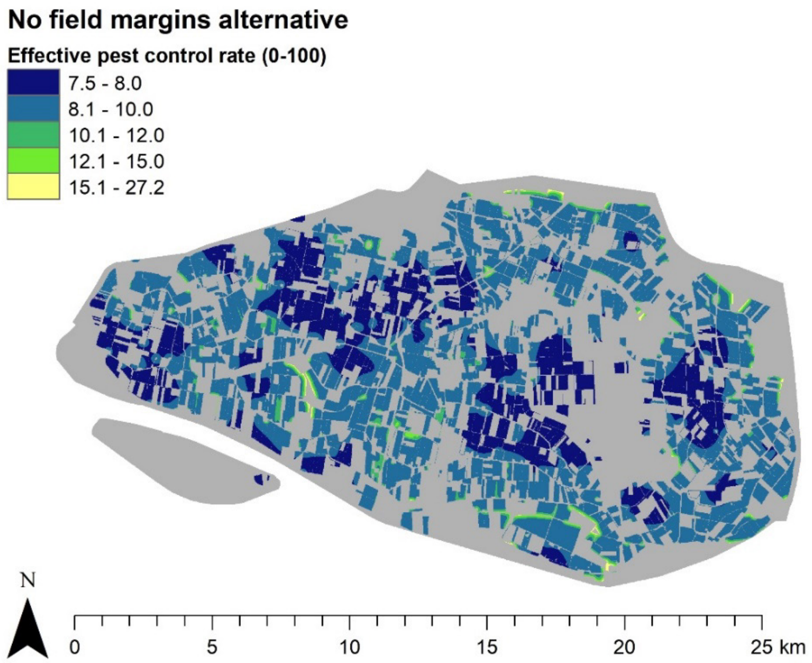

Figure 7.1 Relative visitation rate of crops by natural enemies of crop-feeding pests (0-100, where 100 marks the maximum visitation rate) in the Hoeksche Waard in the No Field Margins alternative.

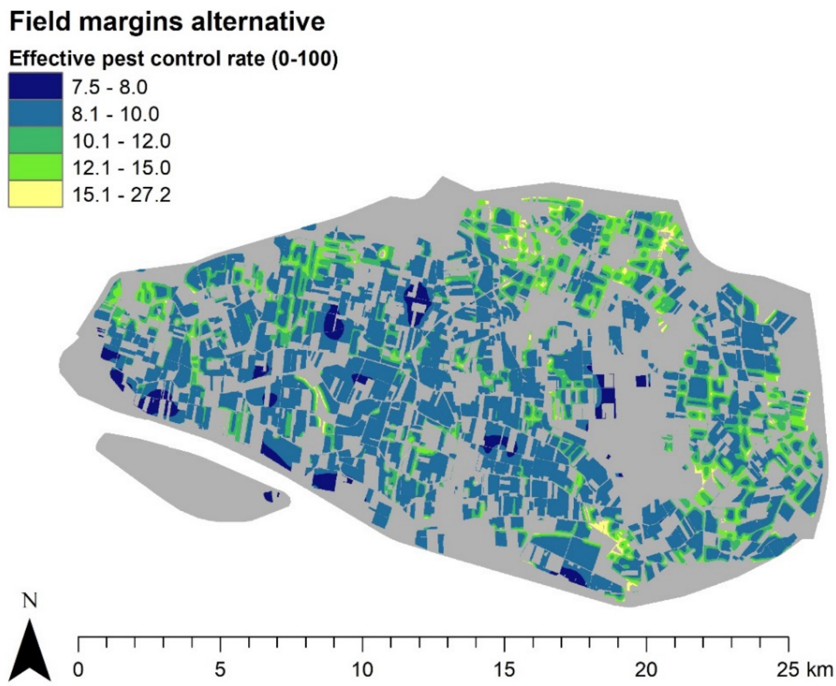

Figure 7.2 Relative visitation rate of crops by natural enemies of crop-feeding pests (0-100, where 100 marks the maximum visitation rate) in the Hoeksche Waard in the Field Margins alternative.

7.2.4 *Pollination benefits*

The creation of field margins leads to an increase in productivity in arable fields in the vicinity, where pollinator-dependent crops are sown. The higher productivity is attributed to a higher effective pollination rate of pollinator-dependent crops. Figure 7.3 illustrates the effective pollination rate of pollinator-dependent crops (%) in the Hoeksche Waard in the No Field Margins and Field Margins alternatives respectively. The effective pollination rate in these maps reflects the contribution of semi-natural landscape features, including field margins, to pollination. Areas are marked in shades between blue and light yellow, indicating a relatively lower or higher contribution to pollination, respectively. The map reveals that the introduction of field margins would increase the effective pollination rate in various areas compared to a situation without field margins. Note that this improvement is only experienced in fields where pollinator-dependent crops are sown (i.e. mainly orchards), accounting for 8% of cultivated land in the Field Margins alternative and for 10% in the No Field Margins alternative. Therefore, not all fields experience improved pollination from being in the vicinity of semi-natural landscape features. The benefits of the field margins mainly end up with the orchard farmers, while the arable farmers bear the costs.

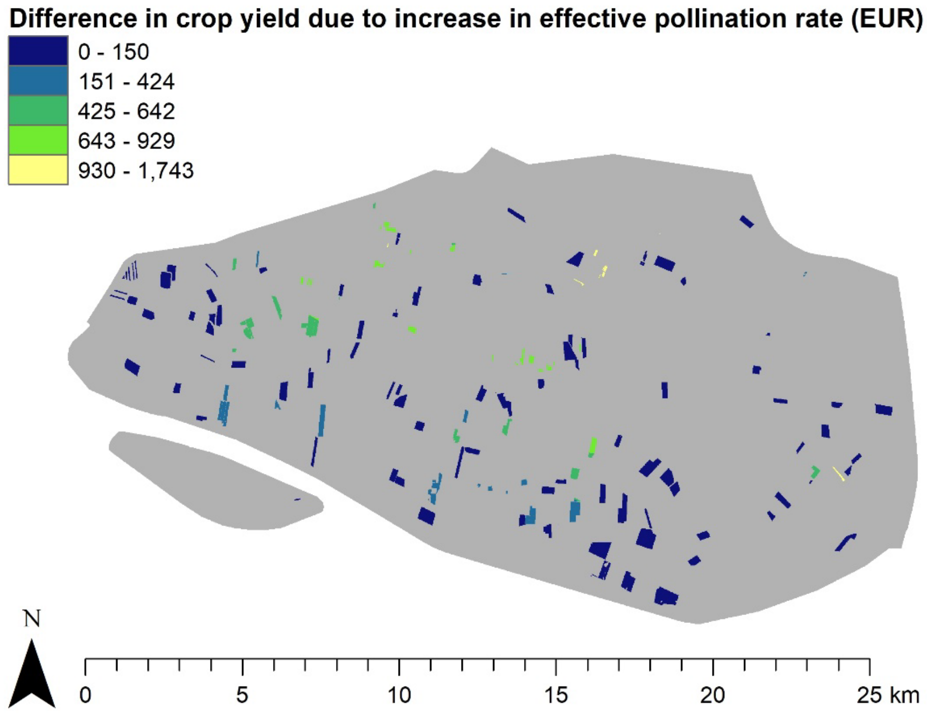

Figure 7.3 Effective pollination rate (%) of pollinator-dependent crops in the Hoeksche Waard in the No Field Margins alternative.

7.2.5 *Crop production benefits*

The creation of field margins leads to a reduction in the land available for growing crops. This, in turn, leads to a reduction in crop yield and thereby in farmers' income (i.e. yield minus production costs minus subsidies). This reduction in farmers' income was valued at € 2.1 million over a 30-year period.

In the calculation of the reduction in crop production and farmers income, we assume that the entire field margin can be used for growing crops. This does not always have to be the case. If so, the loss of crop production and farmers' income will be less.

7.2.6 *Field margin costs*

The reduction in the area available for crop production results in a reduction in crop production costs. Instead, these costs are replaced by costs for the creation, maintenance and management of field margins. In 2019, the costs of crop production in the Netherlands amounted to approximately 1641 €/ha/year. The costs for the creation, maintenance and management of field margins currently amount to approximately 2604 €/ha/year. On the basis of these estimates, the costs related to field margins substantially outweigh the costs related to crop production in the Hoeksche Waard over a 30-year period by approximately € 3.3 million.

7.2.7 *Biodiversity and the natural attenuation capacity of the soil and water system*

It is important to point out that field margins also offer benefits in terms of improved biodiversity. Given the complexity of quantifying the biodiversity in monetary terms, this SCBA has calculated an index for biodiversity capacity (BC). The BC index represents the BC observed in field margins divided by the BC observed in the agricultural fields. The BC in fields and field margins was calculated on the basis of observations that were based on datasets, which were in turn based on samples obtained on field birds, aquatic invertebrates, soil organisms and above-ground insects (see Section 3.3.4 and Appendix 7). A BC index greater than 1 means that the BC in the field margin is higher than in the field. A BC index lower than 1 means that the BC in the field margin is lower than in the field. A BC index equal to 1 means that the BC in the field margin is equal to the BC in the field.

The BC index calculated in this study has a value of 1.3, which suggests that the BC in field margins is 1.3 times higher than in agricultural fields, all target groups combined. Indirectly, the effect of field margin formation on biodiversity has also been included in other aspects of this SCBA. For instance, this SCBA shows that field margin formation has consequences for the biodiversity (i.e. abundance and diversity) of insects that pollinate pollinator-dependent crops, as well as for the biodiversity of natural enemies that prey on pests.

The natural attenuation capacity (NAC) of soils is the ability of soils to provide the service of attenuating and detoxifying pollutants. The results also show that the NAC of soils, a process that is highly dependent on soil (micro)organisms, is 1.8 times higher in field margins than in fields.

7.2.8 *Climate change mitigation through carbon sequestration by soils*

The benefit from field margin formation on carbon sequestration is not as large as other benefits in this SCBA, but nevertheless entails a considerable monetary contribution to society (€ 0.4 million in 30 years). The SCBA assumes that soil carbon sequestration is higher in field margins than in agricultural fields. However, unlike other benefit items, the benefits of enhanced carbon sequestration are not experienced over the thirty-year period analysed in this SCBA. This assumption is based on the fact that the soil carbon content will increase in the first few years after field margin formation but will stagnate once the maximum potential soil carbon sequestration for field margins has been reached.

7.3 Stakeholder analysis

The costs and benefits of creating and managing field margins are not equally borne by society. Instead, costs and effects/benefits are borne disproportionately by different stakeholder groups. In this context, stakeholder groups are groups of individuals in society who (1) are involved in the implementation of measures that impact the delivery of ecosystem services or (2) who are affected by changes in the delivery of ecosystem services as a result of the implementation of these measures.

Table 7.3 provides an overview of the distribution of costs and effects/benefits of field margin implementation in the Hoeksche Waard, across various stakeholder groups. The identified groups include local farmers, various administrative bodies at different levels (i.e. EU, Dutch government, Province of South Holland, municipality, water board) and society as a whole. This table has been drawn up using information from the literature review, interviews with stakeholders and the SCBA results. The table shows the stakeholder groups that are directly affected by the introduction of field margins (beneficiaries and cost bearers). Below, we will elaborate on the reasoning behind this distribution of cost and benefit categories across stakeholder groups. In addition, the stakeholder groups that are indirectly affected by the introduction of field margins are qualitatively described.

Table 7.3 Beneficiaries and cost bearers (stakeholder groups) of field margin implementation. Column 1: Benefit or cost item indicator; column 2: Benefit or cost over a thirty-year period expressed in million €; column 3: Stakeholder group(s) affected by change in the quantity/value benefit or cost item.

Benefit item	**Benefits**	**Primary beneficiary**
Crop production	€ -2.1 m	Farmers
Biological Pest Control	€ 1.1 m	Farmers
Pollination	€ 0.3 m	Farmers
Water quality regulation (nutrient reduction only)	€ 1.2 m	Water board
Carbon sequestration by soils	€ 0.4 m	Society
Natural attenuation capacity (NAC)	+	Water board
Biodiversity capacity (BC)	+	Society
Recreation and health benefits	€ 2.5 m	Society
Cost item	**Costs**	**Cost bearers**
Field margin additional costs	€ 3.3 m	Farmers

Field margins have a direct impact on farmers' crop-related income by reducing the amount of space available for growing crops and thus the crop production. This benefit is negative, with a substantial value of € -2.1 million. This value refers to the reduction in farmers' incomes, excluding subsidies from the EU and other entities.

The distribution of costs and benefits among farmer groups also varies. The costs are borne by arable farmers who create and maintain field margins, who make up about 25% of all arable farmers. A large part of these costs is borne by the EU and other entities that provide subsidies to farmers for the construction and management of field margins. The benefits of field margins are mainly shared by (orchard) farmers, who grow pollination-dependent crops (e.g. fruit, pumpkins).

Field margins influence the effectiveness of biological pest control by enhancing the biodiversity and abundance of natural enemies of pests that cause crop damage. Farmers directly benefit from biological pest control since it leads to a reduction in the costs of insecticide use (€ 1.1 million). The reduction in insecticide use also has indirect consequences for society. It results in an improvement of the water quality, as fewer insecticides end up in the surface water and groundwater. This represents an indirect benefit for the water boards, which are responsible for water quality management. The reduced insecticide use also contributes indirectly to biodiversity maintenance in the agricultural landscape, which supports other essential ecological functions, such as pollination, the NAC of the water and soil systems and the overall resilience of ecosystems. In general, the improvement of water quality and biodiversity benefits society as a whole, as it is the Dutch citizens and society who ultimately faces the consequences of the deteriorating environmental quality and finance the water boards that maintain water quality.

Field margins improve pollinator biodiversity in the agricultural landscape, which benefits crops whose yields depend on pollination. The estimated benefit of this ecosystem service is € 0.3 million. These benefits are shared by farmers growing pollination-dependent crops, such as orchard farmers, while the costs for the creation and maintenance of the field margins are borne by the arable farmers.

Field margins also have a positive effect on local water quality by reducing the amount of insecticides and nutrients that end up in the surface water. While the effect of insecticide reduction on water quality and drinking water production was not quantified, the effect of nutrient reduction of P & N was calculated at € 1.2 million. As mentioned above, improvements in the water quality directly benefit the water boards, which are responsible for maintaining the water quality. Society as a whole indirectly benefits from a better environmental quality, but also from a reduction in the costs borne by water boards, which are financed by the taxpayer.

Field margins also have a substantial effect on recreation and health, valued at € 2.5 million. However, the estimated recreational and health benefits calculated rely strongly on the relative amount of hikes related to the creation of field margins, as will be explained in further detail in the uncertainty analysis (Section 7.4).

In general, society as whole benefits from field margins. Field margins promote biodiversity in the agricultural landscape, which in turn supports key ecological functions essential for healthy environmental quality and farmer productivity (e.g. NAC of soils, water quality, pest control, pollination, etc.). Field margins store more carbon than agricultural fields, which contributes to combating climate change, a critical issue of our time. Their aesthetic component not only benefits the recreationists who experience the landscape of the Hoeksche Waard (e.g. cyclists and hikers), but also the farmers.

Although field margins offer numerous advantages, they also entail considerable costs. The costs for the construction, maintenance and management of field margins are higher than the costs for the production of crops, amounting to € 3.3 million over a period of 30 years. Field margin costs are estimated at 2600 €/ha/year) and are directly borne by arable farmers, who are responsible for creating, maintaining and managing field margins. The creation and maintenance of field margins are also subsidised, with subsidies ranging from 700 to 2400 €/ha/year. In the Hoeksche Waard, these subsidies are borne by the Dutch government (~17%), the water boards (~17%), regional partners (~17%) and the EU (~50%).

7.4 Uncertainty analysis

The quantification and valuation of the costs and effects/benefits of measures are uncertain. To assess uncertainty associated with the parameter values included in calculations, an uncertainty analysis has been performed. In particular, key parameter values used in calculations in this SCBA were replaced by the values presented in Table 7.1, to determine how this would affect the NPV. The parameter values that were adjusted for this uncertainty analysis include the assessment period, the discount rate, the SOC content in field margins and agricultural fields, the market price of CO_2, the shadow prices of P and N and a factor used for the calculation of the recreational and health benefits of field margins (i.e. relative number of hikes carried out in the No Field Margins alternative against the Field Margins alternative). The parameter values on SOC content and CO_2 price both relate to the calculation of the climate change mitigation benefit.

Table 7.4 and Figure 7.4 provide an overview of the scenarios evaluated in this uncertainty analysis. For each scenario, information is provided on the NPV and the annual contribution to the NPV per ha field margin. The lowest values per column are indicated in red and the highest values are indicated in green. The reference scenario (0) comprises the scenario assessed in the main analysis of this SCBA. It serves as a reference for comparing the NPV in the main analysis with the NPV in each uncertainty scenario.

Table 7.4 Net Present Value (NPV) in the reference scenario (Scenario 0) and uncertainty scenarios (Scenarios 1 to 12). Column 2 displays the NPV in € million, Column 3 shows the annual contribution to the NPV per hectare field margin per year.

Scenario	NPV	Ann. Contr. to NPV /ha field margin
0. Main analysis	0.09	**19**
1. Discount rate: 1.85%	0.13	26
2. Discount rate: 2.65%	0.13	26
3. Evaluation period: 50 years	-0.03	-3
4. Evaluation period: 100 years	-0.08	-5
5. SOC content: lower bound	0.01	3
6. SOC content: upper bound	0.18	36
7. WLO-scenario: low	-0.22	-44
8. WLO-scenario: 2 °C	1.23	251
9. P & N: lower bound	-0.46	-93
10. P & N: upper bound	1.17	239
11. Hike Ratio = 0.875	0.72	146
12. Hike Ratio = 0.925	-0.53	-108

The results in Table 7.4 suggest that adjusting key parameter values in the cost-benefit calculations can lead to fluctuations in the NPV, ranging from a decrease of € 0.5 million to an increase of € 1.2 million. The largest increase is related to the carbon price applied in the 2 °C WLO uncertainty scenario. The lowest is related to a relative decrease in the number of hikes in the Field Margin alternative compared to the No Field Margin alternative. Overall, the NPV is positive in seven out of twelve uncertainty scenarios positive.

Figure 7.4 illustrates the uncertainties in the calculation of the NPV. The NPV is expressed on the x-axis and the y-axis expresses the annual average NPV per hectare of field margin. The graph illustrates the major uncertainties in the NPV given uncertainties in reference values adopted in calculation, including the hike ratio, the determined CO_2 prices and discount rate for different welfare scenarios, the evaluation period of the SCBA, the SOC content in field margins compared to fields, and the emission of nitrogen and phosphorus to the surface water.

Sections 7.4.1 to 7.4.6 discuss in more detail the results calculated for each uncertainty scenario on the basis of reference value adjustments. Section 7.4.7 qualitatively analyses uncertainties that have not been quantified in this uncertainty analysis.

Reference = Main analysis; 'P&N: low' = lower bound values for prices of P & N; 'P&N: high' = upper bound values for prices of P & N; 'WLO: low' = lower bound value for CO_2 price (low emissions reduction); 'WLO: 2°C' = lower bound value for CO_2 price (2 °C emissions target achieved); 'SOC: low' = SOC content lower bound values ; 'SOC: high' = SOC content upper bound values; 'DR: 1.85%' = 1.85% discount rate; 'DR: 2.65%' = 2.65% discount rate; '50 yrs.' = Evaluation period of 50 years; '100 yrs.' = Evaluation period of 100 years; 'Recr. Low' = 0.875; 'Recr. High' = 0.925.

Figure 7.4 Annual average NPV and NPV for all scenarios.

7.4.1 *Evaluation period*

The costs and benefits of implementing a particular measure or set of measures can vary in the long term due to a variety of factors. Factors included in this SCBA that can influence the value of costs and benefits over time include the discount rate, the prices used in calculations (e.g. the prices of CO_2, N and P) and the assessment period. In this SCBA, all but one of the evaluated costs and benefits were quantified and valued for the entire assessment period. The benefits of carbon sequestration were only quantified over a five-year period, when SOC levels are assumed to rise to the maximum achievable value in field margins.

Table 7.5 summarises the differences in the values of costs and benefits that would result from adjusting the assessment period from 30 to 50 years. This implies that field margin costs and benefits are calculated over a fifty-year period rather than a thirty-year period.

Table 7.6 summarises the differences in the values of costs and benefits that would result from adjusting the evaluation period from thirty to a hundred years. This implies that field margin costs and benefits are calculated throughout a 100-year period rather than a 30-year period.

Table 7.5 Difference in costs and effects/benefits due to the use of an evaluation period of fifty rather than thirty years. Values represent differences from values in reference scenario. Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Biological pest control	**413**	**2.52**
Avoided insecticide use	413	2.52
Pollination	**116**	**0.71**
Avoided loss in income due pollination	116	0.71
Crop production	**-798**	**-4.86**
Reduction farmers' incomes	-798	-4.86
Water quality regulation	**441**	**2.69**
Avoided P emission (tons)	20	0.12
Avoided N emission (tons)	246	1.50
Avoided P emission	43	0.26
Avoided N emission	398	2.43
Recreation and health benefits	**943**	**5.75**
Additional walks (thousand hikes)	13	0.08
Expenditures daytime recreationists	206	1.25
Expenditures overnight recreationists	114	0.69
Avoided health costs	624	3.80
Difference in total benefits	**1115**	**6.80**
Cost indicator	**Final cost**	**Avg. cost / ha FM**
Additional costs of field margins	1237	7.54
Difference in total costs	**1237**	**7.54**
Difference in net present value	**-122**	**-0.74**

Table 7.6 Difference in costs and effects/benefits due to the use of an evaluation period of a hundred rather than thirty years. Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Biological pest control	**954**	**5.81**
Avoided insecticide use	954	5.81
Pollination	**254**	**1.55**
Avoided loss in income due pollination	254	1.55
Crop production	**-1753**	**-10.69**
Reduction farmers' incomes	-1753	-10.69
Water quality regulation	**1019**	**6.21**
Avoided P emission (tons)	71	0.44
Avoided N emission (tons)	860	5.24
Avoided P emission	100	0.61
Avoided N emission	919	5.60
Recreation and health benefits	**2073**	**12.64**
Additional walks (thousand hikes)	-5	-0.03
Expenditures daytime recreationists	452	2.76
Expenditures overnight recreationists	250	1.52
Avoided health costs	1371	8.36
Difference in total benefits	**2546**	**15.53**
Cost indicator	**Final cost**	**Avg. cost / ha FM**
Additional costs of field margins	2718	16.57
Difference in total costs	**2718**	**16.57**
Difference in net present value	**-172**	**-1.05**

Adjusting the evaluation period to fifty years would lead to a decrease in the NPV of approximately € 122 thousand, while adjusting the evaluation period to a hundred years would lead to a decrease in the NPV of approximately € 172 thousand. In both scenarios, the values for all benefit indicators quantified would increase, except for the indicator calculated for the ecosystem service 'crop production'. The substantial reduction in the NPV occurs due to the application of the discount rate, which puts future values below the current values. In this case, the negative crop production benefits and the increase in costs associated with field margins seem to outweigh the increase in other benefits associated with field margins.

7.4.2 *Discount rate*

Future prosperity may vary due to changes in wealth. These changes may affect the discount rate. In principle, higher prosperity in the future translates into a higher discount rate and lower prosperity into a lower discount rate, due to the welfare effect (Werkgroep Discontovoet, 2020). In the main analysis of this SCBA, a discount rate of 2.25% was applied. For this uncertainty analysis, the discount rate was adjusted to a value of 1.85% and to a value of 2.65%. All applied discount rates have been established by the Discount Rate Working Group (Werkgroep Discontovoet, 2020), which determines the discount rates to be used in SCBAs in the Netherlands.

Table 7.7 Difference in costs and effects/benefits due to the use of lower bound discount rate of 1.85% rather than 2.25%. Values represent differences from values in base alternative. Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Biological pest control	**75**	**0.46**
Avoided insecticide use	75	0.46
Pollination	**20**	**0.12**
Avoided loss in income due pollination	20	0.12
Crop production	**-136**	**-0.83**
Reduction farmers' incomes	-136	-0.83
Water quality regulation	**111**	**0.67**
Avoided P emission (tons)	-	-
Avoided N emission (tons)	-	-
Avoided P emission	11	0.07
Avoided N emission	100	0.61
Carbon sequestration by soils	5	0.03
C-sequestration by soils (tons)	0	0.00
C-sequestration by soils	5	0.03
Recreation and health benefits	**172**	**1.05**
Additional walks (thousand hikes)	0	0.00
Expenditures daytime recreationists	37	0.23
Expenditures overnight recreationists	21	0.13
Avoided health costs	114	0.69
Difference in total benefits	**246**	**1.50**
Cost indicator	**Final cost**	**Avg. cost/ha FM**
Additional costs of field margins	211	1.29
Difference in total costs	**211**	**1.29**
Difference in net present value	**34**	**0.21**

Table 7.7 summarises the differences in the values of costs and benefits that would result from applying a discount rate of 1.85% in all calculations. Table 7.8 summarises the differences in the values of costs and benefits that would result from applying a discount rate of 2.65% in all calculations. A discount rate of 1.85% would lead to an increase in the NPV of approximately € 34 thousand. Interestingly, a discount rate of 2.65% would also lead to an increase in the NPV of approximately € 34 thousand.

In general, a lower discount rate suggests that future costs and benefits have a higher value, while a higher discount rate suggests that future costs and benefits have a lower value . Because the discount rate is compounded on an annual basis, the cost and benefit indicators with the highest (lowest) values in the main analysis also experience the largest increases (decreases) due to changes in the discount rate.

Table 7.8 Difference in costs and effects/benefits due to the use of lower bound discount rate of 2.65% rather than 2.25%. Values represent differences from values in base alternative. Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Biological pest control	**-69**	**-0.42**
Avoided insecticide use	-69	-0.42
Pollination	**-18**	**-0.11**
Avoided loss in income due pollination	-18	-0.11
Crop production	**125**	**0.76**
Reduction farmers' incomes	125	0.76
Water quality regulation	**-36**	**-0.22**
Avoided P emission (tons)	-	-
Avoided N emission (tons)	-	-
Avoided P emission	-4	-0.02
Avoided N emission	-33	-0.20
Carbon sequestration by soils	-5	-0.03
C-sequestration by soils (tons)	0	0.00
C-sequestration by soils	-5	-0.03
Recreation and health benefits	**-157**	**-0.96**
Additional walks (thousand hikes)	0	0.00
Expenditures daytime recreationists	-34	-0.21
Expenditures overnight recreationists	-19	-0.12
Avoided health costs	-104	-0.63
Difference in total benefits	**-160**	**-0.98**
Cost indicator	**Final cost**	**Avg. cost/ha FM**
Additional costs of field margins	-194	-1.19
Difference in total costs	**-194**	**-1.19**
Difference in net present value	**34**	**0.21**

7.4.3 *Soil organic carbon (SOC)*

In the main analysis of this SCBA, changes in the ecosystem service 'climate change mitigation through carbon sequestration by soils' were measured by calculating the SOC content (tons of CO_2) for each alternative. Calculations were based on information on the total carbon content and bulk density of soils in agricultural fields and field margins in the Hoeksche Waard, using data obtained from Sechi et al. (2017).

For this uncertainty analysis, the carbon content values used in the main analysis have been adjusted on the basis of the lower and upper bounds calculated by Sechi et al. (2017). For the lower bound scenario, a carbon content of 2.59 mol/kg was used for the calculation of the SOC in margin's soil and a carbon content of 1.71 mol/kg was used for the calculation of the SOC in field soil. For the upper bound scenario, a carbon content of 3.24 mol/kg was used for the calculation of the SOC in soils in margins and a carbon content of 2.02 mol/kg was used for the calculation of the SOC in fields.

Table 7.9 summarises the differences in the values of benefits that would result from adjusting the carbon content to the lower bound values. Table 7.10 summarises the differences in the values of benefits that would result from adjusting the carbon content to the upper bound values. The values in this analysis do not change, except for the carbon sequestration in each alternative.

Adjusting the carbon content to the lower bound values would lead to a decrease in the carbon sequestration estimate of approximately 1000 tons over a 30-year period, which would in turn lead to a decrease in the NPV estimate of approximately € 81 thousand or € -500 per ha field margin. Adjusting the carbon content to the upper bound values would lead to an increase in the carbon sequestration estimate of approximately 1000 tons over the same period, which would lead to an increase in the NPV estimate of approximately € 81 thousand or € 500 per ha field margin.

Table 7.9 Difference in climate change mitigation benefits and the NPV relative to the reference scenario (main analysis), due to the use of a lower SOC content value. All values represent differences from values used in main analysis. Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Carbon sequestration by soils	-81	-0.50
C-sequestration by soils (tons)	-1	-0.01
C-sequestration by soils	-81	-0.50
Difference in total benefits	**-81**	**-0.50**
Difference in net present value	**-81**	**-0.50**

Table 7.10 Difference in climate change mitigation benefits and the NPV relative to the reference scenario (main analysis), due to the use of a higher SOC content value. All values represent differences from values used in main analysis. Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Carbon sequestration by soils	81	0.50
C-sequestration by soils (tons)	1	0.01
C-sequestration by soils	81	0.50
Difference in total benefits	**81**	**0.50**
Difference in net present value	**81**	**0.50**

7.4.4 *CO_2 price*

Changes in the monetary value of the ecosystem service 'climate change mitigation through carbon sequestration by soils' were measured by multiplying the calculated change in the SOC content (tons of CO_2) per alternative in a given year by the carbon price in that year (€/ton CO_2). The monetary value of carbon sequestration by soils in agricultural fields and field margins in a given year was then recalculated for the base year (2025). The price of CO_2 is defined in the WLO climate scenarios for a 'low WLO scenario' that assumes a lower CO_2 emission reduction by 2050, a 'high WLO scenario' that assumes a higher CO_2 reduction by 2050 and a '2 °C WLO scenario' (i.e. the most ambitious scenario) that assumes that 2 °C climate target is achieved by 2050 (Werkgroep Discontovoet, 2020). The calculation of the monetary benefits of carbon sequestration in the main analysis was based on the CO_2 price for the high WLO scenario (€ 48/ton CO_2 in 2015, with an annual increase of 3.5%). This uncertainty analysis evaluates two additional scenarios, one taking into account the CO_2 price for the low WLO scenario (€ 12/ton CO_2 in 2015, with an annual increase of 3.5%) and one taking into account the CO_2 price for the 2 °C WLO scenario (€ 60/ton CO_2 in 2015, with an annual increase of 3.5%).

Table 7.11 Differences in climate change mitigation benefits and the NPV relative to the reference scenario (main analysis), due to the use of CO_2 prices according the low WLO scenario. All values except last row represent differences from values used in main analysis. Values in k€ unless stated otherwise.

Benefit indicator	Final benefit	Avg. benefit/ha FM
Carbon sequestration by soils	-311	-1.90
C-sequestration by soils (tons)	0	0.00
C-sequestration by soils	-311	-1.90
Difference in total benefits	-311	-1.90
Difference in net present value	-311	-1.90

Table 7.12 Differences in costs and effects/benefits due to the use of CO_2 prices according to the 2 °C WLO scenario. Values represent differences from values in base alternative (except last row). Values in k€ unless stated otherwise.

Benefit indicator	Final benefit	Avg. benefit/ha FM
Carbon sequestration by soils	1141	6.96
C-sequestration by soils (tons)	0	0.00
C-sequestration by soils	1141	6.96
Difference in total benefits	1141	6.96
Difference in net present value	1141	6.96

Table 7.11 summarises the differences in the benefits that would result from adjusting the CO_2 price to that of the low WLO scenario. Table 7.12 summarises the differences in the benefits that would result from adjusting the CO_2 price to that of the high WLO scenario. Adjusting the CO_2 price to that of the low WLO scenario would lead to a decrease in the NPV of approximately € 311 thousand, while adjusting the CO_2 price to that of the 2 °C WLO scenario would lead to an increase in the NPV of approximately € 1.141 thousand. This is a substantial variation, considering that the actual carbon sequestration remains unchanged in these two uncertainty scenarios. This bandwidth can be explained by the fact that the prices of CO_2 increase exponentially by 3.5% on an annual basis. A reduction in the CO_2 price from € 48 / ton to € 12 / ton will therefore have a considerable impact on the NPV, but an increase in the

CO_2 price from € 48 / ton to € 60 / ton will have an even greater impact on the NPV, despite the fact that the initial change in the CO_2 price is higher for the low WLO scenario compared to the 2 °C WLO scenario (a € 36 / ton reduction compared to a € 12 / ton increase).

7.4.5 *Shadow price of P and N*

In the main analysis of this SCBA, changes in the ecosystem service 'water quality regulation (nutrient reduction)' were measured by calculating the reduction of P and N emissions to surface water (kg) for each alternative. Changes in the monetary value of the ecosystem service were measured by multiplying the calculated P and N emission reduction per alternative in a given year by the shadow prices of P and N respectively in the same year (€/kg). The prices of P and N were based on the prices presented in the Environmental Prices Handbook (CE-Delft, 2023). The monetary values of P and N in a given year were then recalculated for the base year (2025) using the discount rate. The shadow price of P (€ 5.53/kg) was adjusted for the uncertainty analysis on the basis of the lower and upper bounds provided (€ 2.56/kg and € 10.13/kg, respectively) in the Environmental Prices Handbook (CE-Delft, 2023). The price of N (€ 4.23/kg) was also adjusted for the uncertainty analysis to lower and upper bound values (€ 2.27/kg and € 8.19/kg, respectively) provided in the Environmental Prices Handbook (CE-Delft, 2023).

Table 7.13 Differences in costs and effects/benefits due to the use of lower bound shadow prices of P & N. Values represent differences from values in base alternative (except last row). Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Water quality regulation	**-549**	**-3.35**
Avoided P emission (kg)	-	-
Avoided N emission (kg)	-	-
Avoided P emission	-61	-0.37
Avoided N emission	-488	-2.98
Difference in total benefits	**-549**	**-3.35**
Difference in net present value	**-549**	**-3.35**

Table 7.14 Differences in costs and effects/benefits due to the use of upper bound shadow prices of P & N. Values represent differences from values in base alternative (except last row). Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Water quality regulation	**1081**	**6.59**
Avoided P emission (kg)	-	-
Avoided N emission (kg)	-	-
Avoided P emission	95	0.58
Avoided N emission	986	6.01
Difference in total benefits	**1081**	**6.59**
Difference in net present value	**1081**	**6.59**

Table 7.13 summarises the differences in values of benefits that would result from adjusting the shadow prices of P and N to their lower bound values. Table 7.14 summarises the differences in values of benefits that would result from adjusting the shadow prices of P and N to their upper

bound values. Adjusting the shadow prices of P and N to their lower bound values would lead to a reduction in the NPV of approximately € 0.55 million, while adjusting the shadow prices of P and N to their upper bound values would lead to an increase in the NPV of approximately € 1.08 million. This variation occurs despite the fact that the actual reduction of P and N emissions remains unchanged in both uncertainty scenarios. Fluctuations in the monetary value of this ecosystem service can be explained by fluctuations in the price of P (-75 to 95%), fluctuations in the price of N (-50 to 50%) and the annual discount rate (2.25%).

7.4.6 *Factor: Number of hikes in the No Field Margins alternative against hikes in the Field Margins alternative*

In the main analysis, the effect of the introduction of field margins on the ecosystem service 'recreation and health' was estimated by calculating the difference in the additional number of hiking activities that would take place in the Field Margins alternative compared to the No Field Margins alternative. The monetary benefits of hiking in each alternative were based on the expenditures recreationists would incur during daytime hiking activities and for any overnight accommodation , as well as the health benefits related to these hiking activities. A factor has been included in the calculations that represents the ratio of the number of hikes carried out in the No Field Margins alternative relative to the Field Margins alternative. The factor assumes that the number of hikes carried out by local and non-local recreationists will be 10% lower in a situation without field margins than in a situation with field margins. This analysis evaluates two uncertainty scenarios. In the first scenario, the number of hikes taken by recreationists in the No Field Margins alternative is 8.75% lower than in the Field Margins alternative (factor: 0.925). In the second scenario, the number of hikes taken by recreationists in the No Field Margins alternative is 12.75% lower than in the Field Margins alternative (factor = 0.875).

Table 7.15 provides an overview of the difference in the value of benefits compared to the main analysis as a result of adjusting the parameter value of the ratio of hikes taken in the No Field Margins alternative against the Field Margins alternative to the lower bound (0.875). Table 7.16 provides an overview of the difference in the value of benefits compared to the main analysis as a result of adjusting the parameter value of the ratio of hikes taken in the No Field Margins alternative against the Field Margins alternative to the upper bound (0.925). Adjusting the reference value to the lower bound leads to a reduction in the NPV of approximately € 623 thousand, while adjusting the reference value to the lower bound leads to an increase in the NPV of approximately € 623 thousand.

The substantial variation in the NPV from these adjustments suggests that these benefits should be addressed with some degree of caution. This is especially important as this benefit contributes significantly to the NPV (€ 2.5 million) and its exclusion from the NPV calculation would result in a negative NPV (€ -2.4 million over a 30-year period). However, excluding this benefit from the NPV would also lead to an underestimation of the benefits of field margins, as field margins in the Hoeksche Waard are clearly a source of cultural services, as described by stakeholder representatives during the scoping phase of this assessment (see section 7.3). A number of these cultural services were not included in this SCBA due to lack of resources (i.e. time and data restraints, as well as lacking models). Therefore, the inclusion of this welfare effect was considered a necessary element in the calculation of the NPV.

Table 7.15 Difference in the recreation and health benefits in the NPV relative to the reference scenario (main analysis), due to the use of a lower factor value representing the ratio of the hikes in the No Field Margins alternative relative to the Field Margins alternative (= 0.875). All values except last row represent differences from values used in main analysis. Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Recreation and health	**623**	**3.80**
Additional hikes by recreationists (physical)	5	0.03
Expenditures made by daytime recreationists	136	0.83
Expenditures made by overnight recreationists	75	0.46
Avoided health costs	412	2.51
Difference in total benefits	**623**	**3.80**
Difference in NPV	**623**	**3.80**

Table 7.16 Difference in the recreation and health benefits in the NPV relative to the reference scenario (main analysis), due to the use of a higher factor value representing the ratio of the hikes in the No Field Margins alternative relative to the Field Margins alternative (= 0.925). All values except last row represent differences from values used in main analysis. Values in k€ unless stated otherwise.

Benefit indicator	**Final benefit**	**Avg. benefit/ha FM**
Recreation and health	**-623**	**-3.80**
Additional hikes by recreationists (physical)	-5	-0.03
Expenditures made by daytime recreationists	-136	-0.83
Expenditures made by overnight recreationists	-75	-0.46
Avoided health costs	-412	-2.51
Difference in total benefits	**-623**	**-3.80**
Difference in NPV	**-623**	**-3.80**

7.4.7 Other uncertainties

The quantification of uncertainties shows that adjusting some elements involved in the calculation of cost and benefit indicators can lead to significant variations in the NPV. If the ratio of the number of hikes in the No Field Margins alternative to the Field Margins alternative were adjusted to 0.925, the NPV would fall to € -0.53 million. If the CO2 price were adjusted to the price for the 2°C WLO scenario, the NPV would rise to € 1.23 million (see also Figure 7.4). This gives us an idea of the extent to which uncertainties can affect the results of an assessment such as this one. Transparency about these uncertainties is therefore necessary in order to be able to draw adequate conclusions from the outcomes of an SCBA.

Uncertainties within SCBAs can arise for various reasons. The implementation of measures generally entails a wide range of societal costs and benefits. The selection of costs and benefits to be included in SCBAs is usually based on their relevance to the assessment. However, relevant effects are often difficult to quantify due to constraints such as the lack of relevant proxy indicators to represent relevant costs and benefits, as well as time, budget, knowledge and data constraints. This leads to uncertainty in the output obtained from models or to the general exclusion of particular effects, despite their relevance to the assessment.

There are many ways in which knowledge constraints can lead to uncertainty in the calculations performed in an SCBA. First, uncertainty may arise when insufficient knowledge is available about the process by which the implementation of measures generates costs or benefits. This can lead to reduced accuracy of the methods employed for assessing costs and benefits. For instance, there may be sufficient scientific knowledge to assume that there is a causal link between the implementation of a measure and a certain (environmental, social, or economic) outcome. However, the exact mechanism underlying this relationship may not be sufficiently understood to develop models that accurately reflect this relationship. Second, methods for calculating costs and benefits may take into account relationships established at a specific location or point in time. However, these relationships may not be fully representative at a different location or point in time, leading to uncertainty when these methods are applied in a different context.

In addition, uncertainty can arise from uncertainty in the data that serve as input for quantifying costs and benefits. For instance, spatial input data can be created by using a variety of techniques, such as images created by satellite imagery, statistics reported by local entities on the distribution of specific features over space (e.g. land use classes, crop types) or maps developed by extrapolating information on the basis of samples obtained in particular locations. The way these datasets are generated carries its own degree of uncertainty. For instance, extrapolations often require the use of models that themselves involve their own degree of uncertainty. Because it is often difficult and time-consuming to accurately estimate the degree of uncertainty of input data, SCBAs tend not to assess this type of uncertainty quantitatively..

Quantification methods often address knowledge and data gaps by incorporating information obtained through expert judgment. During expert judgment consists of experts (e.g. scientists/academics, technicians, stakeholders) making informed estimates about relationships between variables that act as building blocks for a particular quantification method. These informed estimates are then incorporated into calculations. This can be useful when an assessment aims to provide a holistic picture of the outcomes of implementing measures, but also involves a high degree of uncertainty.

The main uncertainties associated with the calculation of the NPV were included in the quantitative uncertainty analysis of this SCBA (sections 7.4.1-7.4.6). However, a series of additional uncertainties can lead to variations in the calculated NPV. This is the case since the calculation of the NPV in an SCBA always requires making a number of assumptions and generalisations. For the sake of clarity, Table 7.17 lays out a few of the uncertainties that may affect the NPV in this SCBA. The table provides an overview of the specific costs or benefits that may lead to uncertainty in the estimated NPV (column 1), a description of the source of uncertainty (column 2), the approximate level of the uncertainty (column 3), the expected effect that accounting for this uncertainty would have on the NPV (column 4) and the question whether or not these costs or benefits were included in the calculation of the NPV (column 5). Uncertainty levels were determined by experts as low, medium or high. The expected effect of each uncertainty source on the NPV was also determined by experts as negative (-), positive (+) or ambivalent (-/+).

Table 7.17 Potential sources of uncertainty in the calculation of costs and benefits in this SCBA, which may negatively (-), positively (+) or ambivalently (-/+) influence the value of the calculated NPV.

Benefit(s)/cost(s)	**Description of uncertainty**	**Uncertainty level**	**Effect on NPV**	**Included in SCBA**
Pollination Crop production	The BRP dataset (RVO, 2020) was used to calculate the effective pollination rate (%) and the crop production income for farmers (€) in each alternative. The dataset shows the distribution of crops across the area and is updated annually for crops produced in specific fields in May of a given year. Most crops are produced in rotational systems, where different crops are sown at different times of the year. This means that estimated crop-related income benefits, which are based on the BRP map, may differ from the actual values. Despite this uncertainty, farmers tend to plan the total <u>production volume of specific crops</u> on the basis of market demand, so the total production of these crops is not expected to vary widely as a result of these rotations.	Low	-/+	Yes
Pollination Crop production	The position of field margins does not change over time, but <u>the distribution of crops</u> does, through rotation. This implies that the effect of field margins on the effective pollination rate will differ depending on which crop type is surrounded by specific field margins at a given time. For a more accurate assessment of the benefits of field margins, crop rotation should be considered when calculating the effect of field margins on pollination and thus on crop production.	Low	-/+	No

Benefit(s)/cost(s)	Description of uncertainty	Uncertainty level	Effect on NPV	Included in SCBA
Pollination Crop production	The dependence of crops on pollinators (%) was determined by experts, as was the suitability of different habitats for pollinators (%). It is true that expert judgment often entails an oversimplification of the system under assessment, introducing a certain degree of uncertainty. However, experts involved in developing these estimates possess considerable expertise in the mechanism by which field margins and other landscape features affect pollinator populations. In addition, research carried out on this subject in the Hoeksche Waard has revealed there is a causal relationship between field margins, pollinator populations and the productivity of pollinator-dependent crops (Balzan & Moonen, 2014; Kennedy et al., 2013; Ricketts et al., 2006; Klein et al., 2007).	Low	-/+	Yes
Crop production	In the No Field Margin alternative it is assumed that the field margins can be used entirely for crop production. This might not always be the case. The reduction in crop production and in farmers' incomes (excl. subsidies) due to field margins might be less. If only 90% of the field margins can be used for crop production, the reduction in crop production and famers income would decrease by € 210 thousand.	Medium	+	No

Benefit(s)/cost(s)	Description of uncertainty	Uncertainty level	Effect on NPV	Included in SCBA
Pollination Crop production	Although it has been well-established that field margins have an effect on pollinator populations, more research is needed into the effect of changes in pollinator populations on a smaller scale (e.g. the impact of smaller solitary bees with small dispersal ranges of 100-300 m, which are important for, for instance, pear orchards). A	Medium	+	No

Benefit(s)/cost(s)	Description of uncertainty	Uncertainty level	Effect on NPV	Included in SCBA
	more accurate assessment of the benefits of field margins should consider non-crop production benefits of improved pollination (e.g. benefits for wild plants).			
Water quality regulation	Field margins lead to enhanced biological pest control and therefore less use of plant protection products. This has a positive effect on the water quality, as fewer plant protection products end up in the surface water and groundwater. Better water quality benefits the water boards, which control the water quality in the Netherlands, drinking water companies and society, which benefits in the short and long term from better environmental quality. A more accurate assessment of the benefits of field margins should consider the effect of changes in the use of plant protection products on the water quality.	High	+	No
Biological pest control	In practice, before an increased effectiveness of natural enemies will result in fewer plant protection products, monitoring (scouting) will often have to be carried out. These costs are temporary and have not been included in this SCBA.	Low	-	No
Biological pest control Human health	Reducing pesticide use benefits the quality of soils, as well as the overall condition and resilience of agricultural ecosystems. Improving the state of agricultural ecosystems positively benefits farmers' productivity, but also society, which benefits from good environmental quality in the short and long term. A more accurate assessment of the benefits of field margins should take into account the effects of changes in the use of plant protection products on the overall quality of agricultural ecosystems (e.g. soil quality, biodiversity) and potential effects on human health. As indicated earlier there are indications that persons with a past history of working over a long period of time with chemical	Medium	+	No

Benefit(s)/cost(s)	Description of uncertainty	Uncertainty level	Effect on NPV	Included in SCBA
	substances, such as farmers who work with plant protection products, are at greater risk of developing diseases that damage the nervous system (neurodegenerative diseases), such as Parkinson disease and Alzheimer disease. Since too little is currently known about the potential effects of plant protection products on human health, these effects have not yet been included in this SCBA (RIVM, 2021).			
Recreational benefits Human health	The calculations of the number of recreational hikes linked to the presence of field margins and the resulting economic benefits were largely based on expert judgment and on information based on somewhat outdated relationships (from 2008). A more accurate estimation of the recreational and health benefits of field margins should be based on quantification methods incorporating recent knowledge. In addition, methods should preferably follow a fully mechanistic approach that excludes expert judgement. This may prove difficult, given the complexity of quantifying sociocultural effects and benefits in measurable units.	High	-/+	Yes
Scientific and educational value	Field margins in the Hoeksche Waard have made a valuable contribution to scientific research and education by universities in the Netherlands for years. A more accurate assessment of the benefits of field margins in the Hoeksche Waard should consider the contribution of field margins to science and academia.	Medium	+	No
Local products	Field margins are linked to the production and value of local agricultural products, such as local honey produced from the contribution of bees that find nectar and habitat in different types of field margins or local chips (e.g. https://hoekschechips.nl). A more accurate assessment of the benefits of field margins should take into	Medium	+	No

Benefit(s)/cost(s)	Description of uncertainty	Uncertainty level	Effect on NPV	Included in SCBA
	account the production of local products and other alternative forms of revenue that have resulted from the introduction of field margins.			
Cultural benefits related to biodiversity	Field margins provide an important contribution to biodiversity, which can generate diverse cultural benefits in the Netherlands and around the world (e.g. intrinsic, recreational, scientific and educational value). While the biodiversity capacity in field margins compared to arable fields was quantified as an index, the cultural benefits to society were not assessed in this SCBA. A more accurate assessment of the benefits of field margins should take into account the contribution of field margins to the tangible and intangible cultural_values_generated by biodiversity in the agricultural landscape.	Medium	+	No
Field margin costs	The annual cost of creating, maintaining and managing field margins has been obtained from a personal communication with a local farmers' representative, who has been involved for many years in the acquisition of subsidies for field margin management in the area. The value used in calculations constitutes but a rough estimate of the costs incurred, where the timing and frequency of each type of cost across time and space is oversimplified. While this estimate carries its own degree of uncertainty, it also represents the best estimate that could be obtained for the area, given the limited knowledge, data and time.	Low	-/+	Yes

8 Discussion

8.1 General discussion

In this SCBA, the societal costs and benefits of field margin adoption were calculated for the Hoeksche Waard in the Netherlands. The NPV for this alternative was calculated taking into account the costs of field margins (i.e. construction, maintenance and management), as well as the effects of field margin creation and the monetary benefits thereof, both positive and negative.

Over a thirty-year period (2025-2055), the benefits of creating field margins appear to outweigh the costs by approximately € 94 thousand (or 500 €/ha field margin). The additional costs associated with field margins relative to the cost that would otherwise be incurred for cultivating crops, were estimated at a value of € 3.3 million or € 20 thousand/ha field margin). Despite this increase in costs associated with field margins, the creation of field margins also leads to a number of additional societal benefits, which is why the NPV is positive. The highest estimated benefits in the Hoeksche Waard consist of the contributions made to recreation and health, water quality and biological pest control. The lowest benefit was associated with the reduction in crop production of € -2.1 million, or € -13 thousand/ha field margin, as space is made available for the creation of field margins where crop production would otherwise take place.

Although the calculated NPV is positive, a number of uncertainties in the calculations in this SCBA suggest that the NPV could vary substantially. To account for this, several potential sources of uncertainty were quantitatively assessed in section 7.4. The uncertainty analysis showed that, after adjusting reference values in the calculations of this SCBA, the calculated NPV would remain positive for seven out of the twelve uncertainty scenarios analysed. Despite the uncertainties, SCBAs are useful in illustrating the advantages and disadvantages of implementing particular measures in a holistic manner, taking into account marketed and non-marketed costs and benefits of implementing measures. This is crucial to eliminating the possibility of external costs and benefits being excluded from the decision-making process, often at the expense of the environment and society as a whole.

To our knowledge, this is the first time an SCBA has been conducted assessing the costs and benefits of field margin implementation. Although the NPV of field margin implementation estimated for the Hoeksche Waard is positive, it should be noted that the costs and benefits of field margins may differ when calculated for a different context (location, time, management, funding). For instance, a negative NPV could occur in situations where the costs of field margins are substantially higher than the otherwise effective costs of crop production in the space where field margins are introduced. This may also be the case if the benefits per ha field margin are substantially lower than in this SCBA. This could occur, for instance, if only a few pollinator-dependent crops are sown near flowery field margins, in which case field margins provide farmers with little to no pollination benefits.

The soil type is a site-specific characteristic that determines the magnitude of the effect of field margins on society . The Hoeksche Waard consists of marine clay, which imply that the results of this study cannot be directly applied to arable farming on other soil types (e.g. sand or peat). For instance the leaching of N and P to surface water is affected. In other arable farming areas, there may also be a higher supply or demand for different ecological functions (e.g. the drinking water supply). In these areas, the benefits of field margins may better match these functions.

The land use is another site-specific characteristic that determines the outcome of the SCBA. For instance field margins (also called buffer strips) at dairy farms may exhibit runoff of nutrients (N and P), but emissions of insecticides are expected to be lower than at arable farming.

In this case study we looked at the arable farming areas on marine clay in the Hoeksche Waard. The results of this study with field margins (also called buffer strips) are not directly applicable in areas with sand, or peat, or loess as soil type or with dairy farming as a contrasting agricultural practise. Several effects will work out differently in a range of areas, such as the leaching of N and P to the surface water. In other areas, other functions may also play a role, such as the supply of drinking water. In those cases, there may be additional benefits related to these functions.

8.2 Field margin benefits

This SCBA shows that the field margins contribute to pollination and increase the production of nearby pollinator-sensitive crops. The benefit from improved pollination is approximately € 306 thousand or € 1,900 /ha field margin. Given this benefit, it may be worthwhile for farmers to consider creating flowery field margins in the vicinity of pollinator-dependent crops.

This SCBA also shows that field margins would lead to enhanced pest control by natural enemies of pests that inhabit crops. This aligns with empirical evidence on the effects of field margins in the Netherlands, which reveals that, in most cases, agricultural fields surrounded by field margins do not require application of insecticides, although herbicides and fungicides are still required (Bos & Musters, 2014; M. Klompe, personal communication, 3 October 2022; W. Dieleman, personal communication, 26 September 2022). This is an important result, since farmers have observed a decrease in the effectiveness of plant protection products over the past years (Janssen & van Rijn, 2021), and this is becoming a source of concern among them. In addition, a number of policy initiatives call for a reduction in the amount of pesticides in surface water and groundwater. This includes the Implementation Programme Future Vision Crop Protection

(Uitvoeringsprogramma Toekomstvisie Gewasbescherming[2]) and the National Programme on Rural Areas (Nationaal Programma Landelijk Gebied[3])at the national level, and on the implementation of the Water Framework Directive (WFD; EC, 2000) and the European Green Deal (which calls for a 50% reduction in the use and risks of chemical pesticides by 2030 to protect ecosystems and enhance biodiversity (EC, 2019)) at the European level.

This SCBA valued the benefits of a reduction in the use of plant protection products by calculating the reduction in costs associated with reduced insecticide use on fields surrounded by field margins. Although this constitutes a considerable benefit for the farmers (€ 1.1 million), a reduction in the use of insecticides also benefits the local water board by improving the water quality, as fewer nutrients and insecticides will end up in the surface water and groundwater, and will also contribute to the goals of the Water Framework Directive. The reduced emissions of nutrients (P and N) to surface water have been quantified and valued at €0.9 million.

The benefits due to the reduced emissions of insecticides have not been calculated for this SCBA, given knowledge and time constraints, but are expected to yield a considerable positive contribution to the NPV.
In addition, the Netherlands must also meet the targets of the WFD in 2027 with regard to plant protection products. If these targets are not met, the European Commission can impose fines. But, perhaps more importantly, if an activity leads to a deterioration in water quality or makes it more difficult to achieve the WFD target, lawsuits can also be initiated (Wieringen et al., 2022). If this is also possible for the application of certain plant protection products, then the application of these products can be limited for certain areas or crops, which in turn may lead to a possible loss in agricultural production. Application of field margins along surface water contributes to the reduction of plant protection products in these waters and to achieving the objectives of the WFD.

Furthermore, the potential risks of the application of plant protection products to human health (Alzheimer's, Parkinson's) are currently being investigated. There are indications that, in particular, farmers who use these products have an increased health risk (Heusinkveld et al., 2021). Since there is too little information about these potential effects, they could not be included in this analysis.

It is recommended to conduct additional research into the benefits of field margins that we could not include in this study, such as reduced leaching and run-off of crop protection agents and the possible health effects.

8.3 Other benefits

The results show that field margin adoption in the Hoeksche Waard generates various other benefits. An expected increase in the amount of

[2] Uitvoeringsprogramma Toekomstvisie gewasbescherming 2030 | Kamerstuk | Rijksoverheid.nl https://www.rijksoverheid.nl/documenten/kamerstukken/2020/09/28/uitvoeringsprogramma-toekomstvisie-gewasbescherming-2030

[3] Ontwikkeldocument Nationaal Programma Landelijk Gebied | Publicatie | Rijksoverheid.nl

carbon sequestered by soils in field margins was valued at € 0.4 million. The performance of the biodiversity capacity appears to be around 1.3 times higher in field margins than in agricultural fields. The performance of the natural attenuation capacity of the water and soil system appears to be around 1.8 times higher in field margins than in fields. These two benefits have not been valued in monetary terms.

The increase in recreational hiking activities due to the improvement of landscape quality through the introduction of field margins was valued at € 2.3 million, on the basis of expenditures made by hikers and the reduction in health costs associated with better health due to additional hiking activities. The relation between the availability of field margins and the number of hikes needs further validation.

In addition, field margin initiatives in the Hoeksche Waard have acquired an important intrinsic and educational value, both within and outside the area. In recent years, farmers have noticed that the quality of the soil is deteriorating, threatening the future profitability and survival of agriculture in the area (M. Klompe, personal communication, 15 March 2018; Lerink & Klompe, 2016). Hence, farmers involved in the application of this practice see it as a promising contribution to the necessary transition to more sustainable agriculture (M. Klompe, personal communication, 15 March 2018).

In addition, the local farmers' intrinsic interest in creating field margins has attracted the attention of scientists studying the effects of field margins as a sustainable agriculture practice. As a result, the Hoeksche Waard has become an important pilot area in field margin research and implementation in the Netherlands and Europe. The educational, scientific and intrinsic value, as well as other cultural services associated with field margins, have not been quantified in this SCBA due to the lack of knowledge and time, but represent an important benefit that, if quantified, would contribute positively to the NPV.

8.4 Financing field margins

The stakeholder analysis showed that the costs and benefits of field margins in the Hoekshce Waard are not evenly distributed across society in the long term. The benefits of biological pest control, pollination, borne by farmers, were estimated at € 1.4. However, farmers would also suffer a loss in income from reduced crop production worth € -2.1 million. Farmers are also responsible for incurring the costs associated with field margins, estimated at € 3.3 million, although they also receive subsidies for these costs. As a whole, the creation, maintenance and management of field margins would lead to a loss of € 4.0 million for farmers in the Hoeksche Waard.

The benefit from field margins for the local water board and society as a whole was estimated at € 4.1 million. This is an important result, as it suggests that farmers bear the costs of establishing field margins, while many of the benefits are enjoyed society as a whole. While farmers receive subsidies for of field margins, these subsidies are declining. This sheds light on the importance of devising new business models for field margin development, to attract new funding opportunities to maximize the benefits of field margins for society as a whole.

Field margins make numerous contributions to society. By focusing on policy initiatives that make money available for nature management and nature restoration, new revenue models for field margins can be devised. For instance, it may be useful to include field margins as a an agricultural measure in the elaboration of the NPLG[4] and the Agricultural Agreement [5]. The question is whether farmers can be rewarded for the various ecosystem services that field margins provide.
Some of the possible funding mechanisms that could be explored to increase funding for field margins include the following:

- **Common agricultural policy (CAP):** In January 2023, the agreement on the reform of the common agricultural policy (CAP) entered into force. The new legislation paves the way for a fairer, greener and more performance-oriented CAP. Of the CAP budget, 25% will be allocated to eco-schemes and 35% to measures in rural areas to support biodiversity, environment and animal welfare. In addition, farms wishing to benefit from the CAP are expected to have at least 3% of arable land devoted to biodiversity (EC, 2022 c).
- **EU Biodiversity Strategy for 2030**: Calls for 25% of the EU budget to be spent on climate action and invested in biodiversity and nature-based solutions (EC, 2020 b). This includes a release of at least € 20 billion annually to be spent in nature and at least € 10 billion to be spent in 10 years on natural capital and the circular economy. The Strategy projects that by 2030, at least 10% of all agricultural areas in the EU should consist of highly diverse landscape features, including field margins, to accommodate wildlife, plants, pollinators and natural pest regulators. It also expects the risk and use of chemical pesticides to be reduced by 50% and pollinator decline to be reversed (EC, 2020).
- **EC's proposal for a Nature Restoration Law**: A key element of the Biodiversity Strategy for 2030, this proposal calls for increasing biodiversity, securing ecosystem services such as water quality regulation, pollination and improving food security. It also expects an increase in organic carbon storage in agricultural ecosystems, as well as an increase in the share of agricultural land with highly diverse landscape features, such as field margins (EC, 2022 a).
- **Soil Strategy for 2030**: A key deliverable of the EU Biodiversity Strategy for 2030 that will contribute to the objectives of the European Green Deal. It contains a framework and concrete soil protection and restoration measures to achieve healthy soils by 2050. The plan still needs to be approved by the EU (EC, 2021a).
- **Farm to Fork strategy:** Central to the European Green Deal, the strategy aims to accelerate our transition to a sustainable food system that provides food security, reverses biodiversity loss and contributes to climate change mitigation and adaptation.

[4] https://www.rijksoverheid.nl/documenten/rapporten/2022/06/10/startnotitie-nplg-10-juni-2022
[5] https://www.rijksoverheid.nl/documenten/kamerstukken/2023/06/23/kamerbrief-aanbieding-concept-landbouwakkoord-en-vervolgtraject

The strategy projects that by 2030, the use and risk of chemical and hazardous pesticides will be reduced by 50% (EC, 2020a).

- **Buzz lines**: In January 2023, the EU presented a seven-year plan to halt the decline of pollinator populations, which are crucial to most crops and wildflowers. One way to achieve this is to support 'buzz lines' or networks of semi-natural landscape features, such as field margins, for bees and other pollinators to move across Europe to find food and shelter. The plan still needs to be approved by the EU (Euronews, 2023).
- **'Polluter pays' principle**: This principle, which is at the heart of EU environmental policy, states that those responsible for environmental damage should pay to cover the costs. This applies to the prevention of pollution, remediation, liability and the social costs of pollution that occurs. This principle can be applied, for instance, by levying taxes, charges and levies on products that cause environmental damage, by introducing tradeable environmental permits (e.g. carbon credits), by establishing schemes whereby consumers pay additional fees for the purchase of polluting products, and by establishing compensation schemes whereby polluters offset their pollution elsewhere. By introducing 'polluter pays' schemes, governments can encourage farmers to pollute less (EC, 2022 b).

8.5 Uncertainties

This SCBA quantitatively analysed the effect of adjusting reference values used in various calculations on the NPV. The NPV is positive in seven of the twelve analyzed uncertainty scenarios. The ecosystem services 'recreation and health benefits' and 'carbon sequestration' showed the greatest uncertainty. Variations in the value of the benefit indicator 'recreation and health' could lead to an NPV ranging between € -0.53 million and € 0.72 million. Adjusting the CO_2 price from the price for the WLO low scenario to the 2° WLO scenario would lead to an NPV varying between € -0.22 million and € 1.2 million. According to the IPCC, current commitments from 191 countries would ensure that emissions would eventually lead to global warming of 2.7 °C. If this is true, the NPV would be much higher.

In addition, the effects of a reduction in the emission of insecticides to surface water have not been calculated for this SCBA in view of the limited knowledge and time, but are expected to make a significant positive contribution to the NPV.

This SCBA quantitatively analysed the effect of adjusting reference values used in various calculations on the NPV. The net present value is positive in seven out of twelve uncertainty scenarios. The ecosystem services 'recreation and health benefits' and 'carbon sequestration' showed the greatest uncertainty. Variations in the value of the 'recreation and health' benefit indicator can lead to an NPV ranging between € -0.53 million and € 0.72 million. Changing the CO_2 price between the WLO-low scenario and the WLO 2 °C scenario would lead to an NPV ranging between € -0.22 million and € 1.2 million. According to the IPCC, current pledges by 191 countries to reduce their emissions could not prevent the world from warming by 2.7 °C. In that case, the NPV would be much higher.

The application of field margins along surface water contributes to reducing leaching and run-off of plant protection products and achieving the objectives of the WFD.

This emission reduction towards surface water by farm fields could not be included in this SCBA given knowledge and time constraints. Including these benefits in the analysis would likely lead to a higher NPV. Also the potential risks, especially for arable farming and flower bulb cultivation, and the associated costs of not achieving the targets for plant protection products of the WFD could not be assessed.

Furthermore, the potential risks of the application of plant protection products to human health (Alzheimer's, Parkinson's) are currently being investigated. There are indications that, in particular, farmers who use these products have an increased health risk (RIVM, 2021). Since there is too little information about these potential effects, they could not be included in this analysis.

Additional research is recommended into these benefits of field margins that we could not include in this study.

Quantifying changes in the NPV on the basis of changes in reference values is useful to demonstrate the variability underlying the results of such an assessment. However, there are a number of other ways in which uncertainties can arise in an SCBA, making the analysis of uncertainties even more complex. Uncertainties can relate, for instance, to the type of data used as input for calculations (e.g. errors resulting from extrapolation of spatial datasets, or due to statistical measurement techniques), but also to the formulation of the models themselves. In addition, costs and benefits assessed in an SCBA take place in the future, which in turn introduces an additional source of uncertainty, as it is impossible to accurately predict future developments. This is not only the case with SCBAs, but also with all other forms of forecasting by models developed in different areas of expertise (e.g. economics, meteorology, epidemiology).

Despite these uncertainties, it is useful to evaluate the possible effects of developing and implementing sustainable measures using evidence-based knowledge and data. Otherwise, the external costs and benefits associated with the implementation of measures affecting the environment and society as a whole will weigh less in decision-making than the marketed costs and benefits of these measures (e.g. production and purchase of material resources). As long as this is the case, sustainable management practices will continue to be viewed as a source of costs, overlooking the vital benefits they bring to society.

9 Conclusions

In this study, an SCBA was performed to assess whether the costs of introducing field margins in the Hoeksche Waard outweigh the benefits. The costs included the costs of creating, maintaining and managing field margins. The SCBA quantified the effects of field margin implementation on (1) crop pollination, (2) crop productivity, (3) the effective control rate of crop pests, (4) water quality regulation, (5) climate change mitigation through carbon storage by soils, (6) the relative biodiversity, (7) natural attenuation capacity in field margins compared to agricultural fields, and (8) the experience of the agricultural landscape through participation in recreational hiking activities. The NPV was calculated as the sum of all future costs and benefits of field margin implementation for a period of thirty years (2025-2055), discounted for the base year 2025. Assumptions in calculations were adjusted in a quantitative uncertainty analysis to evaluate the extent to which the NPV would vary, given these adjustments. Other uncertainties were also evaluated qualitatively. In addition, a stakeholder analysis was performed to analyse the distribution of costs and benefits of field margin implementation across stakeholder groups, as well as the implications.

The calculated NPV of field margin implementation was positive (€ 0.1 million), which suggests that over a 30-year period, the benefits of field margins in the Hoeksche Waard would outweigh the costs. The calculated NPV was also positive in seven out of twelve cases when adjustments were made in the uncertainty analysis to reference values underlying the NPV. Adjusted reference values included the evaluation period (i.e. fifty years, a hundred years), the discount rate and reference values of various benefits (i.e. carbon sequestration, water quality regulation, recreational and health benefits).

One benefit that made a substantial positive contribution to the NPV was the effect of field margins on recreational activities (i.e. hiking) and the resulting health benefits. The estimation of this benefit also carries a high degree of uncertainty, which could possibly lead to the NPV ranging between € -0.53 million and € 0.72 million. The NPV is also strongly dependent on the CO_2 price. Changing the CO_2 price between the WLO-low scenario and the WLO 2 ^{o}C scenario would lead to an NPV of respectively € -0.22 million and € 1.2 million. Although in this study, we assumed a CO_2 price according to the WLO-high scenario, according to the IPCC, current pledges would eventually cause the world to warm by 2.7 ^{o}C. In that case, the NPV would be much higher.

Due to knowledge and time constraints, we could not include the reduced emission of insecticides from farm fields to surface water in this SCBA. Including these benefits in the analysis would be likely to lead to a higher NPV.

A stakeholder analysis showed that the costs and benefits of introducing field margins are not shared equally among the different stakeholder groups. Farmers bear the costs for the creation and management of the field margins (€ 3.3 million) and the loss in crop production (€ 2.1 million). Farmers also share the benefits from the biological pest control (€ 1.4 million) and pollination (€ 0.3 million). If you add up these costs and benefits, the field margins will cost farmers € 4 million over a period of 30 years.

The waterboards benefit from the construction of field margins. he reduction in nutrients is estimated to be € 1.2 million. The benefits of € 2.5 million for recreation and health and the increase in biodiversity and natural attenuation will be shared by society as a whole.

Farmers in the Hoeksche Waard have shown an intrinsic interest in adopting FAB measures and see them as a promising contribution to the necessary transition to sustainable agricultural systems. To make this transition economically feasible for farmers, it is necessary to devise revenue models that attract financing options to get the most out of these measures for both farmers and society as a whole. Currently, new legislation is in force or under development to create restrictions and obligations for farmers, but also provide funding opportunities for FAB practices. Some examples are the CAP, the Biodiversity Strategy for 2030, the Farm to Fork Strategy, the Soil Strategy for 2030 and the European Commission's proposal for a Nature Restoration Law.

This SCBA only provides insight into the welfare effects of one FAB measure, namely field margins in the Hoeksche Waard, the Netherlands. In a follow-up study, the effects of other possible measures could be assessed, e.g. development or preservation of semi-natural landscape features, buffer strips[6], hedges, less tillage, etcetera.

[6] Alles over bufferstroken (rvo.nl)

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Appendices

A1 Input map adaptation

This appendix describes the steps that were taken to create raster maps showing the overall distribution of field margins, crop types, and arable land in each alternative. These maps were used as inputs for all calculations. The steps taken to produce them were the following:

1. **Creating a *Field Margins raster* map**
   First, the *Field margins vector* map was converted into a Boolean (binary) raster file with a resolution of 2.5 m (cell size = 2.5 x 2.5 m). All cells with a positive value (indicating that field margins are present) were assigned a value of 1. All other cells were assigned a value of 0 (field margins not present). This map was then aggregated into a map with a resolution of 10 m, meaning that all cells were given a value ranging between 1 and 16. This resulted in a *Field margins raster* map.
2. **Creating a *BRP raster* map**
   In the Hoeksche Waard, the *BRP vector* map (RVO, 2020) contains 185 agricultural land uses that come under the land use categories ‘arable land’, ‘fallow land’, ‘grassland’, ‘nature reserve’ and ‘other’. To create maps with the distribution of crop type classes for each alternative, land use type classes that come under the ‘arable land’ category on the BRP map were first extracted. On the basis of the new layer, a raster map with a 10 m resolution (cell size = 10 x 10 m) was created. This resulted in a *BRP (arable land) raster* map showing the code numbers assigned to different crop type classes in the Hoeksche Waard on the original *BRP vector* map.
3. **Creating an *Arable land raster* map**
   In this step, the *BRP (arable land) raster* map (Step 2) was first converted to a Boolean raster map with a resolution of 2.5 m (cell size = 2.5 x 2.5 m) in ArcMap. All cells with a positive value (indicating that arable land is present) were assigned a value of 1. All other cells were assigned the value of 0 (arable land not present). This map was then aggregated into a map with a 10 m resolution, meaning that all cells were given a value between 1 and 16. This resulted in an *Arable land raster* map.
4. **Creating a map showing the distribution of *Agricultural fields in the No Field Margins alternative***
   In the No Field Margins alternative, the space currently allocated to field margins would constitute arable land. Therefore, the summation of the *Field margins raster* map (Step 1) and the *Arable land raster* map (Step 3) was obtained. This resulted in a Boolean map showing the distribution of *Agricultural fields in the No Field Margins alternative* (1 = arable land present; 0 = arable land not present). Due to possible mismatches between the *Arable land raster* map and the *Field margins raster* maps (for example, due to mismatches between the *BRP vector* and *Field*

Margins vector maps or their rasterisation process), the newly created map may contain cells with values greater than 16. To correct for this error, all cells with a value greater than 16 were assigned a value of 16.

5. **Creating a map showing the distribution of *Agricultural fields in the Field Margins alternative***
   To create a map showing the distribution of *Agricultural fields in the Field Margins alternative*, the *Field margins raster* map (Step 1) was subtracted from the *Agricultural fields in the No Field Margins* map (Step 4).

NOTE: To perform calculations with PCRaster, all input spatial data must be converted to a raster format, the same resolution and the same extent. Therefore, the *Field margins* and *BRP* vector maps were converted to raster files as described above and used as inputs for all cost/benefit calculations.

A2 Discount rate

Method
This appendix presents the method used in this SCBA for discounting annual costs/benefits taking place in the future. Discounting is done by using the formula below:

$$y = {x_1}/{(1 + x_2)^{t-1}}$$

where

y = Present value of a annual cost/benefit (€);
x1 = Future value of a annual cost/benefit (€);
x2 = Discount rate (%);
t = Year in which annual cost/benefit occurs (base year = 0).

The discount rate to be used in SCBAs in the Netherlands has been determined by the Cabinet, following advice from the Discount Rate Working Group (Werkgroep Discontovoet, 2020). A standard discount rate of 2.25% (adjusted for inflation) was applied. For the uncertainty analysis, a lower bound and an upper bound of 1.85% and 2.65%, respectively were applied. The selection of these discount rates was based on the advice of the Discount Rate Working Group (Werkgroep Discontovoet, 2020).

A3 Crop production

Method
This appendix describes the methodology applied to calculating the change in crop production benefits due to the development of field margins. The crop production benefits are measured as the reduction in farmers' incomes related to crop production (€), which results from the reduction in space available for cultivating crops due to the creation of field margins. These calculations were based on statistics reported between 2017-2019 on crop yield, crop production costs and the subsidies farmers obtain for crop production in the Netherlands (Wageningen University Research, 2022-01-20). These statistics have been updated to values in 2023 on the basis of fluctuations in the CPI for the Netherlands (CBS, 2023-05-02).

The statistics from Wageningen University Research (2022-01-20) reveal that the annual average crop yield per ha arable field in the Netherlands amounts to approximately 5445 €/ha/year. On the basis of this information, the annual reduction in crop yield due to the creation of field margins was calculated by multiplying the area of field margins in the Hoeksche Waard (164 ha) by the average annual crop yield per ha arable field in the Netherlands (5445 €/ha/year). However, the crop yield value includes the costs incurred by farmers, that are associated with crop production. These include for instance the costs for fertiliser, energy and the maintenance of arable fields. After costs are deducted farmers' incomes amount to around 18% of the total value of crop yield. Excluding subsidies received for crop production, farmers' incomes amount to around 10% the value of total crop yield. Hence, to calculate the annual reduction in farmers' income excluding subsidies, the reduction in crop yield associated with field margins was multiplied by 10%.

The present value of this negative benefit over the 2025-2055 period was calculated as the sum of the present value of all annual benefit flows associated with this benefit during this period. Future benefit flows were discounted using a standard discount rate (2.25%; Werkgroep Discontovoet, 2020), according to the method described in Appendix 2.

A4 Pollination

Method
This appendix describes the methodology applied to calculate the change in crop pollination and the associated monetary benefits due to the development of field margins. The pollination benefits in each alternative are measured as the effective pollination rate of pollinator-dependent crops (%). The monetary benefit of the effective pollination rate in each alternative is measured as the avoided loss in farmers' incomes related to crop cultivation due to pollination (€). These calculations were based on a model developed by van Berkel et al. (2021) and adjusted on the basis of annual crop yield statistics (€/ha/year) obtained from van Everdingen & Wisman (2017). Crop yield values have been updated to values in 2023 on the basis of fluctuations in the CPI for the Netherlands in recent years (CBS, 2023-05-02).

To quantify this ecosystem service, spatial modelling took place. Spatial datasets used to calculate the annual pollination benefits per alternative (€/year) include the *Field margins raster* and the *BRP (arable land) raster* maps developed as we described in Appendix 1. In addition, the *Ecotope* map (van Berkel et al., 2021) was used, which displays information on the ecosystem type, respective code and sub type (van Berkel et al., 2021). Algorithms were written in the Python programming language (https://www.python.org/) using the PCRaster library extension (http://pcraster.geo.uu.nl/). The spatial data used as input was pre-processed using the software ArcMap (version 10.6.1) and QGIS (version 3.0.2).

Effective pollination rate and its contribution to crop yield
The model developed by van Berkel et al. (2021) can be used to create two maps. One map shows the Effective pollination rate of crops, based on the suitability of different natural habitats for pollinators (%). The other map shows the annual contribution of pollinators to the crop yield, or the Avoided Yield Loss (€/year). Spatial datasets used as inputs in this SCBA to calculate these indicators include:

1. a map showing the spatial location of crops that need pollination (BRP map; RVO, 2020),
2. a map showing the spatial location of potentially suitable ecosystems of pollinators (Ecotope map; van Berkel et al., 2021) and
3. a map showing the distribution of flower-rich field margins in the Hoeksche Waard (Lerink, 2021).

The map showing the effective pollination rate of crops (%) takes into account the suitability of different ecosystems for pollinators (%), the demand made by different crops for pollination (%) and the distance between the suitable ecosystem and the pollination-demanding crop (m). It is important to consider the distance between ecosystems suitable for pollinators and the demanding crop, as different pollinators move at different dispersal abilities. The map showing the Avoided Yield Loss due to pollination (€) takes into account the Effective pollination rate (%) and the annual yield per crop type (€/year)

The demand for pollination by different crop types (%) was determined by reclassifying the classes in the BRP map on the basis of Table A3.1. The suitability of ecosystems for pollinators (%) was defined by reclassifying the classes on the Ecotope map into Ecosystem type classes and then into Nesting and floral suitability classes (%)on the basis of Table A3.2. On the basis of van Berkel et al. (2021), the Nesting and floral suitability of field margins was assigned a value of 80%.

Looking only at crop yields overstates farmers' actual incomes from arable farming, as crop yields do not exclude the costs farmers incur to grow crops. The income from crop yield does deduct the cost associated with crop production, but it does not exclude subsidies received by farmers to sow crops. In the Netherlands, the incomes of farmers (yield – costs) after deducting subsidies amount to an average of 10% of the original crop yield per farm (Wageningen University Research, 2022-01-20).Therefore, the calculated contribution to crop yield in each scenario is multiplied by 0.10 to accurately represent the value of actual crop production.

Table A4.1 Crop type classes in the Hoeksche Waard, pollination demand by crop types (%) and crop yield per crop type (€/year/ha) (sources: RVO, 2020; van Berkel et al., 2021; van Everdingen & Wisman, 2017).

BRP code	BRP class	Pollination demand (%)	Yield (euro/ha)
2735	Pumpkin, production	95	6340
2328	Cherries, sweet	65	35 000
1097	Pears. Planted current season.	65	22 600
1098	Pears. Planted prior to current season.	65	22 600
1095	Apples. Planted current season.	65	21 000
1096	Apples. Planted prior to current season.	65	21 000
1870	Plums	65	17 100
2325	Berries, red	25	62 500
2702	Strawberries open ground, production	25	55 900
2706	Strawberries on racks, production	25	3030
1923	Rapeseed, summer (incl. butter seed)	25	1315
311	Beans, field (including pigeon, horse, seaweed beans)	25	895
854	Beans, garden (green to be harvested)	5	2980
242	Beans, brown	5	2390
2779	Main green beans (= main green beans), production	5	2320
665	Soybeans	5	1270
666	Flax, oil. Linseed not from fibre flax	5	1270
258	Lucerne	5	900
1075	Ornamental shrubs and creepers, open ground,	0	53 000
174	Flower seeds open ground	0	50 400
991	Other flowers, other flower nursery crops	0	50 400
1025	Peony, other flower nursery crops	0	50 400
1876	Cut green	0	46 900
2645	Walnut trees	0	42 400
2755	Rhubarb, production	0	40 000

BRP code	BRP class	Pollination demand (%)	Yield (euro/ha)
2776	Pointed cabbage, seeds and propagation material	0	40 000
2778	Brussels sprouts/brussels sprouts, seeds and propagation material	0	40 000
1079	Fruit trees, other, open ground,	0	34 000
1023	Parsnip, production	0	28 800
1006	Other flowers, bulbs and tubers	0	27 600
1070	Avenue trees/park trees, rootstocks, open ground,	0	25 000
2771	Lettuce; other, production	0	24 700
1004	Tulip, flower bulbs and tubers	0	24 000
2756	Rhubarb, seeds and propagation material	0	22 700
2745	Bok choy, production	0	22 300
2743	Herbs, production	0	20 500
2799	Leek, winter, production	0	17 400
2759	Red cabbage, production	0	16 400
2789	White cabbage, production	0	14 600
2793	Other vegetables not mentioned, production	0	13 700
2794	Other vegetables, seeds and propagation material not mentioned	0	13 700
992	Other flowers, dried flowers	0	12 700
1039	Chrysanthemum, other flower nursery crops	0	12 700
2777	Brussels sprouts, production	0	12 200
2797	Cauliflower, summer, production	0	10 900
2761	Savoy cabbage, production	0	10 700
2775	pointed cabbage, production	0	10 700
2015	Potatoes, leg NAK	0	10 500
2785	Carrot, production	0	9550
2741	Beets/red beets, production	0	8200
1933	Onion’s leg and plant second year	0	6850
1934	Shallots	0	6850
2725	Celeriac, production	0	6430
2014	Potatoes, consumption	0	6090
262	Onions, sowing	0	5860
2787	Chicory root, production	0	5270
256	Beets, sugar	0	4530
1949	Jerusalem artichokes	0	4330
1022	Quinoa	0	4000
814	Corn, sugar	0	3820
2016	Potatoes, leg TBM	0	3730
511	Chicory	0	3450
257	Beets, feed	0	3180
244	Peas, green/yellow (green to be harvested)	0	2120
233	Wheat, winter	0	1910
2773	Spinach, production	0	1890
241	Capuchins (and grey peas)	0	1860
247	Blue moonseed	0	1800
2652	Other grains	0	1660

BRP code	BRP class	Pollination demand (%)	Yield (euro/ha)
3510	French buckwheat	0	1660
259	Maize, cut	0	1620
234	Wheat, summer	0	1440
236	Barley, summer	0	1390
235	Barley, winter	0	1380
344	Border, adjacent to permanent cultivation, mainly consisting of another crop	0	1250
799	Clover, red	0	1250
803	Vetch, feed	0	1250
3506	Perennial ryegrass	0	1250
3512	Italian ryegrass	0	1250
3519	Sudan grass/Sorghum	0	1250
238	Oats	0	1200
237	Rye (not cut rye)	0	915
670	Japanese oats	0	910

Table A4.2 Ecotope (ECVC) classes in the Hoeksche Waard, ecosystem types, and nesting and suitability of ecosystem types (%) (source: van Berkel et al., 2021).

ECVC codes	ECVC class	Ecosystem type	Nesting and floral suitability (%)
17	Heath	Heath	100
139	Company premises	Forest; deciduous	89
133	Ground-bound	Forest; deciduous	89
132	Sports area	Forest; deciduous	89
131	Overnight recreation	Forest; deciduous	89
130	Semi-op. green	Forest; deciduous	89
129	Landscape garden	Forest; deciduous	89
128	Landscaping	Forest; deciduous	89
127	Gardening	Forest; deciduous	89
126	Park	Forest; deciduous	89
116	Natural forest	Forest; deciduous	89
115	Swamp forest	Forest; deciduous	89
114	Other forest	Forest; deciduous	89
113	Strip of trees and shrubs	Forest; deciduous	89
112	Production forest	Forest; deciduous	89
602	Not flowery margin	Natural grassland, agricultural field margins	80
601	Flowery margin	Natural grassland, agricultural field margins	80
18	Natural margin	Natural grassland, agricultural field margins	80
6	Wildlife margin	Natural grassland, agricultural field margins	80
339	Company premises	Forest; mixed	66
333	Ground-bound	Forest; mixed	66
332	Sports area	Forest; mixed	66
331	Overnight recreation	Forest; mixed	66
330	Semi-op. green	Forest; mixed	66
329	Landscape garden	Forest; mixed	66
328	Landscaping	Forest; mixed	66
327	Gardening	Forest; mixed	66
326	Park	Forest; mixed	66
316	Natural forest	Forest; mixed	66
315	Swamp forest	Forest; mixed	66
314	Other forest	Forest; mixed	66
313	Strip of trees and shrubs	Forest; mixed	66
312	Production forest	Forest; mixed	66
5	Perennial extensive	Perennial crop, extensive	58
9	Grassland extensive	Grassland, extensive	53
19	Roughness	Tall herbs	48
239	Company premises	Forest; coniferous	44

ECVC codes	ECVC class	Ecosystem type	Nesting and floral suitability (%)
233	Ground-bound	Forest; coniferous	44
232	Sports area	Forest; coniferous	44
231	Overnight recreation	Forest; coniferous	44
230	Semi-op. green	Forest; coniferous	44
229	Landscape garden	Forest; coniferous	44
228	Landscaping	Forest; coniferous	44
227	Gardening	Forest; coniferous	44
226	Park	Forest; coniferous	44
216	Natural forest	Forest; coniferous	44
215	Swamp forest	Forest; coniferous	44
214	Other forest	Forest; coniferous	44
213	Strip of trees and shrubs	Forest; coniferous	44
212	Production forest	Forest; coniferous	44
3	Cropland natural	Annual crop, natural or extensive	41
2	Arable extensive	Annual crop, natural or extensive	41
22	Salt marsh	Salt marsh, bog and lowland peat	36
21	Peat bogs	Salt marsh, bog and lowland peat	36
20	Bog	Salt marsh, bog and lowland peat	36
439	Company premises	Grassland	26
433	Ground-bound	Grassland	26
432	Sports area	Grassland	26
431	Overnight recreation	Grassland	26
430	Semi-op. green	Grassland	26
429	Landscape garden	Grassland	26
428	Landscaping	Grassland	26
427	Gardening	Grassland	26
426	Park	Grassland	26
36	Fallow	Fallow land	26
34	Other grassland	Grassland	26
25	Coastal dunes	Beach, sand, coastal dunes	26
24	Drifting sand	Beach, sand, coastal dunes	26
23	Beach	Beach, sand, coastal dunes	26
8	Grassland temporary	Grassland	26
7	Grassland permanent	Grassland	26
539	Company premises	Other (sealed, water)	0
533	Ground-bound	Other (sealed, water)	0
532	Sports area	Other (sealed, water)	0
531	Overnight recreation	Other (sealed, water)	0

ECVC codes	ECVC class	Ecosystem type	Nesting and floral suitability (%)
50	Sandbar	Other (sealed, water)	0
49	Intertidal	Other (sealed, water)	0
48	Estuary	Other (sealed, water)	0
47	Brackish water	Other (sealed, water)	0
46	Sea, other	Other (sealed, water)	0
45	Wadden Sea	Other (sealed, water)	0
44	North Sea	Other (sealed, water)	0
43	Watercourse	Other (sealed, water)	0
42	Lake, pee	Other (sealed, water)	0
41	Other terrain	Other (sealed, water)	0
40	Infrastructure	Other (sealed, water)	0
38	Built up (rural)	Other (sealed, water)	0
37	Built up (urban)	Other (sealed, water)	0
35	Other, other	Other (sealed, water)	0
11	Greenhouse horticulture	Other (sealed, water)	0
10	Pot container	Other (sealed, water)	0
4	Perennial regular	Other (sealed, water)	0
1	Arable regular	Other (sealed, water)	0

A5 Biological pest control

Method
This appendix describes the methodology applied to calculate the effect of field margin creation on biological pest control in the Hoeksche Waard, as well as the implications for the costs of insecticide use. The effective pest control was measured as the relative visitation rate of crops by natural enemies of crop-feeding pests (0-100, where 100 marks the maximum visitation rate), on the basis of a model developed by De Knegt et al. (2023). The avoided costs of insecticide use as a result of field margin formation (€/year) were also calculated.

To quantify this ecosystem service, spatial modelling took place. Spatial datasets used as inputs to calculate all output for this model include the *Field margins raster* and the *BRP (arable land) raster* maps developed as described in Appendix 1. In addition, the *Ecotope* map (van Berkel et al., 2021) was used, which displays information on the ecosystem type, respective code and subtype (van Berkel et al., 2021). Algorithms were written in the Python programming language (https://www.python.org/) using the PCRaster library extension (http://pcraster.geo.uu.nl/). The spatial data used as input was pre-processed using the software ArcMap (version 10.6.1) and QGIS (version 3.0.2).

Potential pest control rate by natural enemies of crop-feeding pests (%)
In the model by De Knegt et al. (2023), four habitats contribute to pest control: flowery herbaceous habitats (including field margins containing flowers), flower-poor herbaceous habitats (including roadsides or ditch sides in agricultural landscapes), woody habitats with shrub layer (including hedgerows) and trees without shrubs. An herbaceous habitat is considered floral when it has a cover of at least 25% forbs (non-grasses) that may produce flowers suitable for natural predators. On the basis of a literature review and expert judgment, these habitats were assigned different levels of suitability for supporting each natural enemy group, ranging from 0 (unsuitable) to 100 (most suitable). Only the outermost 30 meters of larger semi-natural features have been taken into account as habitats for natural enemies, as studies have shown that the length of the boundaries of semi-natural features is often a greater determinant of their suitability as a habitat than their area (De Knegt et al., 2023).

The relative contribution of the three groups of natural enemies to pest control is calculated on the basis of weights determined by experts. The model takes into account three groups of natural enemies with different distribution possibilities and forms of dependence on landscape elements. The model is based on a number of assumptions, including the following:

1. Arthropod natural enemies contribute to the control of pests (i.e. aphids) in all crops in arable farming, fruit and vegetable cultivation and outdoor horticulture.
2. The suitability of semi-natural habitats for specific groups of natural enemies and the dispersal ability of these groups can be

used as a proxy for the distribution of natural enemies across the landscape
3. The distribution of natural enemies follows a negative exponential decay function based on the distance of natural enemies from their suitable habitats. This exponential decay function differs per natural enemy group because different groups have different dispersal abilities.
4. All natural enemies present on a particular crop that depends on pest control contribute to natural pest control.
5. Nectivorous natural enemy groups contribute more to pest control than ground-dwelling and other flying natural enemies.

The relative visitation rate of natural enemies on aphids on certain crop species (0 - 100) is calculated as a function of:
1. The relative abundance of natural enemy groups, based on the suitability of different habitat types for different groups of natural enemies (0 – 100%, where 100% implies maximum suitability)
2. The distance between a particular cell inhabited by a natural enemy group and a particular crop type

Additional (field) research and model validation is necessary to determine the minimum visitation rate by natural enemies on aphids at which insecticides no longer need to be applied.

Avoided costs of insecticide use (€/year)
The avoided costs of insecticide use due to field margin formation (€/year) were performed as a separate calculation to that of the potential pest control by natural enemies of crop-feeding pests (0-100) described above. According to personal communications with locals involved in field margin management in the Hoeksche Waard and in the Netherlands (W. Dieleman, personal communication, 26 September 2022; M. Klompe, 3 October 2022), the development of field margins leads to a situation where no insecticide application is necessary in agricultural fields surrounded by field margins. Meanwhile, the use of insecticides is still required in fields not surrounded by field margins. Herbicide and fungicides are also applied to agricultural fields with and without field margins. According to the personal communications mentioned above, the cost of applying insecticides is about 25 €/ha/year. Therefore, the annual avoided costs of insecticide use due to field margin formation (€/year) were calculated by multiplying the area of fields with field margins (ha) by the annual price per hectare of insecticides (€/year). For each alternative, the avoided costs of insecticide use (€) were calculated for a thirty-year period (2025-2055) by following the process described in Appendix 2. This includes applying a discount rate to future benefit flows.

A6 Water quality (nutrient reduction)

Methods
This appendix describes the methodology used to calculate the benefits associated with reductions in P and N runoff from agricultural fields to surface water due to the realisation of field margins. Agricultural field runoff in each alternative was calculated on the basis of the method presented in STOWA (2010), incorporating statistics obtained from the Dutch emission registry (year of statistics = 2020; http://www.emissieregistratie.nl/). The shadow prices of P and N as published in the Environmental Prices Handbook (*Handboek Milieuprijzen) (*CE-Delft, 2023) were implemented to calculate the costs to society due to P and N runoff.

In order to calculate the additional benefits of nutrient reduction in surface water in the period 2025-2055 that would result from the development of field margins, the present value of this benefit in the Field Margins alternative was deducted from the present value in the No Field Margins alternative. The present value of this benefit for each alternative over the period 2025-2055 is calculated as the sum of the present value of all benefit flows associated with this benefit during this period. Future benefit flows were discounted using a standard discount rate (2.25%; Werkgroep Discontovoet, 2020), according to the method described in Appendix 2.

Table A6.1 provides an overview of the key figures that were used to calculate this effect/benefit, as well as the sources from which these key figures were derived.

Calculation of the average P and N emissions per ha
The average P and N emissions (kg/ha) for agricultural fields with and without field margins were calculated in accordance with Table A6.2. To differentiate between emissions generated by all forms of agricultural land and emissions generated only by agricultural fields, a set of calculations was performed in different stages (stages a-i in Table A6.2). The Field Margins alternative was used as a reference for these calculations since data on P and N emissions has been reported for the current situation in the Hoeksche Waard, which contains field margins.

Stage a
In the first stage, the area of agricultural fields with field margins and without field margins in the Field Margins alternative (as presented in section 4.2) are deducted from the total area of agricultural land in the Hoeksche Waard (15 398 ha).

Stage b
In the second stage, Factor 1 was calculated, which captures the fraction of all agricultural land covered by different agricultural land types (agricultural fields without field margins, agricultural fields with field margins and remaining agricultural land). This was done by dividing the area covered by each agricultural land type by the total area of agricultural land in the Hoeksche Waard (15 398 ha).

Table A6.1 Reference values used for calculating the recreation and health benefits in each alternative (all values are for the Hoeksche Waard).

Agricultural fields	**Value**	**Source**
Area all agricultural land	15 398 ha	RVO (2020)
Area agricultural fields (No field margins alt.)	12 064 ha	Section 4.2
Area agricultural fields (Field margins alt.)	11 900 ha	Section 4.2
Area agricultural fields without field margins	9910 ha	Section 4.2
Area agricultural fields with field margins	1990 ha	Section 4.2
Field margins	**Value**	**Source**
Area field margins	164 ha	Lerink (2021)
Field margin width	3 meter	Section 4.2
P- and N-runoff	**Value**	**Source**
Fraction of runoff that takes place in the presence of a 4 m broad field margin	0.8	STOWA (2010)
P runoff from agricultural land	33 060 kg/year	http://www.emissieregistratie.nl
P price (mean)	5.53 €/kg	CE-Delft, 2023 (2023)
P price (lower bound)	2.56 €/kg	CE-Delft, 2023 (2023)
P price (upper bound)	10.13 €/kg	CE-Delft, 2023 (2023)
N runoff from agricultural land	398 378 kg/year	http://www.emissieregistratie.nl
N price (mean)	4.23 €/kg	CE-Delft (2023)
N price (lower bound)	2.27 €/kg	CE-Delft (2023)
N price (upper bound)	8.19 €/kg	CE-Delft (2023)

Table A6.2 Process implemented to calculate P & N emissions per ha for different agricultural land use types in the Field Margins alternative.

	area land use types	arable land area fraction	Emission rate	area fraction * emission rate	fraction of total emission	emission P per land use type	emission N/ha/year	emission N per land use type	emission N/ha/year
Stages	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**
Agricultural land use type	**Area (ha)**	**Fraction of area agricultural land**	**Fraction of total runoff**	**Factor 1**	**Factor 2**	**P emission (kg)**	**P emission (kg/ha)**	**N Emission (kg)**	**N Emission (kg/ha)**
Description	**-**	**a1/ sum(a)**	**STOWA (2010)**	**b*c**	**dx/ sum(d)**	**e/tot P emission**	**f/a**	**e/tot N emission**	**h/a**
Agricultural fields without field margins	11 900	0.77	0.77	0.80	26 341	2.21	317 411	27	0.77
Agricultural fields with field margins	1990	0.13	0.85	0.11	0.11	3744	1.88	45 120	23
Field margins	164	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Remaining agricultural land	1344	0.09	1.00	0.09	0.09	2975	2.21	35 848	27
Total (all agricultural land)	**15 398**	**1.00**	**2.85**	**0.97**	**1.00**	**33 060**	**2**	**398 378**	**26**

Stage c
In the third stage, Factor 2 was calculated, which represents the fraction of total emissions released by different agricultural land types. According to STOWA (2010), field margins with a width of 4 m will lead to a reduction in emissions from agricultural fields by 20% (= 80% of emissions). On average, field margins in the Hoeksche Waard are 3 m wide, which is why the reduction percentage of emissions from agricultural fields with field margins compared to emissions from fields without field margins is assumed to be proportionately lower (3/4 * 20% = 15% of emissions from agricultural fields without field margins). Hence, the factor capturing the proportion of emissions released to surface water will be 1 for agricultural fields without field margins (no reduction will take place) and 0.85 (= 1 – 0.15) for agricultural fields with field margins. Field margins do not generate emissions, but act as a buffer for emissions released from agricultural fields. Therefore, for field margins, the factor was assigned a value of zero. It is assumed that for all remaining agricultural land uses, field margins do lead to a reduction in emissions, since field margins only surround agricultural fields. Hence, the factor was assigned a value of 1 for remaining agricultural land use types.

Stages d and e
In the fourth stage, Factor 3 was calculated, which combines information on the fraction of agricultural land covered by different agricultural land types and the fraction of total emissions released from agricultural fields. In stage e, this factor was normalised so that the sum of all factors equals 1.

Stages f, g, h, i
In stage f, total P emissions by a particular agricultural land use type are calculated. This was done by multiplying Factor 4 for each land use type with the total amount an emission (P or N) generated by agricultural land in the Hoeksche Waard. In stage g, P emissions per ha as a result of particular agricultural land use type are calculated by dividing the total emission for the Hoeksche Waard (stage f) by the total area of each agricultural land use (stage a). In stages h and i, these steps are repeated for N emissions.

Annual P runoff from agricultural land to surface water
No Field Margins alternative
To calculate the annual P runoff to surface water from agricultural land in the No Field Margins alternative, the area of agricultural fields without any field margins in the alternative (11 900 ha) was multiplied by the average P emissions per ha from agricultural fields without field margins, as calculated in stage g of Table A6.2 (2.21 kg/ha).

Field Margins alternative
To calculate the annual P runoff to surface water from agricultural land in the Field Margins alternative, the area of agricultural fields without any field margins in the alternative (9910 ha) was multiplied by the average P emissions per ha from agricultural fields without field margins, as calculated in stage g of Table A6.2 (2.21 kg/ha). Subsequently, the area of agricultural fields with field margins in the alternative (1990 ha) was multiplied by the average P emissions per ha

from agricultural fields with field margins, as calculated in stage g of Table A6.2 (1.88 kg/ha). The annual P runoff was then calculated as the sum of the annual P runoff emitted by agricultural fields with and without field margins.

Annual N runoff from agricultural land to surface water
No Field Margins alternative
To calculate the annual N runoff to surface water from agricultural land in the No Field Margins alternative, the area of agricultural fields without any field margins in the alternative (11 900 ha) was multiplied by the average N emissions per ha from agricultural fields without field margins, as calculated in stage i of Table A6.2 (27 kg/ha).

Field Margins alternative
To calculate the annual N runoff to surface water from agricultural land in the Field Margins alternative, the area of agricultural fields without any field margins in the alternative (9910 ha) was multiplied by the average N emissions per ha from agricultural fields without field margins, as calculated in stage i of Table A6.2 (27 kg/ha). Subsequently, the area of agricultural fields with field margins in the alternative (1990 ha) was multiplied by the average N emissions per ha from agricultural fields with field margins, as calculated in stage i of Table A6.2 (23 kg/ha). The annual N runoff was then calculated as the sum of the annual N runoff emitted by agricultural fields with and without field margins.

Annual cost (€/year) of P runoff from agricultural land to surface water
No Field Margins alternative
To calculate the annual cost (€/year) of P runoff to surface water from agricultural land in the No Field Margins alternative, the annual P runoff in the alternative (26 704 kg/year) was multiplied by the shadow price of P, according to CE-Delft (2023). The mean value of the shadow price was used in this calculation (5.53 €/kg P). The lower and upper margins of the price of P were used for the uncertainty analysis (2.56 €/kg and 10.13 €.kg respectively).

Field Margins alternative
To calculate the annual cost (€/year) of P runoff to surface water from agricultural land in the Field Margins alternative, the annual P runoff in the alternative (25 680 kg/year) was multiplied by the shadow price of P, according to CE-Delft (2023). Once more, the mean value of the shadow price was used in this calculation (5.53 €/kg P) and the lower and upper margins of the price of P were used for the uncertainty analysis (2.56 €/kg and 10.13 €.kg respectively).

Annual cost (€/year) of N runoff from agricultural land to surface water
No Field Margins alternative
To calculate the annual cost (€) N runoff to surface water from agricultural land in the No Field Margins alternative, the annual N runoff in the alternative (321 785 kg/year) was multiplied by the shadow price of N (4.23 €/kg), according to CE-Delft (2023). The lower and upper margins of the price of N were used for the uncertainty analysis (2.27 €/kg and 8.19 €.kg respectively).

Field Margins alternative
To calculate the annual cost (€) of N runoff to surface water from agricultural land in the Field Margins alternative, the annual N runoff in the alternative (309 448 kg/year) was multiplied by the shadow price of N (4.23 €/kg), according to de CE-Delft (2023). Once more, the mean value of the shadow price was used in this calculation (4.23 €/kg N) and the lower and upper margins of the price of N were used for the uncertainty analysis (2.27 €/kg and 8.19 €.kg respectively).

<u>*Cost (€) of P runoff from agricultural land to surface water over a thirty-year period (2025-2055)*</u>
For each alternative, the cost (€) of P runoff to surface water is calculated for a thirty-year period (2025-2055) by following the process described in Appendix 2. This includes applying a discount rate to future costs. The shadow price of P was obtained from CE-Delft (2023).

<u>*Cost (€) of N runoff from agricultural land to surface water over a thirty-year period (2025-2055)*</u>
For each alternative, the cost (€) of N runoff to surface water is calculated for a thirty-year period (2025-2055) by following the process described in Appendix 2. This includes applying a discount rate to future costs. The shadow price of N was obtained from CE-Delft (2023).

A7 Biodiversity capacity

Method
This appendix describes the method used to calculate the benefits of changes in the biodiversity capacity (BC) due to field margin development in the Hoeksche Waard. To determine the difference in the BC of agricultural fields and field margins, a BC performance index was calculated (equation 1). This calculation was not performed spatially, meaning that the results of the calculation of the BC index applies only to the elements 'field margins' and 'agricultural fields'. The spatial size of these elements has not been included in the calculations.

Equation 1: BC index, calculated for arable land with and without field margins

$$BC\ ^{FM}/_{AL} = 10^{\left(\mp\left(w^i * \left|log\left(\frac{VAR^i_{FM}}{VAR^i_{AL}}\right)\right|\right) \mp \dots \left(w^j * \left|log\left(\frac{VAR^j_{FM}}{VAR^j_{AL}}\right)\right|\right)\right)}$$

where

$VAR^{i\dots j}$ = any variable that contributes to the BC
Subscripts 'FM' = field margins value
Subscripts 'AL' = arable land value
$W^{i\dots j}$ = weight of a variable

Equation 1 comprises two types of variables. Variables where the VAR_{FM} performs better than VAR_{AL} (Equation 2) and variables where the VAR_{AL} performs better than VAR_{FM} (Equation 3). The BC represents the relationship between the performance of field margins and arable land. If the BC < 1, then cropland performs better than field margins. If the BC > 1, cropland performs worse than field margins. If the BC = 1, then cropland and field margins perform equally well.

Equation 2: 'i' type variable

$$+\left(w^i * \left|log\left(\frac{VAR^i_{FM}}{VAR^i_{AL}}\right)\right|\right)$$

Equation 3: 'j' type variable

$$-\left(w^i * \left|log\left(\frac{VAR^i_{FM}}{VAR^i_{AL}}\right)\right|\right)$$

Variables included in this calculation have been aggregated into different tier levels using weights determined by a panel of four experts (i.e. soil scientists). Variables at the lowest tier level include measurable indicators that reflect different characteristics of the system under assessment. These indicators were measured using data from various sources (Fokker, 2020; van Rijn, 2018; Sechi et al., 2017; Schuurmans, 2021). The weight assigned to each variable reflects its contribution to the performance of an indicator at a higher tier level. Indicators at higher tier levels were also given weights to finally calculate one indicator representing the BC. Variables and the weights that reflect their contribution to the BC are displayed in Table A7.1.

Table A7.1 Collected data for quantifying variables relating to biodiversity

Parameter	Weight	Field margins		Arable land		Sign.	Reference(s)
		Mean	SD	Mean	SD		
Aquatic invertebrates							
Shannon index	4.38×10^{-2}	2.93×10^{1}	2.10×10^{-1}	2.45	2.90×10^{-1}	Yes	Schuurmans (2021)
Abundance	6.32×10^{-2}	1.04×10^{3}	6.93×10^{2}	6.66×10^{2}	3.63×10^{2}	Yes	Schuurmans (2021)
Richness	8.23×10^{-2}	4.81×10^{1}	4.25	3.54×10^{1}	9.99	Yes	Schuurmans (2021)
Evenness	5.03×10^{-2}	7.59×10^{-1}	6.00×10^{-2}	7.01×10^{-1}	6.00×10^{-2}	Yes	Schuurmans (2021)
Birds							
Shannon index	4.35×10^{-2}	1.69	-	5.70×10^{-1}	-	No	Fokker (2020)
Abundance	3.69×10^{-2}	1.69×10^{2}	-	9.90×10^{1}	-	No	Fokker (2020)
Richness	6.50×10^{-2}	1.10×10^{1}	-	6.00	-	No	Fokker (2020)
Evenness	3.45×10^{-2}	7.05×10^{-1}	-	3.18×10^{-1}	-	No	Fokker (2020)
Insects							
Shannon index	6.39×10^{-2}	1.96	4.60×10^{-1}	1.40	7.40×10^{-1}	No	van Rijn (2018)
Abundance	7.33×10^{-2}	6.10×10^{1}	7.27×10^{1}	1.34×10^{1}	1.57×10^{1}	No	van Rijn (2018)
Richness	7.10×10^{-2}	1.27×10^{1}	4.72	6.31	4.31	No	van Rijn (2018)
Evenness	5.87×10^{-2}	7.99×10^{-1}	1.30×10^{-1}	7.58×10^{-1}	2.40×10^{-1}	No	van Rijn (2018)
Earthworm community							
Shannon index	7.07×10^{-3}	8.58×10^{-1}	3.50×10^{-1}	6.93×10^{-1}	4.10×10^{-1}	No	Sechi et al. (2017) – Raw data
Richness	8.15×10^{-3}	2.88	9.60×10^{-1}	2.63	1.09	No	Sechi et al. (2017) – Raw data
Biomass	1.09×10^{-2}	4.67×10^{1}	3.82×10^{1}	5.11×10^{1}	2.92×10^{1}	No	Sechi et al. (2017) – Raw data
Density	8.21×10^{-3}	2.95×10^{2}	2.09×10^{2}	3.50×10^{2}	1.75×10^{2}	No	Sechi et al. (2017) – Raw data
Evenness	5.03×10^{-3}	8.57×10^{-1}	1.10×10^{-1}	7.79×10^{-1}	1.70×10^{-1}	No	Sechi et al. (2017) – Raw data
Nematode community							

Parameter	Weight	Field margins		Arable land		Sign.	Reference(s)
		Mean	SD	Mean	SD		
Shannon index	1.27×10^{-2}	2.52	2.70×10^{-1}	2.58	1.80×10^{-1}	No	Sechi et al. (2017) – Raw data
Richness	2.61×10^{-2}	2.61×10^{1}	4.29	2.50×10^{1}	3.06	Yes	Sechi et al. (2017) – Raw data
Density	1.58×10^{-2}	2.60×10^{3}	1.30×10^{3}	2.13×10^{3}	4.86×10^{2}	No	Sechi et al. (2017) – Raw data
Evenness	1.25×10^{-2}	7.76×10^{-1}	5.00×10^{-2}	8.04×10^{-1}	4.00×10^{-2}	Yes	Sechi et al. (2017) – Raw data
Enchytraeids community							
Shannon index	9.90×10^{-3}	1.81	3.00×10^{-1}	1.33	3.70×10^{-1}	Yes	Sechi et al. (2017) – Raw data
Richness	1.52×10^{-2}	8.13	1.63	5.00	1.63	Yes	Sechi et al. (2017) – Raw data
Biomass	9.24×10^{-3}	7.52	5.56	1.51	1.88	Yes	Sechi et al. (2017) – Raw data
Density	1.11×10^{-2}	2.20×10^{4}	1.10×10^{4}	8.07×10^{3}	4.73×10^{3}	Yes	Sechi et al. (2017) – Raw data
Evenness	5.28×10^{-3}	8.69×10^{-1}	6.00×10^{-2}	8.44×10^{-1}	1.00×10^{-1}	Yes	Sechi et al. (2017) – Raw data
Microarthropods community							
Shannon index	1.19×10^{-2}	2.27	3.00×10^{-1}	0.48	1.83	Yes	Sechi et al. (2017) – Raw data
Richness	2.49×10^{-2}	1.57×10^{1}	4.57	1.21×10^{1}	4.02	Yes	Sechi et al. (2017) – Raw data
Density	2.34×10^{-2}	2.34×10^{4}	1.06×10^{4}	2.69×10^{4}	3.75×10^{4}	No	Sechi et al. (2017) – Raw data
Evenness	1.10×10^{-2}	8.37×10^{-1}	6.00×10^{-2}	7.63×10^{-1}	2.00×10^{-1}	No	Sechi et al. (2017) – Raw data
Microbial community							
Bacterial biomass	1.59×10^{-2}	1.33×10^{2}	2.90×10^{1}	7.61×10^{1}	2.11×10^{1}	Yes	Sechi et al. (2017) – Raw data
Fungal biomass	1.13×10^{-2}	9.85×10^{1}	3.53×10^{1}	1.70×10^{1}	7.60	Yes	Sechi et al. (2017) – Raw data
50% soil conversion	2.53×10^{-2}	2.16×10^{3}	9.46×10^{2}	7.25×10^{3}	3.22×10^{3}	Yes	Sechi et al. (2017) – Raw data
Slope	3.27×10^{-2}	5.16×10^{-1}	5.00×10^{-2}	4.82×10^{-1}	5.20×10^{-1}	No	Sechi et al. (2017) – Raw data

A8 Natural attenuation capacity of soils

Method
This appendix describes the method used to calculate the benefits of changes in the natural attenuation capacity (NAC) of soils due to field margin development in the Hoeksche Waard. To determine the difference in the BC of agricultural fields and field margins, an NAC performance index was calculated (equation 1). This calculation was not performed spatially, meaning that the results of the calculation of the NAC index apply only to the elements ‘field margins’ and ‘agricultural fields’. The spatial size of these elements has not been included in the calculations.

Equation 1: NAC index, calculated for arable land with and without field margins against agricultural fields

$$NAC^{FM}/_{AL} = 10^{\left(+\left(w^{i}*\left|log\left(\frac{VAR^{i}_{FM}}{VAR^{i}_{AL}}\right)\right|\right)+\mathrm{I}-\left(w^{j}*\left|log\left(\frac{VAR^{j}_{FM}}{VAR^{j}_{AL}}\right)\right|\right)\right)}$$

where

$VAR^{i\ldots j}$ = any variable that contributes to the NAC
Subscripts ‘FM’ = field margins value
Subscripts ‘AL’ = arable land value
$W^{i\ldots j}$ = weight of a variable

Equation 1 comprises two types of variables. Variables where the VAR_{FM} performs better than VAR_{AL} (Equation 2) and variables where the VAR_{AL} performs better than VAR_{FM} (Equation 3). The NAC represents the relationship between the performance of field margins and arable land. If the NAC < 1, then cropland performs better than field margins. If the NAC > 1, cropland performs worse than field margins. If the NAC = 1, then cropland and field margins perform equally well.

Equation 2: ‘i’ type variable

$$+\left(w^{i}*\left|log\left(\frac{VAR^{i}_{FM}}{VAR^{i}_{AL}}\right)\right|\right)$$

Equation 3: ‘j’ type variable

$$-\left(w^{i}*\left|log\left(\frac{VAR^{i}_{FM}}{VAR^{i}_{AL}}\right)\right|\right)$$

Variables included in this calculation have been aggregated into different tier levels using weights determined by a panel of four experts (i.e. soil scientists). Variables at the lowest tier level include measurable indicators that reflect different characteristics of the system under assessment. These indicators were measured using data from various sources (Sechi et al., 2017; Schuurmans, 2021; Bojacá et al., 2011; van Rijn, 2018). The weight assigned to each variable reflects its contribution to the performance of an indicator at a higher tier level.

Indicators at higher tier levels were also given weights to finally calculate one indicator representing the NAC. Variables and the weights that reflect their contribution to the NAC are displayed in Table A8.1.

Table A8.1 Collected data for quantifying variables relating to natural attenuation

Parameter	Weight	Field margins		Arable land		Sign.	Reference(s)
		Mean	SD	Mean	SD		
Abiotic							
Potential C mineralisation	1.15×10^{-1}	1.49×10^{2}	4.18×10^{1}	9.04×10^{1}	3.11×10^{1}	Yes	Sechi et al. (2017) – Supplementary
Potential N mineralisation	7.21×10^{-2}	8.71×10^{1}	2.04×10^{1}	4.13×10^{1}	1.22×10^{1}	Yes	Sechi et al. (2017) – Supplementary
SOM	1.27×10^{-1}	5.41	8.20×10^{-1}	2.93	4.30×10^{-1}	Yes	Sechi et al. (2017)
pH	1.08×10^{-1}	7.31	1.10×10^{-1}	7.53	1.70×10^{-1}	Yes	Sechi et al. (2017)
Plants							
Coverage	4.61×10^{-2}	1.15×10^{2}	-	8.30×10^{1}	-	No	Bojacá et al., (2011); van Rijn (2018)
Richness	4.21×10^{-2}	1.81×10^{1}	-	1.00	-	No	van Rijn (2018)
Aquatic invertebrates							
Shannon index	2.84×10^{-2}	2.93×10^{1}	2.10×10^{-1}	2.45	2.90×10^{-1}	Yes	Schuurmans (2021)
Abundance	2.61×10^{2}	1.04×10^{3}	6.93×10^{2}	6.66×10^{2}	3.63×10^{2}	Yes	Schuurmans (2021)
Richness	3.26×10^{-2}	4.81×10^{1}	4.25	3.54×10^{1}	9.99	Yes	Schuurmans (2021)
Evenness	2.01×10^{-2}	7.59×10^{-1}	6.00×10^{-2}	7.01×10^{-1}	6.00×10^{-2}	Yes	Schuurmans (2021)
Microbial biomass							
Bacterial biomass	1.23×10^{-1}	1.33×10^{2}	2.90×10^{1}	7.61×10^{1}	2.11×10^{1}	Yes	Sechi et al. (2017) – Raw data
Fungal biomass	6.91×10^{-2}	9.85×10^{1}	3.53×10^{1}	1.70×10^{1}	7.60	Yes	Sechi et al. (2017) – Raw data
Functional microbial activity							
50% soil conversion	8.99×10^{-2}	2.16×10^{3}	9.46×10^{2}	7.25×10^{3}	3.22×10^{3}	Yes	Sechi et al. (2017) – Raw data
Slope	1.02×10^{-1}	5.16×10^{-1}	5.50×10^{-2}	4.82×10^{-1}	5.00×10^{-2}	No	Sechi et al. (2017) – Raw data

A9 Climate change mitigation through carbon sequestration

Method
This appendix describes the method used to calculate the benefits associated with changes in soil carbon sequestration due to field margin creation . Soil carbon sequestration was measured by calculating soil organic carbon (SOC) content in soils in a situation with field margins versus a situation without field margins. The carbon sequestration in soils in field margins and agricultural fields (tons CO_2-eq.) was calculated by combining information on the total carbon content and bulk density of soils in agricultural fields and field margins in the Hoeksche Waard (Sechi et al., 2017) with the molar mass of carbon and the estimated soil depth in the area. The price per ton of CO_2 as defined by the Discount Rate Working Group (Werkgroep Discontovoet, 2020) was implemented to calculate the monetary value of carbon sequestration by soils.

In order to calculate the additional benefits of carbon sequestration in the 2025-2055 period that would result from the development of field margins, the present value of this benefit in the Field Margins alternative was deducted from the present value in the No Field Margins alternative. The present value of this benefit for each alternative over the 2025-2055 period was calculated as the sum of the present value of all yearly benefits that take place during this period. Future benefits were discounted using a standard discount rate (2.25%; Werkgroep Discontovoet, 2020), according to the method described in Appendix 2.

Table A9.1 provides an overview of the key figures that were used to calculate this effect/benefit, as well as the sources from which these key figures were derived.

Table A9.1 Reference values used for calculating the carbon sequestration benefits in each alternative.

Agricultural fields	**Value**	**Source**
Area all agricultural land	15 398 ha	RVO (2020)
Area of agricultural fields (No field Margins alt.)	12, 064 ha	Section 4.2
Area agricultural fields (Field Margins alt.)	11 900 ha	Section 4.2
Area of agricultural fields without field margins	9910 ha	Section 4.2
Area of agricultural fields with field margins	1990 ha	Section 4.2
Field margins	**Value**	**Source**
Area field margins	164 ha	Lerink (2021)
Field margin width	3 m	Section 4.2
Soil indicators	**Value**	**Source**
Total C in agricultural fields (mean)	1.87 mol/kg	Sechi et al. (2017)
Total C in agricultural field margins (mean)	2.91 mol/kg	Sechi et al. (2017)
Carbon molar mass	12 g/mol	-
Bulk density	1.45 g/cm^3	Sechi et al. (2017)
Soil depth	20 cm	Expert judgment
CO_2 price	**Value**	**Source**
CO_2 price (census 2026)	70 €/ton CO_2 eq.	Werkgroep Discontovoet (2020)

Calculation of SOC (%) in agricultural fields
To calculate the SOC content (%) in agricultural fields, the formula below was implemented.

$y = (x_1 \times x_2 \div x_3)$
where

y = SOC content (%);
x_1 = Total C in agricultural fields (mol/kg);
x_2 = Carbon molar mass (g/mol);
x_3 = Conversion factor (g/kg) = 1000

Calculation of SOC (%) in field margins
To calculate the SOC content (%) in field margins, the formula below was implemented.

$y = (x_1 \times x_2 \div x_3)$

where

y = SOC content (%);
x_1 = Total C in field margins (mol/kg);
x_2 = Carbon molar mass (g/mol);
x_3 = Conversion factor (g/kg) = 1000

Calculation of SOC (ton/ha) in field margins
To calculate the SOC content (ton/ha) in field margins, the formula below was implemented.

$$y = (x_1 \times 100) \times x_2 \times x_3$$
where

y = SOC content in field margins (tons/ha);
x_1 = SOC content in field margins (%);
x_2 = Bulk density (g/cm^3);
x_3 = Soil depth (cm)

Calculation of SOC (ton/ha) in agricultural fields
To calculate the SOC content (tons/ha) in agricultural fields, the formula below was implemented.

$$y = (x_1 \times 100) \times x_2 \times x_3$$
where

y = SOC content in agricultural fields (tons/ha);
x_1 = SOC content in agricultural fields (%);
x_2 = Bulk density (g/cm^3);
x_3 = Soil depth (cm)

Calculation of change in carbon sequestration (tons/year) in each alternative
To calculate the carbon sequestration (tons) in each alternative, the formula below was implemented.

$$y = [(x_1 \times x_3) + (x_2 \times x_4)] \div x_5$$

y = Change in carbon sequestration (tons/year);
x_1 = SOC content in field margins (tons/ha);
x_2 = SOC content in agricultural fields (tons/ha);
x_3 = Area field margins (ha);
x_4 = Area agricultural fields (ha);
x_5 = Number of years of change in SOC content = 5 (years)

Calculation of the monetary value of carbon sequestration over a five-year period (2025-2030)
To calculate the monetary value of the change in carbon sequestration (€) for a period of five years (2025-2030), the process described in Appendix 2 was applied. This included applying a discount rate to future carbon sequestration benefits. Carbon sequestration benefits were obtained by multiplying the change in carbon sequestration by the price of carbon in a given year. The carbon price in a given year has been determined by the Discount Rate Working Group (Werkgroep Discontovoet, 2020), which also assumes an annual increase of 3.5% on this price.

A10 Recreation and health

Method
This appendix describes the methodology that was used to calculate the change in recreation and health benefits as a result of the creation of field margins. The calculation takes into account the extra number of hikes that are carried out in the Field Margins alternative compared to the No Field Margins alternative. To estimate the number of hikes that take place in the Field Margins alternative (the current situation), the method by Bos et al. (2008) was implemented. The method calculates the number of recreational hikes that are taken in an agricultural rural landscape due to the presence of hiking paths. Then, on the basis of expert judgment, it is assumed that 10% fewer hikes will be carried out by local and non-local recreationists in a situation without field margins compared to a situation with field margins. The number of hikes per alternative can then be translated into monetary units by estimating the contribution by recreational hikes to the leisure economy (expenditures made for leisure activities) and avoided health costs (Bos et al., 2008).

In order to calculate the additional benefits of recreational hikes in the 2025-2055 period that would result from the development of field margins, the present value of these benefits in the Field Margins alternative was deducted from the present value in the No Field Margins alternative. The present value of this benefit for each alternative over the 2025-2055 period was calculated as the sum of the present value of all future recreational and health benefits that occur during this period. Future recreational and health benefits were discounted using a standard discount rate (2.25%; Werkgroep Discontovoet, 2020), according to the method described in Appendix 2.

Table A10.1 provides an overview of the key figures that were used to calculate this effect/benefit, as well as the sources from which these key figures were derived.

Calculation of number of annual recreational hikes taken in Field Margins alternative
To calculate the number of annual recreational hikes taken by recreationists in the Field Margins alternative, the formula below was implemented. This calculation is based on the current length of hiking paths in the Hoeksche Waard. It is assumed that for each additional km of hiking paths, the additional number of recreational hikes will decrease. Therefore, an exponential decay factor (x_2) was included in the formula:

$$y = \sum_1^m x_1 \times {x_2}^{m-1}$$

where

y = Number of annual recreational hikes – Field Margins (hikes/year);
x_1 = Number of hikes by recreationists per km of hiking path (hikes/km/year);
x_2 = Decay factor (value of 0-1);
m = Total length of hiking paths (km).

Table A10.1 Reference values used for calculating the recreation and health benefits in each alternative

Indicator	Value	Source
Number of hikes by recreationists per km of hiking path	666 hikes/km/year	Bos et al. (2008), De Vries & Goossen (2002), Ruijgrok et al. (2006), Gaaff et al. (2004), Goossen & Ploeger (1997)
Decay factor	0.9	Bos et al. (2008)
Total length of hiking paths in the Hoeksche Waard	470 km	Folkersma (n.d.)
Fraction of total hikes taken due to the absence of field margins	0.9	Expert judgment
Ratio of hikes by non-local recreationists to total number of hikes by recreationists	0.3125	Bos et al. (2008) based on Kroon & Kuhlman (2004)
Average expenditure made during hikes by daytime recreationists	0.33 €/hike	Bos et al. (2008)
Fraction of hikes by daytime recreationists to total number of hikes by non-local recreationists	0.95	Bos et al. (2008)
Fraction of hikes by overnight recreationists to total number of hikes by non-local recreationists	0.05	Bos et al. (2008)
Average expenditure made during hikes by daytime recreationists	3.33 €/hike	Bos et al. (2008)
Average expenditure made during hikes by overnight recreationists	35 €/hike	Bos et al. (2008)
Avoided health costs per hike	3 €/hike	Bos et al. (2008)

Calculation of number of annual recreational hikes taken in No Field Margins alternative
To calculate the total number of hikes taken by all recreationists in the No Field Margins alternative, the formula below was implemented:

$y = x_1 \times x_2$
where

y = Number of annual recreational hikes – No Field Margins (hikes/year);
x_1 = Number of annual recreational hikes – Field Margins (hikes/year);
x_2 = Fraction of number of annual recreational hikes due to the absence of field margins (value of 0-1). This factor represents the fraction of the annual recreational hikes that would be made in a situation without field margins.

Calculation of number of annual recreational hikes taken by non-local recreationists
The number of annual recreational hikes by non-local recreationists refers to recreational hikes that are taken by people who do not live in or near a particular area. As such, they have to travel a greater distance to enjoy the recreational benefits associated with using hiking trails in the rural landscape. To calculate the number of annual recreational hikes by non-local recreationists in each alternative, the following formula was used:

$y = x_1 \times x_2$
where

y = Number of annual recreational hikes by non-local recreationists (hikes/year);
x_1 = Number of annual recreational hikes (hikes/year);
x_2 = Fraction of number of annual recreational hikes taken by non-local recreationists (value 0-1).

Calculation of annual expenditures made by daytime recreationists
Daytime recreationists are non-local recreationists who only spend the day in an area and contribute to the leisure economy, for example by spending money on food or guided hikes. It is assumed that 95% of non-local recreationists are daytime recreationists (Bos et al., 2008). The following formula was used to calculate the annual expenditures made by daytime recreationists per alternative:

$y = x_1 \times x_2 \times x_3$
where

y = Annual expenditures made by daytime recreationists (€/year);
x_1 = Fraction of number of annual recreational hikes by non-local recreationists, taken by daytime recreationists (value 0-1);
x_2 = Number of annual recreational hikes by non-local recreationists (hikes/year);
x_3 = Average expenditure made by daytime recreationists during recreational hikes (€/hike).

Calculation of annual expenditures made by overnight recreationists
Overnight recreationists are non-local recreationists who spend the night in the area and thus make additional contributions to the leisure economy, for instance in the form of expenditure in accommodation. It is assumed that 5% of all recreationists are overnight recreationists (Bos et al., 2008). The following formula was used to calculate the annual expenditure made by overnight recreationists per alternative:

$y = x_1 \times x_2 \times x_3$
where

y = Annual expenditure made by overnight recreationists (€/year);
x_1 = Fraction of number of annual recreational hikes by non-local recreationists, taken by overnight recreationists (value 0-1);
x_2 = Number of annual recreational hikes by non-local recreationists (hikes/year);
x_3 = Average expenditure made by overnight recreationists during recreational hikes (€/hike).

Calculation of annual expenditure made by recreationists
The following formula was used to calculate the annual expenditure made by all recreationists per alternative:

$y = x_1 + x_2$
where

y = Annual expenditure made by all recreationists (€/year);
x_1 = Annual expenditure made by daytime recreationists (€/year);
x_1 = Annual expenditure made by overnight recreationists (€/year).

Calculation of annually avoided health costs
The following formula was used to calculate the avoided health costs due to the number of annual recreational hikes taken by recreationists per alternative:

$y = x_1 \times x_2$
where

y = Annually avoided health costs due to the number of annual recreational hikes taken (€/year);
x_1 = Number of annual recreational hikes taken by recreationists (hikes/year);
x_1 = Avoided health costs per hike (€/hike).

Calculation of the annual monetary value of recreation and health services
The following formula was used to calculate the annual monetary value of recreation and health services per alternative:

$y = x_1 + x_2$
where

y = Annual monetary value of recreation and health services (€/year);
x_1 = Annual expenditure made by all recreationists (€/year);

x_1 = Annually avoided health costs due to the number of annual recreational hikes taken (€/year).

Calculation of the monetary value of recreation and health services over a thirty-year period (2025-2055)

The monetary value of recreation and health services was calculated for each alternative for a period of thirty years (2025-2055), following the process described in Appendix 2. This includes applying a discount rate to future benefits. The values for average expenditures made by recreationists, and for the avoided health costs per recreational hike were obtained from Bos et al. (2008). Therefore, these values were first updated to values price in 2025 on the basis of fluctuations in the CPI for the Netherlands in recent years (CBS, 2023-05-02).

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