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Sustainable Asset Valuation (SAVi) of Agroforestry Nature-Based Infrastructure in Welkenraedt (Belgium)

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The **International Institute for Sustainable Development (IISD)** and **KnowlEdge Srl** have worked on integrating climate data from the Copernicus Climate Data Store (CDS) to improve the analysis of infrastructure projects performed with SAVi. The project serves to demonstrate the importance and usability of climate data generated through the CDS products in deploying sustainable infrastructure projects to contribute to a climate-resilient, low-carbon economy.

The assessment of the Paterson Park's Building Infrastructure is one of the use cases for demonstrating the value of integrating climate data of the Copernicus database into SAVi.

Acknowledgements

We are grateful for the support of the Municipality of Welkenraedt and would like to thank, in particular, Jonathan Leruth for engaging with us and providing us information about the agroforestry project. We would also like to thank the Groupe d'Actions Local (GAL) for providing data. Finally, we are grateful for discussions with Olivier Baudry of the Association pour l'agroforesterie en Wallonie et Bruxelles (AWAF).

About the Sustainable Asset Valuation (SAVi)

SAVi is a simulation service that helps governments and investors value the many risks and externalities that affect the performance of infrastructure projects.

The distinctive features of SAVi are:

- Valuation: SAVi values, in financial terms, the material environmental, social, and economic risks and externalities of infrastructure projects. These variables are ignored in traditional financial analyses.
- Simulation: SAVi combines the results of systems thinking and system dynamics simulation with project finance modelling. We engage with asset owners to identify the risks material to their infrastructure projects and then design appropriate simulation scenarios.
- Customization: SAVi is customized to individual infrastructure projects.

For more information on SAVi: www.iisd.org/savi

About Copernicus Climate Data Store

The European Commission has charged the European Centre for Medium-Range Weather Forecasts (ECMWF) to implement the Copernicus Climate Change Service (C3S). The main goal of C3S is to deliver high-quality data to support climate change adaptation and mitigation policies (ECMWF, 2017). One of the main features of C3S is the Climate Data Store (CDS), which delivers current, past, and future climate indicators. The CDS contains historical climate observations, Earth observation datasets, global and local climate projections, seasonal forecasts, and global and local climate analyses (ECMWF, 2017).

Data obtained from the CDS Toolbox include location-specific, historical, and future weather indicators, such as precipitation and temperature. Historical data (ECMWF Reanalysis 5th generation [ERA5]) and projections (Coupled Model Intercomparison Project Phase 5 [CMIP5]) are available for consultation and download in the CDS. Selected indicators are also accessible through a dedicated online app created to facilitate the exchange of information between the CDS and several SAVi models. The SAVi tool uses climate information to estimate damage resulting from extreme weather events and climate trends, establish the value addition resulting from improved adaptive capacity, and calculate the supply and demand of ecosystem services (Bassi et al., 2020). For example, through the integration of data on precipitation, evaporation, and crop water requirements into the SAVi model, it is possible to evaluate current and future water supply in a specific landscape and inform planning for irrigation infrastructure (Bassi et al., 2020).

The Integration of Climate Data into the SAVi Model (Bassi et al., 2020) outlines the integration of authoritative Copernicus climate data from the CDS into the SAVi tool. It describes how several climate indicators obtained from the CDS were integrated into SAVi and how its analysis has improved as a result. In light of this integration, the International Institute for Sustainable Development can generate sophisticated SAVi-derived analyses on the costs of climate-related risks and climate-related externalities.

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Executive Summary

This report describes the Sustainable Asset Valuation (SAVi) assessment of an agroforestry project in the Municipality of Welkenraedt, Belgium. Agroforestry is nature-based infrastructure (NBI) that aims to maintain and restore soil productivity, combat erosion, maintain high water quality, and strengthen climate resilience in the area. Agroforestry is included in the municipality's climate plans.

This SAVi assessment makes use of the climate data from the Copernicus Climate Data Store (CDS); more specifically, it includes data on precipitation, temperature changes, evaporation, and wind speed parameters from different climate scenarios (Representative Concentration Pathways [RCP] 4.5 and RCP 8.5). Each of these has a significant impact on soil erosion, water quality and availability, agricultural productivity and revenues.

The SAVi assessment on the agroforestry project in Welkenraedt includes:

- An economic valuation of the investment cost, externalities (added benefits/avoided costs), and direct (revenues) benefits from the agroforestry.
- An assessment of the climate impacts on the performance of the agroforestry project.
- A financial assessment of the agroforestry project, assessing how additional revenue streams improve the overall financial performance of investments in agroforestry.

The key messages from this analysis are:

- The net benefits of the agroforestry project are estimated at EUR 3.9 million over a 20-year lifetime period for an investment cost of EUR 607,629. This is due to positive externalities, avoided costs, and additional potential revenue streams, such as, for example, fodder and wood pellet production.
- Due to climate change, these benefits will only increase further and make agroforestry projects even more economically attractive. For example, agroforestry has a cooling effect that reduces heat stress on livestock, improving their milk production and thus farmers' revenues.

Table ES1. How can decision-makers and stakeholders use this analysis?

Stakeholder	Role in the project	How will the stakeholder use the results of the assessment with Copernicus Climate Change Service (C3S) data?
Municipality of Welkenraedt	Design, implementation, and finance of projects Design and implementation of climate adaptation strategy	• Policy-makers can use it to make decisions on climate adaptation planning, biodiversity and forest conservation, sustainable agriculture, and economic development. • Public budget holders can use the analysis to appreciate the value generated by natural capital and the extent to which it generates additional co-benefits and avoided costs. • The Welkenraedt municipality can use the results of the analysis to inform concrete activities as part of their climate change adaptation plan. This plan is currently under development. • The municipality also plans wider outreach, engagement, and awareness raising for citizens on nature-based solutions. They can use the results of the analysis to increase citizens' awareness of the benefits of investing in nature.
Global Covenant of Mayors for Climate & Energy network	Best practice sharing on nature-based solutions for climate adaptation	• The network will benefit from sharing the use cases with climate-related data to expand outreach and identify applications for other local governments.
Local civil society organizations (CSOs)	Consultation with the municipality on the design, implementation, and monitoring of climate resilience and biodiversity benefits of agroforestry projects	• CSOs can use the economic valuations of ecosystem services to fine-tune forest restoration that supports climate resilience and sustainable agriculture, and conduct more targeted advocacy. • CSOs can use the economic valuation of ecosystem services from trees to call for investments in tree planting and sustainable agriculture. • The Groupe d'Action Locale (GAL) Pays d'Herve, a local civil society stakeholder, seeks to use the analysis to inform and promote different uses of NBI, in

		particular the use of biomass for heating. The CSO also provides data and intelligence for the analysis. • The Association pour la promotion de l'agroforesterie en Wallonie et à Bruxelles (AWAF) and Natagriwal have provided input and data into the analysis. They can use the results of the analysis for further promotion of agroforestry projects, especially in their outreach to farmers.
Project developers and sponsors of NBI	Implementation and financing of NBI projects	• Project developers and sponsors can use the valuations to design nature-based financing solutions, potentially raising capital from private investors. • Donors and stakeholders from the private sector can utilize the analysis as a baseline to call for green investments in different sectors, like agriculture or water treatment.
Local farmers	Consultation with the municipality on the design, implementation, and monitoring of the benefits of agroforestry projects	• Farmers can help advocate for nature-based solutions when the economic value of the conservation and restoration of the ecosystem services is understood. • The Municpality of Welkenraedt has indicated that farmers require a better understanding, especially in monetary value, of the benefits of NBI. The analysis responds to this need as well by including additional yield and revenue that can be generated through agroforestry.

Table of Contents

List of Figures

List of Tables

Glossary

Causal loop diagram: A schematic representation of key indicators and variables of the system under evaluation that shows the causal connections between them and contributes to the identification of feedback loops and policy entry points.

Discounting: A finance process to determine the present value of a future cash value.

Feedback loop: "A process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself" (Roberts et al., 1983).

Indicator: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (United Nations Environment Programme [UNEP], 2014).

Internal Rate of Return (IRR): An indicator of the profitability prospects of a potential investment. The IRR is the discount rate that makes the net present value of all cash flows from a particular project equal to zero. Cash flows net of financing give us the equity IRR.

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Model transparency: The degree to which model structure and equations are accessible and make it possible to directly relate model behaviour (i.e., numerical results) to specific structural components of the model (UNEP, 2014).

Model validation: The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net benefits: The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.

Net Present Value (NPV): The difference between the present value of cash inflows net of financing costs and the present value of cash outflows. It is used to analyze the profitability of a projected investment or project.

Optimization: A stream of modelling that aims to identify the policy or set of policies that deliver the best possible outcome from a set of alternatives, given a set of criteria (i.e., parameters to optimize) and/or constraints (i.e., available budget) (UNEP, 2014).

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014).

Stock and flow variables: "A *stock* variable represents accumulation and is measured at one specific time. A *flow* variable is the rate of change of the stock and is measured over an interval of time" (UNEP, 2014, p. 51).

System dynamics: A methodology developed by Forrester in the late 1950s (Forrester, 1961) to create descriptive models that represent the causal interconnections between key indicators and indicate their contribution to the dynamics exhibited by the system as well as to the issues being investigated. The core pillars of the system dynamics method are feedback loops, delays, and non-linearity emerging from the explicit capturing of stocks and flows (UNEP, 2014).

Vertical/horizontal disaggregation of models: Vertically disaggregated models contain a high level of detail on the sectoral level (i.e., energy), while horizontally disaggregated models focus on capturing the interconnections between several sectors and contain less detail on the sectoral level (UNEP, 2014).

List of Abbreviations

BAU	business as usual
C3S	Copernicus Climate Change Service
CBA	cost–benefit analysis
CDS	Climate Data Store
CLD	causal loop diagram
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2e	carbon dioxide equivalent
CSO	civil society organization
DEM	Digital Elevation Model
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA5	ECMWF Reanalysis 5th generation
GDP	gross domestic product
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	Intergovernmental Panel on Climate Change
IRR	internal rate of return
LULC	land use and land cover
N	nitrogen
NBI	nature-based infrastructure
NPV	net present value
O&M	operation and management
P	phosphorus
PAWC	plant available water content
RCP	Representative Concentration Pathways
SAVi	Sustainable Asset Valuation tool
THI	Temperature Humidity Index
UNEP	United Nations Environment Programme
USLE	Universal Soil Loss Equation

1 Introduction

The Municipality of Welkenraedt (Belgium) requested a SAVi assessment to provide an estimation of the value-added of agroforestry projects for climate adaptation.

Welkenraedt is located in the Pays de Herve, an area in the southeast of Belgium close to the Dutch and German borders. At the heart of the Meuse–Rhine region, in the cross-border area called Parc des Trois Pays, the Pays de Herve and the Municipality of Welkenraedt are recognized for their peaceful environment and agriculture, which over the centuries has shaped the landscape: meadows surrounded by hedges and trees called "*bocage*." The municipality has around 10,000 inhabitants (2021).

Welkenraedt, and by expansion the Walloon region in the south of Belgium, is promoting agroforestry projects as a cost-effective solution for the climate and biodiversity challenges that the region faces. The municipality included agroforestry in its climate adaptation strategy and seeks to promote it not only for climate resilience but also other co-benefits.

Thanks to the work of the Groupe d'Actions Local (GAL) Pays de Herve, the municipality also mapped out the areas where additional hedges and trees can be planted, and the SAVi analysis has taken this data as the starting point for the development of spatial maps and an economic analysis.

Hedges (low and high) and trees provide a number of important functions: they provide shade, act as wind- and snow breakers, provide overall protection for cattle from extreme weather events, protect against soil erosion, contribute to biodiversity, and fulfill a generally important function in the ecosystem. Agroforestry projects are complex, and their benefits also depend on the different compositions of species of hedges and trees (Association pour l'agroforesterie en Wallonie et Bruxelles [AWAF], 2020). This document provides an overview of the different species' compositions and their benefits to the area. The SAVi assessment is customized based on the information in this document and on discussions with the municipality on how to best reflect the complexity of the performance of different trees and hedges.

The simulated agroforestry project comprises an area of approximately 100,000 m^2 of low and high hedges and trees.

As is common with nature-based infrastructure (NBI) providing these multiple benefits, they are not being accounted for or valued. This makes it easier to discard maintenance for agroforestry projects and more difficult to demonstrate that investing in agroforestry is worthwhile.

The municipality has been looking for further evidence on the costs, revenues, and co-benefits that agroforestry projects can bring. In addition, the municipality has been looking for more accurate information on climate variables that could potentially impact the projects. In response, we proposed a customized assessment with the SAVi methodology.

The SAVi analysis provides the municipality with a diverse range of information—from spatial maps, climate data, and an economic valuation—that can be used to further advocate for the use of agroforestry projects as a worthwhile investment for citizens, farmers, and the municipality. It provides a first insight into the opportunities that NBI brings, especially in light of the climate and biodiversity crises. The information can also be used to further advance and implement the climate adaptation strategy of the municipality.

Welkenraedt is an active member of the Global Covenant of Mayors for Climate & Energy network and will also be able to share information on the investment case for NBI through that network.

2 Methodology: SAVi Welkenraedt - Agroforestry

2.1 Causal Loop Diagram

The SAVi Nature-Based Infrastructure (NBI) model provides a blueprint for discussions on the risks, benefits, and climate impacts of agroforestry projects (Bassi et al., 2019). For this assessment, we have adjusted and customized the causal loop diagram (CLD) for NBI to the agroforestry project in Welkenraedt.

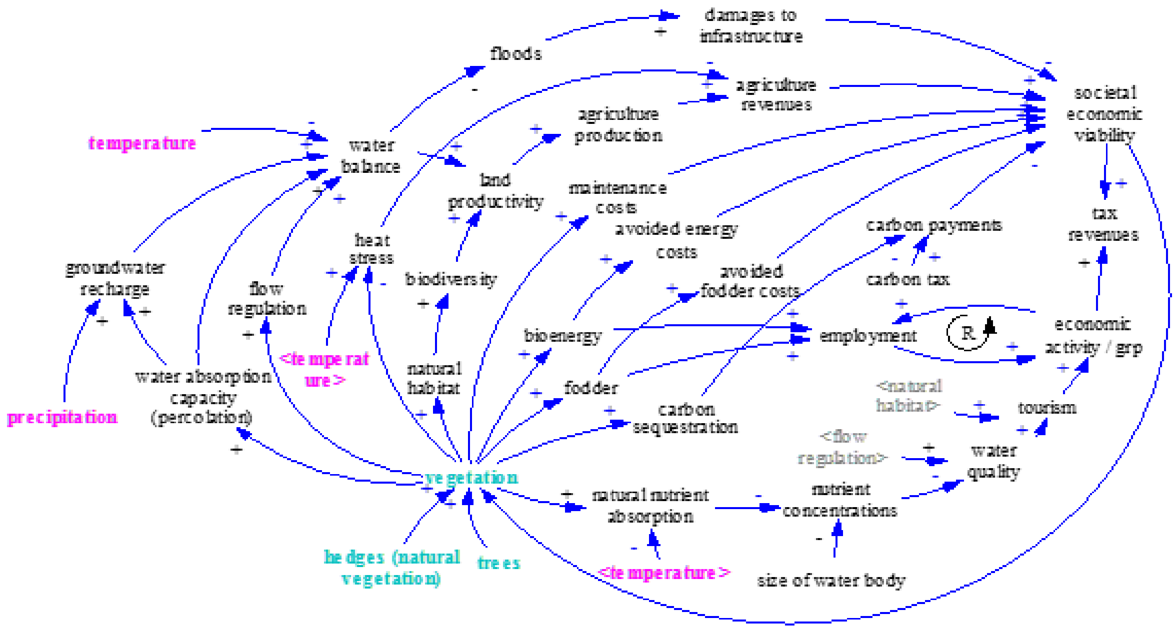
A CLD is an analytical tool that is part of the SAVi assessment and helps to capture the local dynamics around the agroforestry project. It was designed together with the Municipality of Welkenraedt and an agroforestry expert from the Walloon region. The CLD is the first step in customizing the assessment to the local context. The CLD presented in Figure 1 shows the interconnectedness of socio-economic and environmental key indicators. It allows for a greater understanding of the potential impacts of sustainable agroforestry investments and climate change and how these impacts would unfold through the system.

Figure 1 presents the CLD of the basic dynamics that underlie the analysis of the agroforestry project.

How to read a CLD:

- "A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction.
- A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction" (Bassi et al., 2016).

Figure 1. CLD for agroforestry in Welkenraedt



The starting point of the CLD is green variables that refer to the agroforestry project: hedges and trees increase vegetation in the area. These have a variety of impacts. The direct services provided by additional vegetation are presented directly around the vegetation variable. Specifically, vegetation can create bioenergy, produce fodder, absorb nutrients, contribute to water percolation and absorption capacity, increase flow regulation, and reduce heat stress. More specifically:

- More vegetation means more water absorption capacity in the area and better regulation of water flows. Better water absorption has a positive impact on groundwater recharge as well as on overall water balance. Flow regulation also contributes to the water balance, which in turn reduces floods. Fewer floods has a positive impact on damages to water infrastructure, which in this way has a positive impact on the viability of agroforestry projects from a socio-economic perspective. A better water balance also has a positive impact on land productivity, which in turn increases agricultural production and revenues, providing another positive argument for the investment case in agroforestry from a societal perspective.
- More vegetation also means less heat stress for cows, which has a direct impact on agriculture revenues.
- More vegetation has a positive impact on the natural habitat and biodiversity of the area. This also contributes to land productivity and, ultimately, agriculture revenues.
- More vegetation leads to more potential for bioenergy (wood pellets), resulting in lower costs for energy from other sources and a positive impact on the societal economic viability of agroforestry projects.

- More vegetation has a positive impact on fodder production, leading to a reduction in fodder costs for farmers and adding to a positive societal return for agroforestry projects.
- Higher potential for bioenergy and fodder production results in the creation of more local employment, as opposed to purchasing biomass and fodder elsewhere. Jobs are also created from tree planting.
- Agroforestry has a direct carbon sequestration benefit captured in the CLD, as well as a nutrient absorption benefit. The latter is also impacted by temperature changes. Nutrient absorption impacts the nutrient concentration (also impacted by the size of the water body) and that in turn has impacts on the water quality of the area, impacting tourism and tourism-related economic activity, all of which influences the societal economic viability of the project.

The pink variables are climate variables that we link to the CDS and have an impact on different variables in the CLD. While agroforestry is linked to economic benefits, climate change can have a notable effect on project outcomes. Precipitation and temperature have an impact on the water balance and groundwater recharge, which are both eventually linked to floods and increased damage to infrastructure. Temperature has an impact on heat stress in cattle. An increased number of months of heat stress due to climate change has an eventual impact on farmers' revenues. Agroforestry projects have a significant impact on reducing heat stress, and thus, under climate change scenarios, agroforestry projects also become economically more attractive.

2.2 Climate Data and the Climate Impact of Agroforestry Projects

The Copernicus CDS provides data to forecast how different climate variables will change in Welkenraedt over the project timeline. Figures 2 through 11 show how precipitation, runoff, air temperature, evaporation, and wind speed will change in Welkenraedt over the next 40 years. Two climate scenarios are included:

- The Representative Concentration Pathways (RCP) 4.5 climate scenario assumes that emissions peak in 2040 and begin to decline thereafter.
- The RCP 8.5 scenario assumes that fossil fuel-intensive forms of energy generation continue to be used heavily through the remainder of the century.

RCPs are trajectories of the concentration of carbon dioxide equivalent (CO_2e) greenhouse gas emissions used by the Intergovernmental Panel on Climate Change (IPCC) to determine the policy ambition required to realize different global warming outcomes. Originally, four main pathways were used, each considering different radiative forcing values in the year 2100. For instance, the RCP 4.5 scenario corresponds to the 4.5 W/m^2 radiative forcing value. Three additional trajectories have been added since the IPCC Fifth Assessment Report (AR5)[1].

[1] See the report here: https://www.ipcc.ch/report/ar5/syr/

The blue line represents the historical data (ECMWF Reanalysis 5th generation [ERA5] database), and the red line represents the climate projection (Coupled Model Intercomparison Project Phase 5 [CMIP5]) based on different data sets with results from different global circulation models.

The ERA5 is a database of global climate indicators from January 1950 until now.[2] CMIP5 is the database consisting of future projections of global climate indicators.

Figure 1. Predicted change in precipitation under RCP 4.5

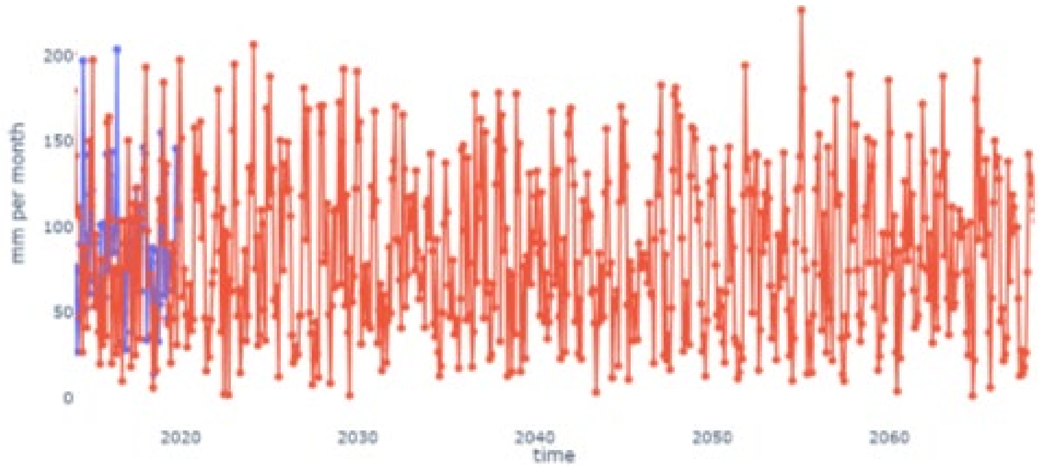
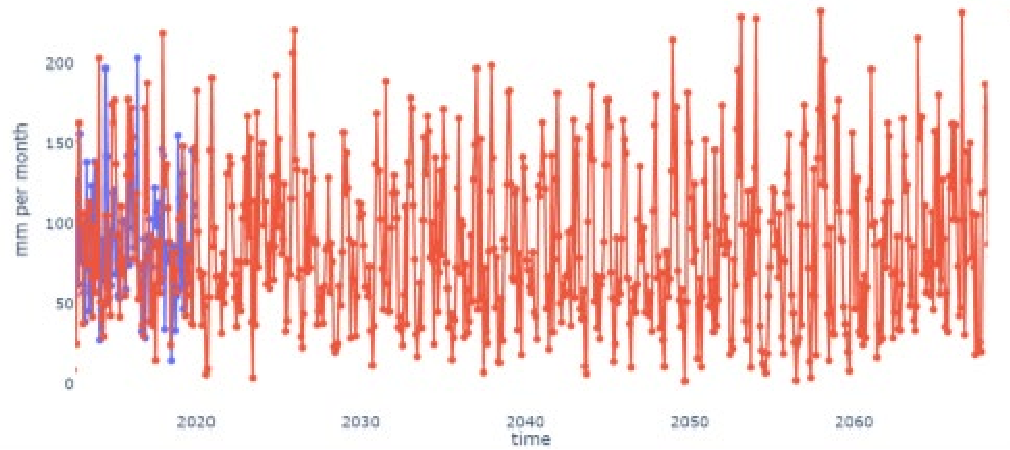


Figure 2. Predicted change in precipitation under RCP 8.5



High precipitation events will be more frequent under both climate scenarios, but this is more evident under the emission-intensive RCP 8.5 climate scenario. The spikes in both figures represent events with high levels of precipitation. These spikes tend to become greater over time under the RPC 8.5 scenario.

[2] https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5

Figure 4. Predicted runoff volume under RCP 4.5

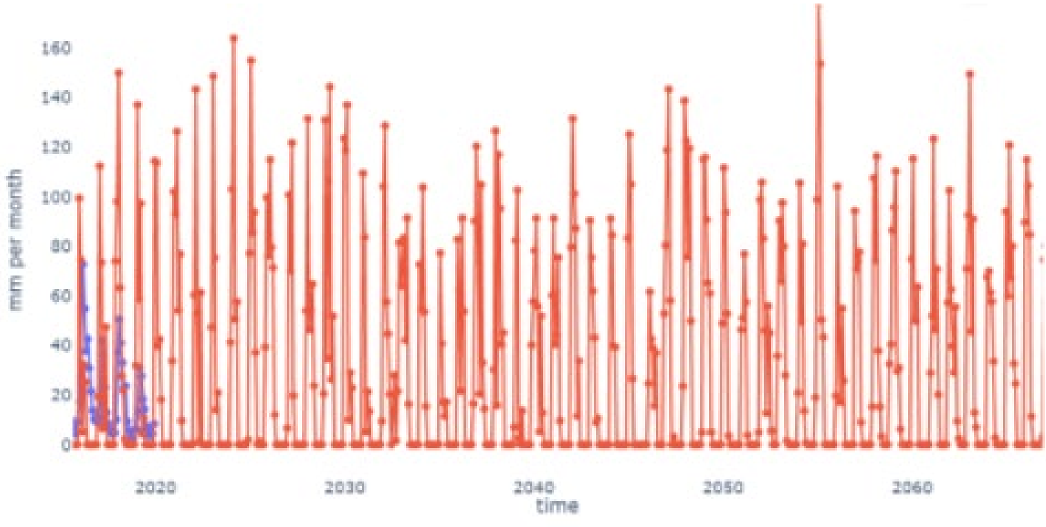
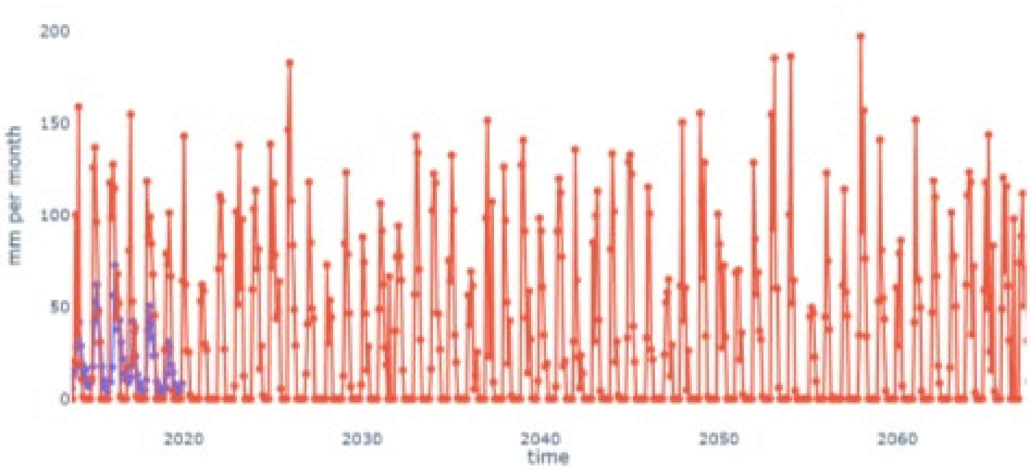


Figure 5. Predicted runoff volume under RCP 8.5



Increased levels of precipitation will lead to a higher volume of surface runoff during heavy rain events. Changes to runoff volumes in Welkenraedt are also included in the Copernicus CDS. The results show that runoff volumes are expected to increase over the coming decades under RCP 8.5, while the changes are less obvious under RCP 4.5. These changes in runoff are in line with what we would expect, given the predicted changes to precipitation under the same scenarios.

If runoff and precipitation increase, the benefits of the agroforestry project that are captured in the integrated cost–benefit analysis (CBA) will be impacted. Runoff from agricultural land is responsible for carrying nutrients, such as nitrogen and phosphorus, to local waterways. These nutrients then need to be removed by a wastewater treatment facility. Thus, with additional runoff expected over the rest of the century, we can expect higher nitrogen and phosphorus concentrations to be found in local waterways. In fact, one study of Jialing River

Watershed, China, found that “the effects from runoff increment leads to approximately 28.6% and 22.5% increases of TN and TP pollution load, respectively” (Wu et al., 2012). As a result, water treatment costs will be higher, with increases in runoff volume expected over the next 40 years.

As agroforestry projects have a natural capability of removing nitrogen and phosphorus, the economic viability for agroforestry increases. Agroforestry avoids wastewater treatment costs by preventing some of these nutrients from ending up in waterways. According to one study conducted at Glensaugh in Scotland, “forest[s] ha[ve] the capacity to not only reduce surface runoff but also to ‘soak up’ runoff generated further up the hillslope” (Chandler et al., 2017).

For this assessment, we do not have location- or project-specific data that would allow us to quantify the extent of the impact of the climate variable on the nitrogen and phosphorus removal potential of agroforestry. However, the literature suggests that the agroforestry project becomes even more economically attractive because runoff will increase in Welkenraedt over the next 40 years. And agroforestry can mitigate some of the additional negative impacts of increased precipitation and runoff.

In addition to avoiding water treatment costs, agroforestry is also associated with avoiding flood damage. Increased runoff has been associated with increased flooding and flood damage costs. It has been shown, however, that “by intercepting rainfall, enhancing soil infiltration and removing water from the soil, trees help regulate storm-water and mitigate local flooding events” (Hirons & Sjöman, 2018). Thus, agroforestry can reduce flooding and resulting flood damages from increased precipitation and runoff.

If levels of precipitation do increase in Welkenraedt in the coming decades, the agroforestry project will become even more economically attractive due to avoided water treatment costs and avoided flood damage.

Figure 6. Changes to air temperature under RCP 4.5

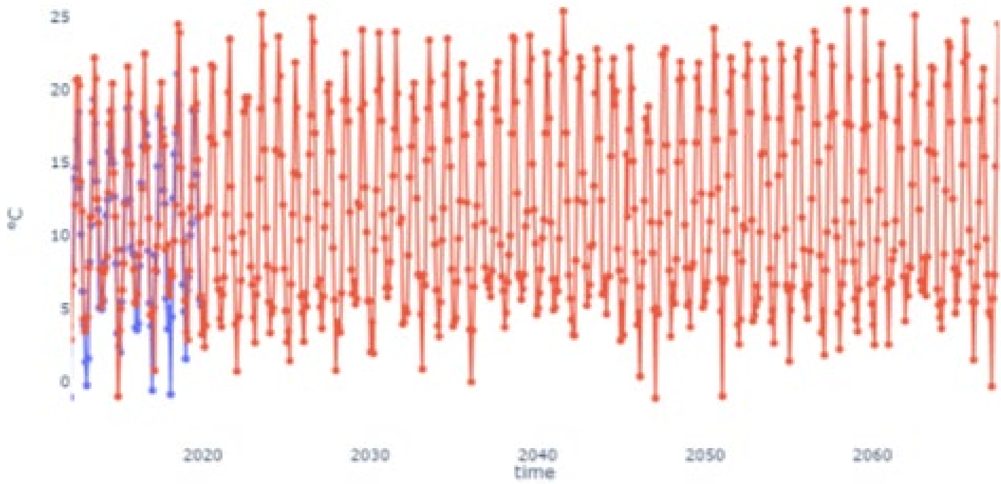


Figure 3. Changes to air temperature under RCP 8.5

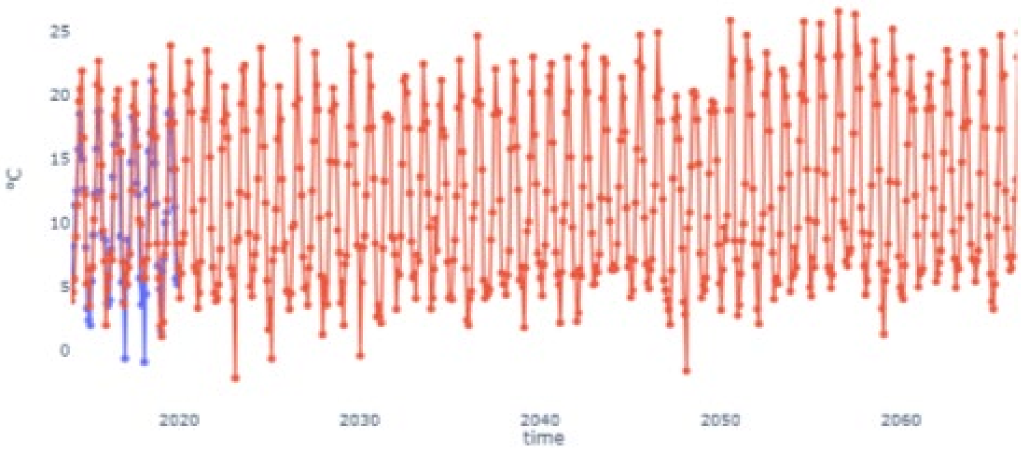


Figure 6 and Figure 7 both show an increasing trend in air temperature; however, this increase is larger under the RCP 8.5 scenario. Temperature changes will impact the effectiveness of the agroforestry project in several ways, which affects the values in the integrated CBA.

The literature indicates that temperature changes impact the carbon sequestration potential of agroforestry projects. One study conducted in China's Yunnan province found that "a temperature increase of 2°C resulted in sharp decreases in the [carbon sequestration potential] of coniferous forest vegetation" (Zhou et al., 2018). Thus, if the agroforestry project is not pursued in Welkenraedt, we can expect the temperature increases to reduce the carbon sequestration potential of the vegetation in the area. However, if the proposed agroforestry project is implemented, some of these negative effects can be avoided or offset. Thus, the project appears even more valuable in the long term if we assume, per the Copernicus CDS, that air temperature will increase in the coming years.

Another benefit of agroforestry is that trees have a cooling effect that can reduce heat stress on both humans and livestock. As seen in the results of the CBA, reduced heat stress for dairy cows improves milk yields. With temperatures expected to increase even more in the coming years, the benefits of reduced heat stress that are attributable to the agroforestry project will be even greater under both climate scenarios.

Additionally, the cooling effect of trees may also increase labour productivity and have a positive effect on health. In fact, it has been shown that the cooling effect of trees is especially beneficial to the health of "the elderly, the sick, and children" (Hirons & Sjöman, 2018). Again, with temperatures expected to increase under both climate scenarios, the benefit of cooling provided by the agroforestry project will be even greater than is estimated in the CBA by mitigating lost carbon sequestration, improving cow milk yields, increasing labour productivity, and improving human health.

Figure 8. Predicted changes to evaporation under RCP 4.5

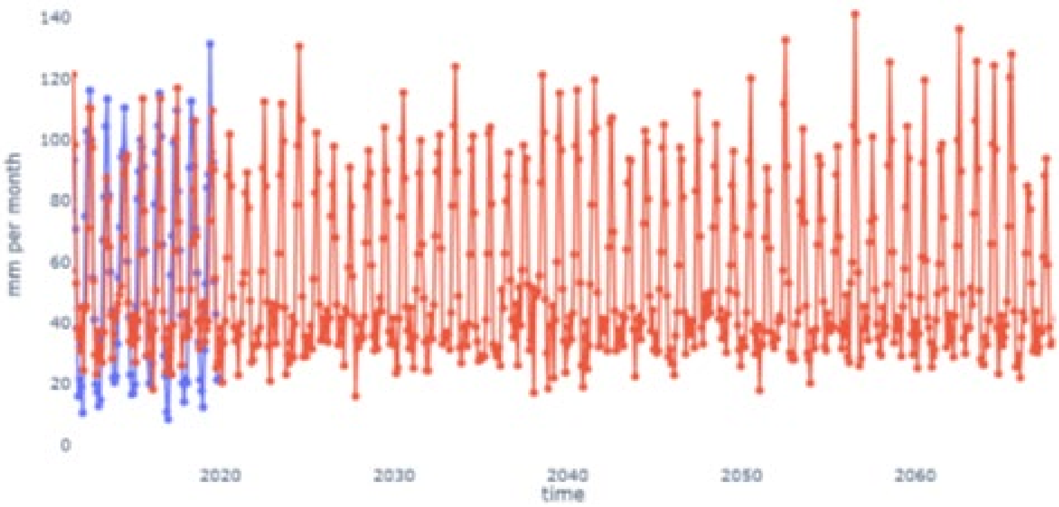
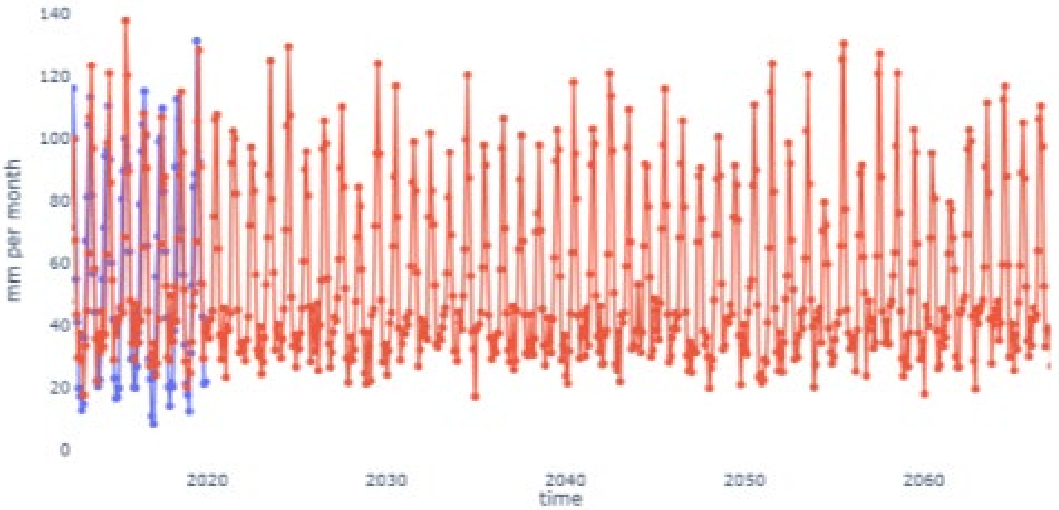


Figure 9. Predicted changes to evaporation under RCP 8.5



Under the RCP 4.5 scenario, evaporation seems like it may increase slightly over the remainder of the decade. On the other hand, under the RCP 8.5 scenario, evaporation seems to be relatively unchanged, if not decreasing slightly, over the coming years. As with changes in the other climate variables, changes in evaporation may change the economic attractiveness of the agroforestry project.

Increased levels of evaporation may have damaging effects on the environment. It has been shown that "evaporation causes the upper levels of soil to become dry and hard. When rain or irrigation water then falls onto the soil, a significant portion of the water runs off of the soil instead of soaking into the ground. When the ground is too dry, plants may fail to grow, and the soil is more susceptible to wind erosion" (Motes, 2019). Thus, if evaporation increases in Welkenraedt, as predicted by RCP 4.5, agricultural yields in the region will suffer. In addition, the negative effects of increased runoff will be amplified.

Agroforestry can prevent these negative climate impacts. One study conducted in Kenya found that "trees could reduce annual soil evaporation directly beneath their canopy by an average of 35%" (Wallace et al., 1999). Thus, if evaporation does increase over the coming years, the agroforestry project will help to mitigate these negative effects. The resulting avoided costs will increase the investment case for the agroforestry project.

Figure 10. Predicted changes to wind speed under RCP 4.5

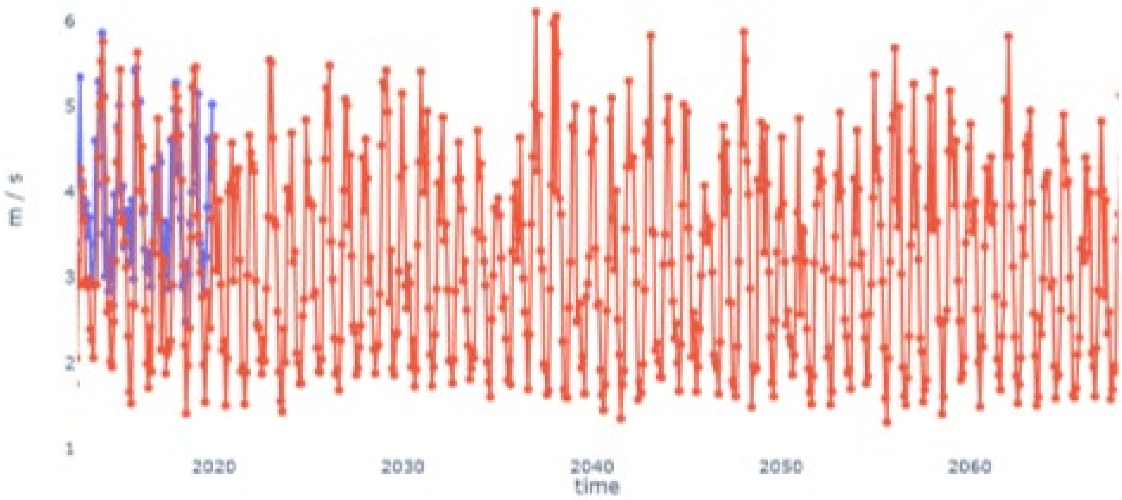
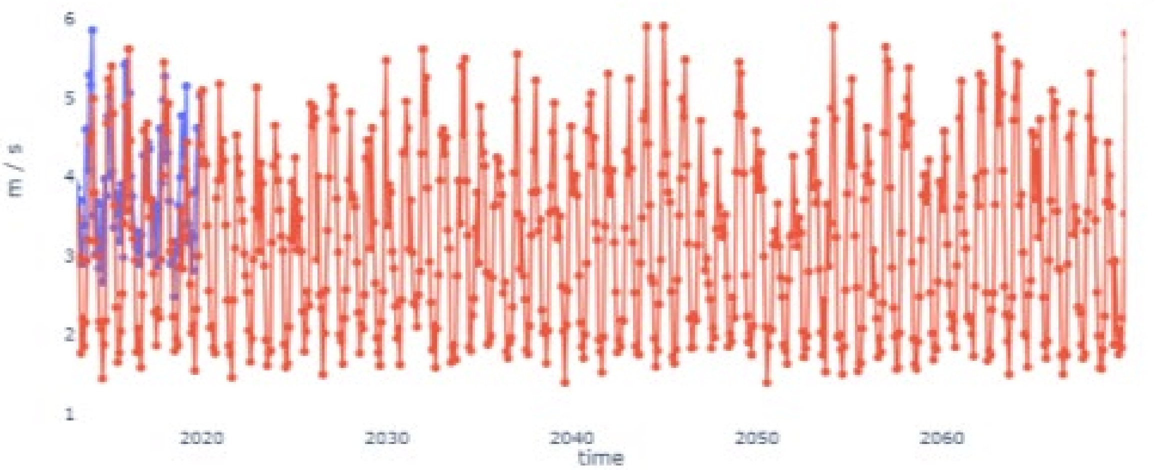


Figure 11. Predicted changes to wind speed under RCP 8.5



Under the RCP 4.5 scenario, it seems as if wind speed will decrease slightly over the remainder of the century. On the other hand, it seems like wind speed may increase slightly under the RCP 8.5 climate scenario. It also seems like there will be more intense high-wind events under the RPC 8.5 scenario, which is evident by the several spikes toward the end of the century.

While a reduction in wind speed and high-wind events, as is predicted under the RCP 4.5 scenario, is not likely to reduce the expected benefits of the agroforestry project, an increase in wind speeds and high-wind events are likely to make the project more economically attractive. The agroforestry project in Welkenraedt will be even more economically attractive if wind increases since it has been shown that when agroforestry projects are implemented near agricultural land, yields tend to increase due to the windbreak provided by the trees.

According to Jude Hobbs, a hedgerow specialist, "when a hedgerow is planted perpendicular to the prevailing winds, it can reduce wind speeds by up to 75% at distances up to ten times the height of the hedgerow on flat land" (Stross, 2020). Further, one study conducted in Canada conservatively estimates that when trees are planted, they can increase crop yields by 5% (Alam, 2014). It is evident, then, that increased wind speed can lead to a reduction in agricultural yields. However, agroforestry can prevent this by protecting crops from climatic changes.

2.3 Spatially Explicit Analysis

Spatial maps generated with the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model were used as a part of this analysis to precisely estimate the extent to which different ecosystem services in Welkenraedt will be affected by the agroforestry project. The InVEST model generates land use and land cover (LULC) maps to estimate the impact of land-use changes on different ecosystem services.

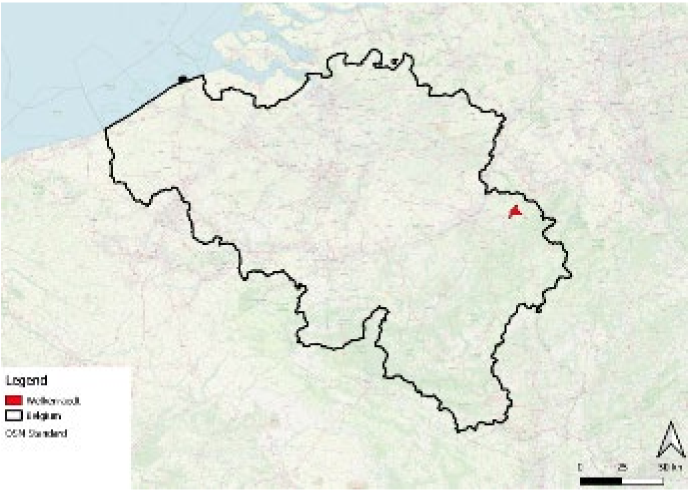
For each model, we used two different LULC maps depending on the two different scenarios that have been considered in this analysis:

- Business as usual (BAU): the original LULC map has been used.
- Tree Rows (ROWS): we added tree rows to the original LULC map that separate crop fields and can be found in the study area.

We include here the results for carbon sequestration and habitat quality, but the full scope of the analysis, which has been used to feed into the results of the integrated CBA, is available in the Annex to this report

Specifically, we found that the agroforestry project will result in an increase in carbon sequestration, pollination, and habitat quality in the region. It will also reduce phosphorus and nitrogen exports in the region. Additionally, spatial analyses were performed to estimate the agroforestry project's impact on habitat quality, water yield, and sediment delivery.

Figure 12. Map of Belgium and Welkenraedt (in red)



Figures 13 and Figure 14 illustrate the changes in carbon sequestration from agroforestry: the analysis demonstrates that the specific agroforestry project in Welkenraedt will lead to 0.5% more carbon sequestration.

Figure 13. Map of Welkenraedt, BAU scenario for carbon sequestration

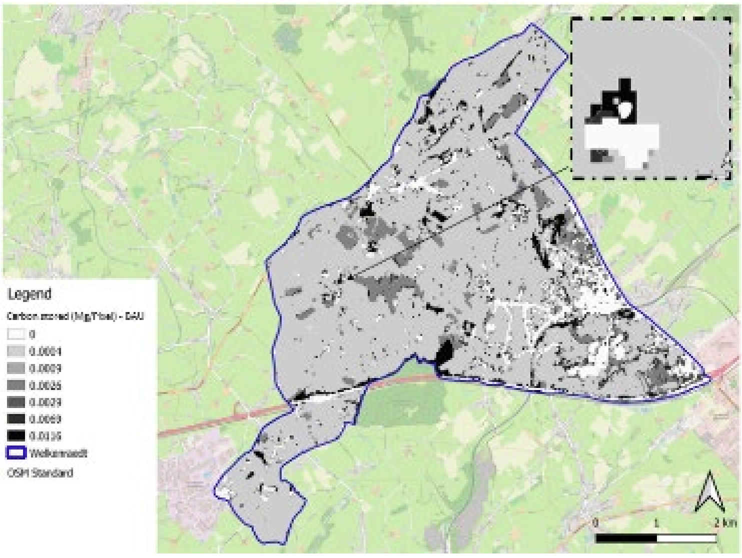


Figure 14. Map of Welkenraedt, ROWS scenario for carbon sequestration

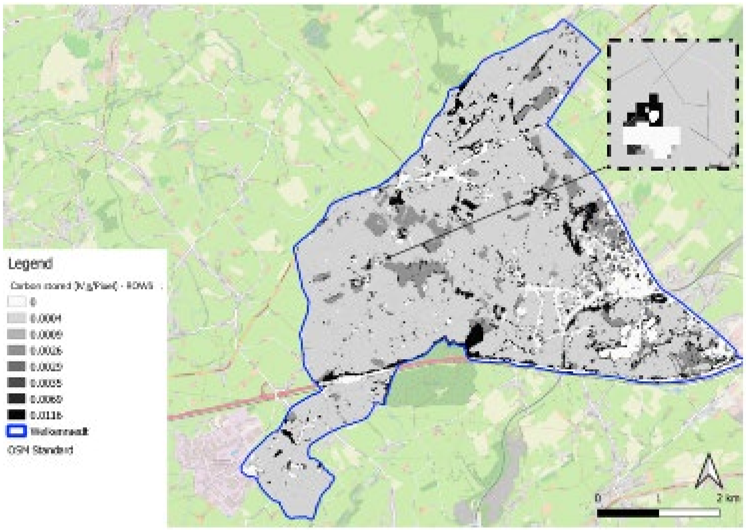


Table 1. Carbon sequestration

	Sum (Mg)	Change from the current scenario %
BAU Scenario	85,789	0.5
ROWS Scenario	86,198	

Figures 15 and 16 represent changes in habitat quality due to the agroforestry projects: the analysis demonstrates that the specific agroforestry project in Welkenraedt will lead to an improvement of 1.8% in habitat quality.

Figure 15. Map of Welkenraedt, BAU scenario for habitat quality

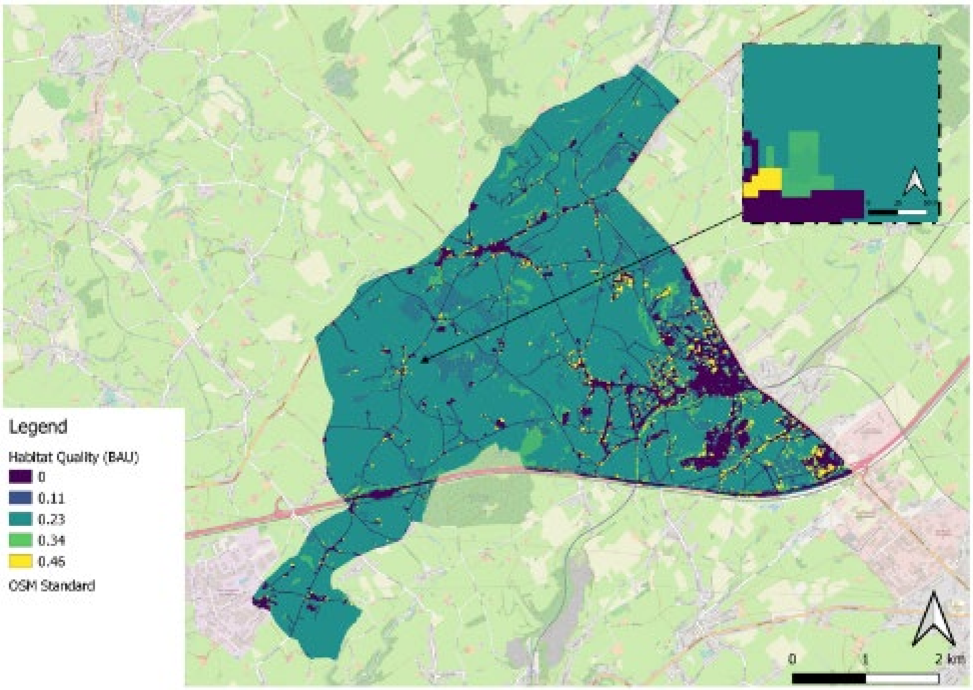


Figure 16. Map of Welkenraedt, ROWS scenario for habitat quality

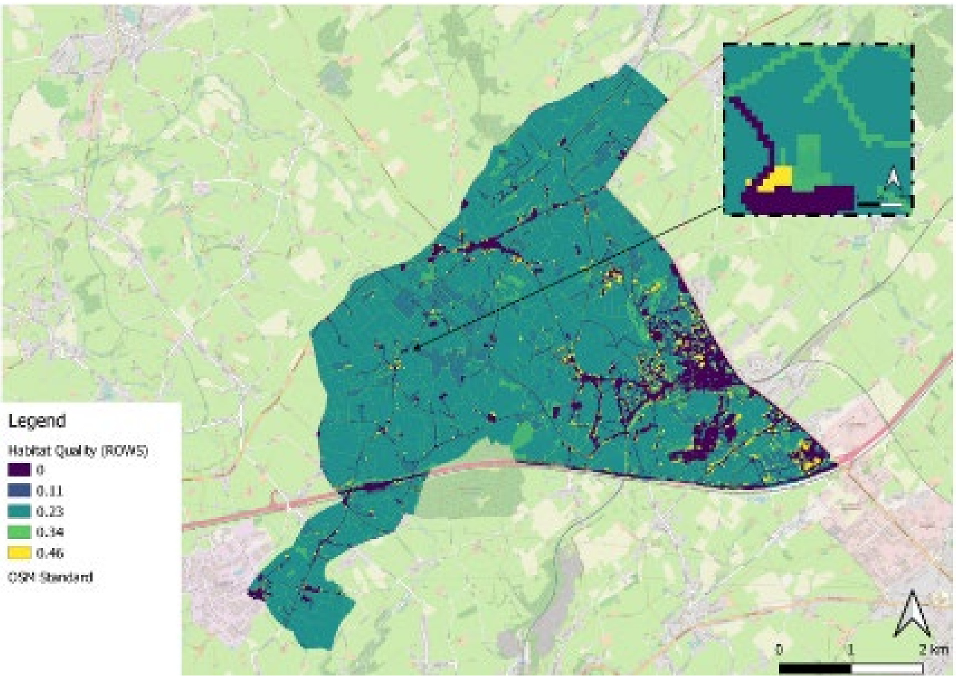


Table 2. Habitat quality

	Mean	Change from the current scenario %
BAU Scenario	0.211	1.896%
ROWS Scenario	0.215	

2.4 Assumptions and Data Inputs for the SAVi Assessment

Tables 3 and 4 provide an overview of the data inputs, assumptions, and calculation of the items in the integrated CBA.

Table 3. Project information

Area (simulated with InVEST model)		
Tree rows area (total)	98,916.30	m^2
Tree rows area (total)	9.89	ha
Tree area (single tree)	0.42	m^2
Trees (pixels)	235,515	unit
Costs (based on Van Raffe & De Jong, 2014)		
Plant purchase	28,262	€
Planting	357,983	€
Plant protection	221,384	€
Total	607,629	€

Table 4. Explanation of the assumptions and data references

Investment and operation and management (O&M)	
Capital cost	Capital costs include investments in plant purchase and planting activities. We calculated the number of pixels representing planted trees, where 1 pixel is equal to a single tree. The number of expected trees in our simulation is 235,515 units. Next, using the data retrieved from Van Raffe and De Jong (2014), we assumed that the cost of plant purchasing and planting is EUR 0.12 for tree-1 and EUR 1.52 for tree-1, respectively. We estimate that the total capital costs will amount to EUR 386,245.
O&M cost	Using the O&M cost of EUR 0.94 for tree-1, retrieved from Van Raffe and De Jong (2014), we estimate that the total costs will amount to EUR 221,384. This O&M cost is for protecting the hedges and maintaining them.
Externalities	
Labour income: Agriculture and other industries	Labour income in agriculture and other industries was calculated using an estimate from Mills (2002), indicating that the total (indirect and direct) income impact from GBP 1 million spent on hedge restoration amounts to GBP 1,364,436. From there, we assumed that the total labour income would amount to EUR 749,612, considering the total investment and O&M costs of the project.
Nitrogen (N) removal	Avoided costs of N removal over 20 years were calculated starting from the outputs of the Annual Nutrient Delivery Ratio InVEST model, which shows that planted trees will decrease N exports by 377 kg in the study area. Next, we multiplied that value by the cost of removing N in waste treatment plants from three different studies, which amounts to EUR 4.44/kg, EUR 7/kg, and USD 8.5/Kg (Alam et al., 2014; Preisner et al., 2020; Tamburini et al., 2020). Finally, we calculated the average value of the avoided cost of N removal in the study area, based on the average of those three values, which amounts to EUR 46,857 in avoided cost over 20 years.
Phosphorus (P) removal	Avoided costs of P removal over 20 years were calculated starting from the outputs of the Annual Nutrient Delivery Ratio InVEST model, which shows that planted trees will decrease P exports by 102 kg in the study area. Next, we multiplied that value by the cost of removing P in wastewater treatment plants from two different studies, which amounts to USD 61.20/kg and EUR 24.46/kg (Alam et al., 2014; Preisner et al., 2020).

Water supply	According to the Annual Water Yield InVEST model, the newly planted trees will increase water yield volume by 10,000 m^3. Assuming that the water price is EUR 0.1/m^3, total avoided costs of water supply will amount to EUR 1,000 per year, or EUR 20,000 over a period of 20 years.
Carbon sequestration	According to the Carbon Sequestration InVEST model, carbon sequestration in the study area will amount to 4.6 tC/ha/year, which corresponds to 16 tCO_2/ha/year. By multiplying that value for the number of ha covered by planted trees (9.89 ha) and by the sequestered carbon value (USD 10/tonne or USD 9/tonne) (Lewandrowski et al., 2004), we obtain that the benefits of carbon sequestration will amount to EUR 27,495 over 20 years.
Biological control	Tree-based intercropping ecosystem services amount to CAD 75/ha/year, according to Alam et al. (2014). By multiplying that value with 9.89 ha, which is the number of ha that will be covered by planted trees, we obtain that the benefits of biological control in the study area will amount to EUR 9,496 over 20 years.
Revenues	
Tourism and landscape	According to Rosenberger et al. (2017), the median value estimate of picnicking is USD 23.62 per person per day. Assuming that planted trees will attract 40 people per weekend over 20 years, the added value of tourism will be EUR 832,705.
Milk production (additional revenues from reduced heat stress)	Temperature Humidity Index (THI) is a measure that combines the impacts of environmental temperature and relative humidity and is a useful way to assess the risk of heat stress in livestock (TermotecnicaPericoli, 2018). The formula to calculate THI is the following: THI =0.8*T + RH*(T-14.4) + 46.4 Where T = ambient or dry-bulb temperature in °C and RH = relative humidity expressed as a proportion. In this analysis, we first calculated additional milk production by estimating THI in July in an area without trees (T=30°C, RH=0.78) and with them (T=27.85°C, RH=0.78), considering that areas with trees are cooler by 2.15˚C (Copernicus Climate Change, 2020). This value is equal to 0.16 kg of milk/cow/day. We then multiplied it by the number of hot days in a year, by 20 (years considered), by 2,762 (number of cows in the study area), and by EUR 0.267/kg (farm-gate prices for milk in Belgium) (European Milk Board, 2016). We deduced that the additional revenues in milk production from planted trees will amount to EUR 139,845.
Fodder production	Starting from the number of trees, 235,515 units, we multiplied that value by the fodder production (kg) of the species *Fraxinus excelsior.*

	Considering that only 6% of the total trees will be similar in size to the *Fraxinus*, we obtain that the total annual fodder production from planted trees will amount to 706,545 kg. Assuming that only 30% of leaves will be collected, we deduced that the total annual fodder production that will be utilized amounts to 211,963.50 kg. Considering that fodder costs approximately EUR 150/kg (CLAL, 2020), the fodder revenues will amount to EUR 31,795/year, or EUR 635,891 over 20 years.
Wood pellet production/biomass projects	Starting from the number of ha that will be covered by trees, 9.89 ha, we multiplied this value by 15 m^3/ha, which is an intermediate value representing biomass production of tree hedges that was provided by the client. Secondly, we multiplied the obtained biomass production (148.37 m^3) by 1.4 in order to express this value in tonnes (207.72 tonnes). Since a tonne of wood corresponds to roughly 3-4 stacked m^3, we multiplied the total tonnes of biomass by 3.5. According to the documents shared by our client, the economic value of one MAP of biomass is EUR 24. Therefore, by multiplying EUR 24 * 727.03 MAP/year * 20 years, we can deduce that the economic revenues from wood pellet production will amount to EUR 348,976 over 20 years.
Crop yield increase from windbreaker effect	National statistics (StatBel, 2019) provide the number of hectares of different crops (grains, forage, apples, pears) in Welkenraedt. We multiplied them by the average land productivity of those crops in Belgium between 2000 and 2018 (FAOSTAT, 2020) to obtain the value of production in the study area (total kg). Furthermore, data from the European Commission (2016) made it possible to assess the average yield increase for different crops thanks to the windbreaker effect of tree rows, which is 19.38% (we also considered 10.00% as a lower expected increase). By multiplying the number of crop yields in Welkenraedt by 19.38% and 10.00%, we obtain the additional annual production caused by the beneficial windbreaker effect. Next, the average sale prices for wheat (and also forage), apples, and pears were extracted from Direction de l'Analyse Economique Agricole (2020) and European Crop Protection (2020), which amounts to EUR 0.16/kg, EUR 0.45/kg, and EUR 0.32/kg, respectively. By multiplying those values by the additional crop production and by 20 (the total number of years), the total additional revenues of agricultural production will amount to EUR 942,747 (windbreaker effect of 10.00%) and EUR 1,826,572 (windbreaker effect of 19.38%).

3 Results: SAVi Welkenraedt – Agroforestry

3.1 Integrated CBA

Table 5 presents the integrated CBA of the agroforestry project in Welkenraedt over a lifetime of 20 years. The table also indicates the externalities and revenues that are impacted by climate variables, as discussed in Section 2.2 of this report.

The investment and O&M costs of the agroforestry project amount to EUR 607,629 over the 20 years. The agroforestry project generates a range of benefits and avoided costs that we quantified and monetized. It also generates direct additional revenues for different stakeholders. Adding the externalities (avoided costs/added benefits) together with added revenues demonstrates that the agroforestry project brings a net benefit to the Municipality of Welkenraedt and its citizens, and from a societal economic perspective, it is an investment opportunity with positive returns.

First, additional labour income is being generated through the planting and maintenance of hedges. Over 20 years, this amounts to EUR 749,612. Second, the added value of selected ecosystem services was assessed. For this assessment, we looked at the value of nitrogen and phosphorus removal, the regulation of water supply, carbon sequestration, and pollination. The assumptions behind these valuations can be found in Table 6.

For example, the economic value of nutrient removal was estimated using the cost of building a wastewater treatment facility that would achieve the same results as nutrient uptake from trees. This is a hypothetical case, both because of the potentially very small size of the treatment plant required and for the difficulty of conveying water across the landscape, which would not make it possible to use a centralized water treatment plant. The results are illustrative and aim to capture a value offered by nature, as compared to the cost of offering built infrastructure.

Finally, we made several estimations of direct monetary benefits and additional revenues that are being generated through the agroforestry project. These include the following:

- Around the agroforestry project in Welkenraedt, there have been discussions on trimming parts of the hedges for **wood pellet production** that can be sold and used as biomass for energy generation. This has the potential to generate an additional EUR 348,976 in revenue.
- The Pays d’Herve **landscape** area surrounding the municipality will benefit from the agroforestry project in relation to **tourism revenues,** which are expected to increase by EUR 832,705.
- The hedges serve as high-quality **fodder** for the cows and save farmers up to EUR 635,891 in fodder.
- Because of the shade that hedges provide, cows suffer less from heat stress and produce more **milk**, corresponding to EUR 139,845 in added revenue. This impact will be even larger under climate scenarios.

- Finally, **agricultural yield** for different crops benefits directly from agroforestry because of the windbreaker effect. This results in an additional EUR 1,384,659 in agriculture production revenues.

Table 5. Integrated CBA on agroforestry in Welkenraedt

Integrated CBA (EUR)	**Agroforestry**	**Related climate variable**	**Impact on economic viability**
Investment and O&M			
Capital	386,245		
O&M cost	221,384		
Total Investment and O&M (1)	**607,629**		
Externalities – avoided costs/added benefits			
Labour income: agriculture and other industries	749,612		
Value of selected ecosystem services			
N removal	46,857	Increase in precipitation and runoff	+
P removal	77,851	Increase in precipitation and runoff	+
Water retention capacity	20,000		
Carbon sequestration	27,495	Increase in air temperature	+
Pollination	9,496		
Total Externalities (2)	**1,227,584**		
Revenues			
Wood pellet production/biomass projects	348,976	Increase in wind speed	+
Tourism and landscape	832,705		
Fodder production	635,891	Increase in wind speed	+
Milk production (reduced heat stress effect)	139,845	Increase in air temperature	+
Agriculture production (wind breaker effect)	1,384,659	Increase in wind speed	+
Total Revenues (3)	**3,342,076**		
Net result (2) + (3) - (1)	**3,962,031**		

3.2 Project Finance Model

The main purpose of the SAVi project finance model is to assess the financial viability of the project and calculate the expected return on investment when the environmental, social, and economic externalities are taken into account. NBI projects, such as the agroforestry project, do not frequently generate revenue in the traditional sense of incoming cash flows. However, as we can see from the integrated CBA, they provide a range of direct benefits for different stakeholders as well as externalities in the form of avoided costs and added benefits.

To demonstrate the investment worthiness of NBI through the calculation of the net present value (NPV) and internal rate of return (IRR), the SAVi project finance model treats those externalities as revenues. This approach makes sense for decision-makers who want to take a more holistic approach when assessing whether the project would deliver value for money to society over its life cycle. When the NPV and IRR calculations integrate externalities, they are referred to as sustainable net present value (S-NPV) and sustainable internal rate of return (S-IRR), respectively.

Table 6 captures the results of the project finance model. Based on revenues from fodder and milk production, the project is hardly investment worthy: the NPV is negative while the IRR is 1.22%, which is below the discount rate used for this valuation. However, when all revenues that the agroforestry project generate are considered, the project generates a positive return, with the IRR increasing to 20.88%. Furthermore, when all additional revenues and externalities are taken into account, the S-IRR increases to 27.85% and the S-NPV to EUR 1,430,000.

Table 6. IRR and NPV for the agroforestry project in Welkenraedt

Scenario	IRR	NPV
Based on additional fodder and milk production	1.22%	- EUR 120,000
Based on all additional revenues	20.88%	EUR 930,000
Based on all additional revenues and externalities	27.85%	EUR 1,430,000

The financial results demonstrate that the project generates a sufficient level of revenue for the different costs involved. Therefore, it can be considered a worthwhile use of public resources. This finding is also confirmed by the attractive S-NPV and S-IRR values. They demonstrate that the externalities assessed are financially material when integrated into the financial model and generate significant returns for local stakeholders as well as for society.

Both the RCP 4.5 and RCP 8.5 scenarios have a significant impact on climate variables, such as temperature and precipitation. We can expect the IRR and NPV to be higher under the RCP 4.5. and RCP 8.5 climate scenarios, as the changes in climate variables are expected to further increase the revenue of the project, such as milk production, as well as the value of some of the ecosystem services.

The financial assessment has been done with the assumption that the agroforestry project would have an operating life of 20 years. Depending on the type of trees planted, this can be much longer in reality. This means that after 20 years of "operation," the project could still have significant terminal value. However, due to limited information available on the lifetime of the trees, this value was not included in the financial assessment. In addition, to reflect the time it takes for the trees to grow, we made the assumption that they will only reach their full revenue-generating potential, including externalities, after 10 years. Therefore, during the first 10 years, only 50% of the revenues were included in the calculations.

4 Conclusions

This SAVi assessment sheds light on the economic attractiveness of agroforestry in Welkenraedt. Spatial analysis and data from the Copernicus CDS allow this analysis to be location-specific, and the SAVi methodology customized the assessment to the specific impacts of agroforestry in the area, thanks to the collaboration and co-creation of the analysis with the Municipality of Welkenreadt.

The results of the integrated CBA and the project finance indicators demonstrate the economic attractiveness and financial viability of the project through net benefits and climate change adaptation.

The net benefits of the agroforestry project are estimated at EUR 3.9 million over a 20 year lifetime period, for an investment cost of EUR 607,629. This is due to positive externalities, avoided costs, and additional potential revenue streams, such as, for example, fodder and wood pellet production.

When taking into account climate change impacts, these benefits will only increase and make agroforestry projects even more economically attractive. Adding the climate impacts demonstrates that the added benefit of agroforestry increases as it mitigates and avoids many of the negative impacts of climate change, including increased flood damage, loss of carbon sequestration, increased levels of heat stress, increased water pollution, and unpredictable agriculture yields. For example, agroforestry has a cooling effect that reduces heat stress on livestock, improving their milk production and thus farmers' revenues.

The analysis demonstrates that agroforestry is investment-worthy and an important component of the climate adaptation strategy of the municipality. The municipality, as well as other stakeholders, can use the results of this analysis to further refine climate adaptation strategies, further promote the investment case of agroforestry, and identify different economic activities and revenue streams that agroforestry helps to unlock.

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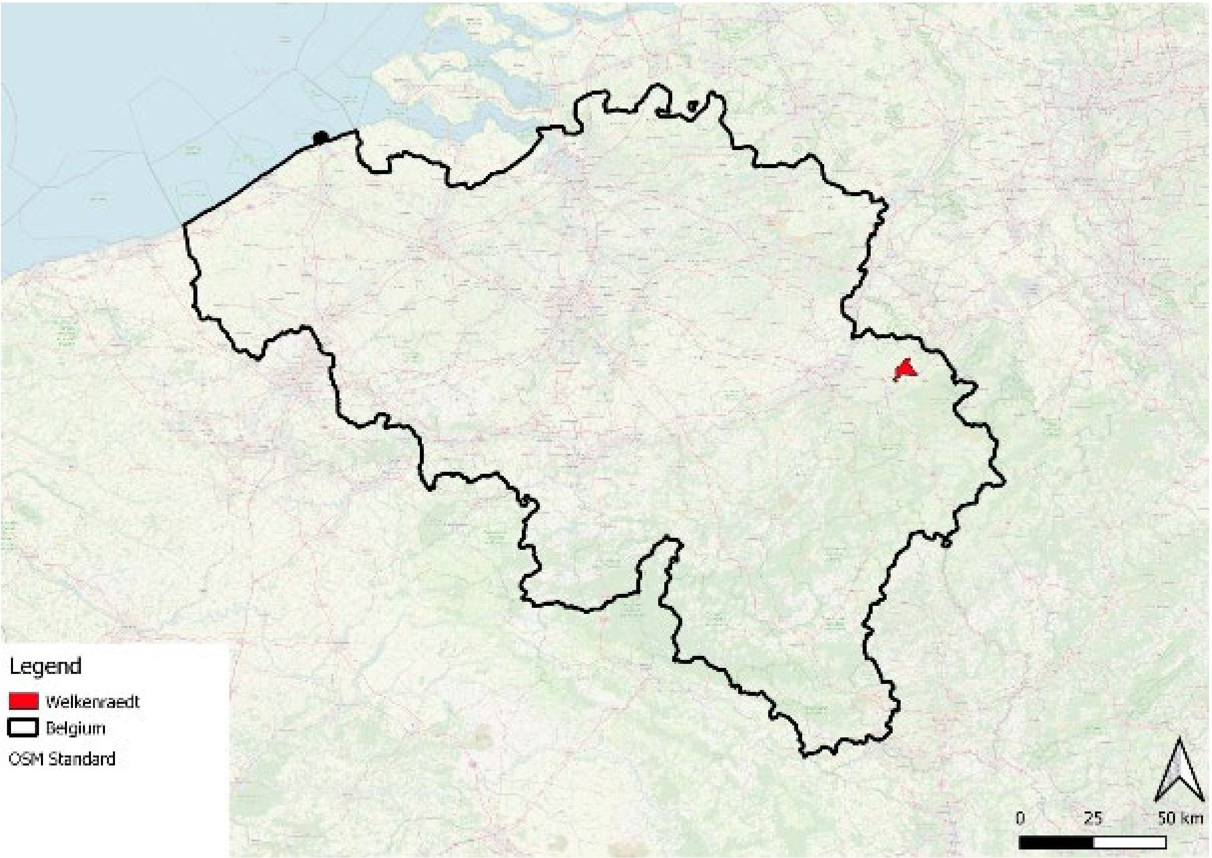
Annex A. Assessing Ecosystem Services Supply in Belgium by applying the Invest Tool

1. Model Set Up

a. Study Area

The study area of this analysis is the Municipality of Welkenraedt in Belgium (Figure A1).

Figure A1. Location of Welkenraedt



b. Coordination System

Based on world project coordinate system called "V WGS 84 / Pseudo-Mercator -- Spherical Mercator – ESPG: 3857"

Here is the detail of the coordinate system:

```
PROJCS["WGS 84 / Pseudo-Mercator",
    GEOGCS["WGS 84",
        DATUM["WGS_1984",
            SPHEROID["WGS 84",6378137,298.257223563,
                AUTHORITY["EPSG","7030"]],
            AUTHORITY["EPSG","6326"]],
        PRIMEM["Greenwich",0,
            AUTHORITY["EPSG","8901"]],
        UNIT["degree",0.0174532925199433,
            AUTHORITY["EPSG","9122"]],
        AUTHORITY["EPSG","4326"]],
    PROJECTION["Mercator_1SP"],
    PARAMETER["central_meridian",0],
    PARAMETER["scale_factor",1],
    PARAMETER["false_easting",0],
    PARAMETER["false_northing",0],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]],
    AXIS["X",EAST],
    AXIS["Y",NORTH],
    EXTENSION["PROJ4","+proj=merc +a=6378137 +b=6378137 +lat_ts=0.0 +lon_0=0.0 +x_0=0.0 +y_0=0 +k=1.0 +units=m +nadgrids=@null +wktext +no_defs"],
    AUTHORITY["EPSG","3857"]]
```

c. Administrative Boundary

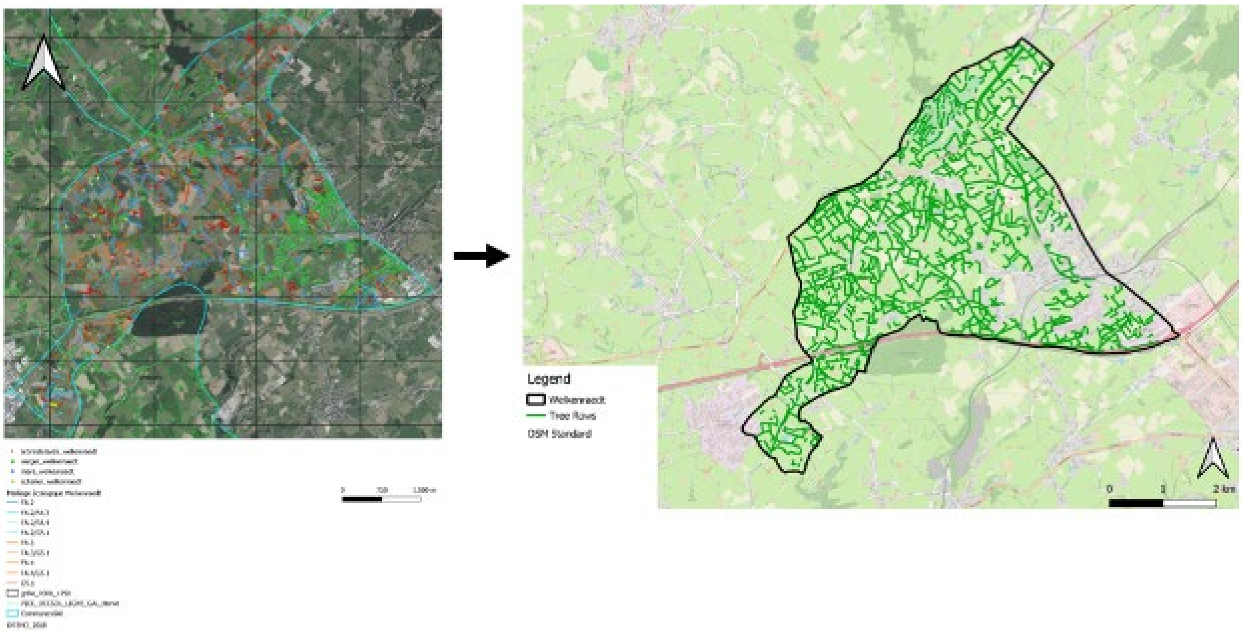
The boundaries of the Welkenraedt municipality have been downloaded from: https://hub.arcgis.com/datasets/esribeluxdata::belgium-municipalities-1/data?geometry=-4.905%2C49.273%2C13.859%2C51.719

d. Rationale

This study aims to assess the delivery of ecosystem services in the study area using different InVEST models. Different models require different inputs, which are described in the next sections. However, each model needs land-use/land cover maps (LULC) as inputs. Therefore, for each model we used two different LULC maps depending on two different scenarios that have been considered in this analysis:

- Business as usual (BAU): the original LULC map has been used (see section “e”).
- Tree Rows (ROWS): we added tree rows that separate crop fields to the original LULC map and can be found in the study area. The original project shows different categories of tree rows. Here, we considered all the tree rows that can be found outside urban areas, as Figure A2 shows.

Figure A2. Tree rows considered in this analysis



e. Land Cover Maps

The Land Cover Map of Europe 2017, a product resulting from Phase 2 of the S2GLC project, was used for this analysis. The LULC has an original resolution of 10 meters and 13 land cover classes. More information can be found here: https://www.esa.int/ESA_Multimedia/Images/2020/03/Europe_land-cover_mapped_in_10_m_resolution

The original map has been reclassified to 0.65-metres resolution and three to four additional classes have been added depending on scenarios. For the BAU scenario, we added streams, ponds, and roads, which can be downloaded from OpenStreet Map. For the ROWS scenario, we also added tree rows (see section 1d).

Figure A3 and Figure A4 illustrate the LULC maps that have been used for each scenario, including a zoom in the same location to show parts of a stream and a road, a pond, and in the case of Figure A4, some tree rows.

Figure A3. LULC map – BAU scenario

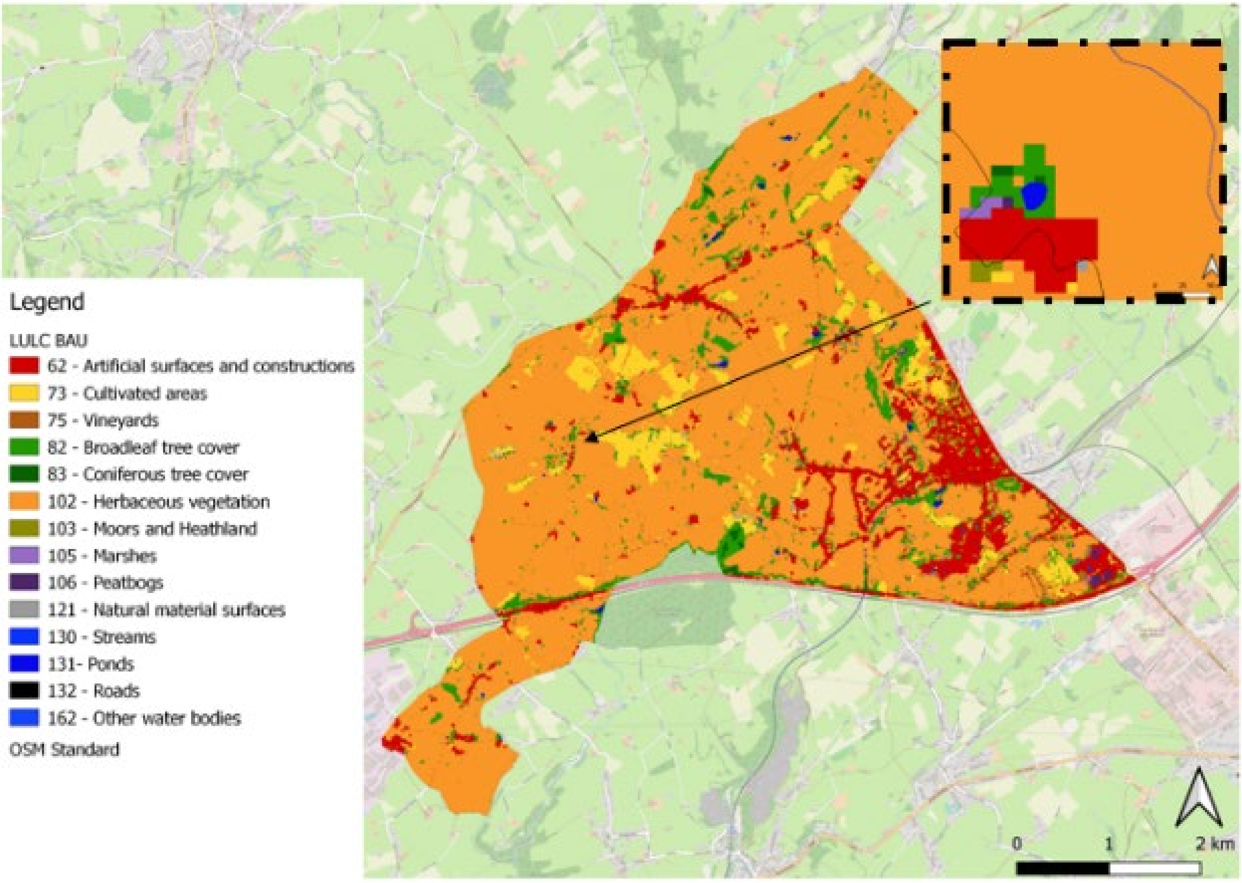
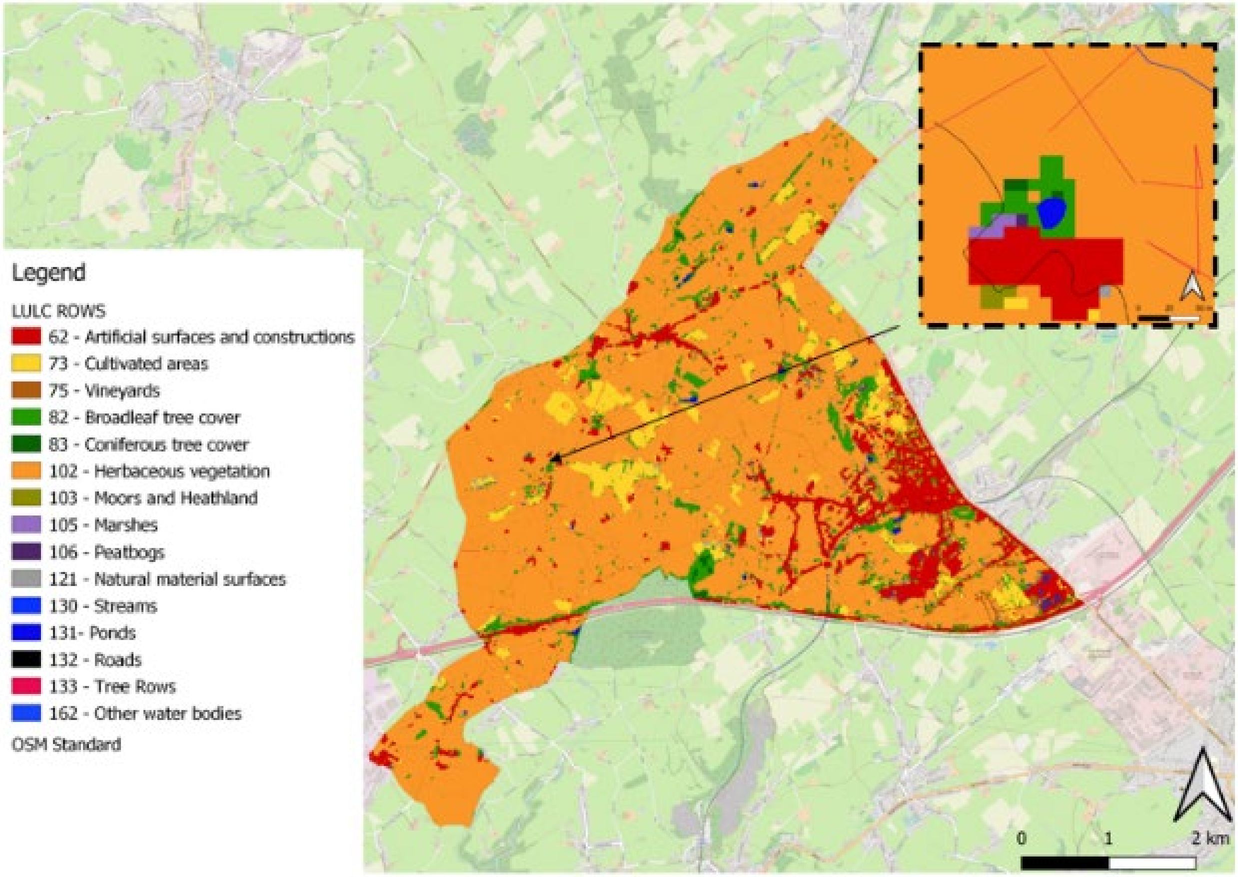


Figure A4. LULC map – ROWS scenario



f. Software and simulation

The ecosystem services map simulation has been performed using InVEST Software V.3.8.0 (https://naturalcapitalproject.stanford.edu/invest/). The inputs spatial data for the InVEST model have been prepared by utilizing QGIS-OSGeoW-3.4.2-1 (qgis.org/downloads/). The tabulated data will be managed and prepared in Ms. Excel V. 2016.

2. Carbon Storage

2.1 Input Data Preparation and Processing

1. Land use/land cover maps – The LULC maps described in section 1e have been utilized. Please note that in this case we assumed that the LULC ROW map shows the landscape after 9 years from the landscape described by the LULC BAU map. The reason for this choice is the fact the carbon model requires the user to define a specific interval to calculate carbon sequestration over time. In other words, the LULC BAU map can describe the landscape as of 2021, while the LULC ROWS map can show the landscape as of 2030.

2. Carbon Pools – Table of LULC classes, containing data on carbon stored in each of the four fundamental pools for each LULC class

- Carbon above ground: The values of carbon density in aboveground mass (Mg/ha or tonnes/ha) of each land-use type are shown in Table A1
- Carbon below ground: The values of carbon density in belowground mass (Mg/ha) of each land use-type are shown in Table A1,
- Carbon stored in organic matter: The values of carbon density in dead mass (Mg/ha) of each land-use type are shown in Table A1.
- Carbon stored in soil: The values of carbon density in dead mass (Mg/ha) of each land-use type are shown in Table A1.

The unit of measurement for these coefficients is Mg/ha. Average carbon coefficients values have been found in the *IPCC Guidelines for National Greenhouse Gas Inventories* report, Chapter 4, “Agriculture, Forestry and Other Land Use” (IPCC, 2006). Please note that for classes 103, 105, and 106, we integrated the carbon pools derived by the IPCC with the InVEST Blue Carbon model inventory, in order to improve the estimates of carbon sequestered into soil from these classes.

Table A1. Carbon pools

lucode	LULC_Name	C_above	C_below	C_soil	C_dead
62	lc_62	0	0	0	0
73	lc_73	18.8	6.204	0.68	0
75	lc_75	23.5	5.405	0.68	0
82	lc_82	94	21.62	0.68	0
83	lc_83	94	21.62	0.68	0
102	lc_102	0.799	3.055	0.68	0
103	lc_103	14.1	54.05	0.68	0
104	lc_104	7.05	1.6215	0.68	0
105	lc_105	14.1	54.05	0.68	0
106	lc_106	14.1	54.05	0.68	0
121	lc_121	7.05	1.6215	0.68	0
123	lc_123	0	0	0	0
130	lc_130	0	0	0	0
131	lc_131	0	0	0	0
132	lc_132	0	0	0	0
133	lc_133	28.2	6.486	0.68	0
162	lc_162	0	0	0	0

2.2 Results

Figure 5 and Figure 6 show the amount of carbon stored in Megagrams (Mg) in each pixel in both the BAU and ROWS scenarios. They are a sum of all the carbon pools provided by the biophysical table.

Figure A5. Carbon stored (Mg/Pixel) – BAU scenario

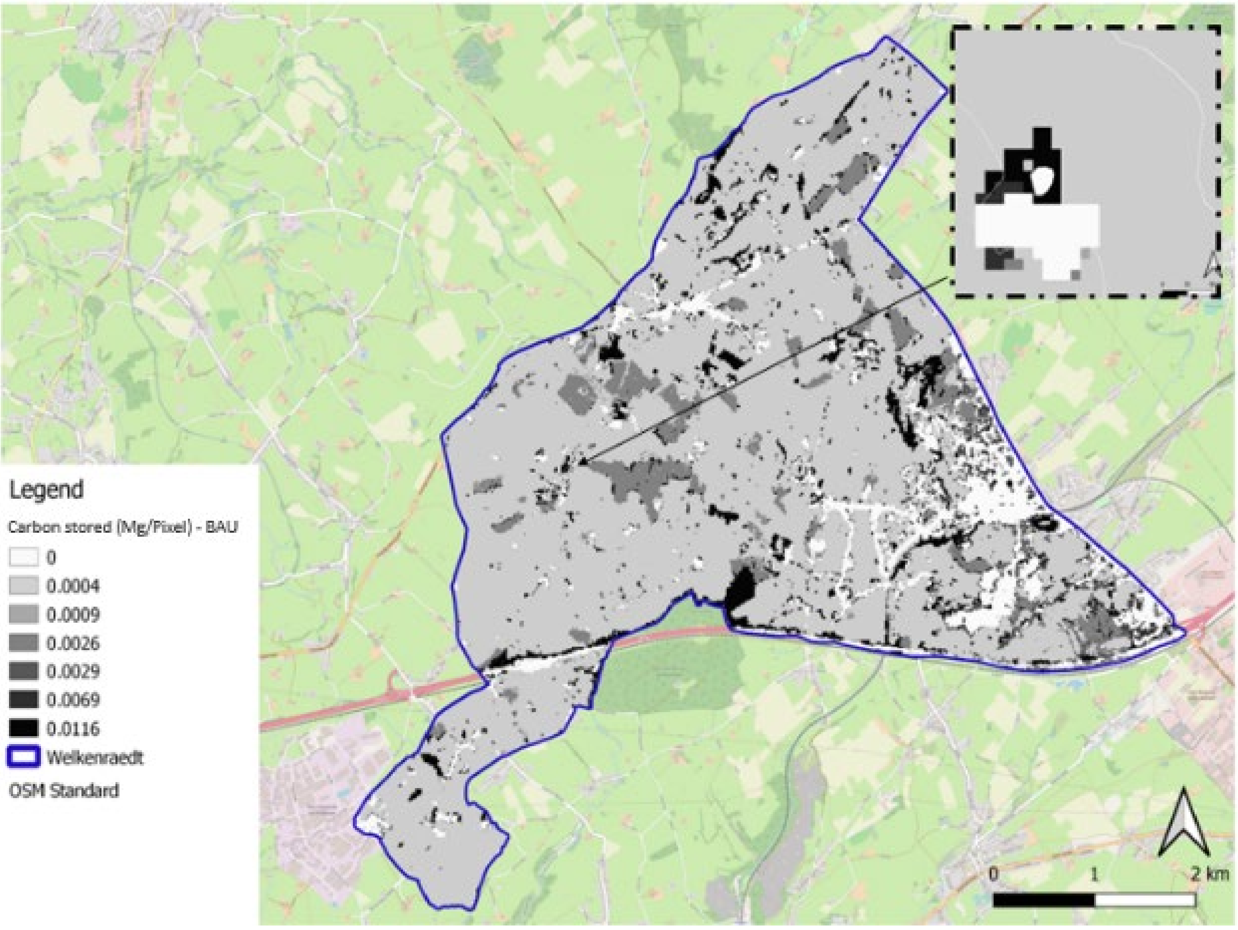


Figure A6. Carbon stored (Mg/Pixel) – ROWS scenario

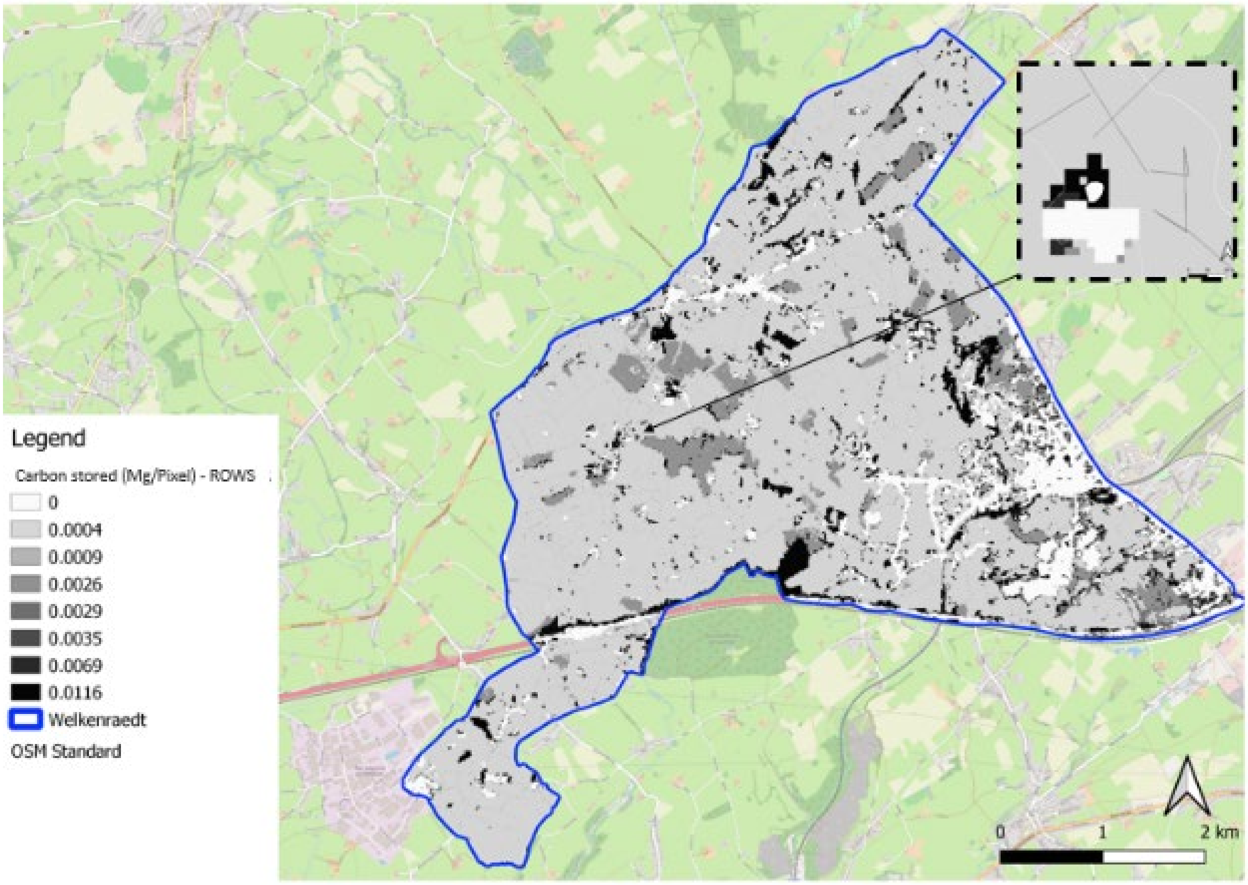


Table A2. Carbon pool statistics

	Sum (Mg)	Change from the current scenario %
BAU Scenario	85,789	0.5
ROWS Scenario	86,198	

As Table A2 shows, under the BAU scenario, the landscape of the Welkenraedt municipality would sequester 85,789 Mg of carbon in the first year, with no tree rows that divide agricultural fields. Under the ROWS scenario the same area would sequester 86,198 Mg of carbon at the end of the 9-year period. In other words, the landscape would be able to sequester +410 Mg of carbon thanks to the additional tree rows, an increase of roughly +0.5% from the BAU Scenario.

3. Habitat Quality

3.1 Input Data Preparation and Processing

1. **Land use/land cover maps –** See section 1e. Please note that in this model we used a larger study area (15km x 20km) that contains the Municipality of Welkenraedt. The reason for this choice was to avoid that locations near the edge of the area of interest had inflated habitat quality scores; otherwise, threats outside the area of interest would not have been properly accounted for. The resolution was also changed to 10 m to improve the speed of the analysis.

2. **Threat Data** – Urban areas and road networks have been identified as the threat sources to the natural habitat and biodiversity. See table below (Table A3). See Table A4 for data sources

Table A3. Table of threats (maximum distance, weighted value, and decay function) for InVEST simulation

N.	Threat name	Max_Distance	Weighted value	Decay function
62	Urban Areas	5 km	1	Linear
132	Road	2 km	0.6	Linear

Table A4. Habitat Quality model – references “threat table”

Threat	Max distance	Max_ distance Adopted sources	Weighted value	Weight value Adopted sources	Decay function	Decay func. Adopted sources
Urban areas	5 km	(Tapaneeyakul, 2015)	1	(Tapaneeyakul, 2015)	Linear	(Tapaneeyakul, 2015)
Roads	2 km	(Morrone, 2019)	0.6	(Morrone, 2019)	Linear	(Morrone, 2019)

Table A5. Habitat Quality model – references "threat sensitivity table"

Value	Habitat	Habitat Adopted sources	Sensitivity to urban areas sources	Sensitivity to urban area Adopted sources	Sensitivity to paved road	Sensitivity to paved road Adopted sources
62	0	(Tapaneeyakul, 2015)	0	(Tapaneeyakul, 2015)	0	(Sulistyawan, et al., 2017)
73	0.4	(Terrado, et al., 2016)	0.5	(Tapaneeyakul, 2015)	0.59	(Terrado, et al., 2016)
75	0.4	(Terrado, et al., 2016)	0.5	(Tapaneeyakul, 2015)	0.59	(Terrado, et al., 2016)
82	1	(Bhagabati, et al., 2012)	0.7	(Tapaneeyakul, 2015)	0.7	(Morrone, 2019)
83	1	(Bhagabati, et al., 2012)	0.7	(Tapaneeyakul, 2015)	0.7	(Morrone, 2019)
102	0.5	(Bhagabati, et al., 2012)	0.5	(Tapaneeyakul, 2015)	0.59	(Terrado, et al., 2016)
103	1	(Bhagabati, et al., 2012)	0.5	(Tapaneeyakul, 2015)	0.59	(Terrado, et al., 2016)
104	1	(Bhagabati, et al., 2012)	0.5	(Tapaneeyakul, 2015)	0.59	(Terrado, et al., 2016)
105	1	(Bhagabati, et al., 2012)	0.5	(Tapaneeyakul, 2015)	0.59	(Terrado, et al., 2016)
106	1	(Bhagabati, et al., 2012)	0.5	(Tapaneeyakul, 2015)	0.59	(Terrado, et al., 2016)
121	0.4	(Terrado, et al., 2016)	0.5	(Tapaneeyakul, 2015)	0.59	(Terrado, et al., 2016)
123	0	Assumed	0	Assumed	0	Assumed
130	1	(Morrone, 2019)	0.85	(Morrone, 2019)	0.5	(Morrone, 2019)
131	1	(Morrone, 2019)	0.85	(Morrone, 2019)	0.5	(Morrone, 2019)
132	0	Assumed	0	Assumed	0	Assumed
133	1	(Bhagabati, et al., 2012)	0.7	(Tapaneeyakul, 2015)	0.7	(Morrone, 2019)
162	1	(Morrone, 2019)	0.85	Morrone	0.5	(Morrone, 2019)

3. **Sensitivity of land cover types to each threat –** Table A6 characterizes each LULC type to be habitat or non-habitat and the type's sensitivity to the threats (see Table A5 for data sources). The table contains the following fields:

   3.1 LULC – codes identify each LULC class

   3.2 Name – abbreviation of each LULC class

   3.3 Habitat – score characterizing each LULC as habitat or non-habitat. The values of 0 and 1 are used for the purpose, in which 0 for non-habitat class and 1 for habitat class of LULC.

   3.4 L_urb_62, L_rd_132– these are columns for the relative sensitivity of LULC classes to the threat. In this case, L_urb_62 and L_rd_132 contain the value for the sensitivity of each LULC class to urban areas and roads respectively.

Table A6. Table of Sensitivity of land cover types to each threat for InVEST simulation

LULC	NAME	HABITAT	L_urb_62	L_rd_132
62	lc_62	0	0	0
73	lc_73	0.4	0.5	0.59
75	lc_75	0.4	0.5	0.59
82	lc_82	1	0.7	0.7
83	lc_83	1	0.7	0.7
102	lc_102	0.5	0.5	0.59
103	lc_103	1	0.5	0.59
104	lc_104	1	0.5	0.59
105	lc_105	1	0.5	0.59
106	lc_106	1	0.5	0.59
121	lc_121	0.4	0.5	0.59
123	lc_123	0	0	0
130	lc_130	1	0.85	0.5
131	lc_131	1	0.85	0.5
132	lc_132	0	0	0
133	lc_133	1	0.7	0.7
162	lc_162	1	0.85	0.5

1. **Half-saturation constraint** – the default value of 0.5 was used

3.2 Results

Figure A7 and Figure A8 show the relative level of habitat quality in the study area considering all scenarios. Higher numbers indicate better habitat quality vis-a-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat get a quality score of 0. The habitat score values range from 0 to 1, where 1 indicates the highest habitat suitability.

Figure A7. Scores of habitat quality (BAU)

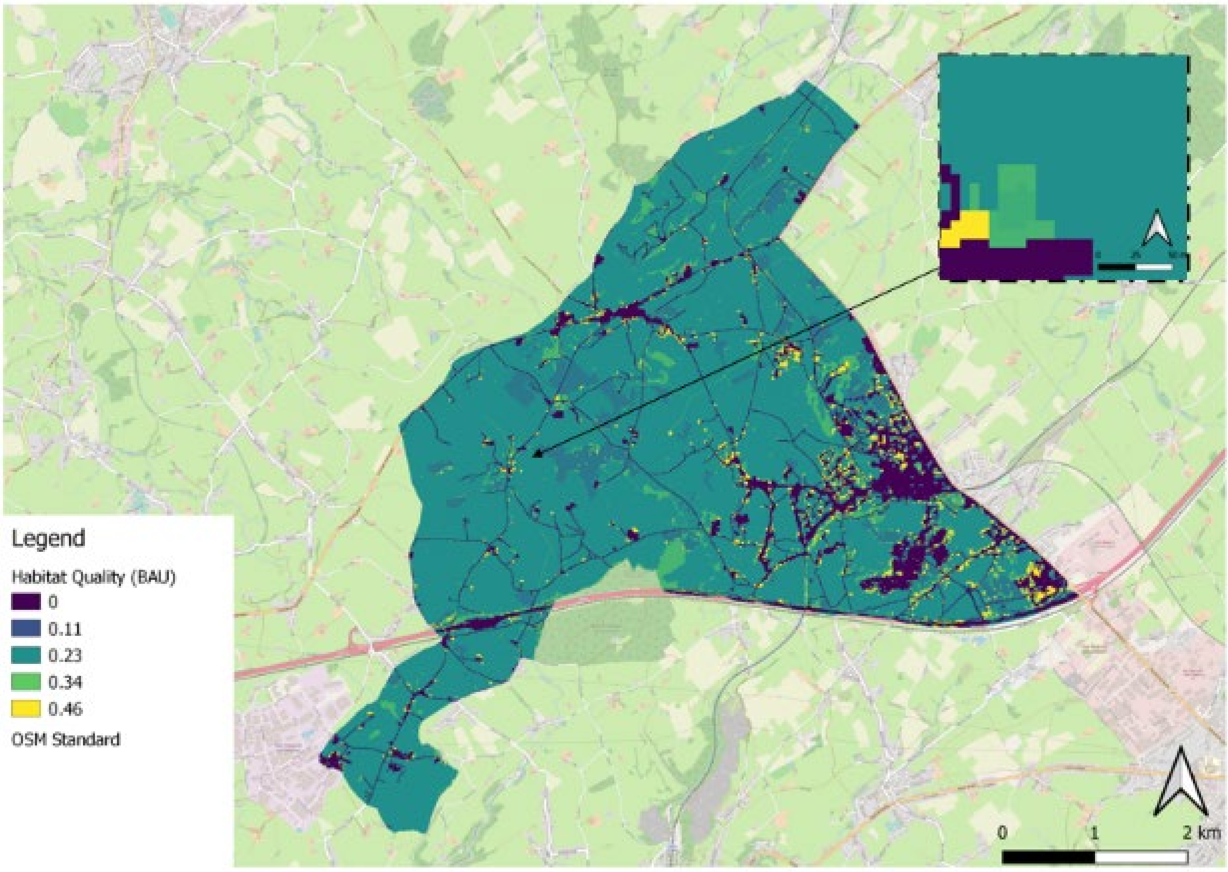


Figure A8. Scores of habitat quality (ROWS)

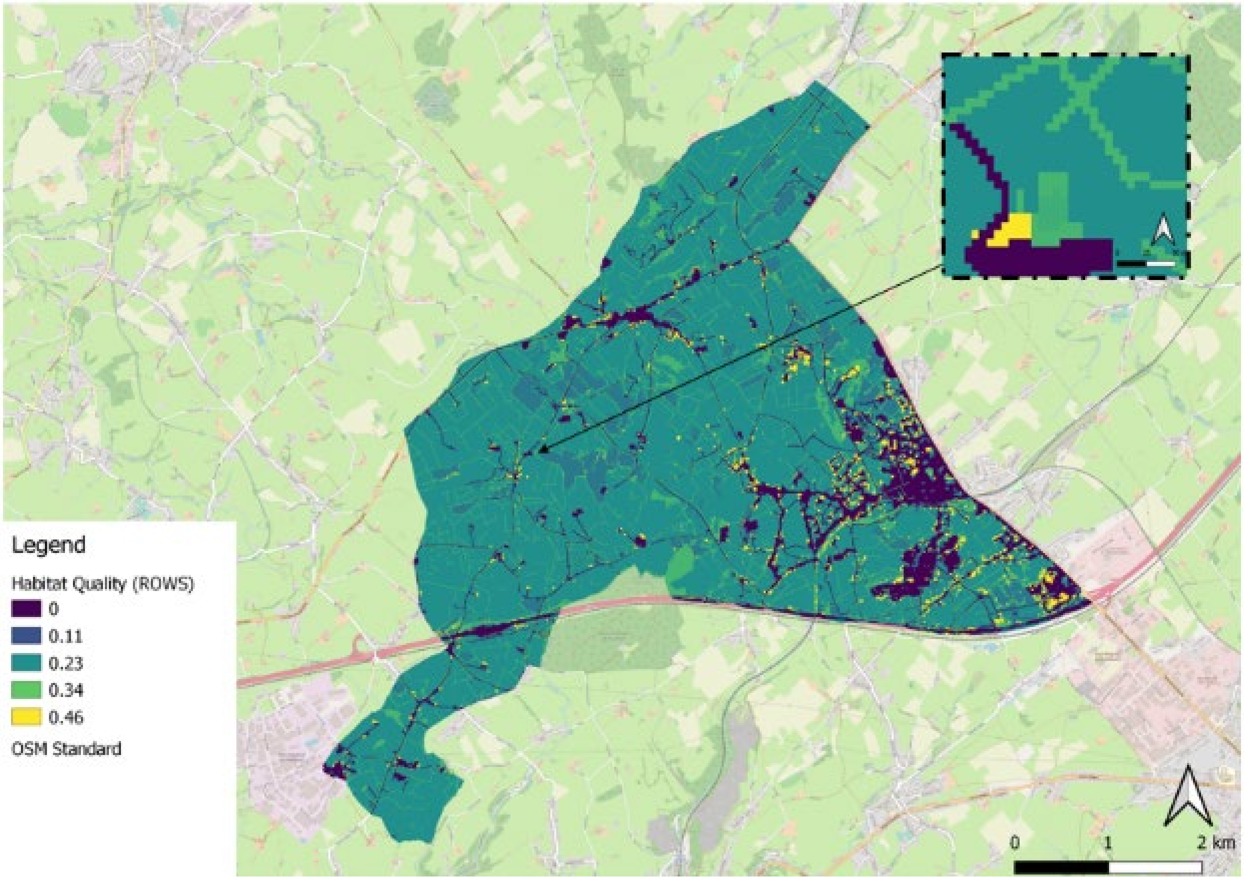
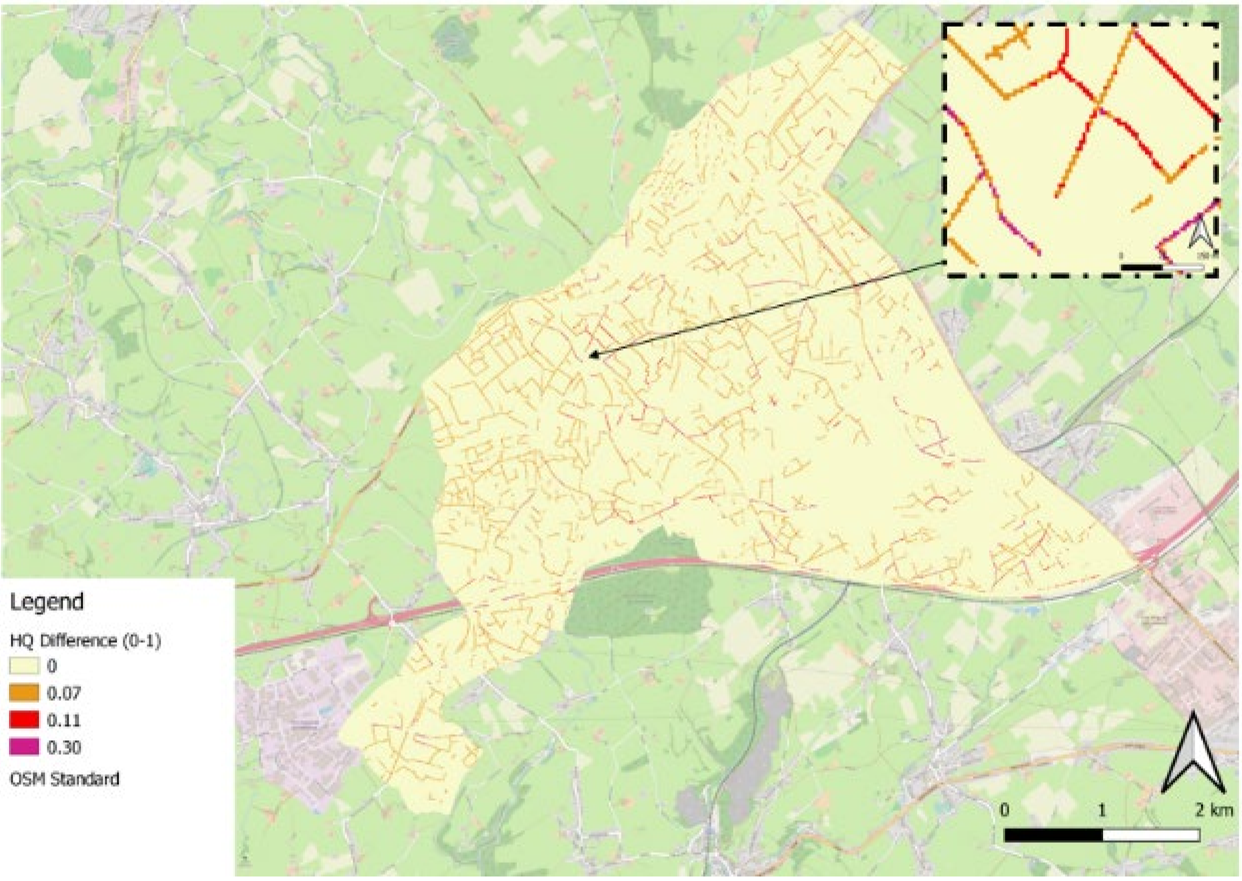


Table A7. Habitat quality statistics

	Mean (from 0 to 1)	Change from the current scenario %
BAU Scenario	0.211	1.896
ROWS Scenario	0.215	

As Table A7 shows, the mean of habitat quality in the study area is 0.211 out of 1 (BAU scenario). In the ROWS scenario this value would increase by almost 2%, reaching a mean of 0.215 per pixel. It is worth noting that the areas with the highest scores of habitat quality roughly correspond with the ones that capture more carbon (see "results" – Carbon storage), proving the consistency of these results. Figure A9 allows a visualization of the locations where the score of habitat quality will increase.

Figure A9. Habitat Quality – difference between ROWS and BAU scenarios



4. Crop Pollination

4.1 Input Data Preparation and Processing

1. **Land use/land cover maps –** See section 1e. Please note that in this model the resolution was changed to 10 m to improve the speed of the analysis.

2. **Guild Table –** A table containing information on each species or guild of pollinator to be modelled. "Guild" refers to a group of bee species that show the same nesting behaviour, whether preferring to build nests in the ground, in tree cavities, or other habitat features. We used InVEST sample data for the species "Apis" (Table A8). Each row is a unique species or guild of pollinator and columns must be named and defined as follows:

   2.1 Species: Name of species or guild (Species names can be numerical codes or strings.)

   2.2 Any number of **nesting_suitability_index columns**, one for each SUBSTRATE defined: Values must be entered as a floating point number between 0 and 1, with 1 indicating a nesting substrate that is fully utilized and 0 indicating a nest substrate that is not utilized at all. Substrates are user defined, but might include ground nests, tree cavities, etc. The SUBSTRATE string must match a nesting_availability_index in the Land Cover Biophysical Table.

   2.3 Any number of **foraging_activity_[SEASON]_index** columns, one for each SEASON defined: Pollinator activity by floral season (i.e., flight season). Values must be entered as a floating point number between 0 and 1, with 1 indicating the season of greatest activity for the guild or species, and 0 indicating a season of no activity. Seasons are user defined but might include spring, summer, fall; wet, dry, etc. The SEASON string must match a floral_resources_[SEASON]_index column in the Land Cover Biophysical Table.

   2.4 Alpha – Average distance each species or guild travels to forage on flowers, specified in integer metres. The model uses this estimated distance to define the neighbourhood of available flowers around a given cell and to weigh the sums of floral resources and pollinator abundances on farms.

   2.5 relative_abundance: A floating point value indicating the weighted relative abundance of the species' contribution to pollinator abundance. Setting this value to the same value for each species will result in each species being weighted equally.

Table A8. Guild table used in this analysis

SPECIES	nesting_suitability_cavity_index	nesting_suitability_ground_index	foraging_activity_spring_index	foraging_activity_summer_index	alpha	relative_abundance
Apis	1	1	1	1	500	0.75

3. **Land Cover Biophysical Table –** A table containing model information corresponding to each of the land-use classes in the Land Cover Map. All LULC classes in the Land Cover raster must have corresponding values in this table. Data needed are relative indices (0-1). Data can be summarized from field surveys, or obtained by expert assessment if field data is unavailable. In this analysis, we used the sample data provided by InVEST (Table A9). Each row is a land use/land cover class and columns must be named and defined as follows:
   - **3.1 lucode:** Land use/land cover class code. LULC codes must match the "value" column in the Land Cover Map raster and must be integer or floating point values, in consecutive order, and unique.
   - **3.2 nesting_availability_index:** Relative index of the availability of the given nesting type within each LULC type, on a floating point scale of 0-1. The SUBSTRATE name must exactly match a substrate given in the Guild Table.
   - **3.3 floral_resources_[SEASON]_index:** Relative abundance (floating point value 0-1) of flowers in each LULC class for the given season. There are two aspects to consider when estimating the relative floral abundance of each LULC class: % floral abundance or % floral coverage, as well as the duration of flowering during each season. For example, a land cover type comprised 100% of a mass flowering crop that flowers the entire season with an abundance cover of 80% would be given a suitability value of 0.80. A land cover type that flowers only half of the season at 80% floral coverage would be given a floral suitability value of 0.40. The SEASON name must exactly match a season given in the Guild Table.

Table A9. Biophysical table – crop pollination

lucode	LULC_Name	nesting_cavity_availability_index	nesting_ground_availability_index	floral_resources_spring_index	floral_resources_summer_index
62	lc_62	0.1	0.1	0.2	0.2
73	lc_73	0.3	0.2	0.3	0.3
75	lc_75	0.3	0.2	0.3	0.3
82	lc_82	0.6	0.7	0.3	0.3
83	lc_83	0.6	0.7	0.3	0.3
102	lc_102	0.3	0.2	0.3	0.3
103	lc_103	0.3	0.3	0.3	0.3
104	lc_104	0.3	0.3	0.3	0.3
105	lc_105	0.3	0.3	0.3	0.3
106	lc_106	0.3	0.3	0.3	0.3
121	lc_121	0.3	0.3	0.3	0.3
123	lc_123	0	0	0	0
130	lc_130	0	0	0	0
131	lc_131	0	0	0	0
132	lc_132	0	0	0	0
133	lc_133	0.4	0.7	0.3	0.3
162	lc_162	0	0	0	0

4.2 Results

The main output of this model is the following:

- **pollinator_supply_[SPECIES]_[Suffix]** – Per-pixel index of pollinator [SPECIES] that could be on a pixel given its arbitrary abundance factor from the table, multiplied by the habitat suitability for that species at that pixel, multiplied by the available floral resources that a pollinator could fly to from that pixel.

Figure A10 and Figure A11 show the per-pixel index of Apis in the BAU and ROWS scenarios respectively.

Figure A10. Apis supply per pixel (BAU)

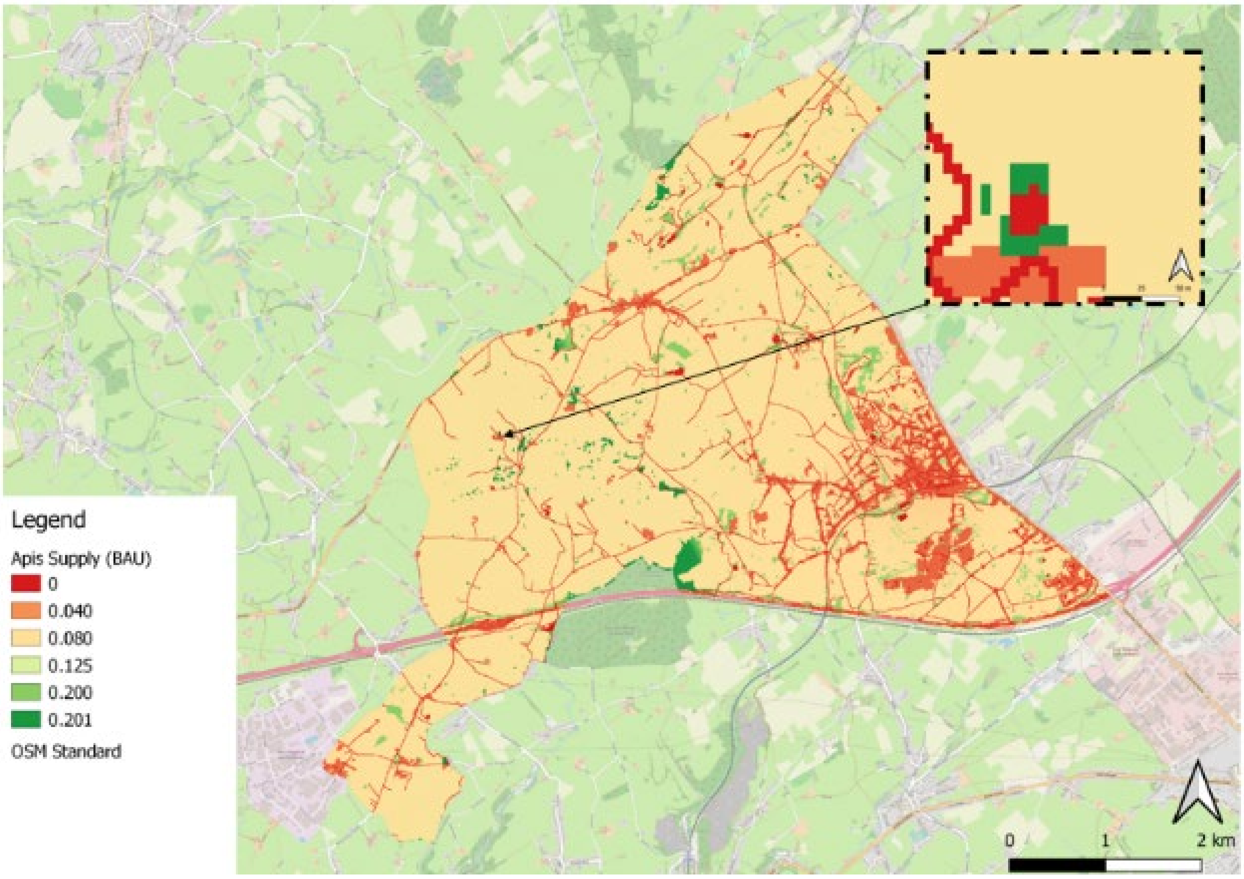


Figure A11. Apis supply per pixel (ROWS)

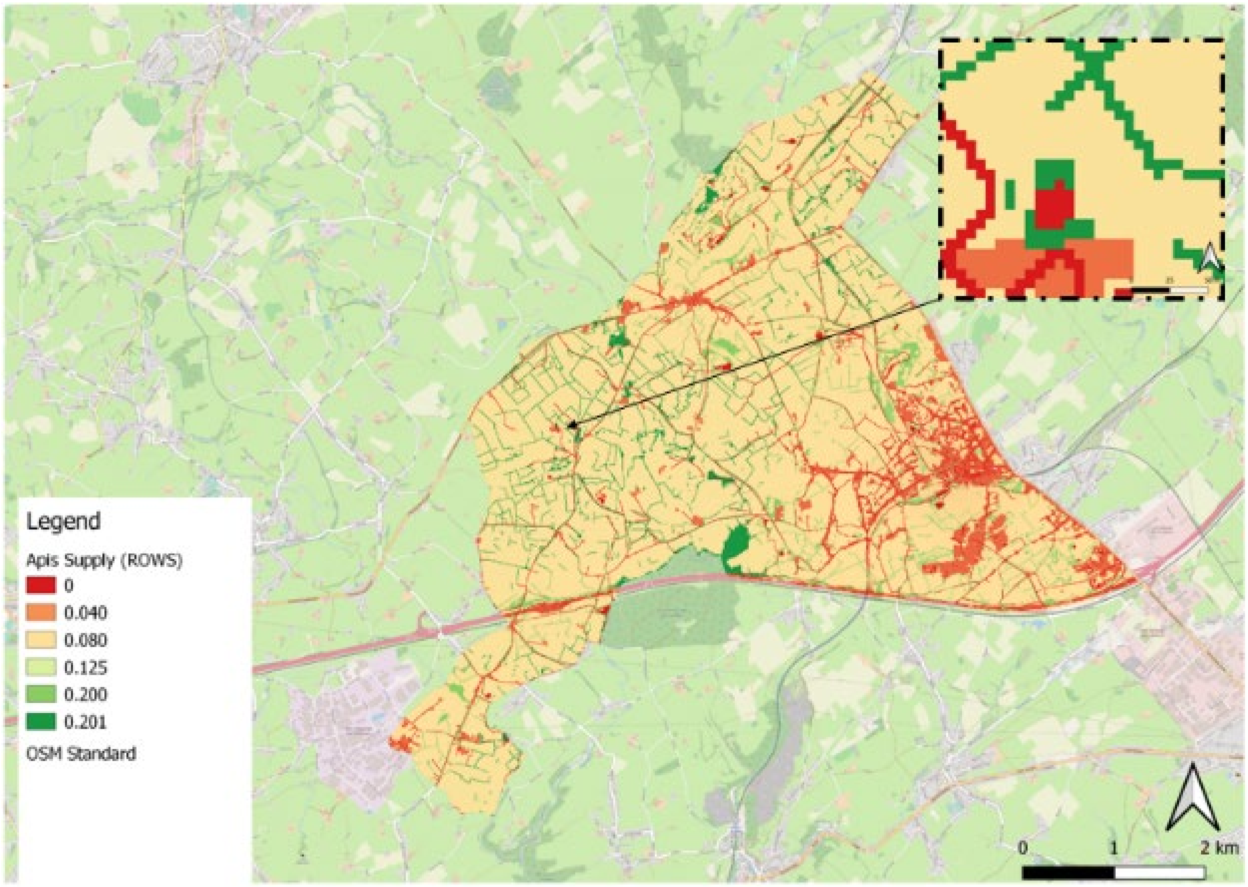


Table A10. Crop pollination statistics

	Mean	Change from the current scenario %
BAU Scenario	0.08	8.06
ROWS Scenario	0.09	

As Table A10 shows, the mean of Apis supply per pixel in the study area is 0.08 (BAU scenario). In the ROWS scenario this value would increase by more than 8%, reaching a mean of 0.09 per pixel. It is worth noting that the areas with the highest scores of Apis supply roughly correspond with the ones indicated by both the Carbon Storage and Habitat Quality models, proving the consistency of these results.

5. Annual Water Yield

5.1 Input Data Preparation and Processing

1. **Precipitation** – *A GIS raster dataset with a non-zero value for average annual precipitation for each cell. Its value is expressed in millimetres.* The average precipitation (in mm) from 1970 to 2000 downloaded from WorldClim version 2 (www.worldclim.com) was used for this study. The dataset was released on the first of June 2016. The original spatial resolution of the data is 30 seconds x 30 seconds (which is approximately 1 km^2).

2. ***Average annual reference evapotranspiration (ET0)*** – *A GIS raster dataset with an annual average evapotranspiration value for each cell in millimetres.* Reference evapotranspiration is the potential loss of water from the soil by both evaporation from the soil and transpiration by healthy alfalfa (or grass) if sufficient water is available. Its value is in millimetres. In this study, the global evapotranspiration of reference crops was adopted from "Global Aridity Index and Potential Evapotranspiration (ET0) Climate Database v2." The spatial resolution of the data is 30 arc-seconds (approximately 1km at the equator). The dataset can be found here:

   (https://figshare.com/articles/Global_Aridity_Index_and_Potential_Evapotranspiration_ET0_Climate_Database_v2/7504448/3)

3. **Root restricting layer depth –** These terms were defined as an average root restricting layer depth value for each cell. It is the soil depth at which root penetration is strangler inhibited because of physical or chemical characteristics. Root restricting layer depth may be obtained from some soil maps. If a root restricting layer depth is not available, soil depth can be used as a proxy. If several soil horizons are detailed, the root restricting layer depth is the sum of the depths of non-restrictive soil horizons. Its value is in millimetres. In this study, the absolute depth to bedrock downloaded from soilgrid.org stored in cm was used to present for root restricting layer depth.

4. **Plant Available Water Content –** Plant available water content (PAWC) is the fraction of water that can be stored in the soil profile that is available for plants' use. PAWC can be measured from 0 to 1. The format of PAWC for the model is a GIS raster dataset.

   PAWC is a fraction obtained from some standard soil maps. It is defined as the difference between the fraction of volumetric field capacity and permanent wilting point. The PAWC is often available as a volumetric value (mm). To obtain the fraction it is necessary to divide it by soil depth. Soil characteristic layers are estimated by performing a weighted average from all horizons within a soil component. If PAWC is not available, raster grids obtained from polygon shapefiles of weight average soil texture (%clay, %sand, %silt) and soil porosity will be needed. In this study, the average calculation of available soil water capacity of the volumetric fraction of 2.0 (pF 2.0) from 0 to 2 m was used to represent the plant available water contents for water yield model simulation.

5. **Land use/land cover maps –** See section 1e

6. **Watersheds –** This is the polygon shapefile representing the watershed that can be found in the study area. While different levels of watersheds can be downloaded from open sources, the municipality of Welkenraedt is too small and none could be found. We decided to use the InVEST tool DelineateIt, which allows the specification of areas from which the watersheds should be delineated. We considered only one watershed that surrounds the city (see Figure A12).

7. **Biophysical Table –** A table of land use/land cover (LULC) classes, containing data on biophysical coefficients used in this tool. These data are attributes of each LULC class rather than attributes of individual cells in the raster map. This table contains 5 variables included: [1] *lucode (Land use code)*, [2] *LULC_desc*, [3] *LULC_veg*, [4] *root_depth,* and [5] K_c. Table 9 shows the biophysical table used in this study. Values have been derived from Tapaneeyakul (2015).

   7.1 Lucode (Land use code): Unique integer for each LULC class (e.g., 1 for forest, 3 for grassland, etc.) must match the LULC raster above.

   7.2 LULC_desc: Descriptive name of land use/land cover class (optional).

   7.3 LULC_veg: Values must be 1 for vegetated land use except for wetlands, and 0 for all other land uses, including wetlands, urban, water bodies, etc.

   7.4 root_depth: The maximum root depth for vegetated land use classes, given in integer millimetres. This is often given as the depth at which 95% of a vegetation type's root biomass occurs. For land uses where the generic Budyko curve is not utilized (i.e., where evapotranspiration is calculated based on the equation below, rooting depth is not needed). In these cases, the rooting depth should be set to NA. The equation can be found here in:

$$AET(x)=Min(Kc(\ell x)\cdot ET_0(x),P(x))$$

where

$ET_0(x)$ is the reference evapotranspiration,

$Kc(\ell x)$ is the evaporation factor for each land use and land cover.

Kc factor is the plant evapotranspiration coefficient for each LULC class. It is used to convert from reference evaporation to potential evaporation for each land use.

7.5 Kc: The plant evapotranspiration coefficient for each LULC class, used to obtain potential evapotranspiration by using plant physiological characteristics to modify the reference evapotranspiration, which is based on alfalfa. The evapotranspiration coefficient is thus a decimal in the range of 0 to 1.5 (some crops evapotranspire more than alfalfa in some very wet tropical regions and where water is always available).

Table A11. Biophysical table (Water Yield)

lucode	LULC_desc	LULC_veg	root_depth	Kc
62	lc_62	0	0	0
73	lc_73	0.6	700	1
75	lc_75	0.6	700	1
82	lc_82	1	7000	1
83	lc_83	1	7000	1
102	lc_102	0.85	1000	1
103	lc_103	0.7	2000	1
104	lc_104	0.6	700	1
105	lc_105	0.7	2000	1
106	lc_106	0.7	2000	1
121	lc_121	0.6	700	1
123	lc_123	0.2	10	0
130	lc_130	0	2000	1
131	lc_131	0	2000	1
132	lc_132	0	0	0
133	lc_133	1	7000	1
162	lc_162	0	2000	1

Z parameter – Z is an empirical constant that captures the local precipitation pattern and hydrogeological characteristics, with typical values ranging from 1 to 30. It is corresponding to the seasonal distribution of precipitation. This parameter is mainly used for model calibration; however, in this study, there is no observed data for the model calibration. Therefore, the recommended default value of the Z parameter (5) was used.

5.2 Results

The main output of this model is a table containing biophysical output values per watershed, with the following attribute:

- *wyield_vol* (m^3): Volume of water yield in the watershed.

Figure A12. Watershed around the Municipality of Welkenraedt

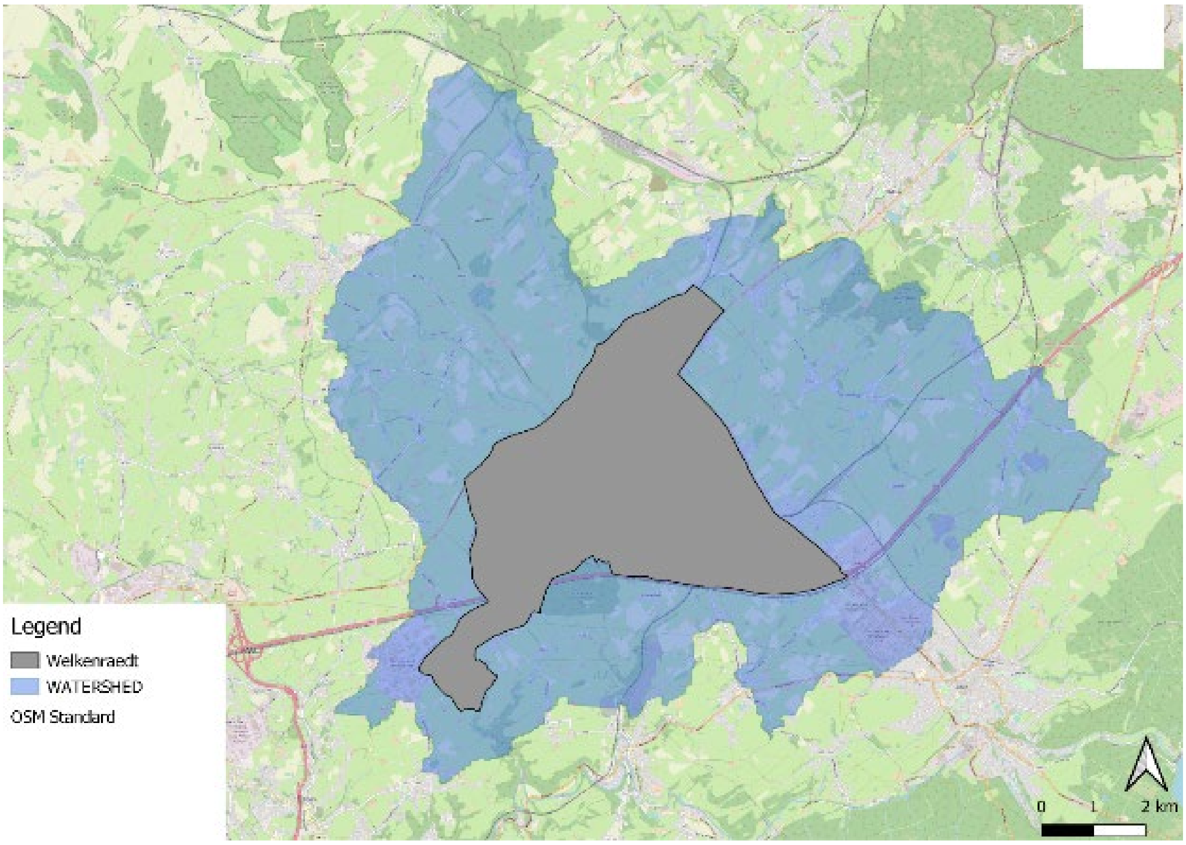


Table A12. Water yield results

	wyield_vol (m3)	Change from the BAU scenario %
BAU Scenario	52,407,189	0.02
ROWS Scenario	52,417,643	

Table A12 shows the volume of water yield (m^3) in the selected watershed under the BAU and ROWS scenarios. The InVEST analysis shows that if trees will be planted on the agricultural rows in Welkenraedt the volume of water yield would increase by 0.02%, which roughly corresponds to 10,000 m^3 of water.

6. Annual Sediment Delivery Ratio

6.1 Input Data Preparation and Processing

4. **Digital Elevation Model (DEM) Raster** – DEM: the hydrologically conditioned elevation dataset which is distributed by EEA (https://www.eea.europa.eu/data-and-maps/data/eu-dem) was downloaded on November 13, 2020, for InVEST sediment model input. The data was prepared for hydrological model input purpose mainly for flow direction, accumulation simulation, river network, and basin delineation. The original spatial resolution of the dataset is 25 metres.
5. **Rainfall Erosivity Index (R) Raster** – A GIS raster dataset containing erosivity index for each cell. This variable depends on the intensity and duration of rainfall in the area of interest. The greater the intensity and duration of the rainstorm, the higher the erosion potential. The erosivity index is widely used, but in case of its absence, there are methods and equations to help generate a grid using climatic data. Its value is MJ*mm*(ha*h*yr)$^{-1}$. The R factor dataset in spatial resolution of 25 km downloaded from https://www.nature.com/articles/s41467-017-02142-7 was employed for this study. The technical report of the data also can be found here: https://static-content.springer.com/esm/art%3A10.1038%2Fs41467-017-02142-7/MediaObjects/41467_2017_2142_MOESM1_ESM.pdf
6. **Soil Erodibility (K) Raster** – A raster dataset of soil erodability. It is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. It value is in T.ha.h.(ha.MJ.mm)$^{-1}$. The spatial resolution of 25 km of soil erodability download from https://www.nature.com/articles/s41467-017-02142-7 was used in this study.
7. **Land use/land cover maps –** See section 1e.
8. **Watershed Polygons** – See Annual Water Yield Inputs.
9. **Biophysical Table** – A table containing model information corresponding to each of the LULC types (see Table 13). These data were derived from Tapaneeyakul (2015). The table has the following field:
   9.1 Lucode (Land use code) – Unique integer to identify each LULC class.
   9.2 LULC_desc – Nominal name for each LULC class.
   9.3 usle_c – It refers to cover management factor or sometimes called cropping management factor (C factor) for the Universal Soil Loss Equation (USLE). This value is used to calculate the cover management in USLE. The C factor represents the effect of surface cover and roughness on soil erosion. The cover factor is the most common factor used to assess the impact of best management practices on reducing erosion because the C factor represents the effect of land use on soil erosion (Renard, 1997). Erosion control blankets and surface applied best management practices such as blown straw are represented as C factors within RUSLE. By definition, C = 1 under standard fallow conditions. As the surface cover is added to the soil, the C factor value approaches zero. For example, a C factor of 0.20 signifies that 20% of the amount of erosion will occur compared to continuous fallow conditions. C factors vary from region to region because they are strongly influenced by different Rainfall Erosivity Index (R factors) (Wischmeier

& Smith, 1978). In the InVEST model, its value is stored in a float value ranging from 0 to 1.

9.4 usle_p – It refers to management practice, support, or conservation practice factor (P factor) in USLE. The P factor reflects the impact of support practices on the average annual erosion rate. P is the ratio of soil loss with a support factor to that with straight row farming up and downslope. Strip-cropping, contouring, and terracing are all activities that are considered support practices by RUSLE. The support factor is unitless and its value is stored in a float value ranging from 0 to 1.

Table A13. Biophysical table annual sediment delivery ratio

lucode	LULC_desc	LULC_veg	usle_c	usle_p
62	lc_62	0.25	0.01	62
73	lc_73	0.5	0.4	73
75	lc_75	0.5	0.4	75
82	lc_82	0.005	0.2	82
83	lc_83	0.005	0.2	83
102	lc_102	0.5	0.4	102
103	lc_103	0.25	0.35	103
104	lc_104	0.5	0.4	104
105	lc_105	0.25	0.35	105
106	lc_106	0.25	0.35	106
121	lc_121	0.5	0.4	121
123	lc_123	0.25	0.01	123
130	lc_130	0	0.01	130
131	lc_131	0	0.01	131
132	lc_132	0.25	0.01	132
133	lc_133	0.005	0.2	133
162	lc_162	0	0.01	162

10. **Threshold flow accumulation** – The number of upstream cells that must flow into a cell before it is considered part of a stream, which is used to classify streams from the DEM. This threshold directly affects the expression of hydrologic connectivity and the sediment export result: when a flow path reaches the stream, sediment deposition stops and the sediment exported is assumed to reach the catchment outlet. It is important to choose this value carefully so modelled streams come as close to reality as possible. The value of 100 was used in this simulation.
11. **Borseli K parameter (kb) and Borseli IC0 parameter (IC_0)** – Two calibration parameters that determine the shape of the relationship between hydrologic connectivity (the

degree of connection from patches of land to the stream) and the sediment delivery ratio (percentage of soil loss that actually reaches the stream). The default values of kb=2 and IC_0=0.5 were used in the simulation.

12. **Max SDR value (SDRmax)** – The maximum SDR that a pixel can reach, which is a function of the soil texture. More specifically, it is defined as the fraction of topsoil particles finer than coarse sand. The default value of 0.8 was used in this simulation.

6.2 Results

The main output of this model are raster files containing biophysical output values per watershed, with the following attribute:

- sed_export (tons/pixel): total amount of sediment exported from each pixel that reaches the stream.

Figure A13 shows the total sediment export (tons) for both the BAU and ROWS scenario.

Figure A13. Total sediment export – BAU and ROWS Scenario

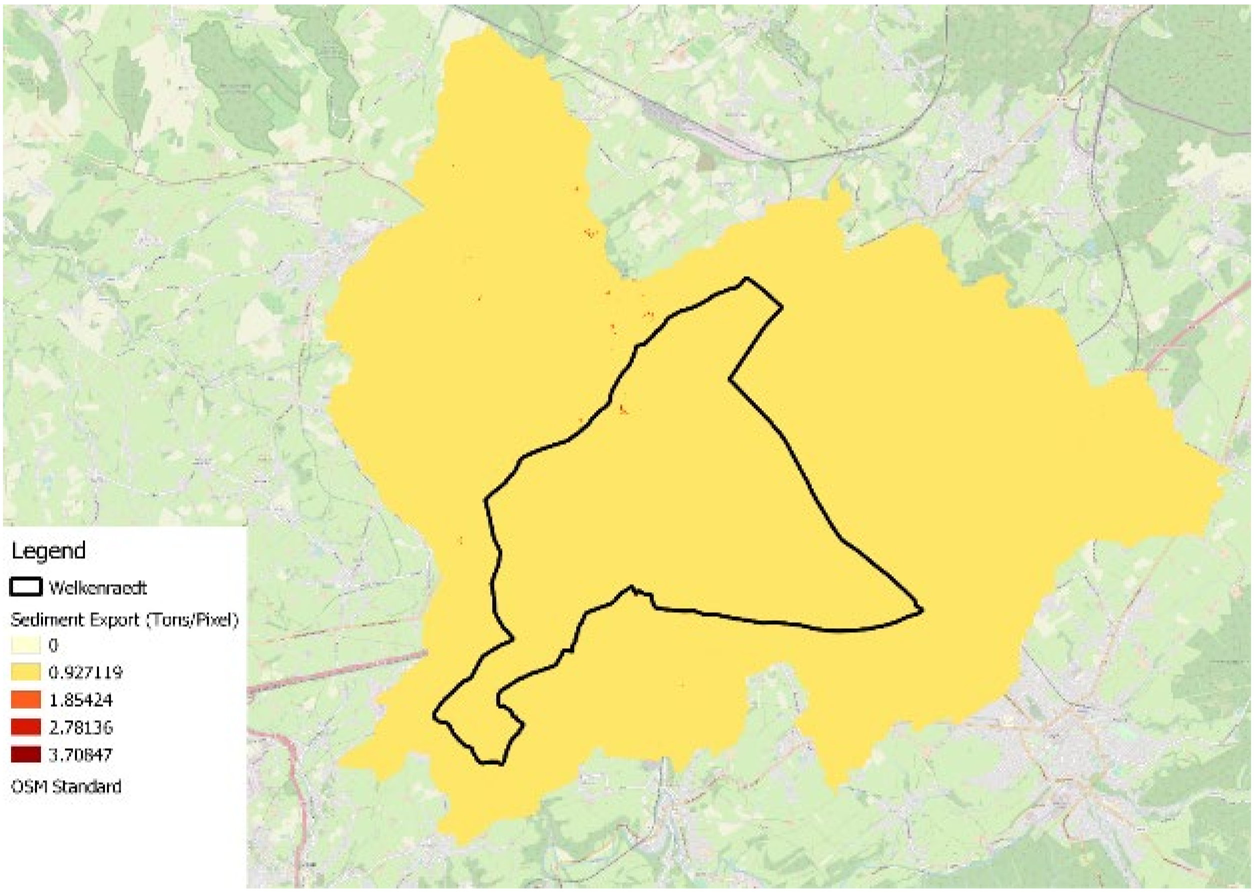


Table A14. Annual sediment delivery ratio statistics

	Sediment exports (Tons)	Change from the BAU scenario %
BAU Scenario	12,606	-0.02
ROWS Scenario	12,604	

Table A14 shows the total sediment export under both the BAU and ROWS scenarios in the whole watershed that surround the municipality. The results indicate that total sediment export will decrease by only 2 tonnes in the ROWS scenario compared to the BAU scenario. In other words, the tree rows that are present only in the ROWS scenario will not produce large changes in the sediment export dynamics in the watershed. However, they may be able to limit the sediment export at a lower level (e.g., banks of local streams).

7. Annual Nutrient Delivery Ratio

71. Input Data Preparation and Processing

1. **DEM Raster** – See input section of Annual Sediment Delivery Ratio
2. **Land use/land cover maps –** See section 1e
3. **Nutrient Runoff Proxy Raster (Precipitation)** – A GIS raster dataset with a non-zero value for average annual precipitation for each cell. Its value is in millimetres. In this study, the data was utilized the same precipitation dataset as employing in water yield model.
4. **Watershed Polygons** – See Annual Water Yield Inputs
5. **Biophysical Table** – A table of LULC classes, containing data on water quality coefficients used in this tool (Table A15). NOTE: these data are attributes of each LULC class rather than attributes of individual cells in the raster map. These data were derived from Tapaneeyakul (2015). The table has the following field:
   5.1 Lucode – Unique identifier for each LULC class.
   5.2 LULC_desc – Nominal name for each LULC class.
   5.3 *load_n / load_p* – The nutrient loading for each land use. If nitrogen is being evaluated, supply values in load_n, for phosphorus, supply values in load_p. The potential for terrestrial loading of water quality impairing constituents is based on nutrient export coefficients. The nutrient loading values are given as integer values and have units of kg. ha^{-1} yr^{-1}.
   5.4 *eff_n / eff_p* – The vegetation filtering value per pixel size for each LULC class, as an integer percent between zero and 1. If nitrogen is being evaluated, supply values in eff_n, for phosphorus, supply values in eff_p. This field identifies the capacity of vegetation to retain nutrients, as a percentage of the amount of nutrient flowing into a cell from upslope. For example, if the user has data describing that a wetland of 5000 m^2 retains 82% of nitrogen, then the retention efficiency that she/he should input into this field for eff_n is equal to (82/5000 * $(\text{cell size})^2$). In the simplest case, when data for each LULC type are not available, high values (60 to 80) may be assigned to all natural vegetation types (such as forests, natural pastures, wetlands, or prairie), indicating that 60–80% of nutrients are retained. An intermediary value also may be assigned to features such as contour buffers. All LULC classes that have no filtering capacity, such as pavement, can be assigned a value of zero
   5.5 *crit_len_n (and/or crit_len_p)* (at least one is required): The distance after which is assumed that a patch of a particular LULC type retains nutrient at its maximum capacity, given in metres. If nutrients travel a distance smaller than the retention length, the retention efficiency will be less than the maximum value *eff_x*, following an exponential decay.
   This value represents the typical distance necessary to reach the maximum retention efficiency. It was introduced in the model to remove any sensitivity to the resolution of the LULC raster. In the absence of local data for land uses that are not forest or grass, it is possible to simply set the retention length constant,

equal to the pixel size: this will result in the maximum retention efficiency being reached within a distance of one pixel only.

5.6 ***proportion_subsurface_n or p (optional):*** The proportion of dissolved nutrients over the total amount of nutrients, expressed as floating point value (ratio) between 0 and 1. By default, this value should be set to 0, indicating that all nutrients are delivered via surface flow.

Table A15. Biophysical table – Annual Nutrient Delivery Ratio

lucode	LULC_desc	load_n	eff_n	load_p	eff_p	crit_len_n	crit_len_p	proportion_subsurface_n
62	lc_62	4	0.05	0.001	0.05	200	200	0
73	lc_73	11	0.25	3	0.25	200	200	0
75	lc_75	11	0.25	3	0.25	200	200	0
82	lc_82	1.8	0.7	0.011	0.7	200	200	0
83	lc_83	1.8	0.7	0.011	0.7	200	200	0
102	lc_102	11	0.25	3	0.25	200	200	0
103	lc_103	11	0.4	3	0.4	200	200	0
104	lc_104	11	0.25	3	0.25	200	200	0
105	lc_105	11	0.4	3	0.4	200	200	0
106	lc_106	11	0.4	3	0.4	200	200	0
121	lc_121	11	0.25	3	0.25	200	200	0
123	lc_123	4	0.05	0.001	0.05	200	200	0
130	lc_130	0	0.6	0	0.6	200	200	0
131	lc_131	0	0.6	0	0.6	200	200	0
132	lc_132	4	0.05	0.001	0.05	200	200	0
133	lc_133	1.8	0.7	0.011	0.7	200	200	0
162	lc_162	0	0.6	0	0.6	200	200	0

- **Threshold flow accumulation value** – Integer value defining the number of upstream pixels that must flow into a pixel before it is considered part of a stream. This is used to generate a stream layer from the DEM. This threshold expresses where hydrologic routing is discontinued, i.e., where retention stops and the remaining pollutant will be exported to the stream. The default value of 1,000 was used in this simulation.
- **Subsurface maximum retention efficiency (Nitrogen or phosphorus)** – The maximum nutrient retention efficiency that can be reached through subsurface flow, a value between 0 and 1. This field characterizes the retention due to biochemical degradation in soils. The default value of 0.8 was used for this study.
- **Subsurface_crit_len (Nitrogen or phosphorus)** (in meter) – The distance (travelled subsurface and downslope) after which it is assumed that soil retains nutrients at its maximum capacity. If dissolved nutrients travel a distance smaller than subsubsurface_crit_len, the retention efficiency is lower than the maximum value

defined above. Setting this value to a distance smaller than the pixel size will result in the maximum retention efficiency being reached within one pixel only. The default value of 150 suggested for the model for the spatial resolution lower than 150 m was used in this analysis.

- **Borselli k** parameter – Calibration parameter that determines the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the sediment delivery ratio (percentage of soil loss that actually reaches the stream). The default value is 2.

7.2 Results – Nitrogen

The main output of this model are raster files containing biophysical output values per watershed, with the following attribute:

- N_export_tot (kg/watershed): total nitrogen export from the watershed

Figure A14 shows the total nitrogen export (Kg/Watershed) for each scenario.

Figure A14. Nitrogen export (kg/pixel)

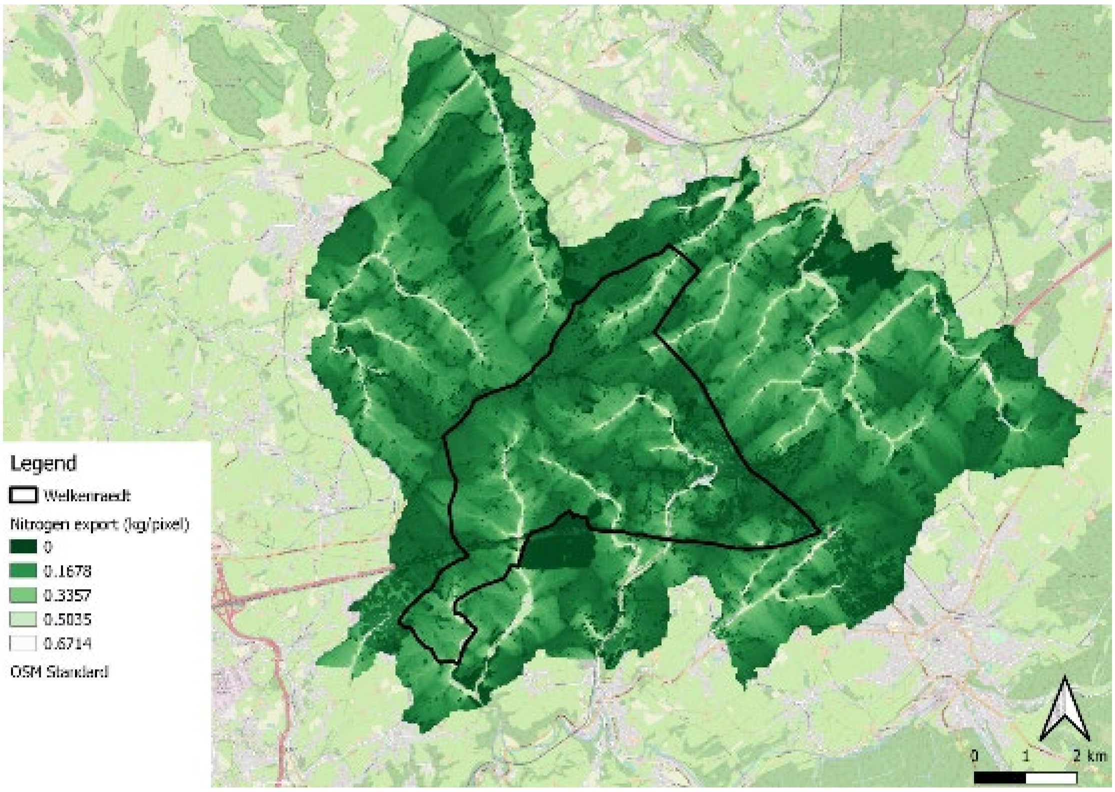


Table A16. Nitrogen Delivery Ratio statistics

	Nitrogen exports (kg)	Change from the BAU scenario %
BAU Scenario	63,438	-0.59
ROWS Scenario	63,061	

Table A16 shows the total nitrogen export under both the BAU and ROWS scenarios in the whole watershed that surround the municipality. The results indicate that total nitrogen export will decrease by only 377 kg in the ROWS scenario compared to the BAU scenario. In other words, the tree rows that are present only in the ROWS scenario will not produce large changes in the nitrogen export dynamics in the watershed. However, they may be able to limit the nutrient export at a lower level (e.g., banks of local streams).

7.3 Results – Phosphorus

The main output of this model are raster files containing biophysical output values per watershed, with the following attribute:

- P_export_tot (kg/watershed): total Phosphorus export from the watershed

Figure A15 shows the total phosphorus export (Kg/Watershed) for each scenario.

Figure A15. Phosphorus export (kg/pixel)

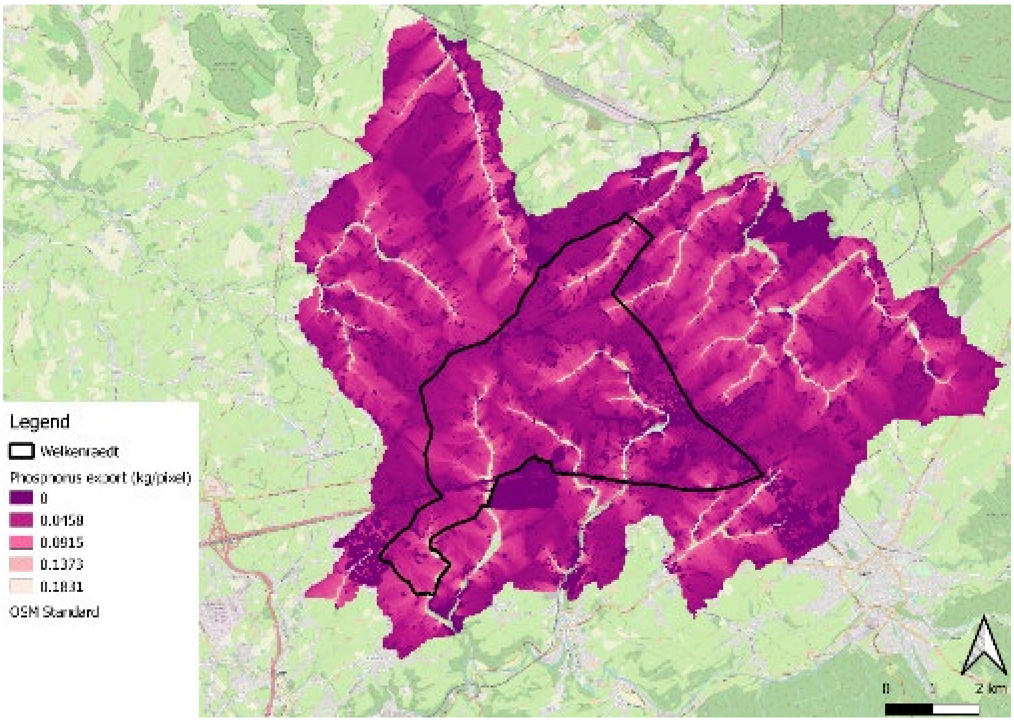


Table A17. Phosphorus Delivery Ratio statistics

<table>
<tr><th></th><th>Phosphorus exports (kg)</th><th>Change from the BAU scenario %</th></tr>
<tr><td>BAU Scenario</td><td>16,646</td><td rowspan="2">-0.62</td></tr>
<tr><td>ROWS Scenario</td><td>16,543</td></tr>
</table>

Table 15 shows the total phosphorus export under both the BAU and ROWS scenarios in the whole watershed that surround the municipality. The results indicate that total phosphorus export will decrease by only 102 kg in the ROWS scenario compared to the BAU scenario. In other words, the tree rows that are present only in the ROWS scenario will not produce large changes in the phosphorus export dynamics in the watershed. However, they may be able to limit nutrient export at a lower level (e.g., banks of local streams).

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