

**Faculté des bioingénieurs**

# **Evaluating the cost-effectiveness of carbon farming practices in Wallonia**

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# Abstract

Climate change poses an urgent threat to global environmental stability, necessitating a transition to carbon neutrality. Agriculture, while being a significant source of greenhouse gas emissions, also presents opportunities for mitigation through carbon farming practices. This thesis focuses on Wallonia, Belgium, to investigate the cost-effectiveness of four carbon farming practices: agroforestry, hedges, compost application, and temporary grasslands.

A Marginal Abatement Cost Curve (MACC) was constructed using a detailed cost model that incorporates data from the Farm Accountancy Data Network (FADN), Mecacost, (2017), and pricing information from seed and plant retailers. Carbon sequestration potentials were derived from existing literature. The analysis reveals varying cost-effectiveness and carbon sequestration potential among the practices, with new organic carbon input (compost application) emerging as the most cost-effective option in most regions.

The study highlights regional variations in costs and sequestration potential, emphasizing the importance of tailoring strategies to specific contexts. Certain regions benefit from negative costs for implementing temporary grasslands due to low crop yields, demonstrating the potential for economic benefits alongside carbon sequestration. Sensitivity analysis reveals the impact of increasing mechanization costs, with compost application being most affected.

The thesis underscores the limitations of the engineering MACC approach, including data gaps and assumptions. The need for further research is highlighted, particularly in developing region-specific carbon sequestration models, conducting more comprehensive cost-effectiveness analyses, and incorporating life cycle assessments.

The findings contribute to a nuanced understanding of the potential and challenges of carbon farming in Wallonia. By providing region-specific insights, the study supports informed policy interventions and sustainable agricultural practices that contribute to climate change mitigation. Policymakers are urged to consider the varying cost-effectiveness and abatement potential of practices when designing incentives. This research ultimately paves the way for a more environmentally and economically sustainable agricultural sector in Wallonia.





# List of Abbreviations

|                    |                                                               |
|--------------------|---------------------------------------------------------------|
| AFAC:              | Association Française d'Agroforesterie                        |
| ALULUCF:           | Agriculture, Land Use, Land Use Change and Forestry           |
| B:                 | Beetroot                                                      |
| CC:                | Cover Cropping                                                |
| CO <sub>2</sub> :  | Carbon dioxide                                                |
| CO <sub>2</sub> e: | Carbon dioxide equivalent                                     |
| CT:                | Crop Total                                                    |
| ECAD:              | Equivalent Constant Annuity over the Duration of the practice |
| EOM:               | Exogenous Organic Matter                                      |
| EU:                | European Union                                                |
| FADN:              | Farm Accountancy Data Network                                 |
| GHG:               | Greenhouse gas                                                |
| IPCC:              | Intergovernmental Panel on Climate Change                     |
| K:                 | Potassium                                                     |
| kt:                | Kiloton                                                       |
| MACC:              | Marginal Abatement Cost Curve                                 |
| MAC:               | Marginal Abatement Cost                                       |
| MS:                | Dry Matter                                                    |
| Mt:                | Mega ton                                                      |
| N <sub>2</sub> O:  | Nitrous oxide                                                 |
| NPV:               | Net Present Value                                             |
| NWW:               | Not enough Winter Wheat                                       |
| P:                 | Phosphorus                                                    |
| PT:                | Potato                                                        |
| SOC:               | Soil organic carbon                                           |

t: tonne

tC: tonnes of carbon

t/ha/year: Tonnes per hectare per year

WB: Winter Barley

WW: Winter Wheat

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# 1 Introduction

Climate change poses an unprecedented challenge to global environmental stability, with significant implications for ecosystems, human health, and economic development. To mitigate the impacts of climate change, it is critical to achieve global carbon neutrality by 2050, a goal underscored by the Intergovernmental Panel on Climate Change (IPCC) to keep global warming below 1.5°C compared to pre-industrial levels (Allen, 2019). Achieving this ambitious target necessitates not only drastic reductions in greenhouse gas (GHG) emissions but also significant enhancements in terrestrial carbon dioxide ( $CO_2$ ) sinks through changes in land use, as well as agricultural and forestry practices that promote carbon sequestration in soils and woody biomass.

Agriculture plays a dual role in this context: it is both a contributor to GHG emissions and a potential mitigator through carbon sequestration practices. In 2019, the agriculture sector accounted for 12.2% of global emissions, equivalent to 4539 kt of  $CO_2$  equivalent (eq.) (SPW, 2019). The European Union (EU) aims to balance 500–600 Mt $CO_2$ e per year of residual emissions with carbon sequestration, expecting 50–85% of this offset to come from soils and biomass (Bamière et al., 2023).

Carbon farming practices, such as implementing temporary Grasslands, agroforestry and implementing new organic Carbon are often proposed as strategies to enhance soil organic carbon (SOC) stocks and mitigate GHG emissions. Despite their potential, evidence on the cost-effectiveness of these practices remains limited (Cara & Jayet, 2006; Feng et al., 2006; Frank et al., 2015; Moran et al., 2011; Pautsch et al., 2001), and they have shown variable effectiveness in increasing SOC, particularly in temperate regions (Haddaway et al., 2017).

There are various decrees and initiatives that set climate goals for Wallonia and Belgium by 2050. The most significant in Wallonia is the "Climate" decree of February 20, 2014, which targets an 80-95% reduction in greenhouse gas (GHG) emissions by 2050 compared to 1990 levels (55 549 kt $CO_2$ e) (SPW, 2019). In Belgium, the European Commission's "Fit for 55" package proposes a 47% reduction by 2030 compared to 2005 levels for non-ETS sectors. The agricultural sector is responsible for a significant portion of these emissions in both Wallonia and Belgium. Although Wallonia achieved its 2020 target by 2012, emissions have stabilized since, necessitating a more dynamic reduction to meet the 2030 and 2050 goals (United Nations, 2018).

Despite this policy framework, there remains a significant research gap in understanding the cost-effectiveness of various carbon farming practices within the region. By focusing on Wallonia, this thesis aims to fill this research gap by providing detailed, region-specific insights that can inform more effective and economically viable carbon neutrality strategies for both Wallonia and the broader EU context.

To achieve this objective, this thesis employs a Marginal Abatement Cost Curve (MACC) to evaluate the cost-effectiveness of implementing new carbon farming practices in Wallonia. A key element of this approach is the construction of a cost model for each individual practice. The construction follows several critical steps:

- First, the selection of practices relevant to the Walloon region
- Second, a detailed cost assessment for each practice using a cost model that incorporates data from the Farm Accountancy Data Network (FADN), Mecacost, (2017), and pricing information from seed and plant retailers
- Third, the evaluation of the carbon sequestration potential of the selected practices based on data from existing literature
- At the End, the construction of the MACC illustrates the cost-effectiveness of each practice and its potential contribution to carbon sequestration in Wallonia. The MACC uses an engineering approach which enables a robust evaluation of the feasibility and financial implications of adopting these practices in the region.

The thesis begins with a thorough literature review, explaining the concept of carbon farming and examining various carbon farming practices and their impact on carbon sequestration. This is followed by a section that provides context by detailing the research background specific to Wallonia. The research questions and Hypothesis guiding the study are then outlined. The methodology used to construct the MACC is elaborated upon, including data sources, model construction, and the criteria for selecting practices. The results are presented next, accompanied by a sensitivity analysis to assess the robustness of the model. The discussion section interprets the results in the context. Finally, the thesis concludes with a summary of the main findings and their relevance to the broader context of carbon farming in Wallonia.

## 2 Literature review

### 2.1 What is carbon farming?

Carbon farming is a strategy implemented at the farm level with the aim of mitigating climate change. It involves managing both land and livestock, as well as all carbon reservoirs in soils, materials, and vegetation. Carbon farming focuses on controlling the fluxes of carbon dioxide, methane, and nitrous oxide ( $N_2O$ ) emissions (COWI, 2021). By adopting these sustainable agricultural practices, farmers can contribute to climate change mitigation, enhance ecosystem services, and potentially gain economic benefits through carbon credits and improved farm productivity.

A key component of carbon farming is carbon sequestration in soil, which involves capturing  $CO_2$  from the atmosphere and storing it in the soil over time (t/ha/year). This process is assessed relative to a business-as-usual scenario to determine the net transfer of carbon into the soil. On the other hand, Soil Organic Carbon (SOC) storage or stocks refer to the current amount of carbon stored in the soil at a specific time, expressed in units like Mg C/ha. While SOC storage provides a snapshot of the existing carbon content, it does not indicate the rate at which carbon is being added or removed (Don et al., 2024).

Farmers participating in carbon farming programs (e.g. Soil Capital) are compensated primarily through result-based payments, where their remuneration is directly tied to the quantifiable amount of carbon they sequester in their soil or biomass. This approach shifts the focus from simply implementing specific practices to achieving tangible environmental outcomes. The more carbon a farmer successfully sequesters, the higher their payment. This creates a strong incentive for farmers to adopt and innovate practices that maximize carbon sequestration, ensuring they are financially rewarded for their contribution to climate change mitigation (Raina et al., 2024).

The European Union (EU) promotes carbon farming through the Common Agricultural Policy (CAP), a key policy instrument designed to support sustainable agricultural practices. The CAP offers financial support through direct payments (Pillar 1) and specific carbon sequestration projects (Pillar 2) (Guyomard et al., 2020). Recent CAP reforms have started to evolve towards result-based payments, aligning financial incentives with environmental performance. This

shift aims to encourage the adoption of more effective carbon farming practices across EU member states (Raina et al., 2024).

The voluntary carbon market provides an additional avenue for farmers to generate income by selling carbon credits. Although unregulated, this market has seen significant growth, with a 3.4% increase in demand between 2021 and 2022 (Spilker & Nugent, 2022). Participation in these markets can connect farmers to global carbon markets, offering financial incentives for sustainable practices. To make carbon markets work better and be more trustworthy, some challenges need to be overcome. It's important to ensure that the carbon credits represent real and lasting carbon reductions, and that these reductions would not have happened without the carbon credit program. The EU is working on developing a certification framework to standardize and regulate these markets (Valiergue, 2018).

## 2.2 Carbon sequestration potential

### 2.2.1 Carbon Farming practices

There are various carbon farming practices, like cover cropping, reduced tillage, crop rotations, agroforestry, hedges, optimized grazing patterns and new organic carbon input. Each of these practices entails different costs and potential for carbon sequestration (see Table 1). This study focuses on four specific practices: agroforestry, the implementation of hedgerows, the addition of new organic carbon inputs, and the establishment of temporary grasslands.

Table 1 : Summary of carbon sequestration potentials from Literature relevant for the Wallonia context based on (Bamière et al., 2023)

| Practice                                          | Carbon Storage Potential from Literature Review                                                                                                                                                                                   | References and geographical context                                                                                                                                     | Geographical context (respectively)                                            |
|---------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Expansion of cover crops                          | $313 \pm 313 \text{ kg C ha}^{-1} \text{ yr}^{-1}$                                                                                                                                                                                | Justes et al. (2013) , McDaniel et al. (2014), Poeplau and Don (2015), Constantin et al. (2010)                                                                         | France, United states, Germany, France                                         |
| New organic C inputs                              | 100 kg C ha <sup>-1</sup> yr <sup>-1</sup> (sewage sludge), 100 kg C ha <sup>-1</sup> yr <sup>-1</sup> (liquid manure), 300 kg C ha <sup>-1</sup> yr <sup>-1</sup> (manure), 500 kg C ha <sup>-1</sup> yr <sup>-1</sup> (compost) | Zavattaro et al. (2017), Morvan et al. (2013), Powlson et al. (2012)                                                                                                    | Italy, France; United Kingdom                                                  |
| Implementing temporary grasslands in croplands    | $\sim 130\text{--}500 \text{ kg C ha}^{-1} \text{ yr}^{-1}$                                                                                                                                                                       | Conant et al. (2001), Franzluebbers et al. (2014), Johnston et al. (2017), Creme (2020)                                                                                 | United States, United States, United Kingdom, Europe                           |
| Agroforestry                                      | 250 kg C ha <sup>-1</sup> yr <sup>-1</sup> (– 230; +730) in the soil (cropland only); 900 kg C ha <sup>-1</sup> yr <sup>-1</sup> (– 430; +1350) in the biomass                                                                    | Cardinael et al. (2017), Lorenz and Lal (2014), Feliciano et al. (2018), Cardinael et al. (2018), Chatterjee et al. (2018), Pardon et al. (2017), Drexler et al. (2021) | France, United states, United Kingdom, France, United States, Belgium, Germany |
| Hedges                                            | 750 kg C.ha <sup>-1</sup> of hedges. yr <sup>-1</sup> (490; 1020) in the soil (cropland only); 240 kg C.ha <sup>-1</sup> .yr <sup>-1</sup> (– 120; +370) in the biomass                                                           | Pellerin et al., 2013, Arrouays et al., 2002, Kumar and Nair, 2011                                                                                                      | France, France, United States                                                  |
| Moderate intensification of extensive grasslands  | $0\text{--}210 \pm 70 \text{ kg C ha}^{-1} \text{ yr}^{-1}$                                                                                                                                                                       | Conant et al. (2017), Sanderman et al. (2015), Abdalla et al. (2018), Franzluebbers & Stuedemann (2009), Poeplau et al. (2018).                                         | United States, United States, Ireland, United States, Germany                  |
| Grazing instead of mowing in permanent grasslands | From $111 \pm 11$ to $380 \pm 20 \text{ kg C.ha}^{-1} \text{ yr}^{-1}$ depending on biomass removal                                                                                                                               | McSherry & Ritchie (2013), Soussana and Lemaire (2014), Abdalla et al. (2018), Eze et al. (2018),                                                                       | United States, France, Ireland, United Kingdom                                 |

Table 1 shows carbon sequestration potential and their range across different carbon farming practices. At the high end, agroforestry systems, integrating trees and shrubs with grassland, stand out with the highest potential, when including biomass sequestration. They can sequester a substantial amount of carbon, ranging from 250 kg C/ha/year in the soil alone to a combined 1150 kg C/ha/year in both soil and biomass. The potential for hedges is expressed for one hectare of hedges and must be adapted to the surface it covers.

On the other end of the spectrum, moderate intensification of extensive grasslands demonstrates the lowest potential for carbon sequestration, and in some cases, it can even lead

to carbon loss, ranging from 0 - 210 kg C/ha/year. Other practices like improved grazing management, adding new organic carbon input, implementing temporary grasslands, and expanding cover crops also offer varying degrees of carbon sequestration potential, falling between these two extremes. This comparison underscores the importance of selecting appropriate grassland management practices to optimize carbon sequestration efforts, with agroforestry presenting a particularly promising option.

### 2.2.2 Impact of carbon farming practices on SOC stock

Agricultural practices impact soil carbon stock through both direct and indirect mechanisms. Direct effects are observed in practices that increase carbon inputs, such as cover cropping and fertilization, which introduce more organic material into the soil. This promotes plant growth, leading to increased plant material deposited in the soil. This belowground carbon input, primarily from plant roots and rhizodeposits, plays a crucial role in soil carbon sequestration, but is often not fully understood or explicitly accounted for in models. Additionally, exogenous carbon inputs from organic amendments like manure and compost directly increase soil carbon content, enhancing carbon stock (Balesdent et al., 2011).

Agricultural practices can indirectly alter conditions that influence the decomposition and stabilization of organic matter. For instance, practices like mulching and the use of cover crops can modify soil temperature and moisture, impacting the rate at which organic material decomposes and, consequently, carbon turnover. Furthermore, some practices influence the activity of soil microorganisms, though these effects are less understood and rarely integrated into existing models. Physical and physicochemical interactions, such as those arising from reduced tillage, can also affect carbon stabilization in the soil by altering the relationship between organic matter and minerals (Pellerin & Bamière, 2020).

The effectiveness of these practices in storing additional carbon varies significantly depending on local conditions, leading to substantial regional differences. For example, colder and/or drier regions generally store more carbon per unit of added carbon compared to warmer and/or wetter areas.

The soil type is another critical factor, with clay soils generally exhibiting a greater capacity for carbon sequestration. However, practices that alter soil moisture or temperature can have complex and sometimes unpredictable effects on carbon stocks. For example, while mulching

might increase carbon stocks in dry climates, it could have the opposite effect in wetter regions (Pellerin & Bamière, 2020).

### 2.2.3 Agroforestry

Agroforestry, which describes incorporation of trees into agricultural systems, represents a multifaceted approach to enhancing carbon sequestration through increased biomass production and SOC sequestration. This encompasses a range of practices, including intercropping, establishing windbreaks, and silvopasture (Ramachandran Nair et al., 2010). Trees improve soil carbon stocks by sequestering carbon in their aboveground biomass, which transfers to the soil over time. Roots enhance soil structure, add organic matter, and improve nutrient and water uptake, potentially boosting ecosystem productivity (Palma et al., 2018).

Many studies compare the amount of carbon stored in agroforestry systems to nearby areas without trees at a single point in time. These studies often find that agroforestry helps increase soil organic carbon SOC levels (Cardinael et al., 2018). However, there is a lack of research that monitors how SOC levels change over a longer period after trees are planted.

A review by Follain et al. (2007) examined SOC sequestration rates in silvoarable, silvopastoral, and hedgerow systems, emphasizing European and North American data relevant to Wallonia. It highlighted the importance of considering system age when estimating carbon sequestration rates, often overlooked in hedgerow studies. In silvoarable systems, the average SOC storage rate is about 0.25 tC/ha/year (see Table 1) at a depth of 36.4 cm, with an average density of 182 trees/ha and an average age of 15.8 years. A French study on five silvoarable plots also found an average SOC sequestration rate of 0.25 tC/ha/year (see Table 1) over a depth of 0-30 cm, with an average density of 75 trees/ha and an average age of 17.8 years (Cardinael et al., 2017a).

In silvopastoral systems, no significant effect of tree planting on permanent grasslands was observed for SOC, with an average sequestration rate of 0.05 tC/ha/year corresponding to a depth of 42.9 cm, an average density of 272 trees/ha, and an average age of 25.3 years (Cardinael et al., 2017). This lack of carbon sequestration contrasts with earlier estimates, which hypothesized additional storage similar to that observed in silvoarable systems (0.30 tC/ha/year) due to the absence of published data (Chenu et al., 2014). However, some studies have noted deeper soil carbon sequestration (Cardinael et al., 2017b).

Implementing agroforestry requires initial capital investment, ongoing maintenance, and potential harvesting costs. While agroforestry can increase overall productivity, it may also reduce primary crop yields due to competition for land, light, and water. Nevertheless, trees can offer additional income through timber (Palma et al., 2018).

#### 2.2.4 Hedges

Hedges, though often classified under agroforestry, have distinct carbon sequestration capabilities compared to other agroforestry practices. These linear plantings of trees and shrubs along field boundaries contribute to carbon sequestration, but their effectiveness is influenced by factors like tree density, species composition, and management practices (Pellerin & Bamière, 2020). Importantly, studies on hedgerows often underestimate their long-term carbon sequestration potential by overlooking the significance of system age (Cardinael et al., 2017).

The average SOC storage rate across selected studies is 0.75 tC/ha/year (see Table 1). For hedges, SOC storage is expressed per hectare of hedge, not per hectare of agricultural land. This rate needs to be adjusted based on the actual area occupied by hedges within agricultural plots or meadows to accurately assess their contribution to landscape-level carbon sequestration (Pellerin & Bamière, 2020). These figures are based on specific parameters: an average depth of 38.8 cm, an average tree density of 739 trees per kilometre, and an average hedgerow age of 26.6 years. This data underscores that hedges, especially mature ones, can play a substantial role in carbon sequestration when properly integrated into agricultural systems (Cardinael et al., 2017).

The co-benefits of hedges are multiple, they promote biodiversity, reduce soil erosion, and improve water quality. Additionally, they enhance agricultural productivity through pollination and pest control. Hedgerows are thus key elements for sustainable and climate-resilient land use (Baumber et al., 2019).

#### 2.2.5 Implementation of temporary grasslands

Temporary grasslands, where perennial grasses or legumes are cultivated for less than six years within a crop rotation system, offer significant agronomic and environmental benefits. These grasslands sequester approximately 0.5 tC/ha/year for up to a decade, a rate notably higher than that of annual crops (Franzluebbers et al., 2014).

Initially, carbon accumulates in the topsoil layers (0-30 cm) and extends to deeper layers after 2-3 years. This sequestration process, involving more labile organic matter with a faster



turnover, is particularly effective in the early years but gradually decreases, eventually aligning with rates observed in long-term pastures (Franzluebbers et al., 2014).

Long-term studies indicate that soil carbon content in grassland-cropping rotations is generally higher than in continuous cropping but lower than in permanent grasslands. Temporal fluctuations in carbon stocks during the succession of grassland and cropping phases can either increase or slow carbon loss compared to continuous cropping systems without grassland phases (Johnston et al., 2017). However, converting grasslands back to cropping can lead to rapid soil carbon loss, potentially reducing the carbon stock in the 0-30 cm soil layer by 20-30% over a decade (Vertès, 2007).

A synthesis of data from temperate agricultural systems in North and South America suggests that maintaining at least 33% of the crop rotation under grassland is crucial for stable long-term soil carbon content. Shorter grassland phases result in a decline in soil carbon, while longer phases (at least 50%) promote an increase. The effectiveness of these phases is influenced by the initial organic carbon content of the soil, with higher initial levels requiring longer grassland periods for optimal results (Franzluebbers et al., 2014).

In addition to sequestering carbon, temporary grasslands contribute to soil fertility by enhancing nitrogen mineralization, especially in legume-rich systems. The improved soil structure and permeability from perennial root systems and increased organic matter reduce the need for herbicides and pesticides, while lower  $N_2O$  emissions result from reduced nitrogen fertilization. These grasslands also support greater biodiversity compared to monoculture systems (Kunrath et al., 2015).

#### 2.2.6 Use of exogenous organic matter in form of compost

Carbon farming with exogenous organic matter (EOM) involves applying organic materials that are not produced on the cultivated land itself. This practice excludes crop residues, intermediate crops and livestock effluents, but includes materials such as composts from green waste, agro-industrial effluents, and sewage sludge. The primary goal is to enhance soil carbon stocks by applying these materials to agricultural land that previously did not receive organic amendments (Pellerin & Bamière, 2020).

The efficiency of carbon sequestration from EOM varies by material type. Compost generally offers the highest potential for carbon sequestration, with an average of 0.5 tC/ha/year (see Table 1). This is followed by other organic fertilizers such as manures (0.31 tC/ha per year),

slurries (0.09 tC/ha per year), and sewage sludge (0.02 tC/ha per year). The conversion of organic residues into soil carbon is influenced by the biochemical composition of these products (Pellerin & Bamière, 2020).

Digestates from anaerobic digestion are less well-studied, with limited long-term field research available. Concerns about reduced soil organic matter due to the conversion of biodegradable waste into biogas have been raised. Additionally, Wentzel et al. (2015) observed no significant differences in organic carbon content between soils treated with digested livestock effluents and soils treated with no organic fertilizer. This suggests that while the transformation process may stabilize organic matter, further research is needed to understand the long-term implications of digestate use.

In 2020, 69% of the sludge produced by wastewater treatment plants in Wallonia was recovered in agriculture, 30% was incinerated with energy recovery, and 1% was incinerated without recovery. This shows that the potential for adding more carbon to the soils with sludge is limited (SPW, 2023a).

Applying EOM improves soil structure stability, reduces compaction risk, and lowers the energy required for tillage. It also enhances water retention and allows for quicker field access after rainfall. EOM applications increase essential nutrients (N, P, K, S), which can potentially substitute for mineral fertilizers and aid in soil pH correction. Additionally, EOM stimulates soil biological activity, including microbial populations, without adversely affecting soil functions (Wentzel et al., 2015).

EOM can contain contaminants such as trace elements, organic pollutants, and biological agents. Repeated applications may lead to increased levels of elements like copper and zinc in soils. While regulations and best practices have been established to improve the quality of applied materials, ongoing research is necessary to ensure the sustainability of EOM recycling practices (Sykes et al., 2020).

The application of organic fertilizers faces several challenges. Financially, they require more labour and time compared to synthetic options, and there may be additional costs if organic amendments are sold or used elsewhere. Non-financial barriers include the need for land managers to have expertise in optimizing application rates and the necessity for an effective and affordable transport network, which can be particularly challenging in developing countries. Environmentally, using manure for fuel or electricity can lead to 'leakage' if more

carbon-intensive processes replace it, and emissions from manure storage and application may vary. Additionally, the production of synthetic fertilizers could be indirectly affected (Sykes et al., 2020).

### 2.2.7 Reduced tillage and no-till

Reduced tillage and no-till are agricultural practices that aim to minimize soil disturbance. In reduced tillage, the soil is minimally disturbed using shallow ploughing or other less intensive methods, while no-till farming eliminates mechanical soil disturbance altogether (Smith, 1997). The reason for adopting these practices is to conserve SOC.

Soil disturbance through conventional tillage methods like ploughing can accelerate the decomposition of organic matter, releasing stored carbon into the atmosphere as  $CO_2$ . Reduced tillage and no-till practices help mitigate this by leaving crop residues on the soil surface, which act as a protective layer and slow down decomposition. This preservation of organic matter contributes to increased SOC levels (Haddaway et al., 2017).

The practice the protective layer of crop residues in reduced tillage and no-till systems safeguards the soil against erosion caused by wind and water. Additionally, these practices require less fuel and energy compared to conventional tillage, as the need for heavy machinery is reduced (Alvarez, 2005).

While reduced tillage and no-till present advantages, they are not without challenges. In the initial years of adoption, crop yields may be lower, and increased herbicide use may be necessary due to the absence of mechanical weed control (Haddaway et al., 2017). Moreover, under specific conditions, these practices can contribute to elevated nitrous oxide ( $N_2O$ ) emissions, a potent greenhouse gas (Sykes et al., 2020).

The impact of reduced tillage and no-till on SOC stocks in temperate regions like Wallonia remains a topic of ongoing research, with some studies indicating limited or no effects. The decision to adopt reduced tillage or no-till should be made on a case-by-case basis, considering the specific site conditions, crop types, and management practices. A comprehensive assessment of the potential benefits and drawbacks is essential to ensure the sustainable and effective implementation of these practices in agricultural systems (Haddaway et al., 2017).

### 2.2.8 Biochar

Biochar is a carbon-rich material derived from the pyrolysis of biomass. Various pyrolysis processes (torrefaction, slow/fast pyrolysis, gasification, hydrothermal carbonization) yield biochar with diverse properties. The stability of carbon within biochar is influenced by both the production process and the original biomass. While a portion of the carbon remains labile and can stimulate microbial activity (Biederman & Harpole, 2013), the majority exhibits high stability, contributing to its amendment value. This value, representing the percentage of carbon expected to persist in the soil over the long term, is notably high for biochar produced via hydrothermal carbonization (80-85%), fast pyrolysis (95%), and slow pyrolysis (97%).

The application of biochar to soil can exert complex effects on soil organic matter mineralization. While short-term stimulation may occur, long-term decomposition tends to be slowed through physical protection mechanisms (Maestrini et al., 2015). The meta-analysis by Wang et al. (2016) confirms these high amendment values and shows that the application of biochar can have contradictory effects on the mineralization of soil organic matter: short-term stimulation, but long-term slowing of decomposition through physical protection processes.

Economic considerations play a crucial role in biochar adoption, presenting both opportunities and challenges. The cost of acquiring or producing biochar can vary, potentially posing a financial barrier. However, utilizing agricultural by-products as feedstock can offset costs, although this limits their alternative uses. Potential benefits like improved crop yields and enhanced nutrient delivery efficiency may provide financial incentives (Sykes et al., 2020).

Beyond financial aspects, non-financial barriers also exist. The perceived complexity and risk associated with biochar, along with the reliance on external inputs, can deter adoption. Additionally, inadequate supply chain infrastructure and regulatory uncertainties create challenges. Nevertheless, biochar's potential to enhance soil resilience to erosion offers a significant advantage. In summary, the economic landscape of biochar adoption is complex, requiring a balanced consideration of potential benefits and barriers to promote wider acceptance and use in agriculture (Sykes et al., 2020).

### 2.2.9 Cover crops

Cover cropping (CC) involves incorporating organic matter from cover crops into the soil to enhance carbon (C) storage compared to practices that do not use cover crops. This practice has been evaluated through laboratory studies and field trials.

Laboratory studies demonstrate that cover crop residues contribute significantly to soil carbon sequestration. The stabilization of carbon from the aerial parts of cover crops is comparable to that of mature plant residues (Justes et al., 2009). Notably, younger cover crops tend to have a higher contribution of root biomass relative to aerial biomass compared to older crops, with a higher conversion factor for carbon stocks (Kätterer et al., 2011).

Field trials, reviewed in meta-analyses by Justes et al. (2013), McDaniel et al. (2014), and Poeplau et al. (2015) generally show that CC leads to additional carbon sequestration. On average, CC results in an additional storage of 313 kg/ha/year over periods exceeding five years. This additional storage varies widely, influenced by biomass production (see Table 1).

The efficiency of carbon sequestration through CC varies by climate. In tropical regions, CC leads to higher carbon storage compared to temperate zones, largely due to greater biomass production under favourable climatic conditions, although the conversion biomass to SOC is lower in tropical climates (Justes et al., 2009).

Legume cover crops specifically have been shown to effectively increase soil carbon and N stocks. They contribute to an average carbon stock increase of 8.5% over 18 years, translating to a storage rate of 236 kg C/ha/year (McDaniel et al., 2014). However, other studies (Poeplau et al., 2015) found no significant difference in carbon storage between legume and non-legume cover crops.

Cover cropping presents a complex cost-benefit analysis for farmers. Potential benefits include reduced  $N_2O$  emissions, improved soil erosion resistance, and possible yield increases through green manure or reduced agrochemical use. However, challenges include additional input and time costs, as well as the risk of yield loss or negative impacts on pest control. The impact on pest control and agrochemical use can vary, and farmers must weigh these factors based on their specific context. Further research is needed to understand these complex interactions and develop strategies to maximize benefits while reducing risks to a minimum (Sykes et al., 2020).

#### 2.2.10 Carbon Farming practices associated to permanent Grasslands

Carbon farming in permanent grasslands involves various practices that can influence carbon stocks in soil. These practices include fertilization, grazing, mowing, and the management of plant species composition (Soussana & Lemaire, 2014).

#### *2.2.10.1 Grazing Practices*

Grazing is a practice in carbon farming within grasslands. Compared to mowing, grazing can increase carbon stocks by returning organic matter to the soil through animal manure and by reducing carbon removal that occurs with hay or silage harvests. Moderate grazing intensity is recommended to optimize carbon sequestration because it promotes nutrient cycling and plant productivity without leading to soil compaction or overgrazing. Rotational grazing, where animals are moved between paddocks, is particularly beneficial for carbon sequestration as it allows grazed areas to rest and recover (Soussana & Lemaire, 2014).

#### *2.2.10.2 Fertilization*

Fertilization in permanent grasslands, particularly with mineral fertilizers such as N, phosphorus (P), and potassium (K), along with lime, can significantly boost plant growth. This increase in growth enhances carbon inputs to the soil through root exudates and plant residues (Soussana et al., 2004). However, excessive fertilization can have the opposite effect by accelerating the mineralization of soil organic matter, which reduces carbon stocks. Organic fertilizers like manure or compost are often more beneficial for carbon stocks due to their carbon content (McSherry & Ritchie, 2013).

#### *2.2.10.3 Plant Species Composition*

The composition of plant species within grasslands also plays a role in carbon sequestration. Diverse grasslands with a variety of species tend to store more carbon compared to those with fewer species, owing to differences in root depths and architectures. Leguminous plants, which fix atmospheric nitrogen, can enhance carbon stocks by improving plant growth and providing additional nitrogen to the soil (Rutledge et al., 2017).

#### *2.2.10.4 Complexities and Uncertainties in Carbon Sequestration*

The analysis of factors influencing carbon sequestration in grasslands is complex due to the variety of practices involved and their dependence on initial soil carbon content, the age of the grassland, botanical composition, and local soil and climate conditions. Significant gaps remain in understanding how these practices affect carbon stocks, particularly over the long term (Sykes et al., 2020).

Few studies have examined the effects of grazing and mowing in temperate climates, making it challenging to analyse the impact of grass use intensity and methods such as rotational and continuous grazing. The proxy variable for grazing intensity, often expressed as livestock units

per hectare, varies between studies, leading to inconsistent results. Additionally, quantifying grass use intensity depends on local production potential, which varies widely (Pellerin & Bamière, 2020).

#### *2.2.10.5 Research Gaps*

Most studies on mineral fertilization focus on N, P, K, and liming, with limited research on other nutrients or comparisons of different fertilizer types and management strategies. Similarly, little research has been conducted on innovative practices such as introducing new forage species, earthworms, or irrigation (Conant et al., 2001).

Meta-analyses often mix incomparable situations by overlooking other influencing factors. Furthermore, the influence of botanical composition, particularly root traits, on ecosystem processes and carbon sequestration needs further study (Hunt et al., 2016). Research by Wardle et al. (2004) discuss the interactions between aboveground and belowground components in ecosystems and their effects on ecosystem processes. Zhou et al. (2018) emphasize the importance of root traits in understanding species' responses to environmental factors in grasslands. Cruz & Theau, (2010) examine how root traits vary with soil fertility and influence plant community dynamics, underscoring the need for a functional classification of grassland species based on both aerial and root traits to help differentiate responses in carbon stocks according to grassland composition. All these studies show the complex relationships that need to be explored to understand the links between carbon sequestration and permanent grasslands.

## **2.3 Costs of carbon farming practices**

Carbon farming incurs costs due to initial investments, operational changes, training needs, and potential short-term income losses (opportunity costs). These costs can hinder adoption, particularly for smallholder farmers, but long-term benefits and policy support can make it economically viable (Moran et al., 2011).

### **Upfront Investments**

Transitioning to carbon farming often requires significant initial investments in equipment, technology, or infrastructure. For example, adopting agroforestry systems involves costs related to planting trees, establishing hedgerows, or purchasing specialized machinery. These one-time expenses are necessary to implement the new practices effectively (Antle et al., 2007).

## **Recurring Expenses**

New carbon farming practices may bring about ongoing costs due to changes in input requirements or management strategies. These recurring expenses include the purchase of seeds, fertilizers, and the additional labour needed to maintain and manage the new systems effectively (Pellerin et al., 2017).

## **Opportunity Costs**

Opportunity costs refer to the value of the best alternative that must be given up when deciding. It is a crucial factor to consider in carbon farming (Moran et al., 2011). Farmers transitioning to sustainable practices may initially face reduced yields as the soil and management systems adjust. These reductions reflect opportunity costs, as the income generated from these practices may be lower compared to the potential earnings from conventional methods (Kragt et al., 2012).

In agroforestry, for example, opportunity costs are crucial in decision-making. When farmers use land for tree rows, they sacrifice the potential income from crops that could have been grown on that land. Additionally, crops planted between trees may yield less due to competition for resources. These opportunity costs highlight the economic trade-offs of adopting agroforestry practices (Pellerin & Bamière, 2020).

## **Training and Education Costs**

The implementation of new agricultural practices often requires training for both farmers and workers. Costs may be incurred through educational programs, workshops, or on-farm demonstrations, which are necessary to ensure that the new practices are applied correctly and efficiently (Pellerin & Bamière, 2020).

## **Transaction Costs**

Beyond direct and opportunity costs, there are transaction costs associated with implementing government policies or incentive programs for carbon sequestration. These costs encompass administrative expenses, as well as the costs of monitoring, verification, and compliance with regulations. For farmers, these transaction costs can represent a significant additional financial burden (Sykes et al., 2020).



## External Costs

Lastly, external costs refer to environmental impacts that are not reflected in market prices. For example, certain carbon farming practices may have unintended negative effects on water quality or biodiversity. These externalities must be considered in economic analyses to provide a complete assessment of the costs associated with carbon farming (Sykes et al., 2020). Cost effectiveness

### 2.3.1 Why is it important to measure cost-effectiveness?

Evaluating the cost-effectiveness of carbon farming practices is essential for several reasons. First, it helps to determine which methods reduce greenhouse gas emissions most cost-effectively, allowing policymakers and stakeholders to focus on approaches that offer the best cost-effectiveness, which helps achieving carbon neutrality and addressing climate change in a financially sustainable way (Bamière et al., 2023). This is especially important in agriculture, where there are many different farming systems and associated costs (Moran et al., 2011).

### 2.3.2 How can cost-effectiveness be measure?

To assess cost-effectiveness, the chosen method in this thesis is the Marginal Abatement Cost Curve (MACC). However, before delving into this approach, it is essential to define some key concepts, which are inherently linked to MACCs.

**Marginal Cost** refers to the additional expense incurred from producing one more unit of a good or service (Smith et al., 2007). **Marginal Abatement Cost (MAC)** is a specific measure within this framework, representing the cost associated with achieving one more unit of emission reduction (Povellato et al., 2007). In the case of the present study, it's measured in euros per ton of carbon sequestered in the soil or biomass (€/tC) (MacLeod et al., 2010; Vermont & De Cara, 2010).

**The carbon sequestration potential** refers to the maximum amount of greenhouse gas emissions that can be reduced from agriculture by adopting available technologies and practices, usually within a given timeframe and considering the associated costs. It is measured in tons of carbon per year (tC/year) (Bamière et al., 2023).

A **Marginal Abatement Cost Curve (MACC)** is a graphical tool used to represent the cost-effectiveness of different options for reducing GHG emissions. (Bamière et al., 2023; MacLeod et al., 2010; Moran et al., 2011; Pellerin et al., 2017; Vermont & De Cara, 2010). To interpret

a MACC, one starts by examining the X-axis, which represents the carbon sequestration potential in tC/year.

The Y-axis shows the marginal abatement cost in €/tC. The curve itself demonstrates the relationship between the quantity of emissions reduced and the associated costs. Points below the X-axis reveal measures that save money while reducing emissions, such as energy efficiency improvements, while points above the X-axis represent actions that require investment (Kesicki, 2010).

The **engineering-type** approach used in this work focuses on a detailed accounting of the costs associated with different carbon sequestration practices rather than economic optimization. It calculates the average cost of each option by dividing its total cost by its carbon sequestration potential. In this approach, the marginal cost is equivalent to the average cost of the action, as it does not vary with the amount of carbon stored. This results in a step-like marginal cost curve (Eory et al., 2018)

A key characteristic of the engineering-type approach is that it operates without requiring assumptions about the rationality of economic agents. This allows for the identification of measures with negative costs, where both carbon stocks and farmer income can be improved simultaneously (Vermont & De Cara, 2010). In economic terms, the existence of profitable practices that are not utilized by farmers is often attributed to market imperfections, such as information deficiencies or issues with dissemination. These imperfections are not typically addressed in other approaches, which assume a perfectly competitive market without such inefficiencies (Bamière, 2014).

### 2.3.3 Marginal Abatement Cost Curve: Utilisation in Literature

MACCs have been widely used to integrate and communicate scientific and economic data to policymakers. Initially applied to energy efficiency assessments (Meier et al., 1982), they have since been used to inform decisions on various policy areas, including air pollution and carbon dioxide emission mitigation (Cowell & Apsimon, 1998; Rentz et al., 1994). MACCs were first used for agricultural GHG emissions in the early 2000s (McCarl & Schneider, 2000; Schneider et al., 2007) and have since become more prevalent.

Three main methodologies for creating agricultural MACCs have emerged (Vermont & De Cara, 2010): the market equilibrium models, the microeconomic models and the **engineering models**.

MACCs have been used extensively in the agricultural sector due to the dual role of the agricultural sector as a significant source of GHG emissions and a potential carbon sink (Smith et al., 2013). The role of agriculture in mitigation is complex, linked to food production, ecosystem services, and climate change risks. Recent studies have focused on assessing the cost-effectiveness of agricultural mitigation measures in various regions, including the European Union (Hendriks et al., 2003), and global, regional, and national contexts (Vermont & De Cara, 2010).

Over the past decade, numerous agricultural **engineering** MACCs have been published. These include studies commissioned by the UK Government. Eory (2015), MacLeod (2015), and Moran et al. (2008) developed an updated Marginal Abatement Cost Curve for the UK Agriculture, Land Use, and Land Use Change and Forestry (ALULUCF) sector to inform the fifth carbon budget.

The following authors have created an engineering MACC specifically for the agricultural sector focusing on GHG mitigation for a certain region. Schulte et al. (2012) created an MACC for Ireland, Pellerin et al. (2017) one for France, H. Wang et al. (2014) one for China, and van den Pol-Dasselaar (2013) one for the Netherlands. Other countries, such as Denmark and Belgium, have developed MACCs that address the entire economy (Cornet et al., 2013; Inter-ministerial working group, 2013). Although the study by Cornet et al. (2013) addresses the Belgian context and touches upon agricultural GHG mitigation aspects, it does not examine the topic of Carbon Farming or SOC sequestration. This indicates a research gap in this area for the Belgian and Wallonia region.

Integrating carbon sequestration into MACCs for agriculture has proven to be a challenging but essential endeavour. Traditionally, MACCs have focused primarily on non- $CO_2$  emissions, such as methane ( $CH_4$ ) and  $N_2O$ , from agricultural activities. They often neglected  $CO_2$  emissions and the potential for carbon sequestration. This omission has been attributed to concerns that land-use changes, like afforestation, could reduce agricultural production and lead to carbon leakage through increased imports (Schulte et al., 2012). Although land management practices such as reduced tillage and cover crops offer potential for carbon sequestration, their impacts are frequently viewed as low or uncertain, and are not always fully captured in national inventories, like the EU Climate and Energy Framework for 2020 (Dimassi et al., 2014).

A significant step forward was made by the French MACC (Pellerin et al., 2017), which was among the first to include measures targeting carbon sequestration in soils and biomass. These measures, including agroforestry, reduced tillage, and the use of cover crops, demonstrated a substantial contribution to overall abatement. Furthermore, studies have highlighted that tailoring land-use management strategies to specific soil types can improve cost-effectiveness (Schulte et al., 2016).

The integration of SOC into MACCs introduces several complexities, largely due to the dynamic and variable nature of SOC across different agricultural practices and environments. However, accurately accounting for SOC in MACCs is challenging due to the site-specific and uncertain nature of SOC sequestration, the long-term measurements required, and the fact that many national inventory systems do not fully capture the potential of SOC-related practices (Eory et al., 2018).

While MACCs offer several advantages, such as helping to prioritize mitigation options, facilitating cost-benefit analysis, and providing guidance for policy development, they also have limitations. MACCs typically represent a single point in time, which may not account for future changes in technology, costs, or emissions. The accuracy of a MACC depends on the quality of the underlying data and assumptions, which can be uncertain, particularly for long-term projections. Additionally, MACCs often focus solely on carbon emissions and may not fully capture other environmental and social impacts. Practical challenges and barriers to implementing mitigation measures may also be overlooked, and existing subsidies and taxes can distort the true cost of abatement measures, complicating the assessment of their cost-effectiveness (Kesicki, 2010).

## 3 Research Background

### 3.1 The Carbon stock situation in Wallonia

Wallonia and Belgium have established several decrees and initiatives aiming for significant climate goals by 2050. Among these, the most notable in Wallonia is the "Climate" decree of February 20, 2014, which seeks to GHG emissions by 80-95% compared to 1990 levels (55,549 ktCO<sub>2</sub>e) (SPW, 2019).

Land use plays a crucial role in determining the distribution of SOC across Wallonia. Regions dominated by grasslands, especially those with soils rich in loam and fine silt, exhibit higher SOC content compared to croplands. Areas such as Fagne, Famenne, Pasture region, and High Ardennes, known for their extensive grasslands, show the highest SOC levels. Conversely, the northwestern region, characterized by intensive cropland agriculture, has notably lower SOC contents (SPW, 2020).

Fields that have been converted from cropland to grassland, or those with greater crop and cover crop diversity, tend to display increased SOC levels (Y. Zhou et al., 2022). However, soils under cropland with SOC levels below 20 g C/kg are particularly vulnerable to structural instability and erosion. The average SOC content in cropland soils sampled between 2015 and 2019 was 13.3 g C/kg, with 90% of Wallonia's cultivated land falling below the 20 g C/kg threshold (see Figure 1). Additionally, significant declines in SOC content have been observed in cropland soils of the Ardennes and Jurassic regions when comparing values from 2004-2014 to values of 2015-2019 (see Figure1). Although grassland soils generally maintain higher SOC content, some regions still register values below the 20 g C/kg threshold, with declines noted when comparing values from 2004-2014 to values of 2015-2019 (see Figure 1) (SPW, 2020b).

These findings underscore the urgent need for enhanced soil management practices in Wallonia to boost SOC levels and mitigate the detrimental effects of low organic matter content on soil health and agricultural productivity.

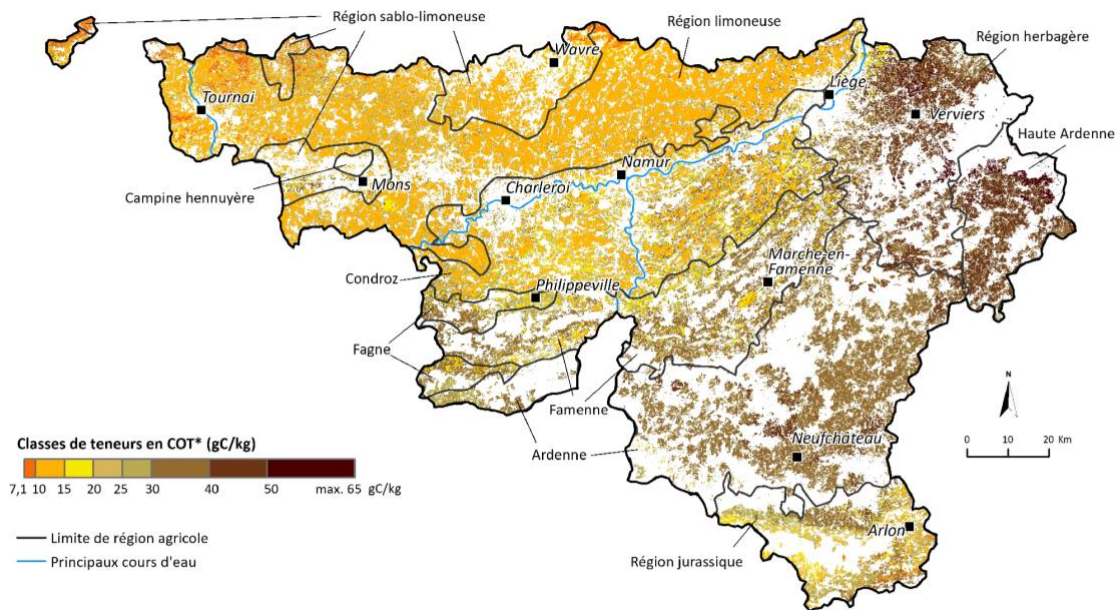


Figure 1: Total Organic Carbon (TOC) content of agricultural soils in Wallonia (2015-2019)

Surface contents predicted by modelling from REQUASUD data collected between 2015 and 2019 (39,086 samples of surface horizons of soils under crops and 8,277 samples of surface horizons of soils under permanent grasslands; temporary grasslands not included in the analysis) - 90 m x 90 m grid. Sources: UCLouvain - ELI - TECLIM; REQUASUD (license A09/2016)

### 3.2 Carbon Farming in Wallonia

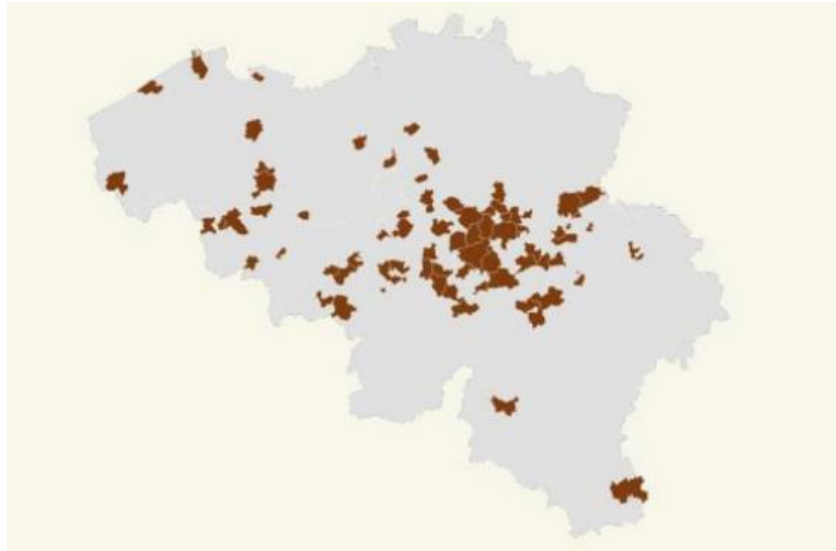
In the Wallonia region of Belgium, characterized by its fertile soils and temperate climate, multiple organizations are facilitating collaborations between farmers and businesses to finance projects aimed at reducing emissions and sequestering carbon. These initiatives can be classified into two primary categories. The first focuses on funding agroecological transition projects, while the second emphasizes the quantification of greenhouse gas reductions and carbon sequestration, thereby enabling businesses to offset their emissions through the purchase of carbon credits (SPW, 2023).

These are some examples of Wallonia's carbon farming projects: *Natagriwal*, which supports agroforestry for soil and carbon benefits; *Yes! We Plant*, which promotes hedges for erosion control and carbon capture; *BioWanze*, focusing on compost use to enhance soil and carbon sequestration; *Greenotec*, which uses temporary prairies to improve soil and capture carbon; and *AWAF Agroforestry Projects*, which integrate trees into farming to boost biodiversity and carbon sequestration.

Soil Capital is a mission-driven company dedicated to promoting carbon farming, with a focus on enhancing the climate impact of agricultural practices. Founded in Belgium in 2013, Soil Capital operates in Belgium, France, and the United Kingdom. The company empowers farmers to annually measure, certify, and monetize their carbon footprint by reducing emissions or increasing soil carbon sequestration in carbon markets. This initiative primarily supports carbon in setting, allowing agri-food and textile industries to finance carbon sequestration and reduction projects within their value chains (Soil Capital, 2024).

The company's carbon farming project began remunerating farmers in 2022, aiming to transition one million hectares to carbon farming by 2025. In its first year, Soil Capital enabled the sequestration or avoidance of 36,000 tons of CO<sub>2</sub> equivalents, resulting in a total payout of €1 million to farmers, with a median remuneration of €5,000 per farm. In 2023, these efforts expanded, with 120,000 tons of carbon sequestered or avoided, and €3.2 million distributed to farmers, increasing the median remuneration to €7,500 per farm (Soil Capital, 2024).

While these figures reflect the overall Soil Capital program, which includes 946 farmers across its operating regions, Belgium plays a notable role, albeit on a smaller scale. Out of the total 233,404.9 hectares involved in the program, Belgium contributes 95 farms covering 14,403.48 hectares, most of which are located in Wallonia, which can be seen in Figure 2. This distribution highlights Wallonia as a significant area within the Soil Capital initiative, even as the company continues to expand its impact across multiple countries (Soil Capital, 2024).



*Figure 2: Distribution of the Soil Capital programmes in Belgium. (Soil Capital, 2024)*

## 4 Research questions and Hypothesis

The growing interest in carbon farming as a climate change mitigation strategy has spurred significant research into the economic viability and environmental impact of various practices. This study investigates the cost-effectiveness of four key carbon farming practices in Wallonia (Agroforestry, Hedges, New organic carbon input through compost application, and the implementation of Temporary Grasslands) using a MACC analysis.

By examining the cost-effectiveness of these practices, this research aims to inform farmers and other stakeholders about the most efficient and feasible approaches to carbon sequestration in the region. Additionally, the study seeks to identify key factors influencing the cost-effectiveness of these practices, to provide guidance on optimizing their implementation.

Specifically, the study aims to address the following research questions:

1. How does the cost-effectiveness of agroforestry, hedges, compost application, and temporary grasslands compare in Wallonia when assessed using a MACC?
2. What are the key factors, that influence the cost-effectiveness of implementing hedges and agroforestry systems for carbon sequestration in Wallonia?
3. How does the cost-effectiveness of carbon farming practices vary across the different agricultural regions in Wallonia?



In addition to these research questions, several Hypothesis are proposed:

**Hypothesis 1:** In regions of Wallonia characterized by low crop yields the implementation of temporary grasslands as a carbon farming practice can lead to net economic benefits for farmers, primarily through reduced costs of new practices compared alternative practices. This scenario is seen for regions in France where yields are low (Pellerin & Bamière, 2020).

**Hypothesis 2:** According to Fabienne Rabier from Mecacost, (2017), the prices for agricultural machinery in Wallonia have increased by 30-40% in recent years. This trend suggests that the costs associated with carbon farming practices are likely to rise in tandem, as these practices heavily depend on mechanization.

**Hypothesis 3:** The adoption and implementation of carbon farming practices within Wallonia's agricultural sector are expected to result in a significant reduction in greenhouse gas emissions. By enhancing soil carbon sequestration, these practices will likely contribute to mitigating the sector's overall carbon footprint. As such, the measurable decrease in emissions would serve as an important indicator of the effectiveness of carbon farming strategies in promoting sustainable agriculture and addressing climate change in the region.

By addressing these research questions and testing these Hypothesis, this study seeks to provide valuable insights into the economic viability and impact of carbon farming practices in Wallonia.

## 5 Data and methodology

### 5.1 Description of the overall approach

This section provides a comprehensive overview of the methodological framework used to construct the MACC for carbon farming practices in Wallonia. The MACC employs an engineering approach. The construction methodology is outlined as follows (see Figure 3):

1. **Identify Mitigation Options:** The process starts with identifying various carbon farming practices. Each option is evaluated based on its associated costs and potential for reducing emissions.
2. **Additional carbon sequestration potential:** This is determined with the help of literature relevant to Wallonia (see Table 1).

3. **Estimate Costs:** The next step is to calculate the costs involved in implementing each technology or practice. This includes capital, operational, maintenance expenses and opportunity costs. For practices extending over a longer period, an annuity is calculated. The costs for the farmer are calculated per hectare and year.
4. **The effective basis** of a practice refers to the surface area on which a certain practice can be implemented (Moran et al., 2011). Assumptions are made to calculate the effective basis (see [Effective Basis](#)).
5. **Determine Carbon sequestration potential:** To determine carbon sequestration potential, the effective basis is multiplied by the additional carbon sequestration potential.
6. **Calculate Abatement Costs:** To determine the abatement cost, the effective basis is multiplied by the additional carbon sequestration potential.
7. **Rank and Plot:** Finally, the carbon farming practices are ranked from the lowest to the highest abatement cost. The MAC curve is plotted with the cost on the X-axis and the cumulative carbon sequestration potential on the Y-axis.

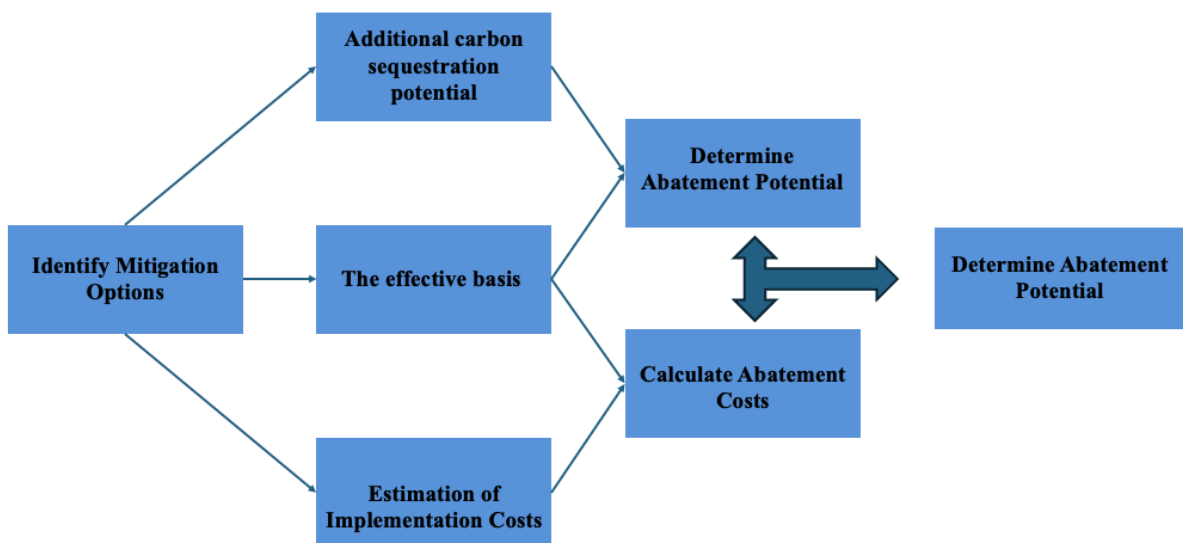


Figure 3: Scheme for the construction of a MACC

## 5.2 Choice of practices

According to Eory et al. (2018), constructing engineering MACCs for agricultural GHG mitigation begins with selecting relevant measures. From the hundreds of potential options, a manageable number is chosen for each MACC study, considering factors like relevance to the

specific agricultural system, potential negative impacts on productivity, environment, and the acceptability and broadness of the measure.

The literature review ([Section 2.2](#)) highlighted a list of carbon sequestration potential measures for  $CO_2$  mitigation. Table 2 repeats the measures identified and evaluated during this literature review. In the following will be discussed which of these measures are taken into account in the present thesis, and the reasoning behind the selection process

*Table 2: Summary of Carbon Farming practices from Literature Review*

| Carbon Farming Practices from Literature Review        |
|--------------------------------------------------------|
| Agroforestry                                           |
| Heges                                                  |
| Implementation of temporary grasslands                 |
| Use of exogenous organic matter in form of compost     |
| Reduced tillage and no-till                            |
| Biochar                                                |
| Cover crops                                            |
| Grazing Practices                                      |
| Fertilization                                          |
| Plant Species Composition                              |
| Complexities and Uncertainties in Carbon Sequestration |

In March 2024, in the context of the MRV4SOC project, a workshop was held in Wallonia that brought together farmers, policymakers, NGOs, and scientists to discuss enabling and hindering factors of adopting carbon farming practices. Participants were asked to identify which carbon farming practices are most favourable for adoption due to their productivity and environmental co-benefits. The answer provided can be assumed to reflect the perception of the actors in Wallonia on the practices, as it is likely based on their experience in the region (MRV4SOC Workshop, Wallonia, unpublished data).

**Agroforestry and hedges** were selected for further analysis due to its frequent mentioning in the MRV4SOC workshop and its high carbon sequestration potential due to carbon sequestration in the biomass. This thesis focuses on carbon sequestration on croplands (see [Agroforestry](#) and [Hedges](#))

**Cover cropping** (Intercropping) and longer cover cropping were not selected in this thesis due to their complex cost-benefit analyses. The actual carbon sequestration by cover crops is highly variable and can be insignificant. Given these uncertainties and the mixed outcomes highlighted in the literature, cover cropping was not included as a focus in this study (see [Cover Cropping](#)).

**Implementing Temporary grasslands** were chosen for this thesis due to its frequent mentioning in the MRV4SOC workshop and their effective carbon sequestration and sustainability benefits (see Temporary grasslands).

**Reduced/no-till's** impact on SOC stocks in temperate regions like Wallonia is debatable, with some studies showing limited effects. This uncertainty makes it less suitable as a focus for a thesis aiming to demonstrate clear SOC sequestration benefits, and was, hence, excluded (see Reduced tillage and no-till).

Enhancing soil fertility through the use of organic matter/fertilizers was selected as a measure, but only in the case of **compost**. Due to the uncertainty regarding the carbon sequestration potential of digestate and biochar, they were excluded from consideration. Manure and slurry from animals were also excluded because, following the hypothesis of Bamière et al. (2023), it was assumed that these materials are already being effectively utilized in agriculture. The same logic was applied to sewage sludge, as 69% of it is used in agriculture in Wallonia and 30% for energy production, with only 1% being lost (SPW, 2023a) (see Use of exogenous organic matter in form of compost).

**Practices associated to permanent grassland** were mentioned frequently during MRV4SOC workshop, but according to the literature review (see Practices associated to permanent grassland), they contribute to maintaining SOC stocks, but it is controversial whether SOC sequestration is really possible with those practices. For this reason, the practice was not chosen.

As noted in the literature review (see Impact of carbon farming practices on SOC stock), **reducing inputs** such as inorganic fertilizers, fuel, and pesticides can enhance carbon sequestration in soil by decreasing mineralization. However, there are also practices that suggest increased nitrogen fertilization leads to greater biomass production, which in turn could increase the potential for soil organic carbon (SOC) sequestration. Further research is necessary to determine which of these effects is more significant. For this reason, the practice was not chosen.

## 5.3 Carbon sequestration potentials

The carbon sequestration potentials were examined in the literature. Care was taken to ensure that the data are relevant to Wallonia. The focus was on data from temperate climates, such as those in Western and Central Europe and North America. For the practice of temporary

grasslands, a central scenario was opted for, as the temperate climate, along with the complexity and diversity of Wallonia's soils, complicates precise determinations without the application of models. The following table summarizes the carbon sequestered utilised for this study.

*Table 3 : Summary of carbon sequestration potentials from Literature chosen for the thesis. Table based on (Bamière et al., 2023)*

| Practice                                              | Carbon Sequestration Potential from Literature Review                       | Carbon sequestered in the soil | Additional carbon sequestration in biomass | Total carbon sequestration associated to Carbon Farming practice | References                                                                                                                                                              | Geographical context (respectively)                                            |
|-------------------------------------------------------|-----------------------------------------------------------------------------|--------------------------------|--------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| <b>New organic carbon inputs in croplands</b>         | 500 kgC/ha/year (compost)                                                   | 0.5 t C/ha/year                | 0 t C/ha/year                              | 0.5 t C/ha/year                                                  | Zavattaro et al. (2017), Morvan et al. (2013), Powlson et al. (2012)                                                                                                    | Italy, France; United Kingdom                                                  |
| <b>Expansion of temporary grasslands in croplands</b> | 130–500 kgC/ha/year                                                         | 0.315 t C/ha/year              | 0 t C/ha/year                              | 0.315 t C/ha/year                                                | Conant et al. (2001), Franzluebbers et al. (2014), Johnston et al. (2017), Creme (2020)                                                                                 | United States, United States, United Kingdom, Europe                           |
| <b>Agroforestry</b>                                   | 250 kgC/ha/year in the soil (cropland only); 900 kgC/ha/year in the biomass | 0.25 t C/ha/year               | 0.9 t C/ha/year                            | 1.15 t C/ha/year                                                 | Cardinael et al. (2017), Lorenz and Lal (2014), Feliciano et al. (2018), Cardinael et al. (2018), Chatterjee et al. (2018), Pardon et al. (2017), Drexler et al. (2021) | France, United states, United Kingdom, France, United States, Belgium, Germany |
| <b>Hedges</b>                                         | 750 kgC/ha hedges/year, kgC/ha/year in the biomass                          | 0,0225 t C/ha/year             | 0.24 ha– 1 yr– 1                           | 0.263 t C/ha/year                                                | Pellerin et al., 2013, Arrouays et al., 2002, Kumar and Nair, 2011                                                                                                      | France, France, United States                                                  |

## 5.4 Cost model

For each carbon farming practice, a specific cost model is developed to calculate the annual cost associated with its implementation. In cases where a practice is implemented for more than one year, a constant annuity is calculated. This annuity represents the average annual cost over the duration of the implementation period. This is the case for the practices agroforestry, hedges and implementation of carbon farming

For practices like composting, which are implemented on an annual basis, the annual cost directly reflects the ongoing expenses incurred each year. Specifically, the annual cost per hectare is indicative of the additional financial burden a farmer must bear annually to adopt a new practice.

Within the scope of this thesis, the term "implementation cost" refers to the annual cost, expressed in euros per hectare per year, associated with adopting a particular agricultural

practice. This cost represents the average annual expense a farmer would incur to implement the practice.

This cost model uses the engineering approach. Engineering approaches resemble accounting logic rather than economic optimization. They aim to evaluate the costs associated with each option for increasing carbon sequestration in detail. The average cost of each action is calculated as the ratio of its total cost to its storage potential. For each action type, the marginal cost equals the average cost because it does not depend on the amount of carbon stored, resulting in a step-shaped marginal abatement cost curve (Soussana & Lemaire, 2014).

The analysis excludes costs related to training and education, transaction costs associated with policy implementation, and external environmental impacts.

The following table summarizes the various costs associated with each carbon farming practice and categorizes them according to the classifications discussed in the literature review:

*Table 4: Summary of costs for carbon farming practices, categorized in types of costs described in Literature*

| Type of cost               | Agroforestry                                     | Hedges                                           | Implementation of temporary grasslands                                                                                                                                                                                           | New organic input in form of compost                          |
|----------------------------|--------------------------------------------------|--------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|
| <b>Upfront Investments</b> | Cost of soil preparation; Planting; Mulching     | Cost of soil preparation; Planting; Mulching     | Implementin temporary Grassland included (included in Production savings)                                                                                                                                                        | Purchase of composts; Transport of Compost;Spreading composts |
| <b>Recurring expenses</b>  | Tree maintenance                                 | Tree maintenance:                                | Costs or gains generated by the modification of the animals' feed ration                                                                                                                                                         | /                                                             |
| <b>Opportunity cost</b>    | Yield reduction on the remaining cultivated area | Yield reduction on the remaining cultivated area | Income that farmers will have to give up by modifying their crop rotation;                                                                                                                                                       | /                                                             |
| <b>Potential income</b>    | Firewood sales; Timber harvest                   | Firewood sales; Timber harvest                   | Savings achieved associated with the elimination of cover crops; Savings achieved in production costs as production of herb silage is cheaper than mais silage; Reduction of mineral fertilization on crops following grasslands | Variation in yields; Variation in fertilization               |

#### 5.4.1 Labour

Labor costs are typically measured in € per hour. To calculate this labour cost per hour FADN data was used. An average salary for the years between 2018 to 2022 was calculated. The average labour cost per hour is 18.29€/h. However, for this thesis, the cost of labour is required

per hectare. The calculation of labour cost per hectare differs based on the nature of the task. For manual labour, a task-specific factor is determined, which will be explained in the corresponding section. For labour associated with machinery, the labour per hectare is calculated by using the performance indicator: the labour is divided by the performance indicator (h/ha). The performance indicator is provided by Mecacost, (2017) data (see [appendix table 43](#)).

$$L_{ha} = L_h \cdot f_p$$

- $L_{ha}$  = Labour cost (€/ha).
- $L_h$  = Labour cost per hour (FADN) (€/h)
- $f_p$  = conversion factor (h/ha). For machinery equal to the performance indicator (h/ha).

#### 5.4.2 Discount rate:

For practices requiring an initial investment and having irregular or deferred costs or revenues over time (intra-parcel agroforestry and hedgerows, temporary Grasslands), a constant annuity is calculated which, over the duration of the practice, would be equivalent for the farmer (equivalent constant annuity). This calculation requires the use of a discount rate, for which the value retained is 4.5% (Pellerin & Bamière, 2020). First, the Net Present Value (NPV) associated with the practice is calculated, which makes it possible to obtain the Equivalent Constant Annuity over the Duration of the practice (ECAD):

$$NPV = \sum_{t=0}^T \frac{\sum_{m=1}^M Q_{m,t} \cdot prix_m}{(1+i)^t} = \sum_{t=0}^T \frac{CP_t}{(1+i)^t}$$

$$ECAD = NPV \cdot \frac{i}{1 - \frac{1}{(1+i)^T}}$$

- $t \in [0, T]$ , the time and T the duration of the practice (corresponding for example to the time required to be able to harvest the wood in agroforestry)
- $[m \in M]$  technical modifications generated by the practice

- $i$  the discount rate

### 5.4.3 Mechanization

For the mechanization calculations, data from Mecacost, (2017) was used, which has a database from 2017. Mecacost is a free online tool that helps farmers calculate the cost of using agricultural machinery. It provides detailed cost breakdowns and allows for customization based on individual situations. It's a valuable resource for making informed decisions about equipment purchases and optimizing farming operations. Since then, machine prices have risen by 30% to 40%, according to experts (Fabienne Rabier Mecacost; Jean-Marie). To analyse the impact of this increase on the results, we will calculate the annuity for the practices for Wallonia with machine prices increased by 30%. Fuel prices will also be increased from the selected average of €1 to €1.30 in this scenario, as was the case in 2022.

### 5.4.4 Cost specific to the practice

#### 5.4.4.1 *Agroforestry*

The following technical itinerary explains how the practice is applied and in which year each action is carried out. It is aligned with sustainable practices, based on a study by Pellerin & Bamière (2020) and AFAC (2015) for agroforestry in cropland. The technical itinerary was chosen because of its low planting density, which was assumed starts reducing yields in year 15 by 7.5%. This value is chosen to be constant for simplicity. It proposes planting 75 trees/hectare in rows spaced 22.5m apart, with trees 5.2 m apart within rows. The process includes soil preparation, planting, protection, mulching, and sowing grass cover. Tree management includes formative pruning from years 1-7, and annual pruning from years 4-12. Tree density is reduced to 49 trees/hectare in year 10. Harvest happens after 50 years, leaving stumps for carbon sequestration. Tree selection prioritizes sparse canopies, late budburst, pruning tolerance, and nitrogen-fixing potential, with timber species like hybrid walnut and wild cherry preferred, for which prices were calculated. The following details how costs for implementing agroforestry were implemented. The protocol assumes a 5% loss of surface due to the trees.

The analysis calculates the costs associated with soil preparation, planting, mulching, and tree maintenance, yield reduction as well as the income/savings from firewood sales, and timber harvest.



**Cost of soil preparation:** To ensure optimal growth of the trees, the soil must be properly worked to loosen it, making planting easier and improving the overall growth conditions. This process involves the burial of vegetation, subsoiling, and crumbling. The specific machinery used for each of these steps is detailed in the appendix. The cost of the machinery per hectare was calculated using (Mecacost, 2017) (see appendix table 15), this tool also provides performance indicators for the machinery, such as 0.8 hectares per hour. This information was then used to calculate the cost of labour per hectare. It is assumed that the area of soil that needs to be worked for planting corresponds to 12.5% of the total land area. Consequently, the calculated cost per hectare is multiplied by 0.125 to reflect this proportion. This 12.5% area is notably larger than the 5% area that the trees will occupy, which is due to the size of the machinery being used. The selection of these machines follows technical itineraries developed by experts. (Angers et al., n.d.; Pellerin & Bamière, 2020; Fabienne Rabier)

$$C_{sp} = C_M + L_{ha}$$

- $C_{sp}$  = Cost of soil preparation (€/ha).
- $C_M$  = Cost of mechanization per hectare (€/ha).
- $L_{ha}$  = Labour cost per hectare (€/ha).

**Planting** is done manually, with the cost of tools like hoes and shovels not factored in. Based on AFAC (2015) tests, one person takes an average of 164 seconds to plant a tree. Given that 75 trees are planted per hectare, the total time required per hectare is 3 hours and 25 minutes for one person. The price of hybrid walnut and wild cherry in Wallonia was researched on gardening websites see appendix. The average price was calculated for the two tree species and multiplied by 32.5. For the more detailed cost of the action see appendix table 16.

$$C_p = C_T + L_{ha}$$

- $C_p$  = Cost of planting (€/ha).
- $L_{ha}$  = Labour cost (€/ha).
- $C_T$  = Cost for the 75 selected trees (€/ha).

**Mulching** is used because it retains moisture, suppresses weeds, protects soil, and provides nutrients. In contrast to the protocol, straw was used instead of plastic because it has better properties for its purpose (AFAC, 2012) and is more sustainable. With the help of

Prom'Haies (2014), the quantity of straw can be estimated per tree (7,7 kg MS/tree). The price of straw is estimated using (Fourrages Mieux, 2018-2022). A value of 82 €/t MS is calculated. A straw blower unit is used, which distributes 1 ton of dry matter per hour (1 t /h). As 577.5 kg are distributed per hectare (ha), 34 minutes and 39 seconds are needed. As time is also needed to cover the distances between the trees, 45 minutes is the estimated time per hectare. For the more detailed costs of the action see appendix table 18.

$$C_{mul} = C_{st/ha} + L_{ha} + C_M$$

- $C_{mul}$  = Cost of mulching (€/ha).
- $C_{st/ha}$  = Cost for the straw used per hectare= 7.7 kg MS/tree x 75 trees/ha x 0.082 €/kg = 47.53€/ha.
- $C_M$  = Cost of mechanization (€/ha).
- $L_{ha}$  = Labour cost (€/ha).

**Tree maintenance:** The trees are pruned annually between year 4 and year 12. In year 10 the number of trees is reduced to 49, which reduces pruning for the years 11 and 12. A chainsaw is utilized for all tasks. Data from AFAC (2015) was used to estimate the time required to complete the work. Pruning was assumed to take 4.2 minutes per tree. A chainsaw with an assumed purchase price of 1000 euros (estimation after looking at prices from Stihl and Husqvarna (*Kettensäge / Motorsäge*, n.d.; *Kettingzagen & Motorzagen* | *STIHL*, n.d.)), an annual running time of 180 hours, and an amortisation period of 16.3 years was considered. The machine was assumed to consume 1.5 litres of fuel per hour (Technical Data of the machines Stihl and Husqvarna (*Kettensäge / Motorsäge*, n.d.; *Kettingzagen & Motorzagen* | *STIHL*, n.d.)). The cost for E10 chainsaw fuel was assumed to be 1.70€/L (*Be.STAT*, n.d.). An annual allowance for maintenance and repairs can often be paid for chainsaws, which is used to estimate those costs (*Forfait Révisions Tronçonneuse*, n.d.). For the more detailed costs of the action see appendix table 19.

$$C_{tm} = C_M + L_{ha}$$

- $C_{tm}$  = Cost of tree maintenance (€/ha).
- $C_M$  = Cost of mechanization (€/ha).
- $L_{ha}$  = Labour cost (€/ha).

**Firewood sales:** After Cardinael R. (personal communication in Pellerin & Bamière, 2020), pruning, estimated at 0.013 steres/tree/year, generates firewood valued at 88.71€ per stère (Bombeck, 2021). Thinning in year 10 generates 0.17 m<sup>3</sup>/tree, also valued as firewood at 88.71€ per stère. As the objective is to store carbon, the stumps are left in the field after harvest. The assumption is made that the harvest of the, at this point, small trees take about the same time as pruning them (AFAC, 2015). For the more detailed cost of the action see appendix table 20.

**Yield reduction on the remaining cultivated area:** The agroforestry practice examined in this study involves introducing trees within a cultivated plot at an initial density of 75 trees per hectare. Following Angers et al. (2013), a surface loss of 5% is considered. The impact of this surface loss varies across agricultural regions due to differences in yield and the resulting higher or lower revenues.

All the Data, which is mentioned now refers to a time from 2018 to 2022. Data on land areas and yields were sourced from (Statbel, 2023) (see appendix table 39) except for Wallonia data was sourced from SPW, (2023b). An average price for the price of every culture is sourced from (SPW, 2023b). By multiplying the yield from every region with the average price per culture, the Gross revenue is calculated (see appendix table 40). Data on expenses (including seeds, pesticides, and fertilizers) of the four main crops (Winter Wheat, Winter Barley, Potatoes, and Beetroot) in Wallonia for every region was also found on (SPW, 2023b). Data for regional calculations on other crops were not available.

To determine the fixed costs of machinery for these four crops, Mecacost, (2017) data were used (see appendix table 38). The technical itineraries for the machinery adapted for the different crops were developed using literature (Agriconomie, 2019; AgroParisBiotech, 2013; Gokelaere, 2021; Johnson & Auat Cheein, 2023; Rémi Michel, 2022; K. Zhou et al., 2015). Labor costs were calculated based on machinery performance indicators.

By subtracting the fixed and input costs, a profit margin was calculated for each region (taxes are not included in the calculation) . As there are different cultures with varying yields in each region, an average profit margin for all cultures per region weighted by their surface was calculated using the following formula (see appendix table 41) :

$$M_c = \frac{S_{WW}}{S_{CT}} \cdot P_{WW} + \frac{S_{WB}}{S_{CT}} \cdot P_{WB} + \frac{S_B}{S_{CT}} \cdot P_B + \frac{S_{PT}}{S_{CT}} \cdot P_{PT}$$

- $M_c$  = Central margin for a specific region (€/ha).
- $S_{FH}$  = The surface that for example winter wheat has in a region (ha) (winter barley=WB, beetroot=B, Potato=P)
- $S_{CT}$  = Total surface area of the four crops in hectares (ha).
- $P_{WW}$  = Profit margin of winter wheat (€/ha) for the region (winter barley=WB, beetroot=B, Potato=P).

From this net margin 5% are deducted because of the surface loss. Starting in year 15, a yield decrease of 7.5% is applied until the trees are harvested in year 50. If the calculated average margin is, for example, 1000€, 5% is deducted and 950€ is found. From those 7.5% is deducted starting in year 15. The result would be 878.5€ ([see appendix table 21](#)).

**Timber harvest:** The final harvest yields an average of 2.47 m<sup>3</sup> of timber per tree. This volume represents the net annual growth over 50 years, after accounting for the volume removed during the first thinning operation. The standing timber is valued at €204/m<sup>3</sup>, a price comparable to that of 2.5 m<sup>3</sup> oak trees (Pellerin & Bamière, 2020). This standing timber price implicitly includes the cost of felling, and the uncertainty associated with wood quality. The price for 49 trees after 50 years is 24690,12 €/ha. After applying the annuity, it becomes -138,32 €/ha.

#### 5.4.4.2 *Implementation of hedges*

This thesis focuses on implementing a technical itinerary for hedge planting that aligns with optimal practices for carbon sequestration, based on the 4p1000 report by Bellassen in Pellerin & Bamière, (2020). The study establishes hedgerows in croplands at 60 linear meters per hectare, targeting structures for their balanced productivity and environmental benefits. The chosen hedgerow consists of alternating shrubs like dogwood, blackthorn, and hazel, planted at 1-meter intervals, and taller trees such as chestnut and oak every 10 meters, creating a dense, diverse hedgerow (AFAC, 2015). Managed on a 45-year cycle, this itinerary includes soil preparation, planting, and regular pruning and coppicing, with firewood harvests every 15 years and a final timber harvest, aiming to maximize carbon sequestration while preserving ecological functions. The Agroforestry protocol is similar to the Hedgerows protocol. The differences in Hypothesis and calculations are detailed here.

The following table outlines the timeline for various tree management activities:

Table 5: Technical operations associated to managing and harvesting of hedges

| Years | Technical operations    |                          |                             |                 |                                  |                           |
|-------|-------------------------|--------------------------|-----------------------------|-----------------|----------------------------------|---------------------------|
|       | Implementation/Planting | Formation of high shoots | Pruning of coppicing shrubs | Lateral pruning | Harvesting of firewood or stakes | Harvesting of timber      |
| 0     | x                       |                          |                             |                 |                                  |                           |
| 1     |                         | x                        | x                           |                 |                                  |                           |
| 2     |                         | x                        | x                           |                 |                                  |                           |
| 3     |                         | x                        |                             | x               |                                  |                           |
| 4     |                         | x                        |                             |                 |                                  |                           |
| 5     |                         | x                        |                             |                 |                                  |                           |
| 6     |                         | x                        |                             | x               |                                  |                           |
| 7     |                         | x                        |                             |                 |                                  |                           |
| 8     |                         | x                        |                             |                 |                                  |                           |
| 9     |                         | x                        |                             | x               |                                  |                           |
| 10    |                         | x                        |                             |                 |                                  |                           |
| 11    |                         | x                        |                             |                 |                                  |                           |
| 12    |                         | x                        |                             | x               |                                  |                           |
| 13    |                         | x                        |                             |                 |                                  |                           |
| 14    |                         | x                        |                             |                 |                                  |                           |
| 15    |                         | x                        |                             |                 | x                                |                           |
| 16    |                         |                          |                             |                 |                                  |                           |
| 17    |                         | x                        |                             |                 |                                  |                           |
| 18    |                         |                          |                             | x               |                                  |                           |
| 19    |                         | x                        |                             |                 |                                  |                           |
| 20    |                         |                          |                             |                 |                                  |                           |
| 21    |                         | x                        |                             | x               |                                  |                           |
| 22    |                         |                          |                             |                 |                                  |                           |
| 23    |                         | x                        |                             |                 |                                  |                           |
| 24    |                         |                          |                             | x               |                                  |                           |
| 25    |                         | x                        |                             |                 |                                  |                           |
| 26    |                         |                          |                             |                 |                                  |                           |
| 27    |                         |                          |                             | x               |                                  |                           |
| 28    |                         |                          |                             |                 |                                  |                           |
| 29    |                         |                          |                             |                 |                                  |                           |
| 30    |                         |                          |                             |                 | x                                | Harvesting chestnut trees |
| 31    |                         |                          |                             |                 |                                  |                           |
| 32    |                         |                          |                             |                 |                                  |                           |
| 33    |                         |                          |                             | x               |                                  |                           |
| 34    |                         |                          |                             |                 |                                  |                           |
| 35    |                         |                          |                             |                 |                                  |                           |
| 36    |                         |                          |                             | x               |                                  |                           |
| 37    |                         |                          |                             |                 |                                  |                           |
| 38    |                         |                          |                             |                 |                                  |                           |
| 39    |                         |                          |                             | x               |                                  |                           |
| 40    |                         |                          |                             |                 |                                  |                           |
| 41    |                         |                          |                             |                 |                                  |                           |
| 42    |                         |                          |                             | x               |                                  |                           |
| 43    |                         |                          |                             |                 |                                  |                           |
| 44    |                         |                          |                             |                 |                                  |                           |
| 45    |                         |                          |                             |                 | x                                | Harvesting oaks           |

The section outlines the detailed costs associated with various stages of tree cultivation and management, starting from soil preparation to timber harvest. It emphasizes the importance of proper soil preparation, including vegetation burial, subsoiling, and crumbling, to ensure optimal tree growth. The costs of mechanization and labour are calculated based on established tools and expert recommendations. Subsequent sections cover the expenses related to manual planting, mulching with straw for better sustainability, tree maintenance, and the potential revenue from firewood and timber sales. Each step is meticulously calculated to ensure the accuracy of cost estimations per hectare, with detailed references to appendices for specific data.

**Cost of soil preparation:** To ensure optimal growth of the trees, the soil must be properly worked to loosen it, making planting easier and improving the overall growth conditions. This process involves the burial of vegetation, subsoiling, and crumbling. The specific machinery used for each of these steps is detailed in the appendix. The cost of the machinery per hectare was calculated using (Mecacost, 2017) (see [appendix table 22](#)), this tool also provides performance indicators for the machinery. This information was then used to calculate the cost of labour per hectare. It is assumed that the area of soil that needs to be worked for planting corresponds to 3% of the total land area. Consequently, the calculated cost per hectare is multiplied by 0.03 to reflect this proportion. This 3% area is larger than the area that the trees will occupy, which is due to the size of the machinery being used. The selection of these machines follows technical itineraries developed by experts. (Angers et al., n.d.; Pellerin & Bamière, 2020; Fabienne Rabier)

$$C_{sp} = C_M + L_{ha}$$

- $C_{sp}$  = Cost of soil preparation (€/ha).
- $C_M$  = Cost of mechanization per hectare (€/ha).
- $L_{ha}$  = Labour cost per hectare (€/ha).

**Planting** is done manually, with the cost of tools like hoes and shovels not factored in. Based on AFAC (2015) tests, one person takes an average of 164 seconds to plant a tree. Given that 61 trees are planted per hectare, the total time required per hectare is 2 hours and 47 minutes for one person. Trees are planted following the instructions at the beginning of this section. The trees are always planted alternately. 54 shrubs and bushes are planted per hectare (18 Dogwoods, 18 Blackthorns, 18 Hazelnuts) and 7 high stemming trees are planted (per hectare 3.5 Chestnut trees and 3.5 Oaks are calculated) (see [appendix table 23 and 24](#)).

$$C_p = C_T + L_{ha}$$

- $C_p$  = Cost of planting (€/ha).
- $L_{ha}$  = Labour cost (€/ha).
- $C_T$  = Cost for the 61 selected trees (€/ha).

**Mulching** is used because it retains moisture, suppresses weeds, protects soil, and provides nutrients. In contrast to the protocol, straw was used instead of plastic because it has better

properties for its purpose (AFAC, 2012) and is more sustainable. With the help of Prom'Haies (2014), the quantity of straw can be estimated per tree (7.7 kg MS/tree). The price of straw is estimated using (Fourrages Mieux, 2018-2022). A value of 82 €/t MS is calculated. A straw blower unit is used, which distributes 1 ton of dry matter per hour (1 t/h). As 469.7 kg are distributed per hectare (ha), 28 minutes and 11 seconds are needed. The time of labour is calculated see appendix table 25.

$$C_{mul} = C_{st/ha} + L_{ha} + C_M$$

- $C_{mul}$  = Cost of mulching (€/ha).
- $C_{st/ha}$  = Cost for the straw used per hectare = 7.7 kg MS/tree x 61 trees/ha x 0.082 €/kg = 38.52 €/ha.
- $C_M$  = Cost of mechanization (€/ha).
- $L_{ha}$  = Labour cost (€/ha).

**Tree maintenance:** For the maintenance of trees, 3 actions are calculated. The formation of high shoots, the pruning of coppicing shrubs and lateral pruning. The durations per hectare are 29.4 minutes, 60.48 minutes and 2 hours and 31 minutes respectively. Those time assumptions are made following the technical itinerary by (Pellerin & Bamière, 2020). The frequency of those tasks is shown in table 5.

A chainsaw with an assumed purchase price of 1000 euros (estimation from Stihl and Husqvarna (*Kettensäge / Motorsäge*, n.d.; *Kettingzagen & Motorzagen* | *STIHL*, n.d.)), an annual running time of 180 hours, and an amortisation period of 16.3 years was considered. The machine was assumed to consume 1.5 litres of fuel per hour (Technical Data of the machines Stihl and Husqvarna (*Kettensäge / Motorsäge*, n.d.; *Kettingzagen & Motorzagen* | *STIHL*, n.d.)). The cost for E10 chainsaw fuel was assumed to be 1.70€/L (*Be.STAT*, n.d.). An annual allowance for maintenance and repairs can often be paid for chainsaws, which is used to estimate those costs (*Forfait Révisions Tronçonneuse*, n.d.). For the more detailed costs of the action see appendix table 26.

$$C_{tm} = C_M + L_{ha}$$

- $C_{tm}$  = Cost of tree maintenance (€/ha).
- $C_M$  = Cost of mechanization (€/ha).
- $L_{ha}$  = Labour cost (€/ha).

**Firewood sales:** After Pellerin & Bamière, (2020), firewood is harvested every 15 years. The technical itinerary estimates an average cost of 2.70€/shrub or tree. So, the cost of harvesting Firewood is equal to 165€/ha. Furthermore, the technical itinerary proposes a harvest of 8.4 m<sup>3</sup>/100 meters of hedge. In our case firewood is valued at 88.71 €/m<sup>3</sup> (Bombeck, 2021). For a hedge of 60 meters, which was assumed in this study, the value is equal to 447.1 €/ha.

**Yield reduction on the remaining cultivated area:** This section follows the same assumptions as the section “Yield reduction on the remaining cultivated area” in agroforestry. In the case of hedges a constant yield reduction of 3% is assumed (see appendix table 27).

**Timber harvest:** The final harvest yields an average of 1.6 m<sup>3</sup> of timber per tree of chestnut in year 30 and 2.4 m<sup>3</sup> of timber for oaks after year 45. The standing timber is valued at 130€/m<sup>3</sup> for chestnut and 180€/m<sup>3</sup> for oaks (Pellerin & Bamière, 2020). This standing timber price implicitly includes the cost of felling, and the uncertainty associated with wood quality. The average price per hectare is calculated as follow as there are 7 trees per hectare ( $3.5 \text{ trees/ha} \times 1.6 \text{ m}^3/\text{tree} \times 130\text{€/m}^3 + 3.5 \text{ trees/ha} \times 2.4 \text{ m}^3/\text{tree} \times 180\text{€/m}^3 = 728 \text{ €/ha} + 1512\text{€/ha} = 2240 \text{ €/ha}$ ).

#### 5.4.4.3 *Implementation of temporary Grasslands:*

This thesis focuses on implementing a technical itinerary for hedge planting that aligns with optimal practices for carbon sequestration, based on the 4p1000 report by Gastal et al. (Pellerin & Bamière, 2020). The master’s thesis explores the introduction of temporary grasslands into crop rotations, particularly in systems that already cultivate forage maize, which indicates the presence of ruminant livestock. The focus is on utilizing these grasslands as carbon sinks by replacing maize with grassland for three years within a five-year rotation cycle, followed by two years of maize cultivation. This approach assumes that maize is not grown as a monoculture but may be cultivated on different plots in line with previous practices. Intermediate crops are also required between maize cycles. Additionally, the thesis considers differences in forage production and nutritional value between maize and grassland.

The costs calculated encompass savings from eliminating cover crops, reduced production costs with grassland management, opportunity costs from modifying crop rotations, potential gains or losses from changing animal feed rations, and reduced fertilization costs after temporary grasslands. Additionally, transportation costs for compost are factored in, affecting



its overall cost-effectiveness. These diverse cost components collectively shape the financial feasibility of each carbon farming practice.

**Savings achieved associated with the elimination of cover crops:** Costs are saved as an intermediate crop is not needed in 4 of the 5 years during the rotation. During a period of 5 years, cover crops only need to be introduced once. The machinery needed for implementing cover crops is detailed in (Pellerin & Bamière, 2020). The cost for Machinery is calculated using (Mecacost, 2017). More detailed values of calculation are shown in the appendix table 28. The choice of seed depends on the crop for which the intercropping is intended and disease control factors. Nitrogen fixation and environmental factors also play a role (Liu et al., 2024). Given the diversity of seed types and mixtures, an average price per hectare was calculated, considering both sowing density and seed cost. Pricing data was sourced from the agricultural supplier BAKO (see appendix table table 29).

$$C_{cover} = C_M + L_{ha} + C_{seeds}$$

- $C_{cover}$  = cost of implementing cover crops (€/ha).
- $C_M$  = cost of mechanization (€/ha).
- $L_{ha}$  = labour cost (€/ha).
- $C_{seeds}$  = cost of seeds (€/ha).

**Savings achieved in production costs,** as managing a grassland is less expensive than managing grain or fodder maize (Pellerin & Bamière, 2020). The technical itinerary for the production of feed maize and grass silage was compiled from the following sources: (Agriconomie, 2019; AgroParisBiotech, 2013; Gokelaere, 2021; Johnson & Auat Cheein, 2023; Rémi Michel, 2022; K. Zhou et al., 2015). The implementation of the temporary grassland Pricing data for the seeds was sourced from the agricultural supplier BAKO (see appendix table 30). It is important to consider the difference in harvest frequency between maize and grass silage. Maize undergoes a single annual harvest, whereas grass silage is commonly subjected to three cuttings per year. To maintain a focus on the core production costs associated with grassland management. The details of the values are in the appendix table 31.

$$C_{saved} = C_{M_{Maize}} + L_{ha_{Maize}} + C_{seeds_{Maize}} + C_{phyto} - (C_{M_{Grass}} + L_{ha_{Grass}} + C_{seeds_{Grass}})$$

- $C_{saved}$  = Savings achieved in variable costs (€/ha).
- $C_M$  = cost of mechanization for maize silage or grass silage (€/ha).

- $L_{ha}$  = labour costs for either practices associated with maize silage or grass silage (€/ha).
- $C_{seeds}$  = cost of seeds per hectare for different varieties of maize or for the creation of temporary Grassland (€/ha).
- $C_{phyto}$  = This is the additional phytosanitary product that the corn crop needs compared to grassland. Assuming that the additional fertilizer is synthetic fertilizer (€/ha).

**Income that farmers will have to give up by modifying their crop rotation:** The profit margins for the four primary crops (winter wheat, winter barley, Potatoes, Beetroot) in Wallonia, previously calculated in the context of agroforestry, are juxtaposed with those of maize and grass cultivation on a yearly basis. In years where maize silage is produced the net revenue of maize production is subtracted from the average net revenue of the 4 main crops in Wallonia. The same is done for the years where Herb silage is produced. It is acknowledged that crop productivity, and consequently the opportunity cost, varies across different regions. Maize productivity data is sourced from (Statbel, 2023) ([see appendix](#)). While productivity data for grass silage from temporary grassland, along with pricing information for both forage types, is obtained from (Forton, 2020; Fourrages Mieux, 2018). The production cost calculated in the previous step are used to calculate the net revenue for maize and herb. The values of the calculations are seen in the [appendix table 32](#).

**Costs or gains generated by the modification of the animals' feed ration:** This value, derived from Pellerin & Bamière, (2020), was calculated by experts who considered factors like animal breed, feed variability, and differences in farm practices. The central value is 10 €/ha/year but can vary between -84 €/ha/year and 166 €/ha/year depending on the circumstances.

**Reduction of mineral fertilization on crops following grasslands:** According to (Pellerin & Bamière, 2020), after 3 to 5 years of temporary grasslands, fertilization can be reduced by 100 units. As our methodology has grasslands in it for at least 3 years, the fertilization will be reduced by 100 units. With data provided by Agraost, (2018-2023). An average price was calculated for 100 units ([see appendix table 33](#)). Additionally, the costs for one less fertilization application, the associated labour, and reduced machine usage were factored in ([see appendix table 34](#)).

$$C_{fert} = C_M + L_{ha} + C_N$$

- $C_{fert}$  = Cost of fertilisation reduction due to the practice (€/ha).
- $C_M$  = Cost of mechanization (€/ha).
- $L_{ha}$  = Cost of labour (€/ha).
- $C_N$  = Cost of 100 units of nitrogen (€/ha).

#### 5.4.5 New exogenous carbon input in form of compost

The study focuses on utilizing new compost resources from urban areas (green waste, biowaste) to enhance soil carbon. It excludes sewage sludge and digestates. The chosen technical itinerary involves applying 15 MB/ha of compost annually, alongside adjusted mineral fertilizer application. The STICS model predicts a 0.5 t/ha productivity increase for winter wheat due to compost (Pellerin & Bamière, 2020).

2 scenarios are differentiated: First, the distribution was calculated of the compost per region. The distribution of the compost is proportional to the total crop size of the region see [appendix table 39](#). Regions where the compost distribution was considerably larger than the possible area of winter wheat on which it could be applied fall in the scenario NWW (Not enough Winter Wheat)

The following describes the costs of using compost in agriculture, specifically in Wallonia, Belgium. It details the cost of purchasing compost, transporting it, and spreading it on fields, as well as the potential impact on crop yields.

**Purchase of composts:** In Wallonia, several intercommunal companies are responsible for waste management and operate recycling centres: IDELUX, Intradel, BEP Environment, Hygea, Tibi, InBW and IPALLE (*Les recyparcs (ou parcs à conteneurs)*, 2015). All of these companies sell compost, and they also accept and collect organic waste. The average price for compost in Wallonia is 5.2 €/t the companies were contacted per mail using this contact data of this website (*Les recyparcs (ou parcs à conteneurs)*, 2015) (see also [appendix table 35](#)).

**Transport of Compost from production site to farmer's premises:** The compost is collected by the farmer. Prices for the tractor and a suitable cart were calculated. A cart was chosen which can transport 15 t of compost. A distance of 13.3 km was assumed that a farmer has to travel. An average speed of 30 km/h was assumed. A sensitivity analysis was also conducted,

considering scenarios of 26.6 km and 40 km travel distances. For the values see [appendix table 37](#).

$$C_{transport} = C_{cart} + C_{tractor} + L_{ha}$$

- $C_{transport}$  = Cost of transport (€/ha).
- $C_M$  = Cost of the cart for transporting (€/ha).
- $C_{tractor}$  = Cost of tractor for driving 13.3 km with an average speed of 30 km/h with 15t gives the price per hectare (€/ha).
- $L_{ha}$  = The labour cost per hectare is equal to the time for driving 13.3 km with an average speed of 30 km/h with 15t gives the price per hectare (€/ha).

**Spreading composts:** Composts are spread using heavy agricultural equipment. That fore a compost spreader and a self-propelled loader to fill the compost spreader are used. The cost of machinery and Labour are calculated with (Mecacost, 2017) and the performance indicator of the machine see [appendix table 37](#).

$$C_{spreading} = C_M + L_{ha}$$

- $C_{spreading}$  = cost of spreading compost (€/ha).
- $C_M$  = cost of mechanisation per hectare (€/ha).
- $L_{ha}$  = labour cost per hectare (€/ha).

**Variation in yields:** In the simulations by Pellerin & Bamière (2020), applying compost slightly increased wheat yields (median increase of 0.5 t MS/ha over 30 years). This increase is due to the gradual rise in soil organic matter from regular compost application, leading to increased nitrogen availability. No effect was observed on other crops. For the NWW scenario the value is equal to 0. For the values see [appendix table 37](#).

$$I_{ad} = Y_{ad} \cdot P_{WW}$$

- $I_{ad}$  = Additional income on Winter Wheat crops (€/ha).
- $Y_{ad}$  = additional yield (t/ha).
- $P_{WW}$  = Price of winter wheat (€/t).

**Variation in fertilization:** After Pellerin & Bamière, (2020), it is assumed that the application of compost reduces on average 30 units of Nitrogen application. With data provided by Agraost,

(2018-2023). An average price was calculated for 100 units (see [appendix table 36](#)). The mechanization and the labour reduction are also calculated:

$$C_{fert} = C_M + L_{ha} + C_N$$

- $C_{fert}$  = Cost of fertilisation reduction due to the practice (€/ha).
- $C_M$  = Cost of mechanization (€/ha).
- $L_{ha}$  = Cost of labour (€/ha).
- $C_N$  = Cost of 100 units of nitrogen (€/ha).

## 5.5 Maximum Basis and technical Basis

Moran et al. (2011), defines the **effective Basis (EB)**: The basis of a practice refers to the surface area on which a certain practice can be implemented. The effective Basis (ha) will be used to calculate the total carbon sequestration potential by multiplying it with the additional carbon sequestration (tC/ha/year).

### 5.5.1.1 *Calculating the basis for the carbon farming practices*

#### 5.5.1.2 *Agroforestry*

After Pellerin & Bamière, (2020), two criteria limit the land area suitable for agroforestry: a minimum field size of one hectare, and soil depth greater than one meter. Plots smaller than one hectare do not have enough space for both trees and tractors. In soils less than one meter deep, trees can grow, but their growth will be significantly affected, and timber harvest will be delayed. In the absence of site-specific data on soil depth or average values for this parameter in Wallonia, as established by Pellerin & Bamière, (2020), the total crop area for winter wheat, winter barley, potatoes, sugar beet was scaled down using the same factor as the ratio between the total crop area for France and the applicability for Agroforestry in France. This assumes a similarity in soil depth and average plot size between France and Wallonia. Pellerin et al. (2017) presents two adoption scenarios, one with a 4% utilization of eligible land for the practice and another with 10%. The effective basis aligns with the more conservative 4% scenario, as it is assumed that Agroforestry adoption is limited. The 10% scenario is also calculated in a sensitivity analysis.

#### 5.5.1.3 *Hedges*

Only one criterion limiting the area is retained: a soil depth greater than 50 cm. In shallower soils, while trees can certainly grow, their growth will be significantly affected, and timber harvesting will be considerably delayed. In the absence of site-specific data on soil depth or average values for this parameter in Wallonia, as established by Pellerin & Bamière, (2020), the total crop area for winter wheat, winter barley, potatoes, sugar beet was scaled down using the same factor as the ratio between the total crop area for France and the applicability for Agroforestry in France. This assumes a similarity in soil depth and average plot size between France and Wallonia.

#### 5.5.1.4 *Temporary Grasslands*

Forage maize was used as an indicator of the presence of ruminant livestock systems in order to insert new temporary grasslands only in systems where they are likely to be valued by animals (Statbel, 2023). These areas were then adjusted by a factor of 3/5 to accommodate a 3/5 rotation of temporary grassland (3) and maize (2) (Pellerin & Bamière, 2020).

#### 5.5.1.5 *Compost*

Since there are no figures on the current use of compost in agriculture, different scenarios are being developed for this calculation. In Belgium, 7,470,883 tons of plant waste are collected annually (Statbel, 2020). A 50% mass loss during the composting process is assumed. This relatively high value enhances the realism of subsequent assumptions. Furthermore, it is assumed that compost production is equally distributed between Flanders and Wallonia, with compost originating from Brussels being allocated proportionally to these regions. The application rate is 15 t/ha. However, there are no statistics available on the usage of compost in Wallonia agriculture. It is unknown how much potential this practice still. The 60 % scenario is the scenario, which was calculated. This scenario was developed under the assumption that there could be a high level of interest in new organic carbon inputs, given that 69% of sewage sludge is utilized in Wallonia. However, in the absence of data on compost usage in Wallonia, it is assumed that a maximum of 9% of composted plant residues are utilized within the region.

## 6 Results

The results of this study are presented in a systematic manner, starting with an analysis of the costs associated with implementing various carbon farming practices in Wallonia (Section 6.1).

This is followed by a detailed breakdown of the constant annuity, showcasing both costs and income streams for each practice (Section 6.2). Subsequently, the carbon sequestration potential of these practices is delved into, quantifying the carbon sequestration potential on both regional and Wallonia levels (Section 6.3). Finally, the marginal abatement costs are presented, providing a clear picture of the cost-effectiveness of each carbon farming practice (Section 6.4). This structured approach facilitates a comprehensive understanding of the economic and environmental implications of carbon farming in Wallonia.

## 6.1 Cost of practices per hectare for the farmer in Wallonia

*Table 6 : Average cost per hectare per year of carbon farming practices in Wallonia with regional highs and lows*

| Storing Practices                 | Farmers cost wallonia (€/ha/year) | Regional low (€/ha/year) | Regional high (€/ha/year) |
|-----------------------------------|-----------------------------------|--------------------------|---------------------------|
| Agroforestry                      | 219.61                            | 119.07                   | 233.23                    |
| New organic C inputs              | 43.2                              | 43.2                     | 151.43                    |
| Hedges                            | 62.61                             | 27.16                    | 67.35                     |
| Expansion of temporary grasslands | 125.09                            | -149.01                  | 187.53                    |

To simplify, costs will be referenced in this section without repeatedly stating per hectare per year. The table presents an overview of the average annual cost incurred by farmers in Wallonia for 4 agricultural practices: Agroforestry, new organic carbon inputs, hedgerows, and the implementation of temporary grasslands. The regional low and high values represent the minimum and maximum average costs observed across the 10 different agricultural regions within Wallonia.

In Wallonia, the average costs of implementing various sustainable agricultural practices are as follows: Agroforestry incurs the highest cost at €219.61, followed by the expansion of temporary grasslands at €125.09, hedges at €62.61, and new organic carbon inputs at €43.20.

The regional low for the expansion of temporary grasslands is the only instance in the table where the cost is negative. This indicates that implementing this practice in the region results in cost savings for the farmer compared to previous agricultural practices.

Agroforestry shows a notable cost variation, with farmers expenses ranging from €119.07 in the High Ardennes to €233.23 in the Loam region. New organic carbon inputs exhibit a broader

cost range, spanning from €43.20 to €151.43 of carbon sequestered. The higher costs are observed specifically in the High Ardennes and Ardennes regions, while other regions incur the lower cost of 43.20. Hedgerows have a cost that varies between €27.16 per hectare in the Ardennes and €67.35 per hectare in the Sand and Loam region. The average cost for this practice across Wallonia is €62.61 per hectare. The expansion of temporary grasslands demonstrates the widest cost range, with values ranging from -€149.01 in regions like Condroz, Ardennes, Haute Ardennes, and Jura, to €187.53 per hectare in the Hainaut-Campine region. The average cost for Wallonia is €125.09.

## 6.2 Constant annuity for agroforestry, hedges a temporary grasslands and implementation cost for new organic carbon inputs

The following tables detail the breakdown of the **constant annuity** for Agroforestry, Hedges and Temporary Grasslands (in €/ha) and the costs for new organic carbon inputs (€/ha). It outlines both the costs and income streams related to such systems. To simplify, costs will be referenced in this section without repeatedly stating per hectare.

### 6.2.1 Agroforestry

*Table 7: Table of yearly implementation costs adjusted with depreciation factor associated to agroforestry in Wallonia with regional highs and lows*

| Description of Costs      | Description                              | Amount (€/ha) |
|---------------------------|------------------------------------------|---------------|
| Initial investments       | Establishment of the agroforestry system | 260.99        |
| Maintenance costs         | Maintenance of grass and trees           | 37.73         |
| Income through wood sales | Sale of wood (pruning and thinning)      | -40.57        |
|                           | Sale of wood (harvest)                   | -138.32       |
| Opportunity costs         | Loss of cultivated area                  | 60.3          |
|                           | Decrease in yield on the remaining area  | 39.48         |
| <b>Total</b>              |                                          | <b>219.16</b> |

The largest expenditure within the agroforestry system implemented in Wallonia is attributed to the initial capital investment (€260.99), which includes costs for machinery, labour, and tree seedling procurement. Opportunity costs also represent a significant share of the total expenses (€99.78). The most substantial revenue, recorded as a negative cost, is derived from timber harvesting after a 50-year period, amounting to -€138.32.



## 6.2.2 Hedges

Table 8: Table of yearly implementation costs adjusted with depreciation factor associated to hedges in Wallonia with regional highs and lows

| Description of Costs     | Cost Item                                | Amount (€/ha) |
|--------------------------|------------------------------------------|---------------|
| Initial investments      | Establishment of the agroforestry system | 35.01         |
| Maintenance costs        | Maintenance of grass and trees           | 30.6          |
| Income trough wood sales | Sale of wood (pruning and thinning)      | -17.73        |
|                          | Sale of wood (harvest)                   | -20.39        |
| Opportunity costs        | Loss of cultivated area                  | 35.12         |
| <b>Total</b>             |                                          | <b>62.61</b>  |

In Wallonia, for Hedges the opportunity costs are slightly bigger 35.12€ then for the implementation of the system. The most significant revenue is generated through the sale of wood from harvests, including both pruning and thinning, as well as final harvests (€38.12). While the final harvest generates the largest income, it typically occurs after a significant period.

## 6.2.3 New organic carbon input in form of Compost

Table 9: Table of yearly implementation costs factor for new organic carbon input in form of compost in Wallonia

| Description of actions for compost use                         | Average annual cost €/ha (WW) | Average annual cost (NWW) |
|----------------------------------------------------------------|-------------------------------|---------------------------|
| Purchase of composts                                           | 75,30                         | 75,30                     |
| Transport of compost from production site to farmer's premises | 51,62                         | 51,62                     |
| Spreading composts                                             | 84,84                         | 84,84                     |
| Winter wheat                                                   | -108,23                       | 0,00                      |
| Variation in fertilization                                     | -60,33                        | -60,33                    |
| <b>Total</b>                                                   | <b>43,20</b>                  | <b>151,43</b>             |

The study distinguishes between two scenarios regarding compost application in Wallonia. According to), incorporating compost into the agricultural system results in a 0.5 t/year increase in winter wheat yield over 30 years. Consequently, two distinct scenarios are evaluated.

The costs are produced by spreading (84.84€), transport by the Farmer (51.62€) and purchase of the compost (75.30€). Income to higher Winter wheat yields is just available in the WW scenario(-108.23€). The variation of fertilization describes the savings due to the reduction of necessary fertilisation through the compost (-60.33€).

## 6.2.4 Temporary Grassland

Table 10: Table of yearly implementation costs adjusted with depreciation factor for temporary Grasslands in Wallonia with regional highs and lows

| Effects to Consider              | Description                                                                                                                         | Average annual cost (€/ha) |
|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| Changes in Crop Rotations        | Elimination of intermediate crops (savings on seeds and soil work)                                                                  | -98.13                     |
|                                  | Reduction in the area allocated to crops (loss of earnings from the sale of these crops, changes in technical itineraries included) | 266.74                     |
|                                  | Cost of implementing Grassland                                                                                                      | 68.71                      |
|                                  | Reduction of variable input costs (From maize silage to grass silage)                                                               | -99.28                     |
| Changes in Farming Practices     | Modification of animal feed rations (increase in grazed grass and hay, and decrease in forage maize)                                | 10.00                      |
|                                  | Reduction of mineral fertilization on crops following grasslands                                                                    | -22.94                     |
| <b>Total cost for the farmer</b> |                                                                                                                                     | <b>125.09</b>              |

The value for “Modification of animal feed rations” comes from literature (Pellerin & Bamière, 2020) and varies from -84 €/ha to 166 €/ha. The variation of this factor can have a big influence and will be analysed in the discussion as well as the variation for “Reduction in the area allocated to crops”, which is the biggest cost factor in this practice. Elimination of intermediate crops (-98.13€) and reduction of variable input costs (-99.28€), save costs compared to the previous system, which is shown by the negative sign.

## 6.3 Carbon sequestration potential

Table 11: Table of the effective basis and the total carbon sequestration potential of Wallonia with regional highs and lows

| Storing Practices                 | Effective basis Wallonia (ha) | Total carbon sequestration potential Wallonia (tC/year) | Regional low (tC/year) | Regional high (tC/year) |
|-----------------------------------|-------------------------------|---------------------------------------------------------|------------------------|-------------------------|
| Agroforestry                      | 2783.70                       | 3201.25                                                 | 1.77                   | 2345.04                 |
| New organic C inputs              | 74708.83                      | 37354.41                                                | 76.98                  | 17502.23                |
| Hedges                            | 141554.83                     | 37228.92                                                | 20.57                  | 27271.64                |
| Expansion of temporary grasslands | 22190.40                      | 6989.98                                                 | 26.65                  | 6974.10                 |

The table shows the total carbon sequestration potential (tC/year) of various agricultural practices in Wallonia and the effective basis (ha). Regional variability in carbon sequestration

potential is also provided, reflecting differences across distinct areas within Wallonia. The regional low and high values represent the minimum and maximum carbon sequestration potentials observed across the 10 different agricultural regions of Wallonia. The cumulative carbon sequestration potential for the 4 assessed practices is estimated at 84 774.56 tC/year.

By observing the effective basis for carbon farming practices in the table. Hedges have the highest effective basis with 141 554.83 hectares. In contrast, agroforestry has the most limited availability at 2 783.70 hectares. New organic carbon inputs have a basis of 74 708.83 hectares, while the expansion of temporary grasslands has 22,190.40 hectares available.

The highest carbon sequestration potential is associated with the implementation of compost in crop systems, with a regional low of 76.98 tC/year in the High Ardennes and a peak of 17 502.23 tC/year in the Loam region. Hedges, as a carbon sequestration practice, present a lower total carbon sequestration potential, quantified at 37 228.92 tC/year, with regional values ranging from 20.57 tC/year in the High Ardennes to 27 271.64 tC/year in the Loam region.

Temporary grasslands offer a more modest carbon sequestration potential, totalling 6 989.98 tC/year. This practice exhibits a regional low of 26.65 tC/year in the Hainaut-Campine region, and a high of 6 974.10 tC/year in the Sand and Loam region. It is important to note that these regions have been analysed in their entirety, even though the Loam and Sand Loam regions extend partially into the Flemish region.

Agroforestry demonstrates the lowest carbon sequestration potential among the practices evaluated, with a total of 3201.5 tC/year. The regional variation is notable, with a minimum of 1.77 tC/year in the High Ardennes and a maximum of 2 345.04 tC/year in the Loam region.

### **Result of sensitivity analyses:**

By calculating a 10% scenario for agroforestry, we find an effective basis of 6959.24 hectares. The total carbon sequestration potential becomes 8003.13 tC/year, which is larger compared to the carbon sequestration potential for temporary grassland.

## 6.4 Abatement costs

*Table 12: The table provides an overview of the marginal abatement costs associated with 4 agricultural practices: Agroforestry, new organic carbon inputs, hedgerows, and the implementation of temporary grasslands in Wallonia, highlighting the variability across different regions.*

| Storing Practices                 | Marginal Abatement Cost for Wallonia (€ tC <sup>-1</sup> ) | Regional low (€ tC <sup>-1</sup> ) | Regional high (€ tC <sup>-1</sup> ) |
|-----------------------------------|------------------------------------------------------------|------------------------------------|-------------------------------------|
| Agroforestry                      | 190.97                                                     | 103.53                             | 202.81                              |
| New organic C inputs              | 86.4                                                       | 86.4                               | 302.86                              |
| Hedges                            | 238.06                                                     | 103.27                             | 256.08                              |
| Expansion of temporary grasslands | 397.12                                                     | -473.04                            | 595.33                              |

New organic carbon inputs emerge as the most cost-effective practice, averaging €86.40 per ton of carbon sequestered. Agroforestry follows with a moderately higher cost of €190.97 per ton. In contrast, hedgerows exhibit a considerably higher cost at €238.06 per ton. Finally, the expansion of temporary grasslands presents the highest average cost at €397.12 per ton.

Agroforestry exhibits a marginal abatement cost ranging from €103.53 per ton of carbon sequestered in the High Ardennes to €202.81 in the Sand and Loam region.

New organic carbon inputs show a broader cost range, from €86.40 to €302.86 per ton of carbon sequestered. The higher cost of €302.86 is specific to the High Ardennes and Ardennes regions, whereas the other regions follow the scenario with a lower cost of €86.40 per ton.

Hedgerows have a marginal abatement cost that varies between €103.27 per ton of carbon sequestered in the Ardennes and €256.08 in the Sand and Loam region.

The expansion of temporary grasslands demonstrates the widest cost range, with values spanning from -€473.04 per ton of carbon sequestered in regions like Condroz, Ardennes, Haute Ardennes, and Jura, to €595.33 in the Hainaut-Campine region. The negative cost indicates potential cost savings.

## 6.5 Marginal abatement cost curve

### 6.5.1 Maximum technical sequestration potential

*Table 13: Maximum technical sequestration potential for Wallonia compared to carbon sequestration potential of the thesis*

| Effects to Consider                 | Description                                                                                                                         | Average annual cost (€/ha) |
|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| <b>Changes in Crop Rotations</b>    | Elimination of intermediate crops (savings on seeds and soil work)                                                                  | -98.13                     |
|                                     | Reduction in the area allocated to crops (loss of earnings from the sale of these crops, changes in technical itineraries included) | 266.74                     |
|                                     | Cost of implementing Grassland                                                                                                      | 68.71                      |
|                                     | Reduction of variable input costs (From maize silage to grass silage)                                                               | -99.28                     |
| <b>Changes in Farming Practices</b> | Modification of animal feed rations (increase in grazed grass and hay, and decrease in forage maize)                                | 10.00                      |
|                                     | Reduction of mineral fertilization on crops following grasslands                                                                    | -22.94                     |
| <b>Total cost for the farmer</b>    |                                                                                                                                     | <b>125.09</b>              |

Assuming that our 4 practices are deployed on 100% of their area base, the maximum cumulated technical potential for carbon sequestration in soil and biomass would amount to 248 187.39 tC/year for Wallonia, of which 151 581.02 tC/year are sequestered in the soil (69%) and 96606.37 tC/year (31%) are sequestered in biomasse.

The biggest difference when looking at the maximum cumulated technical sequestration potential and the normal scenario can be observed for Agroforestry. The carbon sequestration potential increases significantly from 3.78% to 32.25%. For hedges, there is also a big difference, however, the trend is reversed. Hedges in the case of maximum technical potential contributes only for 15% to the total carbon sequestration, while before it was 44.06%. The potential for temporary grasslands also decreases in percentage terms in the case of maximum technical potential contributes only for 4.69% to the total carbon sequestration, while before it was 8.25%. The practice new organic carbon input now contributes over 50% to the total carbon sequestration and thus remains the practice that contributes the most to carbon sequestration, followed by Agroforresty, Hedges and temporary Grasslands at the end.

### 6.5.2 Marginal abatement cost curve of Wallonia

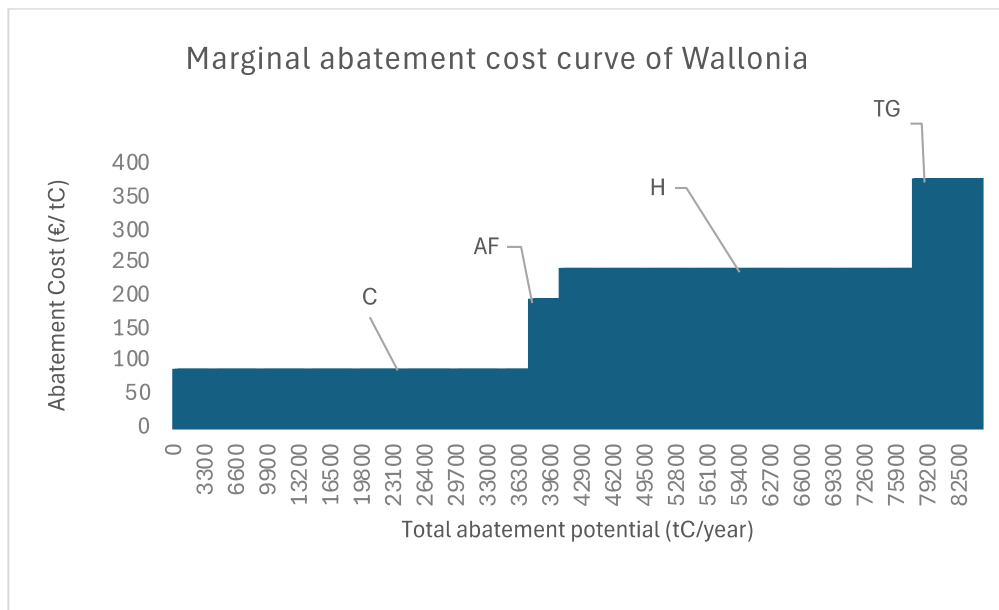


Figure 4 : Marginal abatement cost curve of Wallonia. C: New organic carbon input; AF: Agroforestry; H: Hedges; and TG: Implementation of Temporary Grasslands

In this section, the trends of the MACC of Wallonia are analysed. For the engineering approach of MACC, for each action type, the marginal cost equals the average cost because it does not depend on the amount of carbon stored, resulting in a step-shaped marginal abatement cost curve (Soussana & Lemaire, 2014).

The order of the practices in the marginal abatement cost curve shows the order of the lowest to the highest abatement cost. For Wallonia the order is: New organic carbon input, Agroforestry, Hedges, and Implementation of temporary Grasslands.

The sequestration potential is represented on the X-axis. The wider the bar associated with the practice, the greater the sequestration potential. The MACC for Wallonia shows the biggest carbon sequestration potential for Hedges, followed by New organic carbon input, then temporary grasslands and finally agroforestry.

For Wallonia, only positive costs were observed; none of the practices show a negative abatement cost.

### 6.5.3 Regional Trends for Marginal abatement cost curves in Wallonia

In this section, the MACCs of the 10 different agronomic regions are compared with the MACC of Wallonia. When comparing the different MACCs, it is immediately noticeable that the

MACCs of the regions sometimes deviate significantly from the MACC of Wallonia. There are 4 types of MACC which are similarly structured.

First, the Hainaut-Campine region and the Sand and Loam region have a MACC that is very similar to that of Wallonia. The order of practices and the sequence of sequestration potential are the same.

The second type of MACC is similar for Condroz, Famenne, and the Jura region (see Figure5):

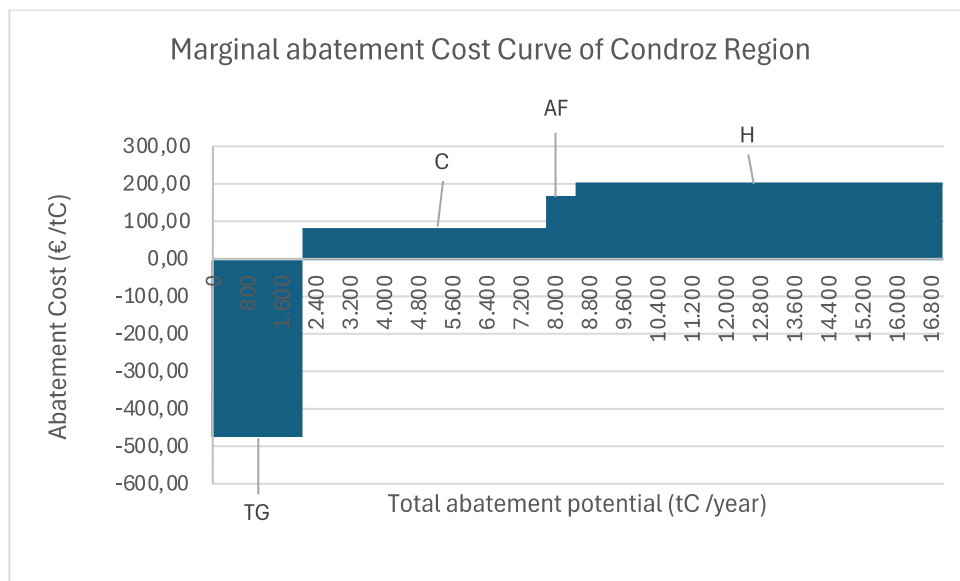


Figure 5: Marginal abatement cost curve of Condroz Region. C: New organic carbon input; AF: Agroforestry; H: Hedges; and TG: Implementation of Temporary Grasslands

The order of the practices in the marginal abatement cost curve shows the order of the lowest to the highest abatement cost. The order for those regions is different from the one for Wallonia: Implementation of temporary grasslands, new organic carbon input, Agroforestry, and Hedges at the end. The MACC for Condroz, Famenne, and the Jura region shows the biggest carbon sequestration potential for hedges, followed by New organic carbon input, then temporary grasslands and finally agroforestry. For temporary grasslands a negative value is observe for the abatement cost. This translates to savings associated to the practice.

The third type of MACC follows the same order of abatement costs and sequestration potentials, but the abatement costs are positive for temporary grasslands. The Loam Region, the Pasture Region, and Fagne belong to this type of MACC.

The fourth type of MACC (Figure 6) has a negative abatement cost for temporary grasslands and the order of the abatement costs changes completely, with implementation of temporary grasslands, hedges, agroforestry, and new organic carbon input at the end.

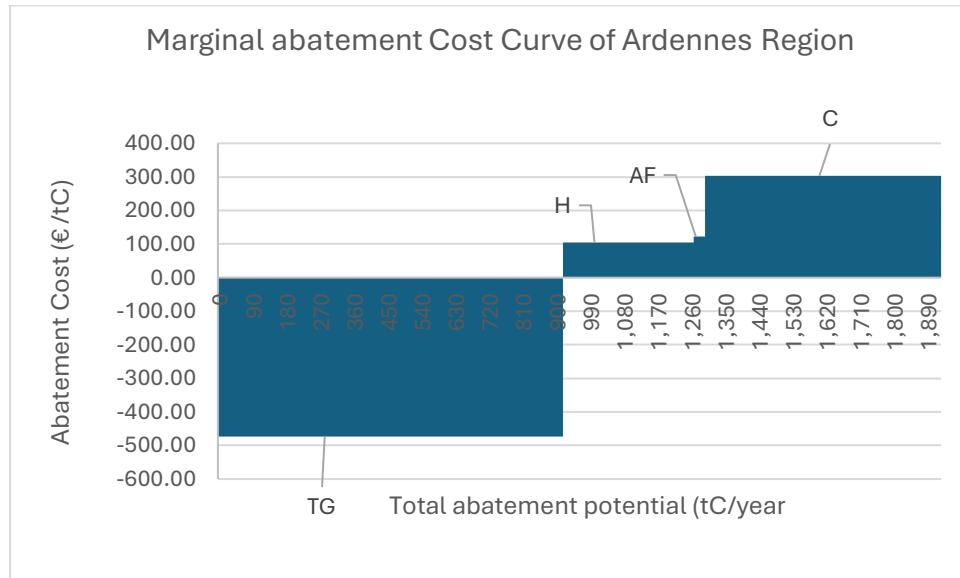


Figure 6 : Marginal abatement cost curve of Ardennes Region. C: New organic carbon input; AF: Agroforestry; H: Hedges; and TG: Implementation of Temporary Grasslands

The cost-effectiveness for the Condroz, Famenne, Jura regions is also negative (Figure 5). The total carbon sequestration potential for the 5 regions with negative cost is 4498.58 tC/year. This corresponds to 64.4% of the total potential of Wallonia, which can be reached while Farmers save cost.

The Loam Region, the Pasture Region, and Fagne (third type of MACC) have a positive marginal Abatement cost. However, this is moderate at 0.19€ /tC, 32.09€ tC<sup>-1</sup>, and 60.14 €/tC respectively. Together, these regions have a total carbon sequestration potential of 5917.59 tC/year. It should be noted that 4951.80 t/ year of this total carbon sequestration potential comes from the Loam region, which is not entirely located in Wallonia.

## 7 Discussion

This section explores the carbon sequestration potential of agricultural practices in Wallonia. We examine the relevance of existing literature, compare sequestration potentials, and assess the total potential against regional emissions. We delve into the economics, analysing potential farmer income and implementation costs. We also discuss the cost-effectiveness of each practice using a Marginal Abatement Cost Curve (MACC) and identify key factors influencing



it. We acknowledge limitations and propose future research directions to refine our understanding and promote carbon farming in Wallonia.

## 7.1 Carbon sequestration potential

### 7.1.1 Relevance of carbon sequestration potentials from Literature

In this study, a uniform carbon sequestration potential was assumed for all regions within Wallonia. However, it is recognized that various factors, such as soil type, land management practices, and climatic conditions, can influence the actual carbon sequestration capacity of a given region. To achieve more precise and regionally specific estimations of sequestration potential, the utilization of models like STICS as shown in (Bamière et al., 2023; Pellerin & Bamière, 2020), which can account for these diverse factors, is recommended for future research.

It Is difficult to say how relevant the values found in the literature for carbon sequestration potential are. It is important to note that these values are averages for large regions, which are not relevant for individual farmers. Wallonia has many different soils that influence the carbon sequestration potential. Depending on the land type (grassland, crops) or practices that farmers implement (e.g. type of fertilization, type of seed), even neighbouring farmers can have different carbon stocks.

### 7.1.2 Comparison of carbon sequestration potentials from Literature

Table 3 shows the different carbon sequestration potentials per year and hectare. Agroforestry has the greatest carbon sequestration potential. However, this is not due to the carbon sequestration potential for soils but to the high carbon sequestration potential in the biomass. The practices “new organic carbon input” and “implementation of temporary grasslands” both sequester more carbon in the soil. For hedges, the same applies as for agroforestry, most of the carbon is stored in the form of biomass.

In this work, only the carbon sequestration potential for soil and biomass is analysed, and not the GHG potential as in comparable studies (Bamière et al., 2023; Pellerin et al., 2017, 2017). The benefit of the carbon sequestration potential also depends on the use of the wood (e.g., timber or firewood).

### 7.1.3 Total Carbon sequestration potentiel compared to emissions of Wallonia

The agricultural sector produced 4 539 000 tCO<sub>2e</sub> in 2019 (tCO<sub>2e</sub> = 1 ton CO<sub>2</sub> equivalent). The total calculated carbon sequestration potential for Wallonia with the 4 selected practices (implementation of temporary grasslands, hedges, agroforestry, and new organic carbon) is 84774.56 tC/year. In CO<sub>2e</sub> (1 tCO<sub>2e</sub> = 12/44 tC), it is equal to 310 840 tCO<sub>2e</sub> /year. With the methodologies described for the 4 carbon farming practices 6.8% of the emission from the agricultural sector can be mitigated.

Assuming that our 4 practices are deployed on 100% of their area base, the maximum cumulated technical potential for carbon sequestration in soil and biomass would amount to 248 187.39 tC/year for Wallonia. In CO<sub>2e</sub>, it is equal to 910 020.43 tCO<sub>2e</sub> /year. With the methodologies described for the 4 carbon farming practices 20.04% of the emission from the agricultural sector in 2019 can be mitigated.

The 4 chosen carbon farming practices have the potential to significantly decrease carbon emissions from the agricultural sector. Hypothesis 3 is therefore confirmed. It is clear that the 4 practices alone will not be enough to turn the agricultural sector from an emitter into a GHG sink. However, carbon farming in synergy with other GHG mitigation practices in agriculture has great potential. Furthermore, it must be said that only 4 practices were investigated. Further investigations into other practices could show whether and where these could also be implemented. This study focuses mainly on arable soils. The processes for grassland are not yet fully understood. Further research in this area could perhaps lead to grassland also being used for carbon farming.

### 7.1.4 Estimation of potential income through carbon farming practices

This section calculates some scenarios for revenues through selling carbon credits for Farmers in Wallonia. Assuming that every practice is applied and a price per tCO<sub>2e</sub> is 27.5€ , farmers in Wallonia can generate a total gross revenue of 8 548 100€.

Assuming only applying practices, which have a cost below 27.5€ per tCO<sub>2e</sub> which is for the whole of Wallonia only the case for new organic carbon input. The carbon sequestration potential for practices cheaper than 27.5€ is 37 354.41 tC/year (which is equal to 136 966.17 tCO<sub>2e</sub> /year). All Farmers in Wallonia can generate a total gross revenue of 3 766 528€.

When looking on a regional level these changes. The carbon sequestration potential for practices cheaper than 27.5€ is 47 077,74 tC/year (which is equal to 172 615 tCO<sub>2e</sub> /year). The farmers can generate 4 746 930€, which is equal 55.5% of the total possible revenue.

## 7.2 Yearly implementation cost of carbon farming practices

### 7.2.1 Comparison of yearly implementation costs between practices

In Wallonia, the average costs of implementing various sustainable agricultural practices are as follows: Agroforestry incurs the highest cost at €219.61, followed by the expansion of temporary grasslands at €125.09, hedges at €62.61, and new organic carbon inputs at €43.20.

The high cost per hectare for agroforestry ([see table 5](#)) stems from substantial implementation and opportunity costs. Hedges ([see table 6](#)) follow a similar technical approach, but their costs are significantly lower for two reasons. Firstly, the cost of trees in agroforestry is much higher because standard trees are used. In contrast, hedges involve only 7 standard trees per hectare, with the rest being smaller, less expensive plants. Agroforestry, on the other hand, requires planting 75 standard trees per hectare. Secondly, opportunity costs are higher in agroforestry. It needs more space, and the trees grow larger and are no longer trimmed after year 13. This leads to a reduction in crop yield (7.5%), which doesn't happen with hedges as they are kept trimmed.

For temporary Grasslands ([see table 8](#)) the biggest cost is the opportunity cost for Wallonia. Implementing a temporary Grasslands instead of a crop implies significant opportunity costs (266.74€). These opportunity costs are bigger compared to those of agroforestry. The modification of animal feed ration is a complex cost factor. The cost can vary a lot from Farmer to Farmer and across regions. Depending on this factor the practice can significantly change its implementation cost. The practice of implementing new organic carbon ([see table 7](#)) input is not influenced by opportunity costs due to crop loss. However, if the compost is not applied to winter wheat, the practice becomes significantly more expensive because the benefit of an increased yield (0.5 t/ha) is not realized. In Wallonia, though, there are enough winter wheat fields available for this practice.

Regional variations in the adoption of agroforestry, hedges, and temporary grasslands can be attributed to the yield potential of the four main crops (winter wheat, winter barley, potatoes, and beetroot) in a given region ([see appendix table 39](#)). In regions with low crop yields,

opportunity costs are lower (see appendix table 42). This may lead to negative costs associated with implementing temporary grasslands.

## 7.2.2 Comparison of costs to values from Literature

Table 14 : Comparison of costs (€/ha/year) to Literature Bamière et al. (2023) and Pellerin & Bamière, (2020)

| Storing Practices                 | Farmers cost wallonia (€/ha/year) | Regional low (€/ha/year) | Regional high (€/ha/year) |
|-----------------------------------|-----------------------------------|--------------------------|---------------------------|
| Agroforestry                      | 219.61                            | 119.07                   | 233.23                    |
| New organic C inputs              | 43.2                              | 43.2                     | 151.43                    |
| Hedges                            | 62.61                             | 27.16                    | 67.35                     |
| Expansion of temporary grasslands | 125.09                            | -149.01                  | 187.53                    |
| Bamière et al., (2023)            |                                   |                          |                           |
| Agroforestry                      | 84                                | 20                       | 136                       |
| New organic C inputs              | 22                                | -92                      | 269                       |
| Hedges                            | 70                                | 49                       | 84                        |
| Expansion of temporary grasslands | 91                                | -41                      | 314                       |
| Pellerin & Bamière (2020)         |                                   |                          |                           |
| Agroforestry                      | 118                               | 63                       | 178                       |
| New organic C inputs              | 22,6                              | -92                      | 268                       |
| Hedges                            | 73                                | 54                       | 86                        |
| Expansion of temporary grasslands | 91                                | -40                      | 314                       |

The two articles (Bamière et al., 2023; Pellerin & Bamière, 2020) were chosen for comparison because they also develop a MACC using models like BANCO, which partially rely on engineering processes, and they examine the same practices as this study. The regional context of those studies is France, which is assumed to be similar to the Belgian context by Pellerin & Bamière, (2020) However, there are differences that limit the relevance of the comparison and make this study only partially comparable to the articles.

One key difference is the regional context. Price levels between Belgium and France can vary, affecting the costs of the practices differently. Additionally, the articles (Bamière et al., 2023; Pellerin & Bamière, 2020) use slightly different methods to determine the costs of the practices compared to this study. Although the methodology largely builds on the same foundations, this study made certain adjustments or assumptions that were not precisely outlined in the articles. Additionally, some assumptions had to be simplified for this article. Due to a lack of data, calculations could only be made for the four main cost components. Furthermore, the articles and this study use different databases, which may affect the results. These differences, both in regional context and in the methods used, limit the validity of the comparison. It is acceptable to assume that the differences are not so large that the cost trends are comparable.

**Agroforestry:** The estimated cost for Wallonia (219.61 €/ha/year) is notably higher than the literature values (€84 and €118/ha/year). Even the regional extremes of the literature do not fit the cost of the Wallonia. Since there is no access to the cost model of the articles, it cannot be said with certainty where these differences come from. It can be assumed that this difference arose from the costs of purchasing the trees. The articles did not specify which size of trees is being planted. In this study, they were high-stemming trees, which are cost intensive.

**New Organic Carbon Inputs:** The cost in Wallonia (€43.20/ha/year) is consistent with the literature (€22 and €22.6/ha/year). The value for Wallonia fits within the range of regional values from the literature. Even the regional extremes of Wallonia of this study fall within this range. However, negative costs were also found in the articles, which was not the case for this study.

**Hedges:** The cost in Wallonia (€62.61/ha/year) falls within the range reported in the literature (€70 and €73/ha/year),

**Expansion of Temporary Grasslands:** The cost in Wallonia (€125.09/ha/year) shows significant variability compared to the literature values (€91/ha/year). This suggests that the economic feasibility of this practice is highly context dependent. Notably, the regional variations in Wallonia highlight the potential for negative costs in certain areas, which is also reflected in the literature in regional extremes but not as extreme. The differences probably come from differences in the cost model assumptions. Since exact cost models cannot be precisely followed in the articles, it is difficult to formulate Hypothesis about them.

### 7.2.3 Discussion of the implication of those costs regarding the farmer

According to Sykes et al. (2020), and also seen in this study, agroforestry brings high initial investments, but one must consider: "The typical farm manager is a 55-year-old man" and often there is also no successor (SPW, 2020a). Consequently, farmers who do not have a successor are generally reluctant to make such investments. Although hedgerows present a similar issue, their investment requirements are lower. Furthermore, long-term agricultural practices, such as agroforestry, are subject to considerable uncertainties over extended periods, such as 50 years. Factors such as fluctuations in timber prices, changing opportunity costs, and shifting land-use priorities (e.g., increased demand for food production) can significantly affect the feasibility and profitability of these practices.

The lower cost of implementing hedge practices and the reduced opportunity costs might be more attractive to farmers. Although agroforestry has higher cost-effectiveness due to its greater carbon sequestration potential, it is likely that a farmer will opt for a less invasive method and invest less to minimize risk.

The use of compost seems to be a good way to store carbon in the soil. The practice is inexpensive compared to others when applied to winter wheat. But farmers have to consider transport cost in function of the distance to the compost distribution centre. The transport was calculated for 3 distances and for the WW and NWW scenario.

WW Scenario: For the basic scenario, a distance of 13.3 km was selected. The 2<sup>nd</sup> scenario is a distance of 26.6 km, and the 3<sup>rd</sup> scenario calculates a transport distance of 40 km. Due to the 2<sup>nd</sup> scenario, the costs per hectare per year increase to €73.26 and in scenario 3 to €101.59.

NWW Scenario: Due to the 2<sup>nd</sup> scenario, the costs per hectare per year increase to €181.5 and in scenario 3 to €209.82.

For the implementation of temporary grasslands, the reduced cost associated with this practice in certain regions appears highly attractive to farmers. However, several factors must be considered. Firstly, this practice can only be applied in areas where livestock is present, as humans cannot utilize forage maize directly (Pellerin & Bamière, 2020). Secondly, the production of high-quality grass silage is more complex, requiring specific expertise and optimal conditions, whereas maize silage almost guarantees high quality (SPW, 2021).

## 7.3 Discussion of the cost-effectiveness

The following discusses the cost-effectiveness of the chosen carbon farming practices. For cost-effectiveness a comparison to Literature was not considered. Similar articles calculate the GHG abatement potential and not the carbon sequestration potential like this study. Those studies account for things like  $N_2O$  emission and emissions from implementing practices for instance. A comparison would be wrong and pointless.

### 7.3.1 Comparison of carbon farming practices using a MACC

The following section discusses my first research question: “How does the cost-effectiveness of agroforestry, hedges, compost application, and temporary grasslands compare in Wallonia when assessed using a MACC?”

To answer this question, the practices are classified in three classes. The classification follows the example of Pellerin & Bamière, (2020). For Wallonia we find the following marginal abatement costs in €/tC. For agroforestry a price of 190.97 €/tC is found, for the practice of implementing new organic carbon in form of compost a price of 86.40 €/tC, for the implementation of hedges a price of 238.06 €/tC was found and for the implementation of temporary grasslands a price of 396.92 €/tC was found.

**Practices with negative marginal abatement costs:** For Wallonia, there are no negative marginal abatement costs.

**Practices with moderate marginal abatement costs** (between 0 and 250 €/tCO<sub>2e</sub>): For Wallonia agroforestry, implementing new organic carbon in form of compost and implementation of hedges belongs to this category.

**Practices with high marginal abatement costs** (>250 €/tCO<sub>2e</sub>): The marginal abatement cost of implementing temporary grasslands is high for Wallonia.

In general, farmers are more likely to adopt carbon farming practices with low marginal abatement cost. There are also other factors to consider which we discussed in section [7.2.3](#), but in general farmers want to sequester as much carbon as possible for the lowest possible price. Soil capital pays 27.50€/tCO<sub>2e</sub> sequestered. Without subsidies only implementing new organic carbon in form of compost would be adopted by farmers. An argument against the practice can be found, when one considers the upstream costs of compost:

Pellerin & Bamière, (2020) review the upstream costs of composting, focusing on the collection and processing of green and food waste. Managing green waste at waste centres is preferred over home collection for cost-effectiveness. The average cost for this waste management is €123 per ton, while household food waste collection costs €377 per ton. The total cost of waste management is 995€ per hectare, when calculated for the Farmer. This indicates that while farmers bear some costs, the public ultimately covers most of the expense through public services.

The government wants to mitigate as much carbon as possible. However, the government is not without a budget and also has an interest in not spending money in a non-cost-effective way. Looking at the MACC for Wallonia, one can see that hedges have a large abatement potential. For this reason, the government has an interest in subsidizing this practice more than agroforestry and temporary grasslands, which have a small abatement potential. Especially because of the high marginal abatement cost of temporary grassland making the practice less cost-effective.

While the most promising practice when looking at the MACC is implementing compost, when considering all those factors, hedges becomes the most promising approach and should be subsidized by the government.

### 7.3.2 Key factors influencing the cost-effectiveness of carbon farming practices in Wallonia

In this section, the second research question is discussed. There are two major factors that influence the cost-effectiveness of carbon farming practices.

Costs inevitably arise when implementing practices and understanding the nature and origin of these costs is crucial for informed decision-making. These costs can be divided into direct and indirect categories. Direct costs are more apparent and include expenses such as materials, labour, and equipment. However, indirect costs, such as opportunity costs, are often more insidious and less visible. Neglecting to consider these indirect costs can lead to a distorted understanding of the true financial implications of a technique or practice. For instance, a method that appears to be cost-effective on the surface may, in reality, generate hidden losses due to unaccounted-for opportunity costs, decreased productivity, or surface losses (agroforestry, temporary grasslands and Hedges). This misconception can result in the underestimation of total expenditures, potentially leading to suboptimal decision-making.



Moreover, the evaluation of costs should also include a thorough analysis of long-term economic impacts, including sustainability and the potential for future cost reductions through innovation or scale. Strategies to mitigate these costs, such as optimizing resource allocation, improving efficiency, or adopting more advanced technologies, are essential for enhancing cost-effectiveness.

The potential for carbon sequestration presents a significant opportunity but is highly dependent on various factors such as soil type, pH, climate conditions, and land management practices. The complexity of these interactions makes it challenging to accurately estimate carbon sequestration potential. In this work, the abatement potential was calculated based on existing literature, which provides a foundational understanding but may not fully capture the regional specifics necessary for precise estimation.

To obtain more accurate and region-specific values for carbon sequestration potential, detailed modelling would need to be conducted within the context of Wallonia.

It is important to acknowledge that the abatement potentials estimated in this work may have been either overestimated or underestimated. Without the development and application of precise, regionally tailored models, definitive conclusions regarding the exact carbon sequestration potential cannot be drawn. Therefore, while the current estimates provide useful insights, they should be interpreted with caution, and further research is needed to refine these estimates through localized modelling efforts.

### 7.3.3 Regional variances of carbon farming practices

This section discusses the third research question. The analysis of marginal abatement costs allows us to distinguish 3 categories of practices which were characterized by Pellerin & Bamière (2020):

**Practices with marginal abatement costs:** In this thesis there was only one practice with negative storage cost for some Regions. Implementing temporary Grasslands had negative costs for this Regions: Condroz, Ardennes Famenne, Jura, and Hautes Ardennes regions is negative. After **Hypothesis 1:** In regions of Wallonia characterized by low crop yields the implementation of temporary grasslands as a carbon farming practice can lead to net economic benefits for farmers is confirmed. When looking at the crop yield of those regions, it is clear that those regions have the lowest yield compared to the other regions (see [appendix](#)).

**Practices with moderate marginal abatement costs** (between 0 and 250 €/tC): The marginal abatement costs for Agroforestry are all within this range. For Hedges there is one Region which is not in this range. For the practice implementing new organic carbon input, there are two regions not in this moderate class. For Wallonia all of the practices belong to this category except for the practice temporary Grasslands.

**Practices with high marginal abatement costs** (>250 €/tC): For the Sand and Loam region the practices Hedges and implementing temporary Grasslands are in this class. New organic carbon input is in this group for the High Ardennes and Ardennes. The marginal abatement cost for implementing temporary Grasslands in Campine-Hainnaut and Wallonia is also high.

Farmers are likely to adopt practices with negative costs, which exist only in certain regions. For instance, the implementation of temporary grasslands incurs a negative cost in some regions, making it an attractive option for farmers there. Although the overall marginal cost of implementing temporary grasslands across Wallonia may be high, this practice remains beneficial in specific areas.

The abatement potential varies significantly between regions. While temporary grasslands are highly cost-effective in some regions, their overall impact in Wallonia is limited due to the small area where they can be applied in those regions. There are two reasons for the small appliance rate. First, the region is dominated by grassland and the productivity of crops is limited, so there are not a lot (e.g. High Ardennes). The other reason is that the region is much smaller compared to others (Fagne compared to Loam Region) limiting the impact on whole Wallonia. This discrepancy explains why Wallonia experiences a high marginal cost, whereas some regions benefit from negative costs.

Subsidizing the practices in the mentioned regions, where they fall into the high marginal cost class, would likely be less effective compared to other regions where the costs are lower. As a result, even with subsidies, the financial incentive may not be sufficient to encourage widespread adoption.

Practices with moderate marginal abatement cost can effectively be subsidized. Policy makers should consider also the abatement potential when deciding which practice to subsidize. Which was the reason why Hedges were considered the best practice to subsidize in the section discussing Wallonia.

## 7.4 Sensitivity analysis

### 7.4.1 Sensitivity analysis mechanization

This section examines the impact of rising mechanization costs on agricultural practices in Wallonia. Using Mecacost, (2017) data, we adjust for a 30% increase in machinery prices and a rise in fuel costs from €1 to €1.30 per litre, reflecting recent trends. We then analyse how these changes affect the costs of agroforestry, hedges, temporary grassland implementation, and compost application. This will test Hypothesis 2.

#### 7.4.1.1 *Agroforestry*

Counterintuitively, increasing mechanization and fuel costs by 30% results in a decrease in the practice's cost from 219.16€/ha/year to 209.55€/ha/year for Wallonia (-4.38%). This phenomenon occurs because the practice requires substantially less machinery compared to the equipment needed for cultivating the necessary crops. As fixed production costs escalate, farmers' profits and consequently opportunity costs diminish, rendering the practice more economically viable. For agroforestry the Hypothesis 2 is not confirmed.

#### 7.4.1.2 *Hedges*

Similarly to agroforestry, the outcome emerges when mechanization and fuel costs increase by 30%: the cost associated with hedge establishment in Wallonia decreases from 62.61€/ha/year to 58.90€/ha/year. The reason for this is the same as for agroforestry, however, the losses for the areas are different and the cost drops by 5.93%. For hedges the Hypothesis 2 is not confirmed.

#### 7.4.1.3 *Implementing Temporary Grassland*

For this practice, the increase in the prices of mechanization and fuel hardly changes anything. With an increase of 30%, the costs for the practice only increase from 125.09 €/ha/year to 125.42 €/ha/year. For this practice the difference is too small to confirm or not the Hypothesis 2.

#### 7.4.1.4 *Compost*

For this practice, the 30% increase in mechanization costs has a major impact on costs, with costs per hectare rising from €43.19/ha to €76.82/ha (+77.86%). However, the practice remains in the category of moderate marginal abatement costs at 153.64€/tC. This is the only, where the Hypothesis 2 can be confirmed.

## 7.5 Different scenarios for carbon sequestration potentials in Agroforestry

By calculating a 10% scenario for agroforestry, we find an effective basis of 6959.24 hectares. The total carbon sequestration potential becomes 8003.13 tC/year, which is larger compared to the carbon sequestration potential for temporary grassland. However, this carbon sequestration potential is still lower than that of hedges and new organic C input with compost. According to Sykes et al. (2020), agroforestry brings high initial investments, but one must consider: “The typical farm manager is a 55-year-old man” and often there is also no successor. Investments from which a farmer without a successor has nothing are usually not made. With hedges, this problem is also present, but the investments are not as high. Additionally, long-term agricultural practices, such as those involving forestry, are inherently susceptible to significant uncertainties over extended timeframes (e.g., 50 years). Fluctuations in timber prices, shifting opportunity costs, or changes in land-use priorities (e.g., increased demand for food production) can all impact the viability and profitability of such practices.

## 7.6 Limitations

### 7.6.1 Limitations of Engineering Marginal Abatement Cost Curves (MACCs) in Agriculture

While MACCs are valuable tools for policymakers to understand the cost-effectiveness of various greenhouse gas mitigation strategies in agriculture, it is acknowledged that the MACC developed in this study is subject to certain limitations. Data gaps and the need for assumptions are recognized, which may affect the accuracy of carbon sequestration potential and cost estimates. The inherent heterogeneity of agriculture, with varying practices and emissions across farms and regions, poses a challenge in fully capturing this diversity and accounting for uncertainties in data and future projections.

The primary focus on GHG mitigation may lead to the overlooking of other crucial environmental and social impacts, such as biodiversity, which can significantly influence the overall cost-effectiveness and sustainability of mitigation measures. Furthermore, the emphasis on direct technical costs, with the neglect of transaction costs, and public costs, might present an incomplete picture of the economic implications of mitigation. The focus on on-farm

emissions could potentially underestimate the total carbon sequestration potential and risk emissions leakage by not considering upstream and downstream emissions.

Finally, the potential gap between the hypothetical carbon sequestration potential shown in the MACC and actual on-farm implementation due to barriers like financial constraints, lack of information, and social acceptance is recognized. Despite these limitations, the engineering MACC developed in this study is considered a valuable tool for facilitating informed discussions, visualizing mitigation opportunities, and supporting the development of effective policies to address climate change in the agricultural sector (Eory et al., 2018).

### 7.6.2 Limitations carbon sequestration potential

In this study, a uniform carbon sequestration potential was assumed for all regions within Wallonia. However, it is recognized that various factors, such as soil type, land management practices, and climatic conditions, can influence the actual carbon sequestration capacity of a given region. To achieve more precise and regionally specific estimations of sequestration potential, the utilization of models like STICS, which can account for these diverse factors, is recommended for future research.

## 7.7 Further research considerations

The findings of this study illuminate various avenues for future research in the field of carbon farming within Wallonia. Firstly, the development and implementation of regionally specific carbon sequestration models, like STICS, are essential. These models would account for the unique variations in soil type, land management practices, and climatic conditions across different regions, enabling more accurate estimations of carbon sequestration potential.

Secondly, comprehensive cost-effectiveness analyses of carbon farming practices need should go further. These analyses should go beyond direct technical costs and encompass transaction costs, public costs, and potential co-benefits such as enhanced biodiversity and improved soil health.

Thirdly, the incorporation of life cycle assessment methodologies is crucial for evaluating the full environmental impact of these practices, considering both on-farm and off-farm emissions throughout the entire production chain.

Further research should also account for interactions between carbon farming practices. Similar to studies in France (Bamière et al., 2023), studies should use models like BANCO, for a more holistic view of the Carbon farming practices.

Finally, developing and evaluating policy instruments, such as carbon pricing mechanisms and payment for ecosystem services schemes, is vital to incentivize the adoption of carbon farming practices and ensure their long-term sustainability. By addressing these research gaps, future studies can contribute to a more comprehensive understanding of the potential and challenges of carbon farming in Wallonia, ultimately paving the way for effective policy interventions and sustainable agricultural practices that benefit both the environment and local communities.

## 8 Conclusion

The findings of this thesis provide critical insights into the cost-effectiveness and potential of various carbon farming practices in Wallonia, contributing to the broader discourse on climate change mitigation strategies within the agricultural sector. Through a detailed analysis using the Marginal Abatement Cost Curve (MACC) approach, this study identified the economic viability and carbon sequestration potential of different practices, highlighting significant regional variations within Wallonia.

The analysis revealed that the practice of Implementing temporary grasslands exhibited the most promising cost-effectiveness in specific regions such as Condroz, Ardennes, Famenne Jura, and Hautes Ardennes, where the marginal abatement costs were negative. This suggests that not only does this practice effectively sequester carbon, but it also presents cost savings for farmers in these regions. Conversely, in regions like the Sand and Loam, and Campine-Hainnaut, the same practice was associated with higher marginal abatement costs, underscoring the importance of region-specific assessments when considering the adoption of carbon farming practices.

Agroforestry and hedges, though associated with higher initial costs, were found to offer substantial carbon sequestration potential, particularly when considering the broader adoption scenarios. However, the study emphasized the role of opportunity costs in determining the overall cost-effectiveness of these practices, with regions characterized by higher crop yields incurring greater costs. This highlights the delicate balance between maintaining agricultural

productivity and enhancing carbon sequestration—a balance that is particularly challenging in regions with high agricultural output.

The study also provided a nuanced understanding of the role of compost application in carbon farming. While composting emerged as a highly effective practice in terms of carbon sequestration, particularly in regions with extensive winter wheat cultivation, its cost-effectiveness varied significantly depending on transportation distances and mechanization costs. This underscores the need for tailored approaches that consider the logistical and economic realities of each region.

However, this study also acknowledges several limitations, particularly in the application of the MACC approach within the agricultural sector. The inherent variability in agricultural practices, combined with the challenges of accurately capturing opportunity costs and the broader environmental impacts, suggests that the results presented here should be interpreted with caution. Additionally, the study highlights the potential disconnect between theoretical carbon sequestration potential and actual on-farm implementation, influenced by factors such as financial constraints, lack of information, and social acceptance.

Economic uncertainties and implementation barriers also impede the progress of carbon farming. The financial viability of adopting carbon sequestration practices is often clouded by uncertainties surrounding costs and benefits, making it challenging to develop effective incentive programs. Social and environmental complexities further complicate the adoption of carbon farming practices. Resistance to change, rooted in behavioural and cultural norms, can hinder the implementation of new practices, particularly when they deviate significantly from traditional farming methods (Sykes et al., 2020). The successful application of certain sequestration measures may require specialized knowledge and expertise, which can be a limiting factor for some farmers. Moreover, while carbon farming aims to deliver environmental benefits, potential trade-offs with other ecosystem services, such as biodiversity or water quality, must be carefully considered.

Despite these limitations, this thesis contributes valuable data and insights that can inform future policy decisions aimed at achieving carbon neutrality in Wallonia and beyond. By providing a detailed, region-specific analysis of carbon farming practices, this study offers a practical framework for evaluating the cost-effectiveness of different mitigation strategies within the agricultural sector. The findings underscore the importance of integrating economic,

environmental, and social considerations into the design and implementation of carbon sequestration initiatives, ensuring that they are both effective and sustainable in the long term. As policymakers and stakeholders work towards the ambitious climate goals set for 2050, the insights gained from this study can help to guide the development of more targeted, efficient, and regionally adapted carbon farming practices.



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## 9 Appendix

### 9.1 Tables for the parameters of the cost model

#### 9.1.1 Agroforestry

##### 9.1.1.1 Cost of soil preparation

Table 15: Table showing the cost of soil preparation in €/ha for agroforestry

| Description of action    | Technical implementation cost for farmer (€/ha) |        |
|--------------------------|-------------------------------------------------|--------|
| Cost of soil preparation | Burial of vegetation                            | 30,06  |
|                          | Labour force                                    | 9,62   |
|                          | Subsoiling                                      | 43,86  |
|                          | Labour force                                    | 18,29  |
|                          | Crumbling                                       | 36,47  |
|                          | Labour force                                    | 14,07  |
|                          | Total labour force per hectare (Lha)            | 41,98  |
|                          | Total mechanization cost per hectare (CM)       | 110,39 |
|                          | Cost of soil preparation (Csp)                  | 152,37 |

##### 9.1.1.2 Cost associated to planting

Table 16 : Table showing the cost of planting trees in €/ha

| Description of action | Technical implementation cost for farmer (€/ha) |         |
|-----------------------|-------------------------------------------------|---------|
| Planting              | Labour force                                    | 62,47   |
|                       | Tree (Walnut - Juglans regia x nigra)           | 2722,50 |
|                       | Tree (Cherry - Prunus avium)                    | 2274,75 |
|                       | Total labour force per hectare (Lha)            | 62,47   |
|                       | Cost for trees (CT)                             | 4997,25 |
|                       | Cost of planting (Cp)                           | 5059,72 |

Table 17: Prices of trees in €/plant

| Name                  | Price of trees |
|-----------------------|----------------|
| Juglans regia x nigra | 83,6           |
|                       | 61,606         |
|                       | 52             |
| Average               | 72,603         |
| Cherry tree           | 74,5           |
|                       | 65             |
|                       | 42,5           |
| Average               | 60,6666667     |

Sources: (*Ecoflora - Prunus Avium*, n.d.; *Fruitiers : JUGLANS REGIA NOYER*, n.d.; *Pépinières Hamblenne - Liste Des Prix - Pépiniériste Namur Belgique*, n.d.; *Prunus avium 'Bigarreau Napoléon'*, n.d.)

### 9.1.1.3 Costs associated to mulching

Table 18: Table showing the cost of mulching trees in €/ha

| Description of action | Technical implementation cost for farmer (€/ha) |       |
|-----------------------|-------------------------------------------------|-------|
| Mulching              | Straw                                           | 47,53 |
|                       | Straw blower                                    | 17,72 |
|                       | Labour force                                    | 13,71 |
|                       | Total labour force per hectare (Lha)            | 13,71 |
|                       | Total mechanization cost per hectare (CM)       | 17,72 |
|                       | Cost of straw (Cst/ha)                          | 47,53 |
|                       | Cost of mulching (Cmul)                         | 78,96 |

### 9.1.1.4 Costs associated to tree management

Table 19: Table showing the cost of tree management in €/ha

| Description of action | Technical implementation cost for farmer (€/ha) |        |
|-----------------------|-------------------------------------------------|--------|
| Managment trees       | Chainsaw                                        | 1,43   |
|                       | Chainsaw package                                | 1,40   |
|                       | Fuel                                            | 13,15  |
|                       | Labour force                                    | 96,00  |
|                       | Total labour force per hectare (Lha)            | 96,00  |
|                       | Total mechanization cost per hectare (CM)       | 15,98  |
|                       | Cost of tree managment (Ctm)                    | 112,01 |

### 9.1.1.5 Costs associated to sales of firewood

Table 20 : Table showing the cost firewood sales €/ha

| Description of action | Price of Firewood €/stere | Cost of firewood sales |
|-----------------------|---------------------------|------------------------|
| Pruning (Year 4-10)   | 88,71                     | -86,49225              |
| Pruning (Year 11-12)  | 88,71                     | -56,50827              |
| Thinning (Year 10)    | 88,71                     | -392,0982              |



### 9.1.1.6 Opportunity costs due to the yield reduction associated to hedges

Table 21: Opportunity costs due to the yield reduction associated to hedges

| Crops weighted with the areas (-5%)   |                        |
|---------------------------------------|------------------------|
| Regions                               | Yield reduction (€/ha) |
| Région limoneuse                      | 150,023124             |
| Condroz                               | 108,8802898            |
| Ardenne                               | 51,70746471            |
| Famenne                               | 74,21055069            |
| Région herbagère liégeoise            | 139,3089763            |
| Région sablo-limoneuse                | 163,0714867            |
| Région jurassique                     | 31,75484326            |
| Haute Ardenne                         | -1,087197262           |
| Région herbagère (Fagne)              | 88,70660876            |
| Campine hennuyère                     | 154,4336086            |
| Wallonie                              | 143,479332             |
|                                       |                        |
| Crops weighted with the areas (-7,5%) |                        |
| Regions                               | Yield reduction (€/ha) |
| Région limoneuse                      | 78,76214009            |
| Condroz                               | 57,16215212            |
| Ardenne                               | 27,14641897            |
| Famenne                               | 38,96053911            |
| Région herbagère liégeoise            | 73,13721258            |
| Région sablo-limoneuse                | 85,6125305             |
| Région jurassique                     | 16,67129271            |
| Haute Ardenne                         | -0,570778562           |
| Région herbagère (Fagne)              | 46,5709696             |
| Campine hennuyère                     | 81,0776445             |
| Wallonie                              | 75,32664929            |

## 9.1.2 Hedges

### 9.1.2.1 Cost of soil preparation

Table 22 : Table showing the cost of soil preparation in €/ha for hedges

| Description              |                                      | Cost €/ha |
|--------------------------|--------------------------------------|-----------|
| Cost of soil preparation | Burial of vegetation                 | 39,08     |
|                          | Labour force                         | 9,62      |
|                          | Subsoiling                           | 57,02     |
|                          | Labour                               | 18,29     |
|                          | Crumbing                             | 47,41     |
|                          | Labour force                         | 14,07     |
|                          | Total labor (Lh)                     | 41,98     |
|                          | Total mechanization cost(CM)         | 143,51    |
|                          | Total cost of soil preparation (Csp) | 185,48    |

### 9.1.2.2 Costs associated to planting

Table 23: Table showing the cost of planting hedges in €/ha

| Description |                             | Cost €/ha |
|-------------|-----------------------------|-----------|
| Planting    | Labour force (Lh)           | 50,84     |
|             | Dogwoods                    | 32,76     |
|             | Blackthorns                 | 33,30     |
|             | Hazelnuts                   | 100,53    |
|             | Chestnut trees              | 212,35    |
|             | Oaks                        | 199,36    |
|             | Total cost of trees (CT)    | 578,30    |
|             | Total cost of planting (Cp) | 629,13    |

Table 24: Prices of tree seedlings and trees

| Price of trees €/plant   |                |
|--------------------------|----------------|
| Description of tree type | Dogwoods       |
| Shrubs and bushes        | 2,13           |
|                          | 1,55           |
|                          | 2,60           |
|                          | 1,43           |
|                          | 1,37           |
| Average                  | 1,82           |
| Shrubs and bushes        | Blackthorns    |
|                          | 2,12           |
|                          | 1,80           |
|                          | 1,65           |
| Average                  | 1,86           |
| Shrubs and bushes        | Hazelnuts      |
|                          | 4,72           |
|                          | 6,45           |
| Average                  | 5,59           |
| High stemming trees      | Chestnut trees |
|                          | 67,75          |
|                          | 61,00          |
|                          | 53,38          |
| Average                  | 60,71          |
| High stimulating trees   | Oaks           |
|                          | 52,00          |
|                          | 58,05          |
|                          | 65,00          |
|                          | 48,25          |
|                          | 57,75          |
| Average                  | 56,96          |

Sources: (*Châtaignier* | *Pépinières de La Hunelle*, n.d.; *Cornouiller*, n.d.; *Haies à Baies* : *PRUNUS SPINOSA PRUNELLIER*, n.d.; *NOISETIER COMMUN*, *COUDRIER* - *Corylus avellana*, n.d.; *Pépinières Hamblenne - Liste Des Prix - Pépiniériste Namur Belgique*, n.d.; *Prunus Spinosa*, n.d.)

### 9.1.2.3 Cost of mulching

Table 25: Table showing the cost of mulching hedges in €/ha

| Description |                              | Cost €/ha |
|-------------|------------------------------|-----------|
| Mulching    | Cost of straw                | 38,52     |
|             | Straw blower                 | 11,09     |
|             | Labour force                 | 8,59      |
|             | Total labour force (Lh)      | 8,59      |
|             | Total mechanization cost(CM) | 11,09     |
|             | Cost of mulching (Cmul)      | 58,20     |

### 9.1.2.4 Costs associated to tree management

Table 26 : Table showing the cost of tree management in €/ha

| Managment trees/Hedges                | Decription                          | Cost €/ha |
|---------------------------------------|-------------------------------------|-----------|
| Shaping the jets                      | Chain saw                           | 0,13      |
|                                       | Chain saw package                   | 0,13      |
|                                       | Fuel                                | 1,23      |
|                                       | Mechanization of action             | 1,49      |
|                                       | Labour force                        | 8,96      |
|                                       | total                               | 10,45     |
| Pruning for pruning shrubs and bushes | Chain saw                           | 0,27      |
|                                       | Chain saw package                   | 0,27      |
|                                       | Fuel                                | 2,53      |
|                                       | Mechanization of action             | 3,07      |
|                                       | Labour force                        | 18,43     |
|                                       | total                               | 21,51     |
| Lateral sizing                        | Chain saw                           | 0,69      |
|                                       | Chain saw package                   | 0,69      |
|                                       | Fuel                                | 6,31      |
|                                       | Mechanization of action             | 7,69      |
|                                       | Labour force                        | 46,08     |
|                                       | total                               | 53,77     |
| Total                                 | Total Labour cost (Lha)             | 73,47     |
|                                       | Total cost of mechanization (CM)    | 12,25     |
|                                       | Total cost of tree amnagement (Ctm) | 85,73     |

### 9.1.2.5 Opportunity costs due to the yield reduction associated to agroforestry

Table 27: Opportunity costs due to the yield reduction associated to agroforestry

| Region                     | Yield reduction (€/ha) |
|----------------------------|------------------------|
| Région limoneuse           | 36,01                  |
| Condroz                    | 26,13                  |
| Ardenne                    | 12,41                  |
| Famenne                    | 17,81                  |
| Région herbagère liégeoise | 33,43                  |
| Région sablo-limoneuse     | 39,14                  |
| Région jurassique          | 7,62                   |
| Haute Ardenne              | -0,26                  |
| Région herbagère (Fagne)   | 21,29                  |
| Campine hennuyère          | 37,06                  |
| Wallonie                   | 30,80                  |

### 9.1.3 Implementing temporary grasslands

#### 9.1.3.1 Savings achieved associated with the elimination of cover crops in the rotation

Table 28 : Savings in cost achieved by not applying cover crops

| Description                                                     |                                       | Cost in €/ha |
|-----------------------------------------------------------------|---------------------------------------|--------------|
| Savings achieved associated with the elimination of cover crops | Cost of mecanisation (implementation) | 63,42        |
|                                                                 | Cost of mecanisation (destruction)    | 58,80        |
|                                                                 | Labour cost imp.                      | 17,78        |
|                                                                 | Labour cost dest.                     | 24,38        |
|                                                                 | Cost of seeds (Cseeds)                | 51,42        |
|                                                                 | Labor cost (Lha)                      | 42,16        |
|                                                                 | Cost of mechanisation (CM)            | 122,22       |
|                                                                 | Total (Ccover)                        | 215,80       |

Table 29 : Cost of seeds (€/kg) and density of seed (kg/ha)

|                                                 | Price od seeds €/kg | Density of seed kg/ha |
|-------------------------------------------------|---------------------|-----------------------|
| White Mustard MARYNA/ROTA/CABRI 25 kg (JPS)     | 2.525               | 15-20                 |
| Phacelia NATRA20 kg/STALA10 kg/BEEHAPPY25kg     | 3.825               | 8-12                  |
| Alexandrian Clover AXI/ALEX 25 kg (JPS)         | 4.475               | 25-30                 |
| Persian Clover GORBY/MARCO POLO/LIGHTNING 25 kg | 4.975               | 18-20                 |
| Crimson Clover ALBEROBELLO/CONTEA/HEUSERS 25 kg | 2.975               | 25-30                 |
| Summer Forage Rape HELGA 25 kg                  | 2.575               | 25-30                 |
| Winter Forage Rape LICAPO 25 kg                 | 2.475               | 10-15                 |
| Oil Flax LIRINA 25 kg                           | 2.275               | 8-15                  |
| Oil Radish LITINIA 25 kg                        | 2.775               | 18-25                 |
| Deep (Melioration) Radish STRUCTURATOR 25 kg    | 3.975               | 18-25                 |
| Fodder Radish RAMBA-ZAMBA 25 kg                 | 2.525               | 18-25                 |
| Summer Vetch CATARINA 25 kg (JPS)               | 2.375               | 80-100                |
| Winter Vetch (Pannonian Vetch) 25 kg            | 2.775               | 80-100                |
| Winter Turnip Rape MALWIRA / LENOX 25 kg        | 2.925               | 12-15                 |
| Oat GIRAFFE/SPIRALE 25 kg                       | 1.975               | 12-15                 |
| Summer Forage Oats                              | 0.48                | 15-25                 |
| Summer Forage Peas DOLORES 25 kg                | 1.175               | 15-25                 |
| Serradella 25 kg                                | 4.325               | 15-25                 |

### 9.1.3.2 Savings achieved in cost because of lower production costs for Herb silage compared to maize silage

Table 30: Savings achieved in cost because of lower production costs for Herb silage compared to Maize silage

| Description                                                                                         |                                             | Cost in €/ha |
|-----------------------------------------------------------------------------------------------------|---------------------------------------------|--------------|
| Savings achieved in cost because of lower production costs for Herb silage compared to Maiz silage: | Cost plowing                                | 47,41        |
|                                                                                                     | Labour plowing                              | 12,19        |
|                                                                                                     | Cost vibrocultivator                        | 19,77        |
|                                                                                                     | Labour vibrocultivator                      | 4,81         |
|                                                                                                     | Rotary harrow                               | 44,35        |
|                                                                                                     | Labour harrowing                            | 6,77         |
|                                                                                                     | Harvest                                     | 196,11       |
|                                                                                                     | Labour harvest                              | 13,06        |
|                                                                                                     | Slurry barrel 2x (after cut) 20m3/ha        | 70,80        |
|                                                                                                     | Cost fertilizer per hectare <b>(C fert)</b> | 140,60       |
|                                                                                                     | Labour                                      | 14,63        |
|                                                                                                     | Cost com seed                               | 215,80       |
|                                                                                                     | Transport                                   | 90,44        |
|                                                                                                     | Labour                                      | 46,81        |
|                                                                                                     | Phyto machine 3x                            | 24,98        |
|                                                                                                     | Labour                                      | 6,10         |
|                                                                                                     | Cost phyto <b>(Cphyto)</b>                  | 92,20        |
|                                                                                                     | Total cost of machinery (CM)                | 493,86       |
|                                                                                                     | Cost of additional fertilizer (Cfert)       | 140,60       |
|                                                                                                     | Cost of additional Phyt. (Cphyto)           | 92,20        |
|                                                                                                     | Total cost of Labour per hectare (Lha)      | 104,37       |
|                                                                                                     | Total cost Maiz production                  | 831,04       |
|                                                                                                     |                                             |              |
|                                                                                                     | Slurry barrel 2x (after cut)                | 70,80        |
|                                                                                                     | Cost fertilizer per hectare                 | 140,60       |
|                                                                                                     | Labour                                      | 14,63        |
|                                                                                                     | Fauche                                      | 84,84        |
|                                                                                                     | Labour                                      | 42,20        |
|                                                                                                     | Adainage                                    | 56,07        |
|                                                                                                     | Labour                                      | 36,57        |
|                                                                                                     | Remorque autochargeuse                      | 208,05       |
|                                                                                                     | Labour                                      | 16,62        |
|                                                                                                     | Total cost of machinery (CM)                | 419,76       |
|                                                                                                     | Total cost of Labour per hectare (Lha)      | 180,82       |
|                                                                                                     | Total cost of herb silage production        | 600,58       |
|                                                                                                     |                                             |              |
|                                                                                                     |                                             |              |
|                                                                                                     | Difference Herb and Maiz silage             | -230,45      |

Table 31: Prices of Maize seed from BAKO

01.12.2023 11:58 **MAIS 2024**

| SORTE          | S/K     | FAO   | BEIZE  | V.K.P.2024 | Note                              |
|----------------|---------|-------|--------|------------|-----------------------------------|
| Resolute       | S+LKS   | 180   | K-P    | 107        | Gr.8/BI.8/Stg.9/K.16/20//HDI+A    |
| Aasgard        | S+LKS   | 185   | K-P    | 105        | Gr.7/BI.8/Stg.8/K.16/20/HDI+A     |
| Lg31160        | S+LKS   | 180   | K-P    | 110        | Gr.7/BI.8/Stg.7/K.14/21/NL        |
| Sunshinos      | S+LKS+K | 200   | K-P    | 106        | Gr.7/BI.9/Stg.9/K.16/20/N. T.S.   |
| Lg31.224       | S       | 210   | BIO    | 145        |                                   |
| Jakleen        | S+LKS+K | 210 S | K-P KF | 105        | Gr.8/BI.9/Stg.9/K.16/21/Hydr.     |
| Michelleen     | S+LKS   | 215 S | K-P    | 105        | Gr.9/BI.9/Stg.9/K.16/21/HDI+AA    |
| LG 31.245      | S+LKS+K | 220 S | K-P    | 105        | Gr.9/BI.9/Stg.7/K.16/20//Rot+Entr |
| Geraldeen      | S+LKS+K | 230   | K-P    | 108        | Gr.8/BI.9/Stg9/K.14/20//HDI+AA    |
| LG 31.276      | S       | 240   | K-P    | 105        | Gr.9/BI.9/Stg.9/K.16/20//HDI+A    |
| Total Lg       |         |       |        |            |                                   |
| Sorte          |         |       |        |            |                                   |
| Pixxon         | S+LKS   | 180   | K      | 106        | Gr.7/BI.9/Stg.9/K.18/20/HDI NL    |
| Korfu (SMF016) | S+LKS+K | 190 S | KB-up  | 104        | Gr.7/BI.9/Stg.9/K.18/20/HDI+AA    |
| Torpid         | S+LKS   | 210 S | KB-up  | 104        | Gr.8/BI.8/Stg.8/K.16/20/HDI+A     |
| Privat         | S+LKS   | 210 S | KB-up  | 110        | Gr.9/BI.8/Stg.8/K.16/20/HDI       |
| Cohiba         | S+LKS   | 220 S | KB-up  | 104        | Gr.9/BI.8/Stg.9/K.16/22/ ++       |
| Kokuna         | S+LKS   | 220 S | KB-up  | 103        | Gr.9/BI.8/Stg.9/K.20/20/ AA++     |
| Dogena         | S+LKS   | 230 S | KB-up  | 105        | Gr.9/BI.9/Stg.9/K.18/20/HDI+AA    |
| Gisella        | S+LKS   | 230 S | KB-up  | 113        | Gr.9/BI.9/Stg.9/K.16/20/Kolbenbr  |
| Avicii         | S+LKS   | 230 S | KB-up  | 103        | Gr.9,5/BI.9/Stg.9/K.14/20/Masse   |
| Sucorn         | S+LKS   | 235 S | K      | 105        | Gr.9,5/BI.9/Stg.9/K14/20/HDI      |
| Total JPS      |         |       |        |            |                                   |

VKP: This is the price per unit of Maize. For one Hectare of silage Maize 2 units are recommended.

### 9.1.3.3 Income that farmers will have to give up by modifying their crop rotation

Table 32: Net revenues of the 4 main crops of Wallonia subtracted by the net revenues of maize or herbs.

| cultures                   | Average Net revenu €/ha | Herbe tMS/ha | Prix €/ha | Net revenue Herb €/ha  | Difference between revenues €/ha |
|----------------------------|-------------------------|--------------|-----------|------------------------|----------------------------------|
| Région limoneuse           | 1200,18                 | 12,00        | 1920,00   | 1177,45                | 22,74                            |
| Condroz                    | 871,04                  | 11,25        | 1800,00   | 1057,45                | -186,41                          |
| Ardenne                    | 413,66                  | 10,50        | 1680,00   | 937,45                 | -523,79                          |
| Famenne                    | 593,68                  | 9,00         | 1440,00   | 697,45                 | -103,77                          |
| Région herbagère liégeoise | 1114,47                 | 11,25        | 1800,00   | 1057,45                | 57,02                            |
| Région sablo-limoneuse     | 1304,57                 | 12,00        | 1920,00   | 1177,45                | 127,12                           |
| Région jurassique          | 254,04                  | 11,25        | 1800,00   | 1057,45                | -803,41                          |
| Haute Ardenne              | -8,70                   | 9,25         | 1480,00   | 737,45                 | -746,15                          |
| Région herbagère (Fagne)   | 709,65                  | 8,25         | 1320,00   | 577,45                 | 132,20                           |
| Campine hennuyère          | 1235,47                 | 11,25        | 1800,00   | 1057,45                | 178,02                           |
| wallonie                   | 1147,83                 | 11,00        | 1760,00   | 1017,45                | 130,38                           |
|                            | Average Net revenu €/ha | Maize tMS/ha | Prix €/ha | Net revenue Maize €/ha | Difference between revenues €/ha |
| Région limoneuse           | 1200,18                 | 12,69        | 1903,50   | 856,66                 | 343,52                           |
| Condroz                    | 871,04                  | 11,46        | 1719,00   | 672,16                 | 198,88                           |
| Ardenne                    | 413,66                  | 12,48        | 1872,00   | 825,16                 | -411,50                          |
| Famenne                    | 593,68                  | 11,13        | 1669,50   | 622,66                 | -28,98                           |
| Région herbagère liégeoise | 1114,47                 | 12,33        | 1849,50   | 802,66                 | 311,81                           |
| Région sablo-limoneuse     | 1304,57                 | 12,30        | 1845,00   | 798,16                 | 506,41                           |
| Région jurassique          | 254,04                  | 10,50        | 1575,00   | 528,16                 | -274,12                          |
| Haute Ardenne              | -8,70                   | 10,68        | 1602,00   | 555,16                 | -563,86                          |
| Région herbagère (Fagne)   | 709,65                  | 10,32        | 1548,00   | 501,16                 | 208,49                           |
| Campine hennuyère          | 1235,47                 | 11,46        | 1719,00   | 672,16                 | 563,31                           |
| wallonie                   | 1147,83                 | 11,54        | 1730,25   | 683,41                 | 464,42                           |



### 9.1.3.4 Reduction of mineral fertilization on crops following grasslands:

Table 33: Calculation of average price of 1 unit of nitrogen from different sources for Wallonia from 2018-2024 by (Agraost, 2018)

| Year    | Costs in €       |                   |      |        |          |           |
|---------|------------------|-------------------|------|--------|----------|-----------|
|         | Ammonium Nitrate | Nitrogen solution | Uree | 1 Unit | 20 Units | 100 Units |
| 2018    | 0,93             | 0,74              | 0,83 |        |          |           |
| 2020    | 0,83             | 0,75              | 0,65 |        |          |           |
| 2023    | 2,33             | 2,00              | 1,37 |        |          |           |
| 2024    | 1,26             | 1,05              | 1,05 |        |          |           |
| average | 1,34             | 1,14              | 0,98 | 1,15   | 34,48    | 114,92    |

Table 34: Costs less fertilization application, the associated labour, and reduced machine usage factored in.

| Description                   |                         | Cost €/ha |
|-------------------------------|-------------------------|-----------|
| Savings associated fertilizer | Cost of spreader (CM)   | 35,40     |
|                               | Labour Cost (Lha)       | 7,31      |
|                               | 100 units of fertilizer | 114,92    |

## 9.1.4 Implementing new organic carbon input in form of Compost

### 9.1.4.1 Prices of compost associated to new organic carbon input

Table 35: Prices of compost of companies (Les recyparcs (ou parcs à conteneurs), 2015)

| Company  | Are of responsibility | Price per ton ( €/t) | Sources                |
|----------|-----------------------|----------------------|------------------------|
| Intradel | Liege                 | 6,13                 | Personal communication |
| Tibi     | Charleroi             | 4,00                 | Personal communication |
| Hygea    | Mons                  | 7,56                 | Personal communication |
| in BW    | Brabant wallon        | 3,00                 | Personal communication |
| IPALLE   | Wallonia picarde      | 4,00                 | Personal communication |
| BEP      | Namur                 | 6,00                 | Personal communication |
| IDELUX   | Luxemburg             | 5,74                 | Personal communication |
| Average  |                       | <b>5,20</b>          |                        |

#### 9.1.4.2 Reduction of mineral fertilization on crops following application of compost

Table 36: Calculation of average price of 1 unit of nitrogen from different sources for Wallonia from 2018-2024 by (Agraost, 2018)

| Year    | Costs in €       |                   |      |        |          |           |
|---------|------------------|-------------------|------|--------|----------|-----------|
|         | Ammonium Nitrate | Nitrogen solution | Uree | 1 Unit | 20 Units | 100 Units |
| 2018    | 0,93             | 0,74              | 0,83 |        |          |           |
| 2020    | 0,83             | 0,75              | 0,65 |        |          |           |
| 2023    | 2,33             | 2,00              | 1,37 |        |          |           |
| 2024    | 1,26             | 1,05              | 1,05 |        |          |           |
| average | 1,34             | 1,14              | 0,98 | 1,15   | 34,48    | 114,92    |

#### 9.1.4.3 Details of costs associated to new organic carbon input in Wallonia for the scenarios NWW and WW

Table 37: Details of costs associated to new organic carbon input in Wallonia for the scenarios NWW and WW

| Description of action            | scenario WW (€/ha) | scenario NWW (€/ha) |
|----------------------------------|--------------------|---------------------|
| Purchase of composts (15t)       | 75,30              | 75,30               |
| Transport of compost             |                    |                     |
| Cart for transport (Ccart)       | 18,58              | 18,58               |
| Tractor (Ctractor)               | 20,05              | 20,05               |
| Labour (Lha)                     | 6,10               | 6,10                |
| Cost of spreading                |                    |                     |
| Loading                          | 3,84               | 3,84                |
| Labour                           | 3,05               | 3,05                |
| Spreading composts:              | 69,60              | 69,60               |
| Labour                           | 15,24              | 15,24               |
| Total labour cost (Lha)          | 18,29              | 18,29               |
| Total cost of mechanization( CM) | 73,44              | 73,44               |
| Variation in yields              |                    |                     |
| Winter wheat                     | -108,23            | 0,00                |
| Variation in fertilization       |                    |                     |
| 30 Units N                       | -35,40             | -35,40              |
| Spreader (CM)                    | -11,52             | -11,52              |
| Labour (Lha)                     | -14,33             | -14,33              |
|                                  | 43,20              | 151,43              |

## 9.1.5 Fixed costs associated to the 4 main crops of Wallonia

Table 38 : Fixed costs associated to Winter Wheat, Winter Barley ,Potatoes and Beetroot in Wallonia (€/ha)

| Fixed Costs per hectare per culture |                                     |                |
|-------------------------------------|-------------------------------------|----------------|
| Winter Wheat                        | Plow                                | 47,41          |
|                                     | Labour force                        | 12,19          |
|                                     | Vibro cultivator                    | 19,77          |
|                                     | Labour force                        | 4,81           |
|                                     | Harrow + seeder                     | 44,35          |
|                                     | Labour force                        | 6,77           |
|                                     | Fertilizer spreader 2x              | 8,74           |
|                                     | Labour force                        | 1,59           |
|                                     | Combine harvester                   | 113,31         |
|                                     | Labour force                        | 8,13           |
|                                     | Crop protection products/Pesticides | 12,49          |
|                                     | Labour force                        | 3,05           |
|                                     | Transport /2                        | 17,67          |
|                                     | Labour force                        | 10,07          |
|                                     | Total of fixed costs Winter Wheat   | <b>310,35</b>  |
| Winter Barley                       | Plow                                | 47,41          |
|                                     | Labour force                        | 12,19          |
|                                     | Vibro cultivator                    | 19,77          |
|                                     | Labour force                        | 4,81           |
|                                     | Harrow + seeder                     | 44,35          |
|                                     | Labour force                        | 6,77           |
|                                     | Fertilizer spreader 2x              | 8,74           |
|                                     | Labour force                        | 1,59           |
|                                     | Combine harvester                   | 113,31         |
|                                     | Labour force                        | 8,13           |
|                                     | Crop protection products/Pesticides | 12,49          |
|                                     | Labour force                        | 3,05           |
|                                     | Transport /2                        | 17,67          |
|                                     | Labour force                        | 10,07          |
|                                     | Total of fixed costs Winter Wheat   | <b>310,35</b>  |
| Potatoes                            | Plow                                | 47,41          |
|                                     | Labour force                        | 15,11          |
|                                     | Vibro cultivator                    | 19,77          |
|                                     | Labour force                        | 5,97           |
|                                     | Planter                             | 64,10          |
|                                     | Labour force                        | 19,25          |
|                                     | Hoe/Weeder                          | 28,23          |
|                                     | Labour force                        | 18,29          |
|                                     | Ridger/Hiller                       | 69,71          |
|                                     | Labour force                        | 20,32          |
|                                     | Mower/Shredder                      | 29,87          |
|                                     | Labour force                        | 15,24          |
|                                     | Harvester/Puller                    | 405,05         |
|                                     | Labour force                        | 73,14          |
|                                     | Crop protection products/Pesticides | 37,47          |
|                                     | Labour force                        | 9,14           |
|                                     | Fertilizer spreader 2x              | 8,74           |
|                                     | Labour force                        | 1,59           |
|                                     | Transport 2.5x                      | 88,33          |
|                                     | Labour force                        | 73,14          |
|                                     | Total of fixed costs Winter Wheat   | <b>1049,86</b> |
| Beetroot                            | Plow                                | 47,41          |
|                                     | Labour force                        | 15,11          |
|                                     | Harrow                              | 32,65          |
|                                     | Labour force                        | 14,07          |
|                                     | Cultivator                          | 30,06          |
|                                     | Labour force                        | 9,62           |
|                                     | Beet seeder                         | 25,80          |
|                                     | Labour force                        | 20,32          |
|                                     | Weeder/Hoer                         | 38,23          |
|                                     | Labour force                        | 18,29          |
|                                     | Defoliator                          | 49,89          |
|                                     | Labour force                        | 18,29          |
|                                     | Topper/Cleaner                      | 96,74          |
|                                     | Labour force                        | 18,29          |
|                                     | Harvester/Puller                    | 51,76          |
|                                     | Labour force                        | 18,29          |
|                                     | Crop protection products/Pesticides | 24,98          |
|                                     | Labour force                        | 6,10           |
|                                     | Fertilizer spreader 2x              | 8,74           |
|                                     | Labour force                        | 3,17           |
|                                     | Total of fixed costs Winter Wheat   | <b>547,79</b>  |

## 9.1.6 Areas and Yields of the 10 Agricultural Regions in Wallonia

Table 39 : The table shows the yields(t/ha) and areas (ha) of Winter Wheat, Winter Barley ,Potatoes and Beetroot in the agronomic regions of Wallonia

| Average 2018-2022          | Winter wheat |           | Winter Barley |           | Forage Maize |           |
|----------------------------|--------------|-----------|---------------|-----------|--------------|-----------|
| Localisation               | Yield (t/ha) | Area (ha) | Yield (t/ha)  | Area (ha) | Yield (t/ha) | Area (ha) |
| Région limoneuse           | 9,43         | 86200     | 8,62          | 12600     | 42,3         | 26200     |
| Condroz                    | 8,58         | 28300     | 7,95          | 9590      | 38,2         | 10600     |
| Ardenne                    | 6,84         | 833       | 5,99          | 1110      | 41,6         | 4830      |
| Famenne                    | 7,35         | 4400      | 7,04          | 2420      | 37,1         | 5300      |
| Région herbagère liégeoise | 8,92         | 1280      | 6,45          | 219       | 41,1         | 3930      |
| Région sablo-limoneuse     | 9,15         | 38900     | 8,36          | 9220      | 41           | 36900     |
| Région jurassique          | 6,19         | 773       | 5,46          | 273       | 35           | 2350      |
| Haute Ardenne              | 4,66         | 73,3      | 6,25          | 31        | 35,6         | 722       |
| Région herbagère (Fagne)   | 7,41         | 864       | 7,01          | 529       | 34,4         | 1180      |
| Campine hennuyère          | 9,05         | 190       | 7,98          | 14,7      | 38,2         | 141       |
| Average 2018-2022          | beetroot     |           | Potato        |           |              |           |
| Localisation               | Yield (t/ha) | Area (ha) | Yield         | Area      |              |           |
| Région limoneuse           | 89,7         | 33000     | 38,2          | 34700     |              |           |
| Condroz                    | 73,8         | 7540      | 36            | 6760      |              |           |
| Ardenne                    | 74           | 19,7      | 31,6          | 144       |              |           |
| Famenne                    | 69,2         | 489       | 37,4          | 293       |              |           |
| Région herbagère liégeoise | 85,2         | 339       | 42            | 359       |              |           |
| Région sablo-limoneuse     | 84           | 12300     | 40,5          | 24900     |              |           |
| Région jurassique          | 0            | 0         | 21,3          | 59,3      |              |           |
| Haute Ardenne              | 87,3         | 9         | 13            | 12,3      |              |           |
| Région herbagère (Fagne)   | 68,6         | 80        | 42,5          | 129       |              |           |
| Campine hennuyère          | 85,2         | 55,3      | 38,6          | 110       |              |           |

## 9.1.7 Calculation of the average yields and prices for the 4 main crops in Wallonia (2018-2022)

Table 40 :Calculation of the average yields t/ha and prices €/t for Winter Wheat, Winter Barley ,Potatoes and Beetroot in Wallonia between 2018 and 2022

|          | winter wheat |         | Winter barley (€/t) |         | Beetroot(€/t) |        | Potato (€/t) |        |
|----------|--------------|---------|---------------------|---------|---------------|--------|--------------|--------|
| Wallonie | t/ha         | €/t     | t/ha                | €/t     | t/ha          | €/t    | t/ha         | €/t    |
| 2022     | 9,41         | 275,3   | 8,58                | 265,96  | 89,53         | 47,45  | 171,26       | 40,06  |
| 2021     | 7,93         | 260,87  | 8,37                | 243,84  | 85,19         | 29,44  | 140,65       | 43,25  |
| 2020     | 9,47         | 195,04  | 7,97                | 178,67  | 86,54         | 27,78  | 122,53       | 39,69  |
| 2019     | 9,69         | 167,59  | 8,99                | 151,23  | 88,17         | 27,58  | 118,93       | 39,7   |
| 2018     | 8,84         | 183,51  | 7,89                | 183,79  | 82,6          | 26,64  | 152,78       | 32,49  |
| Average  | 9,068        | 216,462 | 8,36                | 204,698 | 86,406        | 31,778 | 141,23       | 39,038 |

## 9.1.8 Calculation of the average net profit for the 4 main crops in Wallonia (2018-2022)

Table 41 : Calculation of the average net profit for Winter Wheat, Winter Barley ,Potatoes and Beetroot in Wallonia between 2018 and 2022

| Winter wheat                  | Revenu (€/ha) | Variable costs (€/ha) | Marge brute (€/ha) | Fixed cost (€/ha) | Marge nette model (€/ha) | Area culture/Total Area |
|-------------------------------|---------------|-----------------------|--------------------|-------------------|--------------------------|-------------------------|
| Région limoneuse              | 2041,24       | 693,38                | 1347,86            | 310,35            | 1037,51                  | 0,52                    |
| Condroz                       | 1857,24       | 693,38                | 1163,86            | 310,35            | 853,52                   | 0,54                    |
| Ardenne                       | 1480,60       | 693,38                | 787,22             | 310,35            | 476,87                   | 0,40                    |
| Famenne                       | 1591,00       | 693,38                | 897,62             | 310,35            | 587,27                   | 0,58                    |
| Région herbagère<br>liégeoise | 1930,84       | 693,38                | 1237,46            | 310,35            | 927,11                   | 0,58                    |
| Région sablo-<br>limoneuse    | 1980,63       | 693,38                | 1287,25            | 310,35            | 976,90                   | 0,46                    |
| Région jurassique             | 1339,90       | 693,38                | 646,52             | 310,35            | 336,17                   | 0,70                    |
| Haute Ardenne                 | 1008,71       | 693,38                | 315,33             | 310,35            | 4,99                     | 0,58                    |
| Région herbagère<br>(Fagne)   | 1603,98       | 693,38                | 910,60             | 310,35            | 600,26                   | 0,54                    |
| Campine hennuyère             | 1958,98       | 693,38                | 1265,60            | 310,35            | 955,25                   | 0,51                    |
| Wallonie                      | 1962,88       | 693,38                | 1269,50            | 390,91            | 878,59                   | 0,51                    |
| Winter barley                 | Revenu (€/ha) | Variable costs (€/ha) | Marge brute (€/ha) | Fixed cost (€/ha) | Marge nette model (€/ha) | Area culture/Total Area |
| Région limoneuse              | 1764,50       | 624,68                | 1139,82            | 310,35            | 829,47                   | 0,08                    |
| Condroz                       | 1627,35       | 624,68                | 1002,67            | 310,35            | 692,33                   | 0,18                    |
| Ardenne                       | 1226,14       | 624,68                | 601,47             | 310,35            | 291,12                   | 0,53                    |
| Famenne                       | 1441,07       | 624,68                | 816,40             | 310,35            | 506,05                   | 0,32                    |
| Région herbagère<br>liégeoise | 1320,30       | 624,68                | 695,63             | 310,35            | 385,28                   | 0,10                    |
| Région sablo-<br>limoneuse    | 1711,28       | 624,68                | 1086,60            | 310,35            | 776,25                   | 0,11                    |
| Région jurassique             | 1117,65       | 624,68                | 492,98             | 310,35            | 182,63                   | 0,25                    |
| Haute Ardenne                 | 1279,36       | 624,68                | 654,69             | 310,35            | 344,34                   | 0,25                    |
| Région herbagère<br>(Fagne)   | 1434,93       | 624,68                | 810,26             | 310,35            | 499,91                   | 0,33                    |
| Campine hennuyère             | 1633,49       | 624,68                | 1008,81            | 310,35            | 698,47                   | 0,04                    |
| Wallonie                      | 1711,28       | 624,68                | 1086,60            | 390,91            | 695,69                   | 0,11                    |
| beetroot                      | Revenu (€/ha) | Variable costs (€/ha) | Marge brute (€/ha) | Fixed cost (€/ha) | Marge nette model (€/ha) | Area culture/Total Area |
| Région limoneuse              | 2850,49       | 1292,10               | 1558,39            | 547,79            | 1010,59                  | 0,20                    |
| Condroz                       | 2345,22       | 1292,10               | 1053,12            | 547,79            | 505,32                   | 0,14                    |
| Ardenne                       | 2351,57       | 1292,10               | 1059,47            | 547,79            | 511,68                   | 0,01                    |
| Famenne                       | 2199,04       | 1292,10               | 906,94             | 547,79            | 359,14                   | 0,06                    |
| Région herbagère<br>liégeoise | 2707,49       | 1292,10               | 1415,39            | 547,79            | 867,59                   | 0,15                    |
| Région sablo-<br>limoneuse    | 2669,35       | 1292,10               | 1377,25            | 547,79            | 829,46                   | 0,14                    |
| Région jurassique             | 0,00          | 1292,10               | -1292,10           | 547,79            | 0,00                     | 0,00                    |
| Haute Ardenne                 | 2774,22       | 1292,10               | 1482,12            | 547,79            | 934,32                   | 0,07                    |
| Région herbagère<br>(Fagne)   | 2179,97       | 1292,10               | 887,87             | 547,79            | 340,08                   | 0,05                    |
| Campine hennuyère             | 2707,49       | 1292,10               | 1415,39            | 547,79            | 867,59                   | 0,15                    |
| Wallonie                      | 2745,81       | 1292,10               | 1453,71            | 669,67            | 784,04                   | 0,17                    |
| Potatoes                      | Revenu (€/ha) | Variable costs (€/ha) | Marge brute (€/ha) | Fixed cost (€/ha) | Marge nette model (€/ha) | Area culture/Total Area |
| Région limoneuse              | 5440,83       | 2471,75               | 2969,07            | 1049,86           | 1919,21                  | 0,21                    |
| Condroz                       | 5127,48       | 2471,75               | 2655,73            | 1049,86           | 1605,86                  | 0,13                    |
| Ardenne                       | 4500,79       | 2471,75               | 2029,03            | 1049,86           | 979,17                   | 0,07                    |
| Famenne                       | 5326,88       | 2471,75               | 2855,13            | 1049,86           | 1805,27                  | 0,04                    |
| Région herbagère<br>liégeoise | 5982,06       | 2471,75               | 3510,31            | 1049,86           | 2460,44                  | 0,16                    |
| Région sablo-<br>limoneuse    | 5768,42       | 2471,75               | 3296,66            | 1049,86           | 2246,80                  | 0,29                    |
| Région jurassique             | 3033,76       | 2471,75               | 562,01             | 1049,86           | -487,86                  | 0,05                    |
| Haute Ardenne                 | 1851,59       | 2471,75               | -620,16            | 1049,86           | -1670,03                 | 0,10                    |
| Région herbagère<br>(Fagne)   | 6053,28       | 2471,75               | 3581,52            | 1049,86           | 2531,66                  | 0,08                    |
| Campine hennuyère             | 5497,80       | 2471,75               | 3026,04            | 1049,86           | 1976,18                  | 0,30                    |
| Wallonie                      | 5513,34       | 2471,75               | 3041,58            | 1289,46           | 1752,12                  | 0,21                    |

### 9.1.9 Results of the average net profit for the 4 main crops in Wallonia (2018-2022)

*Table 42 : Results of the average net profit for Winter Wheat, Winter Barley ,Potatoes and Beetroot in Wallonia between 2018 and 2022*

| Region                            | Average net margin for the for main crop (€/ha) |
|-----------------------------------|-------------------------------------------------|
| <b>Région limoneuse</b>           | 1200,18                                         |
| <b>Condroz</b>                    | 871,04                                          |
| <b>Ardenne</b>                    | 413,66                                          |
| <b>Famenne</b>                    | 593,68                                          |
| <b>Région herbagère liégeoise</b> | 1114,47                                         |
| <b>Région sablo-limoneuse</b>     | 1304,57                                         |
| <b>Région jurassique</b>          | 254,04                                          |
| <b>Haute Ardenne</b>              | -8,70                                           |
| <b>Région herbagère (Fagne)</b>   | 709,65                                          |
| <b>Campine hennuyère</b>          | 1235,47                                         |
| <b>Wallonie</b>                   | 1026,68                                         |

## 9.2 Cost and performance of Mechanization

Table 43: Cost and Performance of machinery used for mechanization after (Mecacost, 2017)

| Description of action                 | Tractor (WD=Wheel Drive; hp=Horse Power) | Description of machinery                                                                                                       | Performance (h/ha) | Cost per hectare(€/ha) |
|---------------------------------------|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|--------------------|------------------------|
| Baling                                | 4WD 110hp                                | Variable chamber 120 x 160 pickup (chamber 150x120 pickup) 100ha/year and engine rate 36.36% standard upgrade                  | 1,4                | 113,19                 |
| Building and maintaining ridges/hills | 4WD 150hp                                | Potato ridger, 4 rows - with rotary tiller                                                                                     | 0,9                | 69,71                  |
| Burial of vegetation                  | 4WD 110 hp                               | Heavy cultivator 4m                                                                                                            | 1,9                | 30,06                  |
| Compaction                            | 4WD 100hp                                | Silo spreader;1 rotor; None                                                                                                    | /                  | 29,03                  |
| Crumbing                              | 4WD 110 hp                               | Rotary harrow + packer 3m (80 hectares/year)                                                                                   | 1,3                | 36,47                  |
| Destroying intermediate crops         | 4WD 120hp                                | Mechanical destruction ( plow) 3Bodies, 50ha/year                                                                              | 0,75               | 58,8                   |
| Fertilizing                           | 4WD 110hp                                | Fertilizer spreader, Mounted centrifuge, 2500- 3000l (> 24 m)                                                                  | 11,52              | 4,37                   |
| Forage wagon/Loader wagon             | 4WD 100hp                                | Self-loading trailer; 20 - 25 m³ (DIN); None                                                                                   | 1,1                | 69,35                  |
| Harvest                               | /                                        | Self-propelled forage harvester 330 to 350HP with 6 rows instead of 4) and 150ha/year and engine rate 40% 350 hp, 2 RM, 4 rows | 1,4                | 196,11                 |
| Harvest                               | /                                        | 6-axis tedder, 6.5m reach, hydraulic folding                                                                                   | 2,25               | 113,31                 |
| Harvest                               | /                                        | Potato harvester, trailed, combined 2 row                                                                                      | 0,25               | 405,05                 |
| Harvest                               | 4WD 100hp                                | Beet harvester, 6 rows, none                                                                                                   | 1                  | 51,76                  |
| Harvest                               | 4WD 100hp                                | Pulled Sugar Beet Topper                                                                                                       | 1                  | 96,74                  |
| Harvest                               | 4WD 100hp                                | Front-Mounted Sugar Beet Defoliator                                                                                            | 1                  | 49,89                  |
| Loading                               | 2WD 80hp                                 | Front loader 2 functions, bucket & fork (front loader, 60-80hp) and 100h/year engine rate 18.75%                               | /                  | 17,74 (€/h)            |
| Loading                               | /                                        | Self-propelled loader; With telescopic arm;5 m                                                                                 | /                  | 23,04                  |
| Mowing                                | 4WD 110hp                                | Mower Conditioner 2.80 m, mounted, finger conditioner (mower for rejected crops, 30 hectares/year, engine rate 18.18%)         | 1,3                | 28,28                  |

|                                          |            |                                                                                                             |      |                |
|------------------------------------------|------------|-------------------------------------------------------------------------------------------------------------|------|----------------|
| Mulching                                 | 2 WD 80 ch | Straw blower unit<br>Semi-mounted<br>8 m³                                                                   | 0,75 | 22,16          |
| Phytosanitary (Crop protection products) | 4WD 100hp  | Sprayer                                                                                                     | 6    | 12,49          |
| Planting potatoes                        | 2 WD 70 hp | Potato planter                                                                                              | 0,95 | 64,1           |
| Removing foliage (haulm) from plants     | 4WD 100hp  | Haulm topper/destroyer, 4 rows                                                                              | 1,2  | 29,87          |
| Residue managment from previous crop     | 4WD 120hp  | Residue shredded ( disc harrow 3M)<br>50 ha/year                                                            | 1,5  | 43,14          |
| Rolling intermediate crops               | 4WD 90hp   | crosskill roller (6M), 50 ha/year                                                                           | 4,5  | 46,62          |
| Sowing beets                             | 2WD 70hp   | Precision seeder, for mechanical beets, 6 rows                                                              | 0,9  | 35,8           |
| Sowing intermediate crops                | 4WD 80hp   | centrifugal spreader (40 ha/year),<br>100l-centrifugal                                                      | 12   | 3,66           |
| Subsoiling                               | 4WD 130 hp | Mounted subsoiler 4 bodies (40 hectares/year) 2.33m                                                         | 1    | 43,86          |
| Tillage/Plowing                          | 4WD 150hp  | 6-furrow plow (120 hectares/year)<br>engine rate 60%                                                        | 1,5  | 47,41          |
| Tillage/Plowing                          | 4WD 150hp  | Combined vibro cultivator + Roller 6 m (150 hectares/year and engine rate 40%)                              | 3,8  | 19,77          |
| Tillage/Plowing                          | 4WD 230hp  | Rotary harrow + integrated cereal seed drill 6 m (direct seed drill, 300 hectares/year, engine rate 17.39%) | 2,7  | 44,35          |
| Tillage/Plowing                          | 4 WD 80hp  | Powered Harrow, Vertical Axis, 3 m                                                                          | 1,3  | 32,65          |
| Transport                                | 2WD 80hp   | 8 m 8 ton platform (8-10m flatbed trailer) 50 loads/year and engine rate 43.75%)                            | /    | 36,49 €/charge |
| Transport                                | 4WD 110hp  | Dump truck 15 to 16 tons 2 axles (14m³) (100 loads/year and 36.36%)                                         | /    | 35,33          |
| Turning/Aerating (compost)               | 4WD 110hp  | Combine harvester Thresher + 6 shakers + 6.5 m 300 hp                                                       | 3    | 17,96          |
| Weed control and soil loosening          | 4 WD 120hp | Weeder, none, 3m                                                                                            | 1    | 38,23          |
| Windrowing/Raking                        | 2WD 80hp   | Windrower 3.5 m (only 3.3 meters available) mounted (30 hectares/year, engine rate 22.5%)                   | 1,5  | 18,69          |



### 9.3 Marginal abatement cost curve

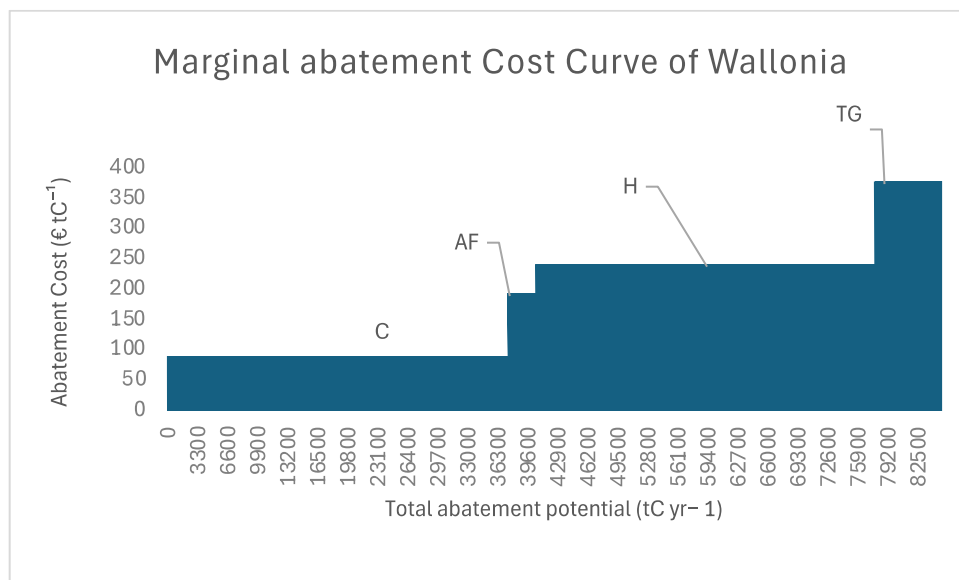


Figure 7 : The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices in Wallonia

**New organic carbon inputs:** The abatement cost is 86.40€ per ton of carbon (tC) with a total abatement potential of 37,354.41 tons of carbon per year (tC/year).

**Agroforestry:** The abatement cost is 190.97€ per ton of carbon. The total abatement potential is 3,201.25 tons of carbon per year.

**Hedges:** The abatement cost is 238.06€ per ton of carbon, with a total abatement potential of 37,228.92 tons of carbon per year.

**Expansion of temporary grasslands:** The abatement cost is 373,75€ per ton of carbon, with a total abatement potential of 6,989.98 tons of carbon per year.

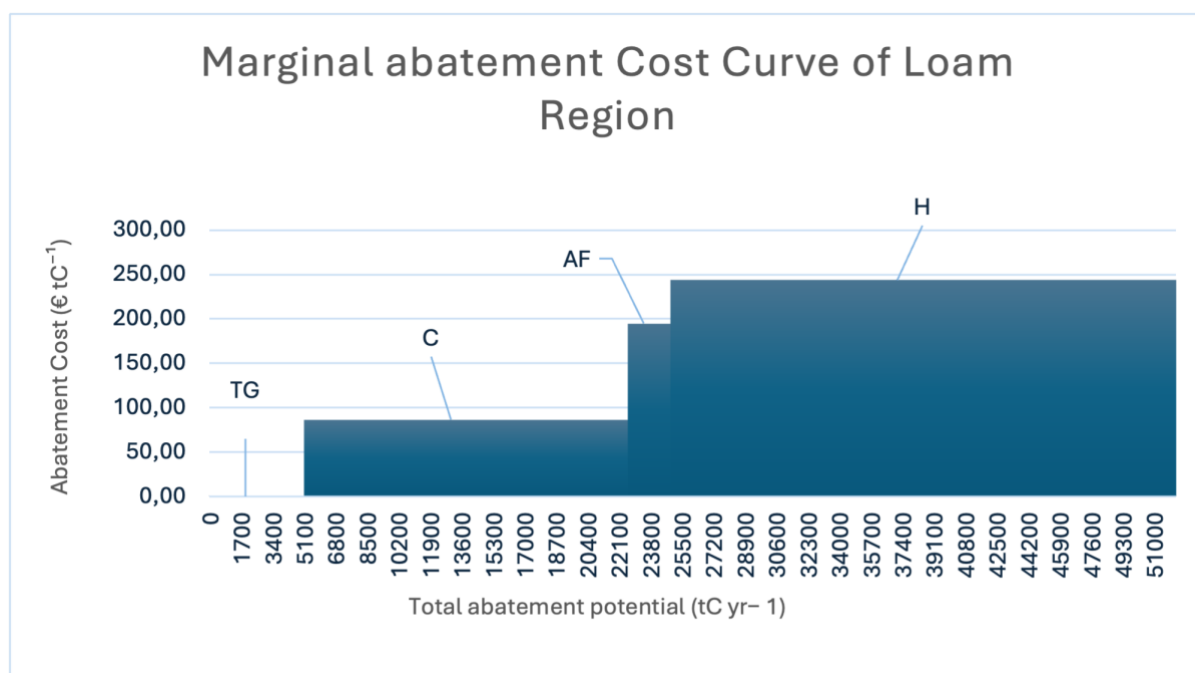


Figure 8 The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the Loam region

**Expansion of temporary grasslands:** The abatement cost is 0.19 € per ton of carbon (tC), with a total abatement potential of 4,951.80 tons of carbon per year (tC/year).

**New organic carbon inputs:** The abatement cost is 86.40€ per ton of carbon (tC), with a total abatement potential of 17,502.29 tons of carbon per year.

**Agroforestry:** The abatement cost is 194.91€ per ton of carbon (tC), with a total abatement potential of 2,345.04 tons of carbon per year.

**Hedges:** The abatement cost is 243.95€ per ton of carbon (tC), with a total abatement potential of 27,271.64 tons of carbon per year.

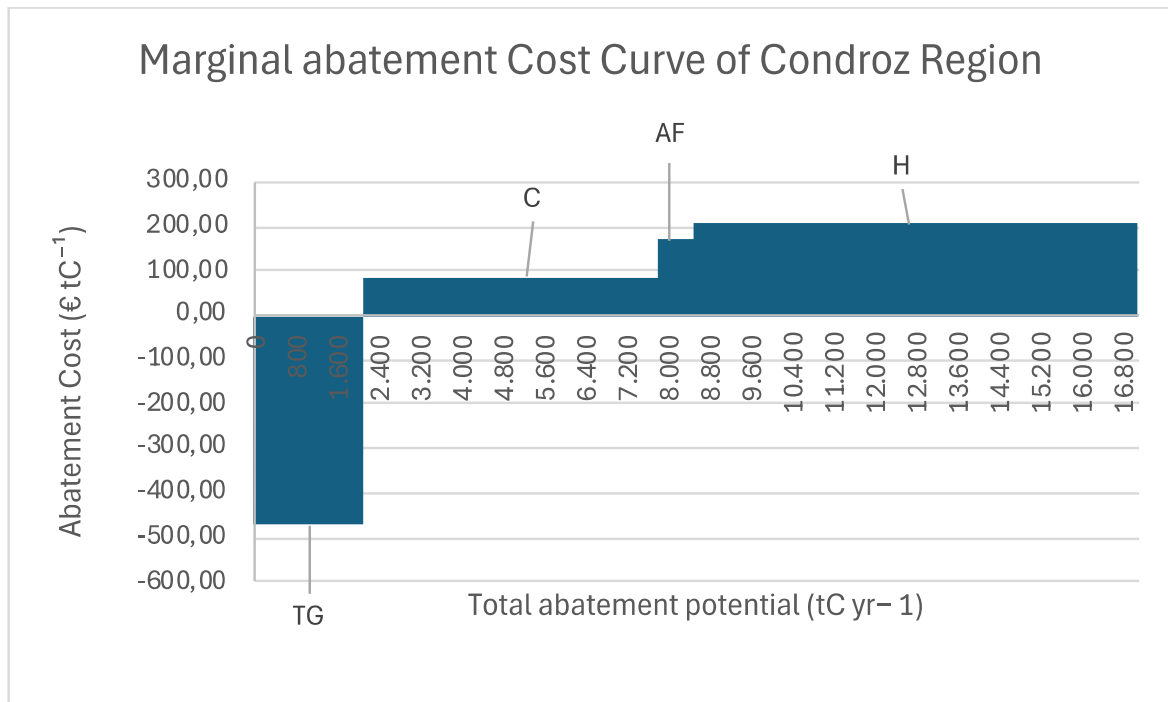


Figure 9 : The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the Condroz region:

**Expansion of temporary grasslands:** The abatement cost is -473.04€ per ton of carbon (tC), indicating a net gain or savings, with a total abatement potential of 2,003.40 tons of carbon per year (tC/year).

**New organic carbon inputs:** The abatement cost is 86.4€ per ton of carbon, with a total abatement potential of 5,703.00 tons of carbon per year.

**Agroforestry:** The abatement cost is 170.03€ per ton of carbon, with a total abatement potential of 735.06 tons of carbon per year.

**Hedges:** The abatement cost is 205.63€ per ton of carbon, with a total abatement potential of 8,548.39 tons of carbon per year.

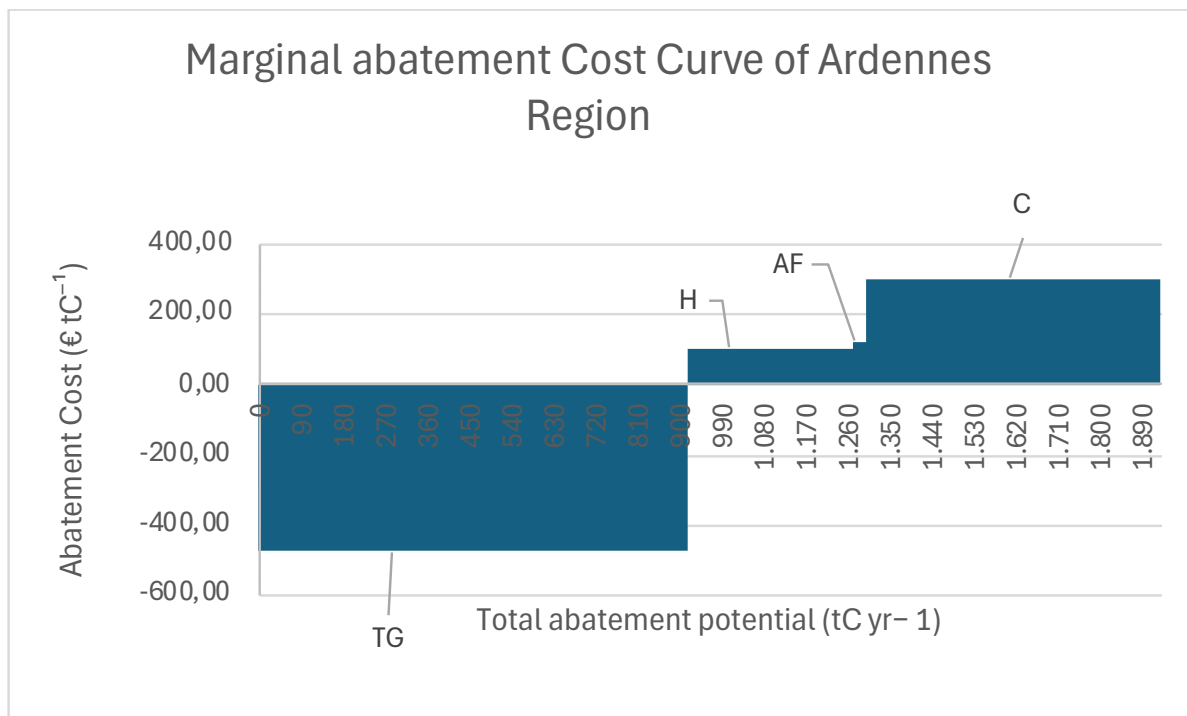


Figure 10 : The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the Ardennes

**Expansion of temporary grasslands:** The abatement cost is -473.04€ per ton of carbon (tC), indicating a net gain or savings, with a total abatement potential of 912.87 tons of carbon per year (tC/year).

**Hedges:** The abatement cost is 104.30€ per ton of carbon, with a total abatement potential of 345.06 tons of carbon per year.

**Agroforestry:** The abatement cost is 123.10€ per ton of carbon, with a total abatement potential of 29.67 tons of carbon per year.

**New organic carbon inputs:** The abatement cost is 302.86€ per ton of carbon, with a total abatement potential of 630.04 tons of carbon per year.

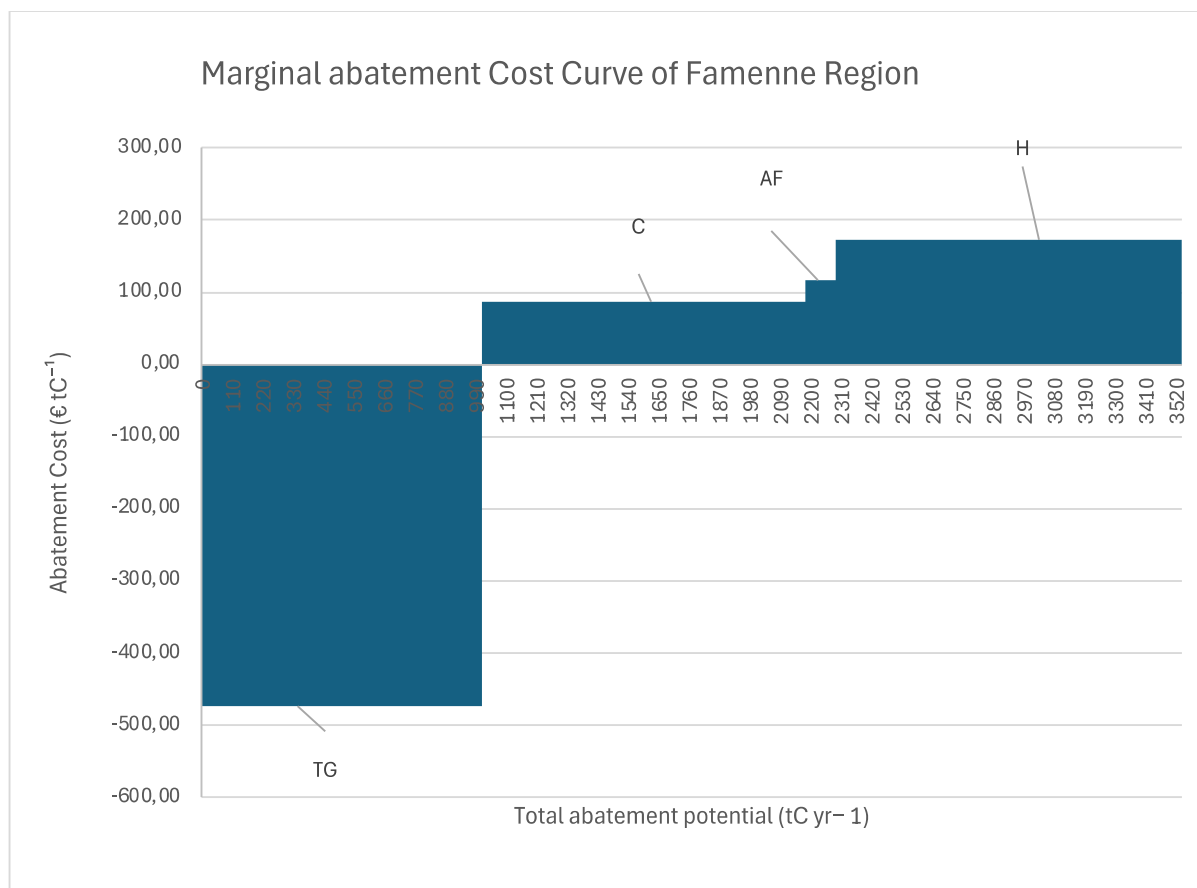


Figure 11 : The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the Famenne region

**Expansion of temporary grasslands:** The abatement cost is -473.02€ per ton of carbon (tC), indicating a net gain or savings, with a total abatement potential of 1,001.70 tons of carbon per year (tC/year).

**New organic carbon inputs:** The abatement cost is 86.40€ per ton of carbon, with a total abatement potential of 1,171.85 tons of carbon per year.

**Agroforestry:** The abatement cost is 117.37€ per ton of carbon, with a total abatement potential of 107.07 tons of carbon per year.

**Hedges:** The abatement cost is 173.38€ per ton of carbon, with a total abatement potential of 1,245.16 tons of carbon per year.

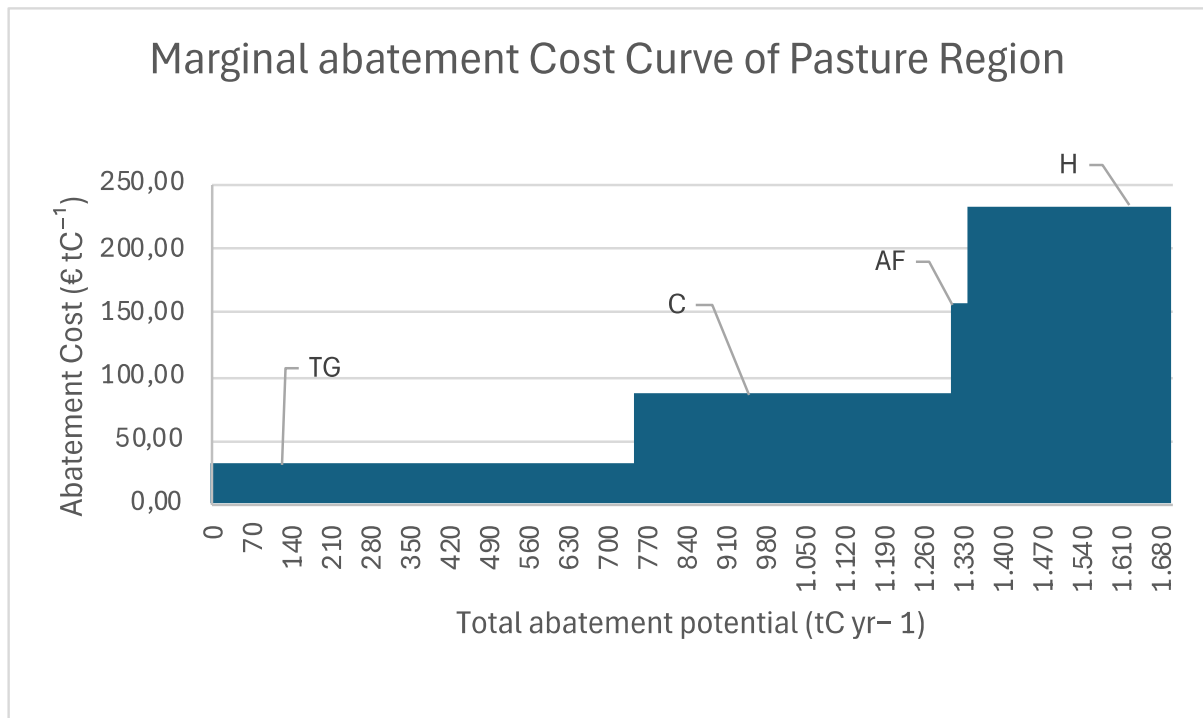


Figure 12: The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the pasture region:

**Expansion of temporary grasslands:** The abatement cost is 32.09€ per ton of carbon (tC), with a total abatement potential of 742.77 tons of carbon per year (tC/year).

**New organic carbon inputs:** The abatement cost is 86.40€ per ton of carbon, with a total abatement potential of 556.49 tons of carbon per year.

**Agroforestry:** The abatement cost is 156.73€ per ton of carbon, with a total abatement potential of 30.94 tons of carbon per year.

**Hedges:** The abatement cost is 233.99€ per ton of carbon, with a total abatement potential of 359.85 tons of carbon per year.

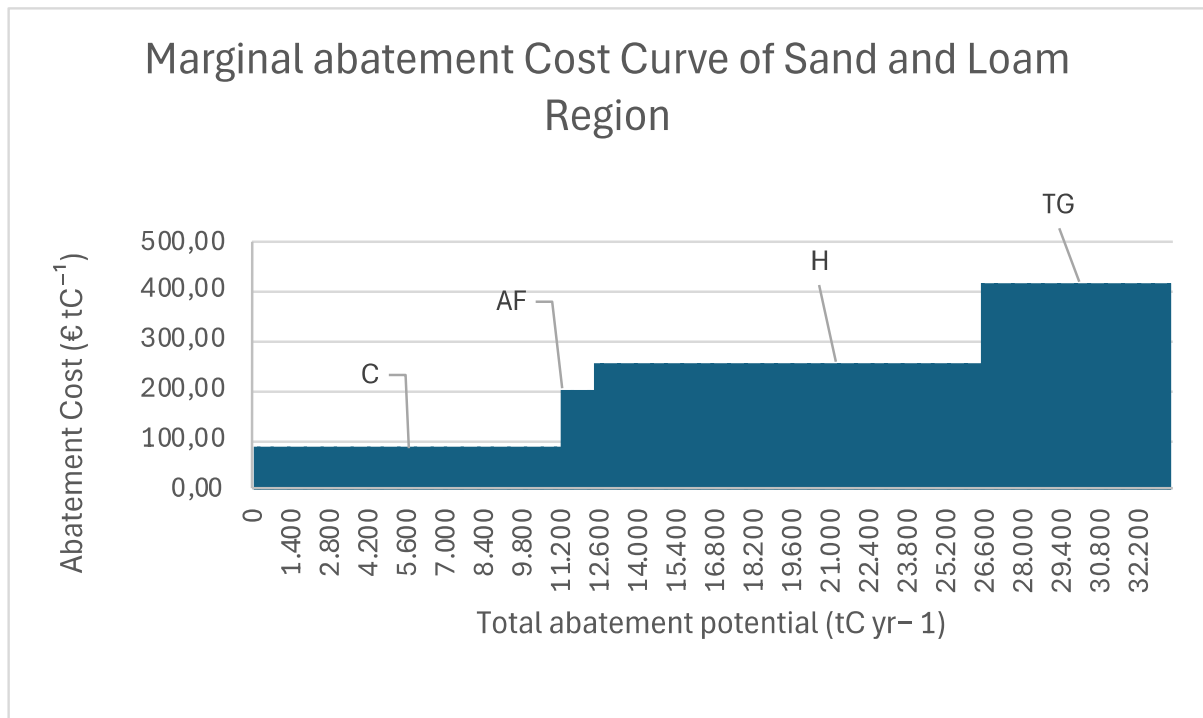


Figure 13 : The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the Sand and Loam region

**New organic carbon inputs:** The abatement cost is 86.40 € per ton of carbon (tC), with a total abatement potential of 11,100.83 tons of carbon per year (tC/year).

**Agroforestry:** The abatement cost is 202.81€ per ton of carbon, with a total abatement potential of 1,201.68 tons of carbon per year.

**Hedges:** The abatement cost is 256.08€ per ton of carbon, with a total abatement potential of 13,974.87 tons of carbon per year.

**Expansion of temporary grasslands:** The abatement cost is 419.04€ per ton of carbon, with a total abatement potential of 6,974.10 tons of carbon per year.

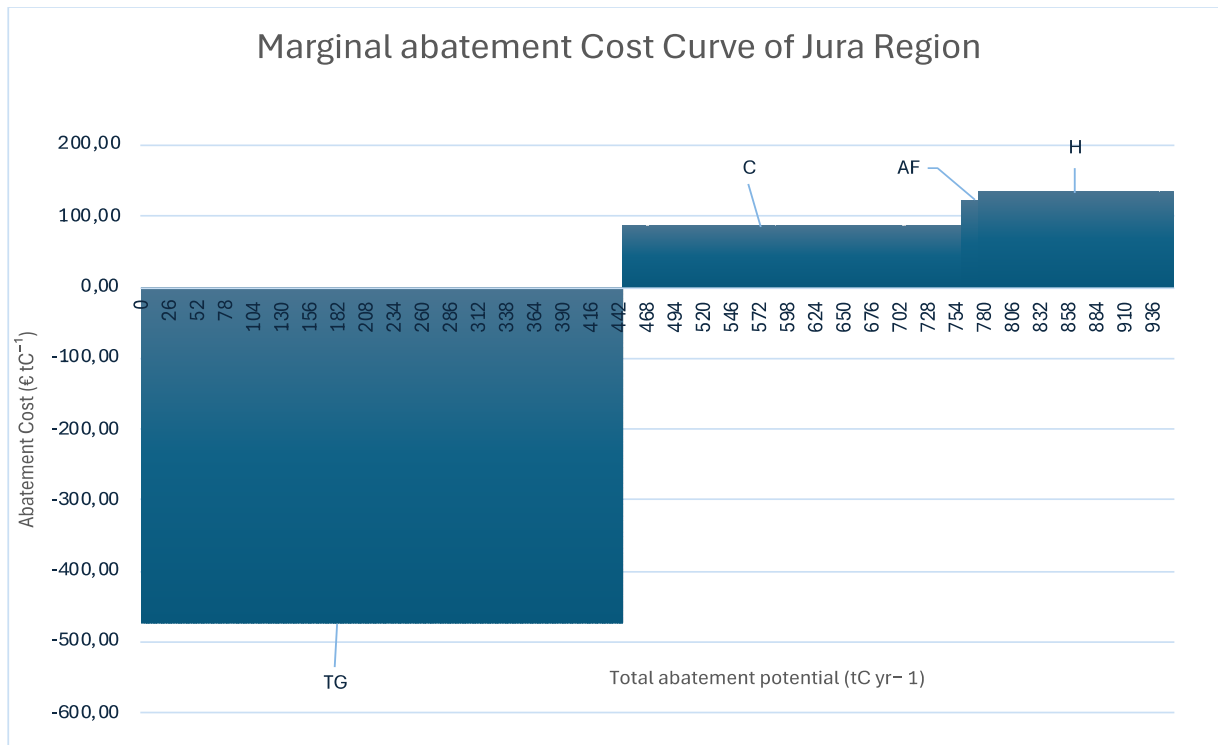


Figure 14 : The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the Jura Region:

**Expansion of temporary grasslands:** The abatement cost is -473.04€ per ton of carbon (tC), indicating a net gain or savings, with a total abatement potential of 444.15 tons of carbon per year (tC/year).

**New organic carbon inputs:** The abatement cost is 86.40€ per ton of carbon, with a total abatement potential of 313.83 tons of carbon per year.

**Agroforestry:** The abatement cost is 123.40€ per ton of carbon, with a total abatement potential of 15.57 tons of carbon per year.

**Hedges:** The abatement cost is 133.84€ per ton of carbon, with a total abatement potential of 181.04 tons of carbon per year.



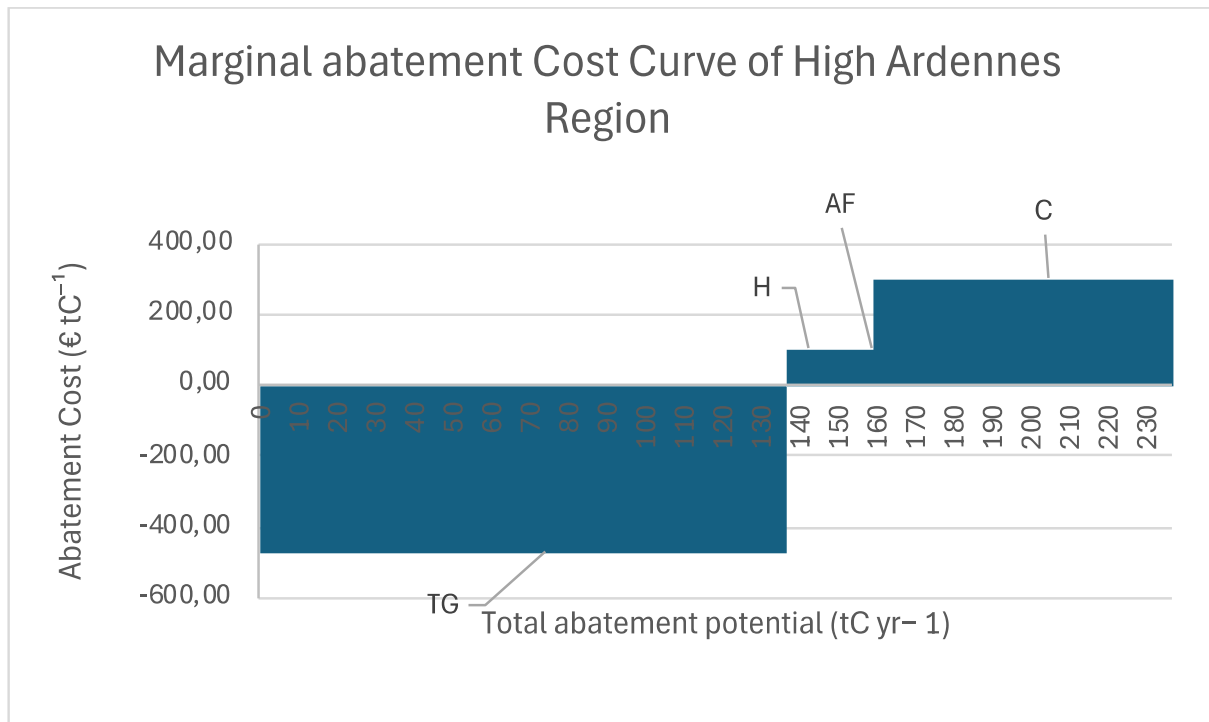


Figure 15 : The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the High Ardennes

**Expansion of temporary grasslands:** The abatement cost is -473.04€ per ton of carbon (tC), indicating a net gain or savings, with a total abatement potential of 136.46 tons of carbon per year (tC/year).

**Hedges:** The abatement cost is 103.27€ per ton of carbon, with a total abatement potential of 20.57 tons of carbon per year.

**Agroforestry:** The abatement cost is 103.54€ per ton of carbon, with a total abatement potential of 1.77 tons of carbon per year.

**New organic carbon inputs:** The abatement cost is 302.86€ per ton of carbon, with a total abatement potential of 76.98 tons of carbon per year.

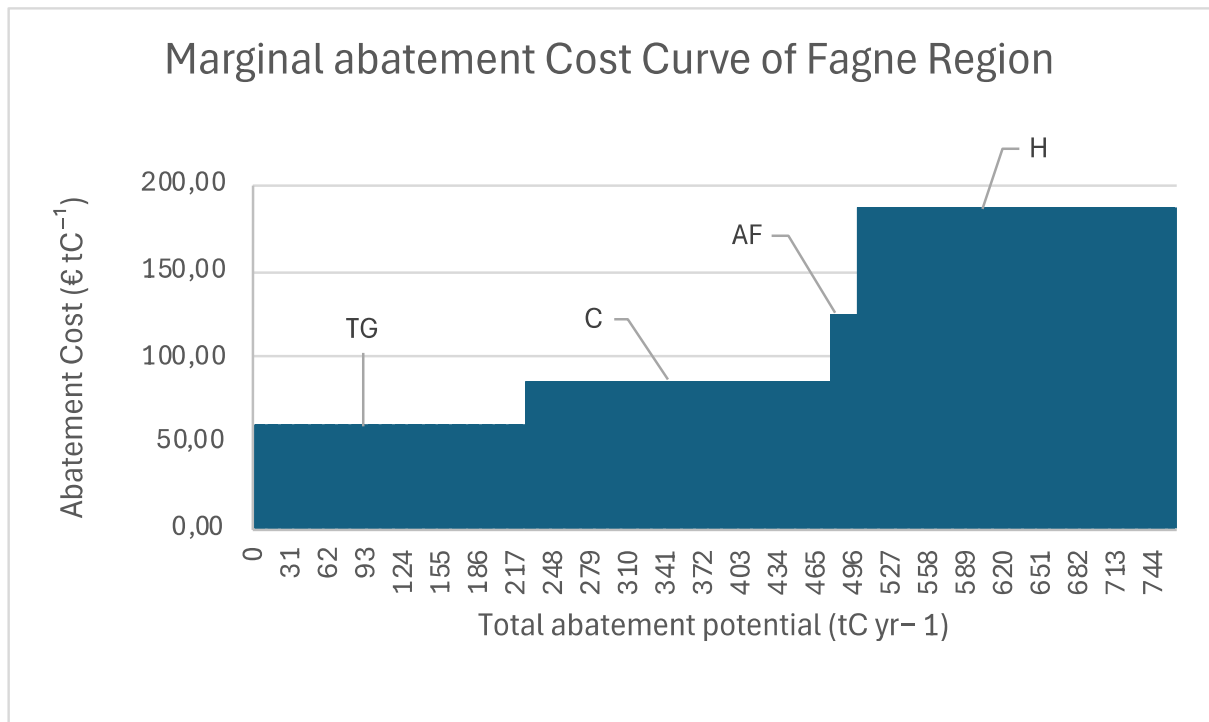


Figure 16: The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the Fagne Region

The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the Fagne Region:

**Expansion of temporary grasslands:** The abatement cost is 60.14€ per ton of carbon (tC), with a total abatement potential of 223.02 tons of carbon per year (tC/year).

**New organic carbon inputs:** The abatement cost is 86.40€ per ton of carbon, with a total abatement potential of 252.68 tons of carbon per year.

**Agroforestry:** The abatement cost is 126.13€ per ton of carbon, with a total abatement potential of 22.56 tons of carbon per year.

**Hedges:** The abatement cost is 186.88€ per ton of carbon, with a total abatement potential of 262.40 tons of carbon per year.

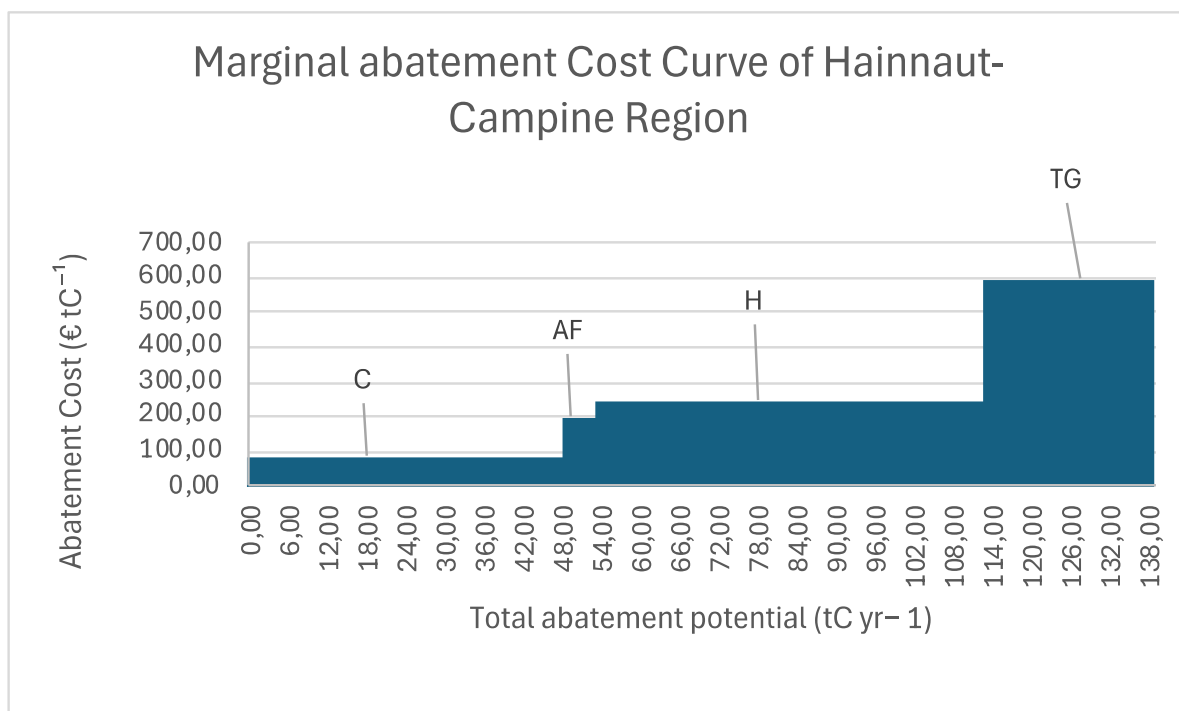


Figure 17: The MACC shows the marginal abatement costs (€/tC) and total abatement potential (tC/year) of various carbon storage practices for the Hainnaut-Campine Region

**New organic carbon inputs:** The abatement cost is 86.40€ per ton of carbon (tC), with a total abatement potential of 46.41 tons of carbon per year (tC/year).

**Agroforestry:** The abatement cost is 197.58€ per ton of carbon, with a total abatement potential of 5.21 tons of carbon per year.

**Hedges:** The abatement cost is 248.02€ per ton of carbon, with a total abatement potential of 60.60 tons of carbon per year.

**Expansion of temporary grasslands:** The abatement cost is 595.33€ per ton of carbon, with a total abatement potential of 26.65 tons of carbon per year.

# Evaluating the cost-effectiveness of carbon farming practices in Wallonia

**Julian Mertes**

Climate change poses an urgent threat to global environmental stability, necessitating a transition to carbon neutrality. Agriculture, while being a significant source of greenhouse gas emissions, also presents opportunities for mitigation through carbon farming practices. This thesis focuses on Wallonia, Belgium, to investigate the cost-effectiveness of four carbon farming practices: agroforestry, hedges, compost application, and temporary grasslands.

A Marginal Abatement Cost Curve (MACC) was constructed using a detailed cost model that incorporates data from the Farm Accountancy Data Network (FADN), Mecacost, (2017) , and pricing information from seed and plant retailers. Carbon sequestration potentials were derived from existing literature. The analysis reveals varying cost-effectiveness and carbon sequestration potential among the practices, with new organic carbon input (compost application) emerging as the most cost-effective option in most regions.

The study highlights regional variations in costs and sequestration potential, emphasizing the importance of tailoring strategies to specific contexts. Certain regions benefit from negative costs for implementing temporary grasslands due to low crop yields, demonstrating the potential for economic benefits alongside carbon sequestration. Sensitivity analysis reveals the impact of increasing mechanization costs, with compost application being most affected.

The thesis underscores the limitations of the engineering MACC approach, including data gaps and assumptions. The need for further research is highlighted, particularly in developing region-specific carbon sequestration models, conducting more comprehensive cost-effectiveness analyses, and incorporating life cycle assessments.

The findings contribute to a nuanced understanding of the potential and challenges of carbon farming in Wallonia. By providing region-specific insights, the study supports informed policy interventions and sustainable agricultural practices that contribute to climate change mitigation. Policymakers are urged to consider the varying cost-effectiveness and abatement potential of practices when designing incentives. This research ultimately paves the way for a more environmentally and economically sustainable agricultural sector in Wallonia.

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