Carbon sequestration on land through nature-based solutions and land-use trade-offs

Key questions and answers

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Contents

3 Background
4 Objective
6 Results and discussion
3.1 What is the current objective of carbon sequestration in terms of volume, set by the EU?
3.2 What are the different types of landscapes capable of sequestering carbon?
3.3 What would be their respective storage capacities if they were in their optimal state of conservation/restoration and what volumes of carbon are they currently storing respectively?
3.4 What could the EU's capacity on natural carbon sequestration in the EU?
3.5 What are the main threats to natural carbon sequestration in the EU?
3.6 What are the opportunity of costs of growing bioenergy crops on land that could instead be used for nature-based carbon sequestration?
3.7 What are the opportunity costs of logging European forests for bioenergy, when these could instead be left growing to sequester more carbon?
40 Conclusion
42 References

LIST OF FIGURES AND TABLES

Figure 1: Sequestration, which occurs in the 4 scenarios, against the background of the goal of the EU for natural sinks (LULUCF target)".
Figure 2: Carbon opportunity costs (COC) of biofuels consumed in the EU27 & UK from (Fehrenbach et al. 2023). 21
Figure 3: Greenhouse gas emission reduction of different wood products compared to their fossil alternatives under the assumption of 4 different carbon storage with different carbon storage (CSBF) values from (Fehrenbach et al. 2022).

Table 1: Spatial extent of different ecosystems within the EU27 & UK (tier 1); reference year 2018
Table 2: Decomposition of the ecosystems (tier 1) into sub-ecosystems (tier 2)
Table 3: Total carbon storage of sub-ecosystems in the EU27 & UK
Table 4: Annual carbon sequestration of sub-ecosystems in the EU27 & UK Table 5: Comparison of the sequestration potential of the four scenarios considered.

Background

The European Union, with its EU Green Deal, aims at becoming the first carbon neutral continent by 2050. To achieve this, a range of climate and energy laws are being reviewed, including an increase in the GHG emissions reduction target by 2030 - at least **55%** compared to 1990 levels.

There are two ways to reduce the amount of carbon in the atmosphere: reducing emissions and increasing carbon sequestration capacities. Land based solutions can absorb part of anthropogenic CO_2- emissions, particularly in the vegetation and soil. For example, intact forests or peatlands can store large amounts of carbon.

The problem is that nearly **60%** of the world's land surface is under anthropogenic pressure, which degrades its condition and thus decreases its sequestration capacity.

Natural carbon sinks are disappearing to large parts because of the conversion to agricultural land and forest logging. A substantial amount of agricultural land in the EU is now used for bioenergy crops and an equivalent of **50%** of the wood harvest is burned for energy. In this context, there is an urgent need to improve the condition of soils and ecosystems, to find alternatives that allow carbon sequestration without jeopardizing biodiversity - and to consider realistic land use allocations between those needed for food production, energy needs, biodiversity and the climate (e.g. land that is currently used to grow biofuel feedstocks, could grow food or it could be afforested; drained peatland could be rewetted; a reduction in livestock farming could free up further land for carbon sequestration etc.). Ideally, climate protection and biodiversity protection go hand-in-hand in the context of nature-based solutions.

Nearly

60%

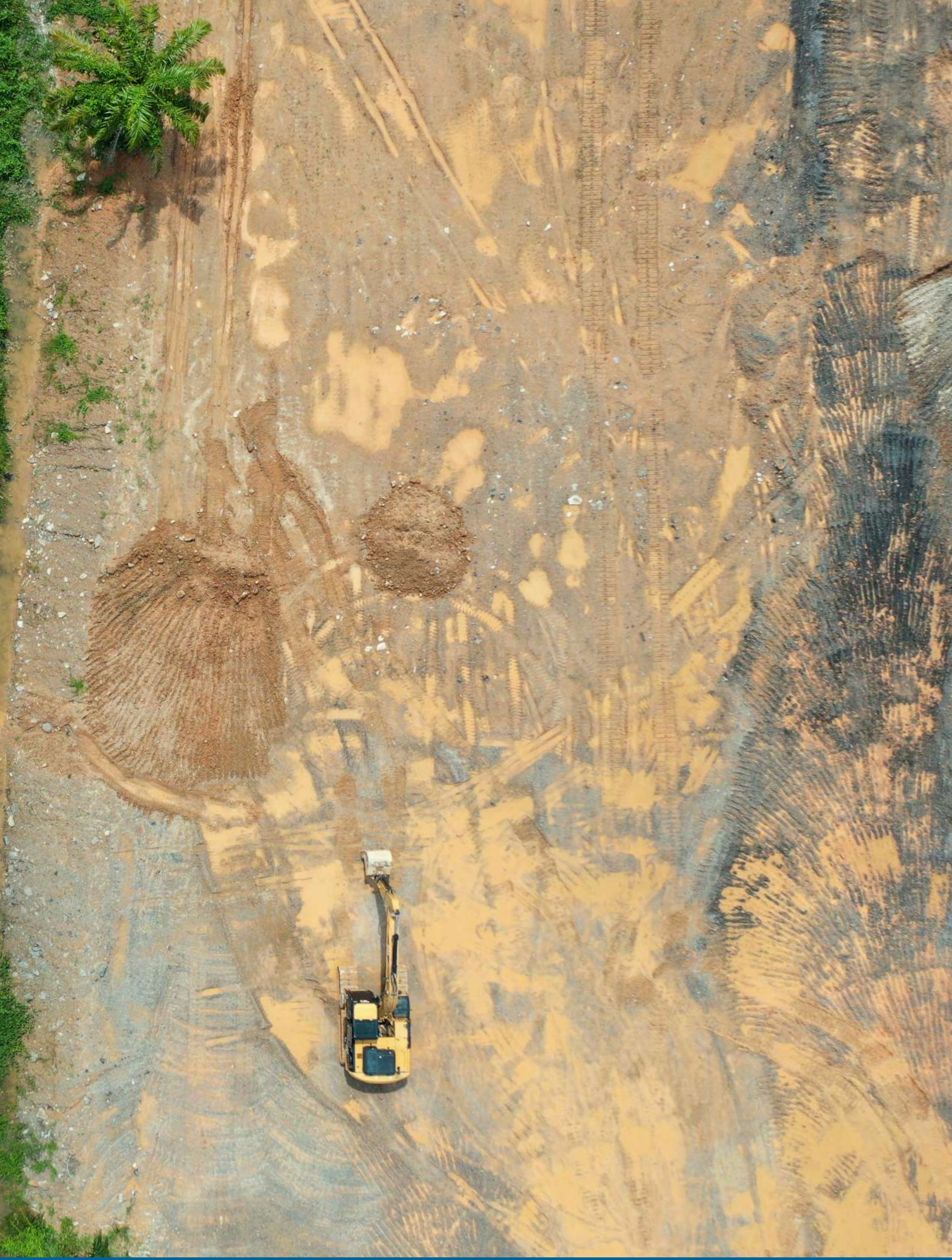
of the world's land surface is under human-generated pressure.

Objective of this Q&A report and procedure

The goal of this short report is to provide answers to some key questions in the context of nature-based solutions in the EU. On the one hand, questions concerning the political situation will be addressed (chapter 3.1), on the other hand, the ecosystems existing in the EU27 & UK, which (can) play a role in nature-based solutions, will be described (chapter 3.2). In addition, their current potential carbon storage (chapter 3.3) as well as their future carbon sequestration capacity (chapter 3.4) will be discussed.

Furthermore, questions in the context of threats to nature based solutions (chapter 3.5) and opportunity costs will be answered (chapter 3.6 and 3.7).

The results will be presented within one to three pages for each of the research questions. The aim is to provide answers to these questions that are as focused and comprehensible as possible and which are based on published factual knowledge and data. The aim is not to produce a comprehensive research report, which could certainly be written about each of the questions in detail. However, this is not within the scope of this short report.



Results and discussion

3.1 What is the current objective of carbon sequestration in terms of volume, set by the EU?

All **27** EU members have committed to making Europe the first climate neutral continent by **2050**.

On average, approx.

267,704 kt

CO_2 were stored in the years 2016-2020 in the EU27.

With the Green Deal, all 27 EU member states have committed to making Europe the first climate-neutral continent by 2050. In order to achieve this goal, emissions need a) to be reduced and b) removed from the atmosphere. Nature-based solutions play an essential role in CO_2-removal by capturing atmospheric CO_2 through natural vegetation and storing it in biomass. To preserve this natural sink ability in the future and to meet climate targets, ecosystems must be conserved and restored. Besides other objectives, this is one of the goals of the Green Deal (European Commission 2019).

With respect to sequestration objectives, new targets have recently been adopted. Thus, in 2023, the European Union, the European Parliament and the European Council have agreed to increase the target for net carbon removals by natural sinks to 310 million tonnes of CO_2-equivalents in 2030 (European Union 2023). This means that in 2030, 310 million tonnes of CO_2 should be stored in natural sinks, i.e. in vegetation. On average, approx. 267,704 kt CO_2 were stored in the years 2016-2020 in the EU27 (European Union 2023). Thus, these natural sinks must be expanded in the future. The central question is whether the ecosystems of the EU are currently and in the future able to provide this function at all. In this context, further political strategies play an important role, which among other things aim to improve the condition of the ecosystems in Europe.

The Biodiversity strategy for 2030 is a core part of the European Green Deal. It is a long-term plan to protect nature and reverse the degradation of ecosystems. The Biodiversity strategy aims to benefit the people, climate and the planet.

The strategy contains various actions, which are:

1. The EU will establish a larger EU-wide network of protected areas for areas of very high biodiversity and climate value (European Commission 2020).

2. The EU will also launch an EU nature restoration plan, to put in place effective restoration measures to restore degraded ecosystems, especially those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters (European Commission 2020). To ensure that, the EU Commission proposed the nature restoration law, with binding restoration targets for specific habitats and species. By 2030 the measures should cover at least 20% of the EU´s land and sea areas, and ultimately all ecosystems in need of restoration by 2050. For example, degraded peatlands are to be rewetted, rivers renaturalized, or forests replanted. The proposal contains several targets, among these it has been mentioned, that the stock of organic carbon in forest ecosystems should be increased (European Commission 2022). The EU countries must submit restoration plans to the Commission within two years of the regulation coming into force, showing how they intend to achieve the targets. Progress must also be monitored and reported Commission 2022). After months of intense negotiations, co-legislators ultimately adopted the final text in June 2024, with the law entering officially into force on August 18th[1].

3. A strengthened governance framework to ensure better implementation and track progress, to improve knowledge, financing and investments so as better respecting nature in public and business decision making (European Commission 2020).

4. Introducing measures to tackle the global biodiversity challenge (European Commission 2020).

Another strategy that is directly linked to the EU biodiversity strategy for 2030 and the Green Deal is the new EU forest strategy for 2030 (European Commission 2021a). The aim of the new EU forest strategy for 2030 is to improve the quantity and quality of European forests. Forests should be better protected, their resilience increased and forests restored to combat climate change and reverse biodiversity loss (European Commission 2021a). This is to be achieved, among other things, by protecting the last remaining primary forests and old-growth forests in the EU, by ensuring reforestation and by planting an additional 3 billion trees by 2030 (European Commission 2021a). This last element has been included as EU-wide target in art. 13 of the Nature Restoration Law.

Consequently, the overarching goal is to achieve sequestration rates of 310 million tonnes of CO_2-equivalents in 2030. Achieving this goal will require, among other things, major efforts in ecosystem restoration. The biodiversity strategy, in particular with the new restoration law and the new forest strategy provide essential directives for this.

The aim of the new EU forest strategy for 2030 is to improve the **quantity** and **quality** of European forests.

EU institutions have committed to planting

3 billion trees

SPREAD OVER 2 MILLION HECTARES WITHIN THE NEXT DECADE.

[1] Regulation - EU - 2024/1991 - EN - EUR-Lex (europa.eu)

3.2 What are the different types of landscapes capable of sequestering carbon?

Europe is characterized by a mosaic of different ecosystems. While some of the ecosystems are under strong human influence, such as agricultural ecosystems, other ecosystems, such as forests or peatlands, can be far more natural ecosystems. In 2020, an assessment of ecosystems in the EU has been conducted by (Maes et al. 2020). The assessment covers the total EU area and EU marine regions.

With regard to the research question, only the ecosystems that are capable of sequestering carbon will be considered within this study. Thus, we exclude urban ecosystems and we select relevant sub-categories under the ecosystems which are described below. In (Maes et al. 2020), data from (EEA 2021) are used for the most part. While answering the research question of chapter 3.2, the information from (Maes et al. 2020) will be referred to.

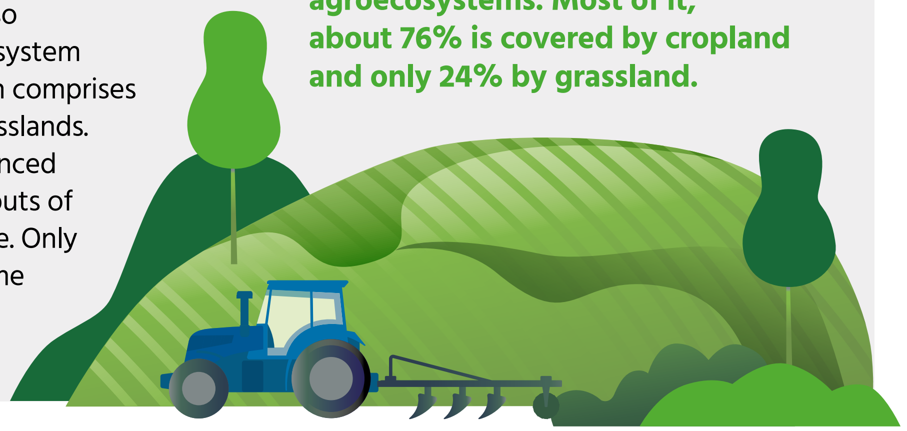
Within the assessment the following ecosystems have been investigated:

AGROECOSYSTEMS

Agroecosystems are composed of cropland and grassland. Cropland is land on which crop production occurs on a continuous or temporary basis. This includes also horticulture. The grassland sub-ecosystem includes grass-covered areas, which comprises pastures, meadows and natural grasslands. Agroecosystems are strongly influenced by humans, for example by high inputs of fertilizers or pesticides in agriculture. Only in the grassland sub-ecosystem some semi-natural areas are still present.

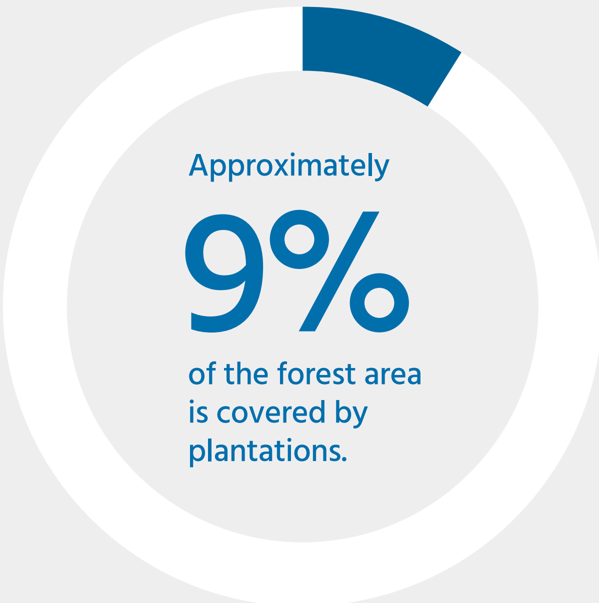
47%

of the EU is covered by agroecosystems. Most of it, about 76% is covered by cropland and only 24% by grassland.



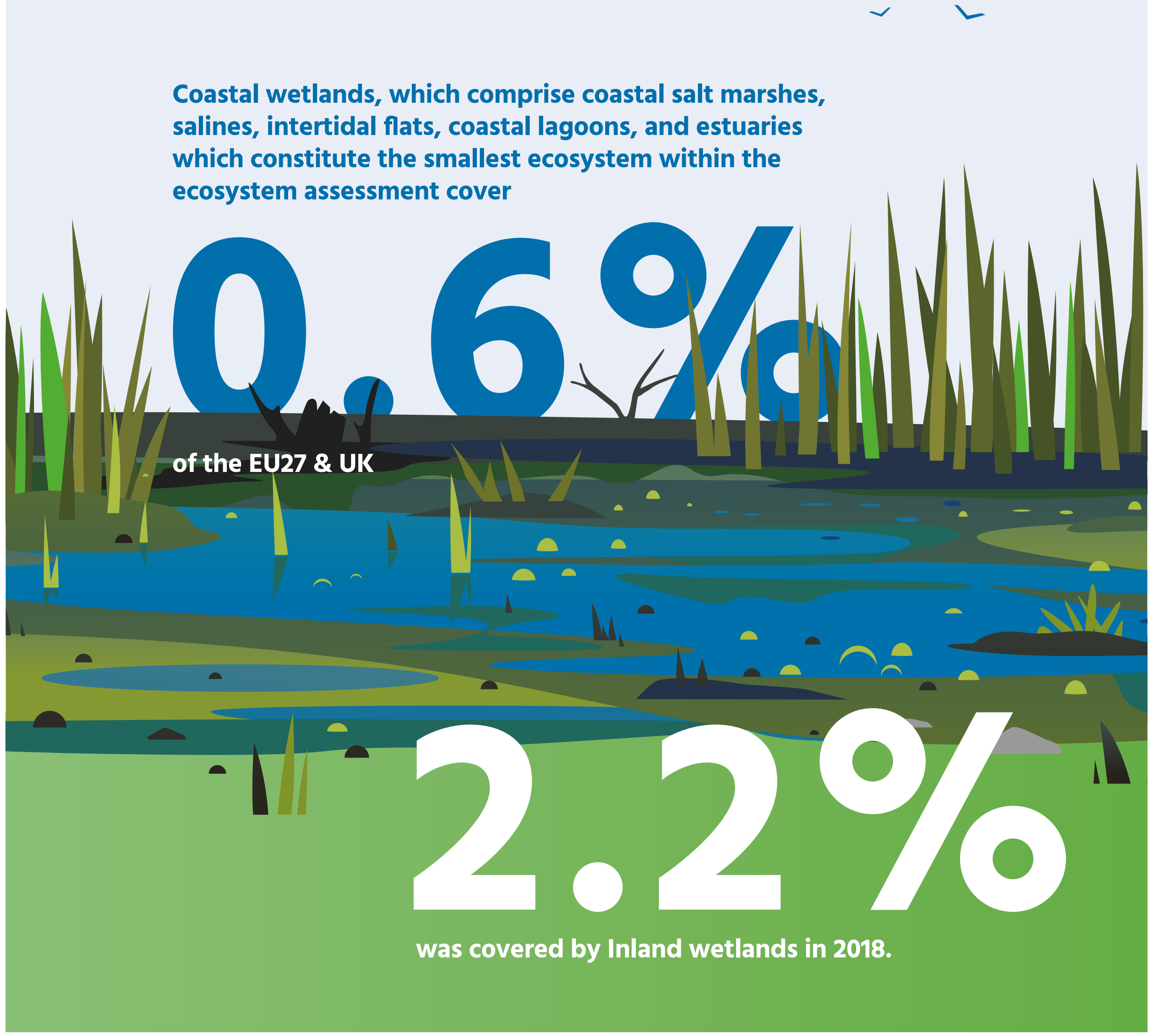
FOREST ECOSYSTEMS

Forest ecosystems are the largest terrestrial ecosystem of the EU27 & UK and cover approximately **38%** of the entire EU27 & UK land area. However, only a small proportion of this Forest ecosystem can be considered as entirely natural, as only **2-4%** of the forest area is primary forest. About **89%** of the forest area are semi-natural forests which means that they are neither undisturbed by humans nor plantations. It has to be noted here, that semi-natural forests contain also stands, which have been established as plantations but have not been managed intensively for a certain time. Plantations on the contrary are established artificially and are intensively manged.



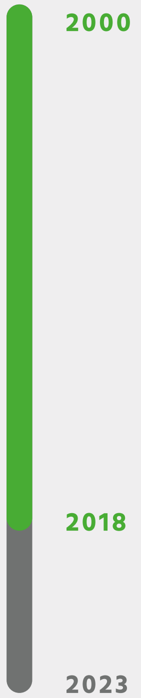
WETLANDS

There exist different types of wetlands. (Maes et al. 2020) distinguish between inland wetland, coastal wetland and extended wetland. The sub-ecosystem inland wetlands is defined as a predominantly water-logged plant and animal community, which conducts water regulation and peat development. In the EU27 & UK, inland wetlands cover **2.2%** of the EU27 & UK land area in 2018. Approximately **90%** of this area are peatbogs and **10%** inland marshes. The largest inland marshes can be found in Romania and Poland, the major peat-bogs in Sweden, the UK, Finland and Ireland. Between 2000 and 2018 approximately **0.5%** of inland wetlands have been lost. Coastal wetlands, that comprise coastal salt marshes, salines, intertidal flats, coastal lagoons and estuaries cover **0.6%** of the EU27 & UK and constitute the smallest ecosystem within the ecosystem assessment. Intertidal flats are the main ecosystem among coastal wetlands. In order to include further wetland ecosystems, that match the hydro-ecological wetland dimension, the ecosystem assessment of (Maes et al. 2020) contains the ecosystem type extended wetland ecosystem, which contains for example rice fields, beaches etc. besides inland wetlands and coastal wetlands.



HEATHLANDS, SHRUBS AND SPARSELY VEGETATED LANDS

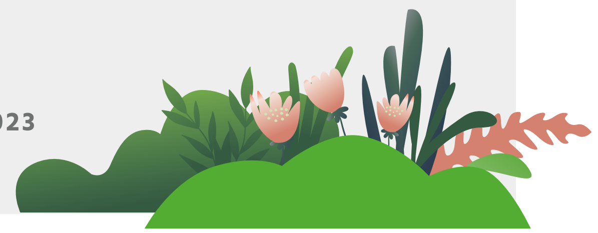
While heathlands and shrubs are characterized by small woody plants together with herbs, mosses and lichens and sparsely vegetated lands, sparsely vegetated lands comprise bare or sparsely vegetated substrate such as rock, lava, ice etc. This ecosystem type can be found all over Europe. In the EU27 & UK, heathlands and shrubs cover approximately **4%** and sparsely vegetated lands **1.5%** of the land area. Within the ecosystem assessment, this eco-system heathland and shrubs contains the largest loss compared to the other ecosystems. Contrary, sparsely vegetated lands have increased by **1.5%** due to burnt areas.



Between 2000 and 2018

1.2%

of heathlands and shrubs have been lost.



RIVERS AND LAKES

Rivers and lakes constitute freshwater ecosystems together with riparian areas and flood-plains. Especially in Scandinavia, the abundance of lakes is very high. Rivers are very numerous in the Mediterranean region.

Approximately 367,000 km² comprise the potentially flooded floodplains. According to the assessment, the extent of this ecosystem type has been stable since 1980.

In the EU27 & UK

RIVERS HAVE A TOTAL LENGTH OF 1.3 MILLION KM

LAKES COVER AN ENTIRE AREA OF 84,000 KM²

RIPARIAN AREAS COVER 297,000 KM²

MARINE ECOSYSTEMS

Marine ecosystems comprise marine inlets and transitional waters, coastal waters, shelf waters and open ocean. Thus, this ecosystem type contains all marine waters. Shelf waters and open ocean can be considered as stable with regard to the extent. However marine inlets and transitional waters can change within their extent over time due to their close interlinkage to land ecosystems.

The extent of this ecosystem can be assessed at the basis of marine regions. Following the ecosystem assessment of (Maes et al. 2020), the four marine regions North-East Atlantic Ocean, Baltic Sea, Mediterranean Sea and Black Sea cover an area of 9.9 million km².

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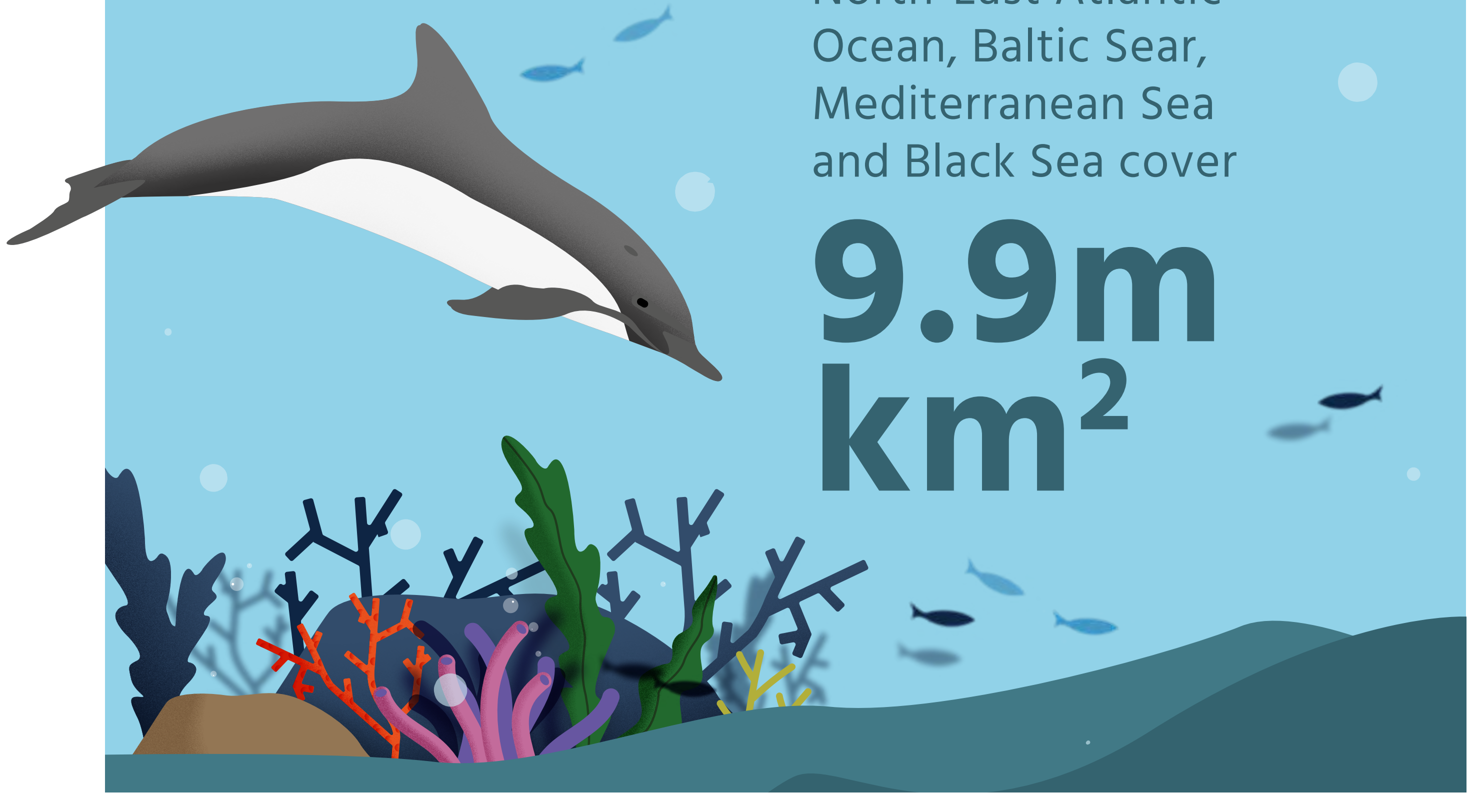


The ecosystems listed here represent the ecosystems of the EU27 & UK. While some of these ecosystems are still under strong anthropogenic influence (e.g. croplands), other ecosystems are more natural (e.g. semi-natural grassland). Provided that the ecosystems described here are in an intact state, they are capable of sequestering large amounts of carbon. The following chapters provide a more differentiated analysis of these ecosystems broken down by sub-ecosystems and their respective contributions as natural sinks.

3.3 What would be their respective storage capacities if they were in their optimal state of conservation/restoration and what volumes of carbon are they currently storing respectively?

Based on the findings in chapter 3.2, this chapters deals with the derivation of the carbon storage potential of these ecosystems. In order to determine the potential storage, the areas of the respective ecosystems are first compiled. These areas are then multiplied by the respective storage values. In concrete terms, this means that the area of the forest ecosystem (in ha), for example, are multiplied by an average carbon storage value of forests (t C/ha). By summing up the total potential, the volume of carbon potentially stored in the EU's natural ecosystems can be inferred. This first consideration assumes storage values of intact ecosystems, allowing a determination of the storage capacity of ecosystems if they were in an intact state.

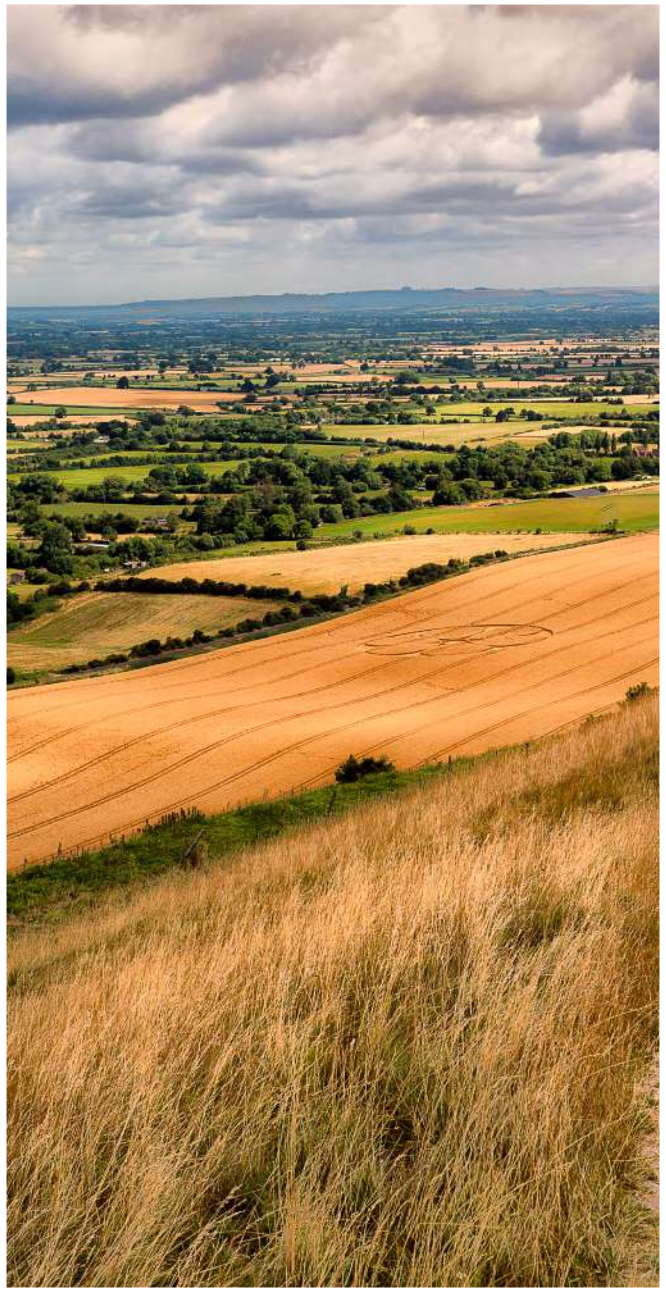
It is important to emphasize at this point that the storage capacity derived in this chapter does not describe the real storage, but corresponds exclusively to a potential storage based on the use of the listed storage rates. Determining real carbon storage is an extremely large undertaking and is not possible within the frame of this short report. This requires a separate extensive research project. However, this information provides a first guidance.

Table 1 provides an overview of the spatial extent of the ecosystems in the EU27 & UK. The data are taken from (EEA 2021) and represent the data cited in (Maes et al. 2020). However, there may be slight variations in the naming of ecosystems and their delimitations between chapter 3.2 (based on (Maes et al. 2020)) and 3.3 (based on (EEA 2021)). For example, in (Maes et al. 2020), grasslands were added to the agroecosystem; in (EEA 2021), grasslands are a separate ecosystem, along with croplands, forest, and the others. The aggregation level of the representation in Table 1 corresponds to tier 1.

TABLE 1: SPATIAL EXTENT OF DIFFERENT ECOSYSTEMS WITHIN THE EU27 & UK (TIER 1); REFERENCE YEAR 2018

Ecosystem Type	Area (Million ha)	Percentage (%)
Urban	22.23	5.1
Cropland	159.61	36.3
Grassland	50.06	11.4
Forest and Woodland	159.77	36.3
Heathlands and shrub	18.19	4.1
Sparsely vegetated lands	6.55	1.5
Inland wetlands	9.80	2.2
Rivers and lakes	10.93	2.5
Marine inlets and traditional waters	2.52	0.1
Balancing Items	0.25	0.1
Total	439.92	100

Source: (EEA 2021)



In total, cropland and forest & woodland each cover **36%** of the EU27 & UK land area. Grass-land covers about **11%** of the area and heathland & shrubs about **4%**. Inland wetlands, and rivers & lakes each cover **2%** of the area. With **1%** area each, sparse vegetated land and marine inlets & transitional waters make up only a small part of the area. Urban systems cover about **5%** of the area.

Some of the ecosystems listed in Table 1 include both, (semi-)natural and anthropogenic systems. This differentiation is not visible in the aggregation in tier 1. In order to understand which sub-ecosystems represent the ecosystems in Table 1, it is necessary to look at the tier 2 level. This consideration is also taken from (EEA 2021).

Table 2 shows which sub-ecosystems fall under each ecosystem. There is a range from anthropogenic sub-ecosystems (such as "dense urban areas") to near-natural sub-eco-systems (such as "semi-natural grassland"). Only natural or near-natural ecosystems that are expected to be able to sequester carbon in vegetation are considered in the study. These are marked in green in Table 2.

TABLE 2: DECOMPOSITION OF THE ECOSYSTEMS (TIER 1) INTO SUB-ECOSYSTEMS (TIER 2)

Level	Ecosystems								
Tier 1	Urban	Cropland	Grassland	Forest and Woodland	Heathlands and shrub	Sparsely vegetated lands	Inland wetlands	Rivers and lakes	Marine inlets and transitional waters
Tier 2	Dense urban area	Arable land	Modified grassland	Broad-leaved forest	Sclero-phyllous vegetation	Sparsely vegetated habitats	Inland marshes	Water courses	Salt marshes
	Dispersed urban area	Rice fields	Semi-natural grassland	Coniferous forest	Moors and heathland	Glaciers and perpetual snow	Peat bogs	Water bodies	Salines and intertidal area
		Permanent crops		Mixed forest					Coastal waters
		Mixed farmland		Transitional wood-shrub					

Source: (EEA 2021)

In order to provide an orientation as to how large the carbon storage of these ecosystems potentially is, carbon storage values from official sources and scientific publications are assigned to the area data of the selected 11 sub-ecosystems. Table 3 provides an overview of the area values and the ecosystem-specific carbon storage values referring to intact ecosystems. If there were ranges for the storage values, the lowest storage value was always used to stay as conservative as possible.

Cropland areas cover more than one third of the area of the EU27 & UK. They are not considered here in detail because this analysis is focussed on ecosystems that are influenced as little as possible by humans and thus represent more natural ecosystems. However, they also store carbon to a certain extent. This is particularly true for permanent crops and mixed farmlands, especially organic farming. Therefore, their storage is also estimated in the end of this chapter in order to complete the picture.

Assuming the area and storage data from Table 3, the 11 semi-natural ecosystems of the EU27 & UK would store 13.22 billion tonnes carbon on 199.7 million ha. This means that more than 13 billion tonnes of carbon – corresponding with 48.5 billion tonnes of CO_2 – would be stored on **45%** of the land area of the EU & UK.

However, it must be taken into account that this estimation is based on generic factors assuming intact ecosystems. In order to make statements about the current carbon storage, it is essential to consider the current state of these ecosystems.

(Maes et al. 2020) describe that current ecosystem conditions in the EU27 & UK are largely unfavourable. This statement refers to the protection status of ecosystems. Consequently, the majority of ecosystems are not subject to any protection status, which means that ecosystems cannot develop naturally and self-dynamically without disturbance. This in turn means that ecosystem services, including carbon storage, are only possible to a limited extent.

A methodology has been developed to assess the state of ecosystems in the EU (Vallecillo et al. 2022). Extensive documentation is already available. However, no results on the state of the ecosystems of the EU27 & UK are available at this stage.

TABLE 3: TOTAL CARBON STORAGE OF SUB-ECOSYSTEMS IN THE EU27 & UK

Ecosystem type	Area (Million ha)[1]	Ecosystem-specific carbon storage value (t C/ha)	Source of the ecosystem-specific values	Carbon storage (Million t C)
Semi-natural grassland	10.6	6.8	(European Commission 2010)[3]	72.1
Broad-leaved forest	44.15	87	(European Commission 2010) [3]	3,841
Coniferous forest	67.22	53	(European Commission 2010) [3]	3,563
Mixed forest	26.27	70	Own calculation[2,3]	1,839
Transitional wood-shrub	22.13	35	(European Commission 2010)	774
Sclerophyllous vegetation	9.2	37	(European Commission 2010) [3]	340
Moors and heathland	8.99	88	(Malak et al. 2020)	791
Inland marshes	1.07	150	(Malak et al. 2021)	160
Peat bogs	8.74	186	(Malak et al. 2021)	1,625
Salt marshes	0.39	200	(Malak et al. 2021)	77.6
Coastal waters	0.97	141	(Malak et al. 2021)	137
Total	199.7			13,220

[1] Area values are obtained from (EEA 2021).
[2] Average values, based on the values of coniferous forest and mixed forest.
[3] Values refer to above-ground biomass (excluding soil).

81%

of protected habitats, 39% of protected birds and 63% of other protected species are in a poor or bad state (EEA 2020).

In 2020, a report has been released about the state of nature in the EU under the nature directives 2013-2018. The description of the state of nature in the EU was largely based on the level of species and habitats. According to the results **81%** of protected habitats, **39%** of protected birds and **63%** of other protected species are in a poor or bad state (EEA 2020). In Addition, there are statements about the poor shape of the ecosystems (UNEP 2022). However, these statements refer to the condition according to the conservation objective of the habitats and tells nothing about the capacity for carbon storage.

In short, the authors of this study at present do not know of any study on the state of European ecosystems that could be used to draw conclusions about the actual current storage capacity of ecosystems, which might be lower than the estimated 13 billion tonnes of carbon.

Besides the 11 sub-ecosystems considered, cropland and managed grassland also cover 200 million ha in the EU27 & UK. Assuming conservative storage values between 5 and 15 t C/ha, we estimate for this area about another 2 billion tonnes carbon. This shows the importance and high storage efficiency of the 11 semi-natural ecosystems considered.

However, improved measures and more organic farming can also lead to storage increases within managed ecosystems such as cropland and managed grassland. Nevertheless, such potentials remain limited compared to the semi-natural ecosystems.

Within the reporting of greenhouse gas emissions from the European Union under the UN Framework Convention on Climate Change (UNFCCC), emissions of the individual sectors are published. In 2020, for the sector land use, land-use change and forestry (LULUCF), greenhouse gas emissions of approx. -226 million tonnes of CO_2 are reported (European Union 2022). Thus, this sector, which includes some of the ecosystems explained in this study, acts as a carbon sink. However, this value (226 million tons of CO_2) cannot be compared with the 13.22 billion tons of carbon (48.5 billion tonnes of CO_2) identified in this brief study, as they do not include the same areas. It is interesting to note, however, that this sector is currently acting as a carbon sink according to (European Union 2022). However, to the analysis of (Hyyrynen et al. 2023) shows a decreasing trend for most European regions, challenging the LULUCF goals of the EU and most member states.

3.4 What could be EU's capacity on natural carbon sequestration in the future?

Analogously to the estimation of the carbon storage in chapter 3.3, carbon sequestration rates for these sub-ecosystems from official sources and scientific publications are assigned to the area data of the 11 sub-ecosystems.

Again, it is important to emphasize at this point that the sequestration capacity derived in this chapter does not describe the real sequestration, but corresponds exclusively to a potential sequestration based on the use of the listed sequestration rates. Determining real carbon sequestration is an extremely large undertaking and is not possible within the frame of this short report. This requires a separate extensive research project. However, this information provides a first guidance.

Table 4 provides an overview of the area values and the ecosystem-specific carbon sequestration rates per year. If there were ranges for the sequestration rates, the lowest sequestration rate was always used. In the same way as in chapter 3.3, ecosystem-specific sequestration rates refer to intact ecosystems.

The carbon sequestration values differ among the sub-ecosystems from ~ 0 (Sclerophyllous vegetation) to 2.63 (salt marshes) t C per ha and year.

Given these ranges, we estimate the sequestration potential for four different scenarios.

1. **A complete attribution of the factors from Table 4 for the entire area of the 11 sub-ecosystems as an optimal case.**
2. **A limitation of scenario 1 calculation to the area of the ecosystems classified as intact.**
3. **Limiting the calculation to the areas that are currently under protection.**
4. **A calculation of the area that is to be placed under strict protection by 2030 according to the EU biodiversity targets.**

SCENARIO 1

The "optimal case" results in a total of 103.2 million tonnes of carbon or 378 million t CO_2 which can potentially be stored annually in the ecosystems of the EU27 & UK. About half of this potential capacity comes from broad-leaved forest, **83%** from forest and woodland in total.

However, this value must be viewed with caution. This calculation assumes that the 11 sub-ecosystems represent intact ecosystems. These 11 sub-ecosystems cover about **45%** of the EU's surface area. This means that the calculation assumes that all these ecosystems are intact and largely uninfluenced by humans.

However, it is already clear in the case of the forest ecosystem that this ecosystem (sub-ecosystems broadleaved forest, coniferous forest and mixed forest) is by no means unaffected by humans. The same applies to the heathland and peatland sub-ecosystems. Thus, this figure can be understood as an optimal sequestration value, assuming that all of Europe's ecosystems are intact.

RESULTS

103.2m

tonnes of carbon can potentially be stored annually in the EU27 & UK ecosystems.

83%

capacity comes from forest and woodland.

SCENARIO 2

Considering the degraded state and poor condition of **80%** of Europe's ecosystems are, scenario 2 assumes a drastically reduced sequestration, corresponding to **20%** of the designated area. With a reduction of this magnitude, an annual sequestration of 75 million t CO_2 can be estimated. According to the authors, this value represents a more pessimistic view of sequestration potential with regard on the reality of European ecosystems.

Within the period from 2023 until 2030, based on the hypothesis that the amount of 75 million t CO_2 is continuously sequestered each year, an additional cumulative storage of 454 million t of CO_2 could have been established. Assuming that ecosystems are in a very good condition and that 378 million tonnes CO_2 would be sequestered annually, an additional 2,270 million t CO_2 could be removed from the atmosphere by 2030. All corresponding values of the scenarios a) ecosystems are in an optimal condition and b) ecosystems are in poor condition can be found in Table 5.

It can be argued that sequestration only occurs to its full extent when ecosystems are completely unaffected by humans and are placed under strict protection. Another argument in favour is that in an ecosystem that is still managed, the carbon sink on the land is reduced by the corresponding harvesting. For example, the carbon sink in the forest is reduced when wood is removed from the forest. According to a recent study (Cazzolla Gatti et al. 2023), about **3.4%** of the EU's land area is under strict protection. The EU's goal is to increase this share up to **10%** by 2030.

SCENARIO 3

Only strictly protected areas store carbon resulting in

28.34m

tonnes of CO_2 annually.

Scenario 3 describes the status quo of strict protected areas in the EU, i.e. **3.4%** of the land area is under strict protection and carbon is sequestered on this area. This means that instead of 200 million ha as in scenario 1 (see Table 3), only 15 million ha are available for carbon sequestration. This corresponds to a reduction of **93%**. In terms of sequestration, such a reduction would result in a sequestration of 28.34 million tonnes of CO_2 annually. If this value is stored annually, 170 million t CO_2 could have been removed from the atmosphere by 2030.

TABLE 4: ANNUAL CARBON SEQUESTRATION OF SUB-ECOSYSTEMS IN THE EU27 & UK

Ecosystem type	Ecosystem-specific carbon sequestration rate (t C/ha*a)	Source of the ecosystem-specific values	Carbon sequestration (scenario 1) (Million t C *a)[1]
Semi-natural grassland	0.24	(Hendriks et al. 2020)	2.54
Broad-leaved forest	1.15	(Domke et al. 2019)[3]	50.77
Coniferous forest	0.3	(Domke et al. 2019) [3]	20.17
Mixed forest	0.7	Own calculation[2,3]	19.05
Transitional wood-shrub	0.2	(Domke et al. 2019) [3]	4.43
Sclerophyllous vegetation	-0.02	(Hendriks et al. 2020)	-0.18
Moors and heathland	0.02	(Hendriks et al. 2020)	0.18
Inland marshes	1.73	(Malak et al. 2021)	1.84
Peat bogs	0.34	(Malak et al. 2021)	2.97
Salt marshes	2.63	(Malak et al. 2021)	1.02
Coastal waters	0.43	(Malak et al. 2021)	0.42
Total			103.2

[1] Area values are obtained from (EEA 2021), see Table 3.
[2] Average values, based on the values of coniferous forest and mixed forest.
[3] Values refer to above-ground biomass (excluding soil).

SCENARIO 4

However, assuming that **3.4%** of the area is strictly protected each year, the EU target of **10%** will not be reached. Scenario 4 tries to do justice to this circumstance. Similar to scenario 3, it is assumed that strict nature conservation is carried out on **3.4%** of the area of the EU in 2023 and that 28.34 million t CO_2 are sequestered there. But this share increases, so that in 2030 **10%** of the EU area is under strict protection.

The annual sequestration rate would then be approximately 83.35 million t of CO_2 in 2030. Added up over the period 2023-2030, this would result in carbon dioxide removal of 335.08 million t CO_2. All corresponding values of the scenarios 3 and 4 can be found in Table 5.

If the share increases, so that in

TWENTY TWENTY THREE

10%

OF THE EU AREA IS UNDER STRICT PROTECTION SEQUESTRATION RATE WOULD BE APPROX.

83M TONNES OF CO_2

TABLE 5: COMPARISON OF THE SEQUESTRATION POTENTIAL OF THE FOUR SCENARIOS CONSIDERED

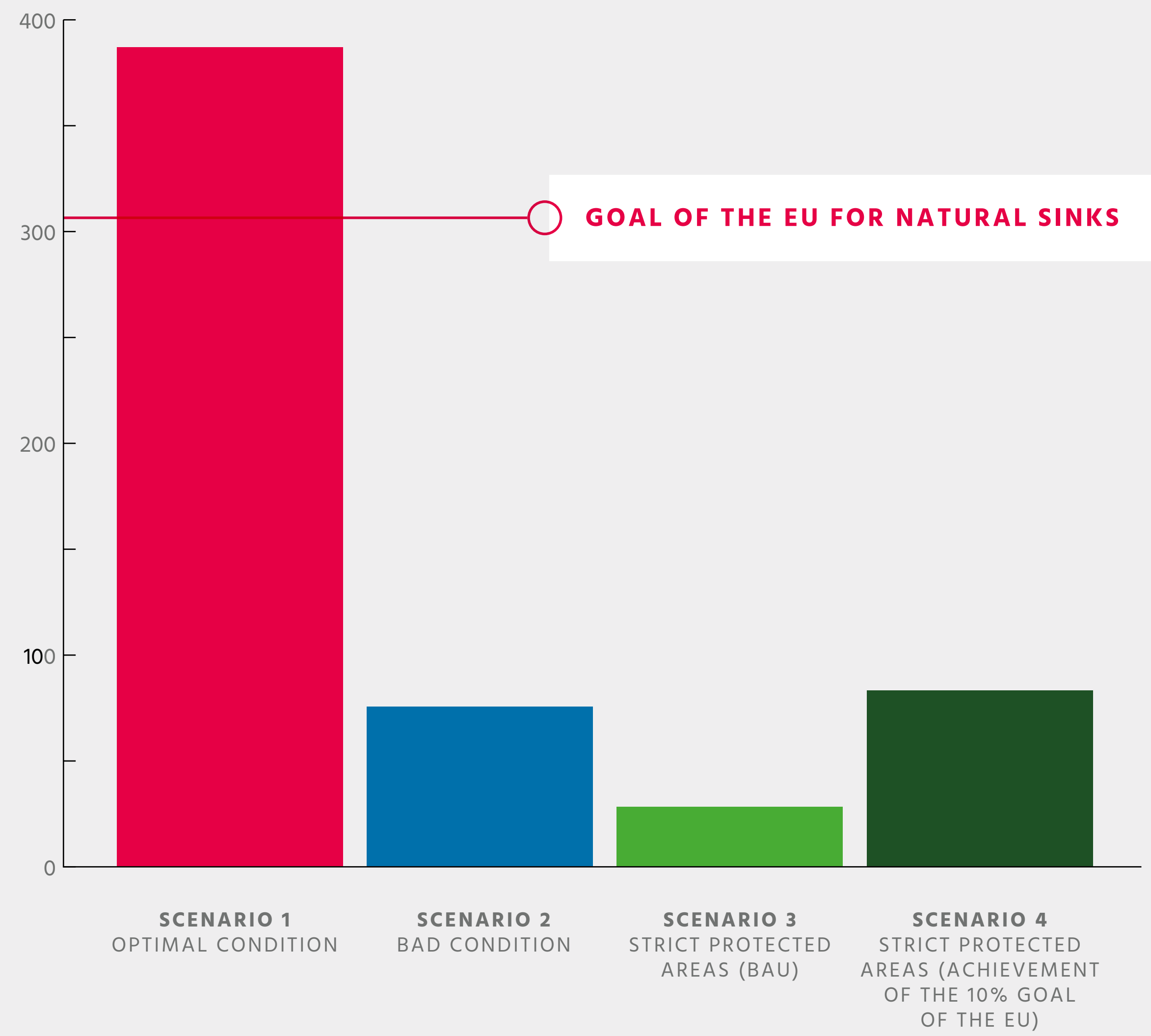
	Sequestration in Million t CO_2		
	In 2023	In 2030	Cumulative in 2030 (8 years)
Scenario 1: Optimal condition	378.0	387.0	2,270
Scenario 2: Bad condition	75.7	75.7	454
Scenario 3: Strict protected areas (BAU)	28.3	28.3	170
Scenario 4: Strict protected areas (Achievement of the 10% goal of the EU)	28.3	83.4	335

However, as can be seen in Figure 1, the goal of the EU for natural sinks (LULUCF target) cannot be achieved if

- **a** **The proportion of protected areas remains at the current level.**
- **b** **The proportion of protected areas is increased to only 10%.**
- **c** **The ecosystems of the EU remain in a degraded state. Only under the assumption that large areas of intact ecosystems exist and are under strict protection, the goal of the EU on natural sinks can be achieved.**

Depending on the future state of the ecosystems, a sequestration capacity of 75.7 - 378 million t CO_2 could be achieved in the EU27 & UK in 2030.

FIGURE 1: SEQUESTRATION, WHICH OCCURS IN THE 4 SCENARIOS, AGAINST THE BACKGROUND OF THE GOAL OF THE EU FOR NATURAL SINKS



3.5 What are the main threats to natural carbon sequestration in the EU?

Carbon storage in natural ecosystems, through natural sinks, is fraught with uncertainty due to climate change. Due to increasing environmental catastrophes and "stress situations" such as droughts, fires, storms, pest infestations, but also due to use and changes in use, natural CO_2 sequestration is not permanent. Competition for land use and mitigation measures in other sectors also affect the potential of natural carbon sinks (Reise et al. 2021). A major risk is that carbon stored in nature is not permanently removed from the atmosphere. Captured carbon can be released back into the atmosphere in the form of CO_2 through natural disturbance, deliberate human action or unintentional misbehavior (Erxleben et al. 2022). The threats to various natural carbon sinks in the EU are described in more detail below based on (Böttcher et al. 2022). It is estimated that between 2021 and 2030, the carbon storage potential of European forests could be reduced by about 180 million t CO_2 per year due to disturbances, reducing the expected net sink of forests by more than **50%** (Böttcher et al. 2022).

It is estimated that between 2021 and 2030, the carbon storage potential of European forests could be reduced by

180m tonnes of CO_2

FORESTS

Forests are strongly affected by climate change; especially young trees are vulnerable to droughts because their roots are not yet well developed. The sequestration potential depends on the future species composition of forests and the adaptability of species to climate change. Improved forest management can increase carbon sequestration in forests. Reduced timber harvesting can also increase the resilience of forests to drought.

Due to climate change, the main threats to European forests are abiotic disturbances such as drought and wind. These threats will increase in frequency and intensity as a result of climate change. Biotic disturbances such as bark beetle outbreaks will also reduce European forests' carbon sequestration potential.

AGROFORESTRY

Agroforestry integrates woody vegetation with crop and animal systems, creating carbon removals from the atmosphere and its sequestration into biomass and soil. Carbon storage occurs both in above ground biomass as well as in the soil. Climate change will affect biomass growth and therefore the potential for sequestration. Yields are expected to generally decrease in the Mediterranean region, increase in northern Europe and remain at current levels in the temperate zone. However, climate change will increase the risk of forest fires, which will reduce natural carbon stocks (Böttcher et al. 2022).

PEATLANDS

Drainage has led to a decline in groundwater levels in managed and unmanaged peatlands in Europe. Ongoing climate change will lead to less rainfall and higher average air temperatures. This will further reduce groundwater levels and lead to the drying out of unmanaged peatlands. To preserve peatlands as important carbon sinks, it is necessary to reduce human impacts on peatlands and increase their resilience to the impacts of climate change (Böttcher et al. 2022).

COASTAL MARINE

Coastal marine ecosystems such as mangroves, salt marshes and seagrass meadows sequester carbon from the atmosphere. These ecosystems are threatened by water quality degradation, eutrophication and artificial coastal modifications. Climate change can negatively affect these ecosystems through the combined effects of heat waves, hypersaline conditions and increased turbidity and nutrient levels associated with flooding. This threatens these important carbon sinks (Böttcher et al. 2022).

In summary, the main threats to natural sinks are climate change on the one hand and human activity on the other.

3.6 What are the opportunity costs of growing bioenergy crops on land that could instead be used for nature-based carbon sequestration?

A study was recently commissioned by Transport and Environment and carried out by (Fehrenbach et al. 2023) with precisely this question in mind. The overall objective of this study was to compare the official net greenhouse gas savings of biofuels consumed in the EU27 & UK with the so-called carbon opportunity costs. In order to ultimately answer this question, the following sub-questions were answered:

1. **Which amount of crop-based biofuels and biomethane are produced and consumed in Europe and how much land is occupied for this production?**
2. **How much land would be occupied if the same driving distance were to be covered by electromobility based on solar power?**
3. **Which (near) natural vegetation could potentially cover the respective cropland and how much carbon could be stored by this natural succession?**
4. **What are the carbon opportunity costs (COC) of crop-based biofuels and biomethane consumed in the EU27 & UK?**
5. **What are the food opportunity costs of crop-based biofuels and biomethane consumed in the EU27 & UK?**
6. **What further ecological effects would come with renaturation instead of cultivation of energy plants?**

The conclusion of the study was that

a. **Large quantities of biofuels are consumed in the EU27 & UK**
b. **Large land occupations are also required outside the EU to provide these biofuels**
c. **The carbon opportunity costs far outweigh the net greenhouse gas savings that should theoretically accompany biofuel consumption.**

In addition, an alternative, namely electromobility, was considered. It was found that with the option of electromobility based on solar power, only **2.5%** of the cropland required for the provision of biofuels is occupied. This presupposes that the same mileage is provided. Furthermore, the study concludes that the energy crops or the land they occupy could feed over **40%** of the EU27 & UK population.

The authors of the study were able to compile data on the production and consumption of biofuels consumed in the EU for the first time. Overall, 99 PJ of bioethanol and 213 PJ of biodiesel were produced in the EU27 & UK in 2020. This data also includes quantities made available for export. The volume of biofuels consumed was 102 PJ of bioethanol and 349 PJ of biodiesel imported into Europe. These quantities are accompanied by an area occupation of 3.7 million ha in the case of biofuels produced and 5.27 million ha in the case of biofuels consumed. Going further, the authors assumed that natural vegetation would develop on these 5.27 million ha if the areas were left to themselves. They identified (1) what forms of vegetation would develop on these areas and (2) what carbon sequestration would be associated with these forms of vegetation. This was used to determine the foregone storage that would be lost if the land was still dedicated to biofuel production instead of being left to natural succession. This foregone storage effect is the so-called carbon opportunity cost.

In total, natural vegetation growth would sequester 66.3 million t of CO_2 per year. This means that the carbon opportunity costs are 66.3 million t of CO_2. The theoretical net green-house gas savings associated with the consumption of biofuels are 25.2 - 32.9 million t of CO_2, depending on the basis of calculation. These net greenhouse gas savings describe the substitution of fossil fuels by biofuels.

With regard to the LULUCF target of 310 million t of CO_2 in 2030, a sequestration of 66.3 million t of CO_2 through vegetation growth would already contribute to the target by approximately **20%**.

The following figure (Figure 2) is taken from the study and compares the two metrics, namely carbon opportunity costs and net greenhouse gas savings of crop-based biofuels.

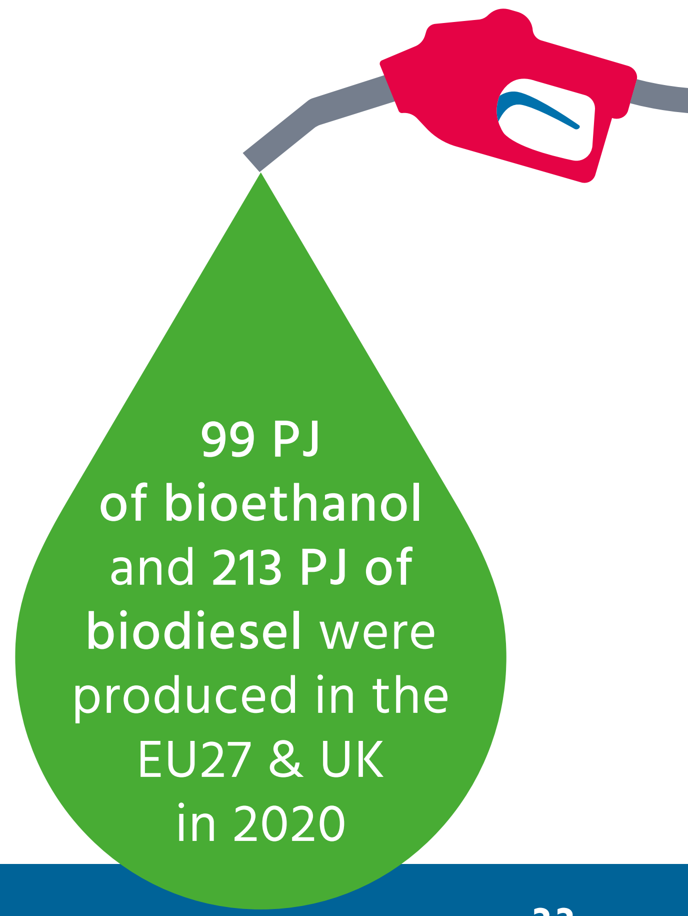
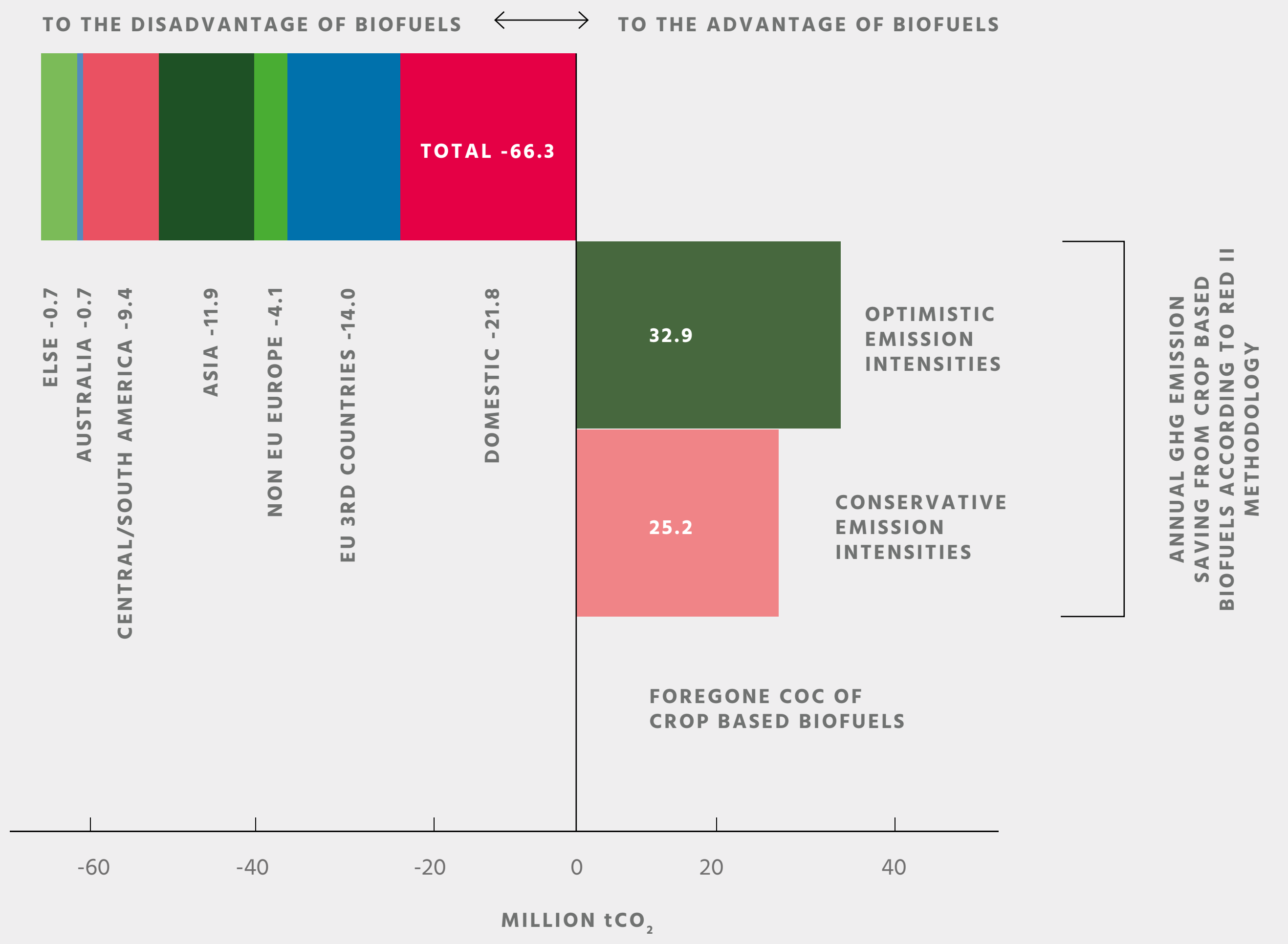


FIGURE 2: CARBON OPPORTUNITY COSTS (COC) OF BIOFUELS CONSUMED IN THE EU27 & UK FROM (FEHRENBACH ET AL. 2023)



As soon as the COC are put in relation to the net greenhouse gas savings, it becomes apparent that the option of natural vegetation growth saves 30 million t CO_2 more than if the land is used for biofuel production and thus saves fossil fuels. This means that with regard to the carbon impact and also against the background of ambitious climate protection targets in the LULUCF sector, among others, it makes more sense to promote natural vegetation growth in the future instead of producing biofuels. In addition, biofuels directly re-emit the carbon bound in the product during combustion. Thus, a storage effect is not given.

Since driving performance must nevertheless be achieved, the alternative of electromobility was examined more specifically in the study. As already explained, it was found that significantly less area, namely **97.5%** less area, is required for the provision of solar power for electromobility.

To gain an understanding of the climate impact of the biofuels option and an alternative, the individual emissions contributions of both options were identified and compiled.

Option a, driving performance by biofuels, includes the emissions from the production of the biofuels and the emission savings from the substitution of fossil fuels. Option b describes the option driving performance through electromobility based on solar power on **2.5%** of the cropland and natural vegetation growth on **97.5%** of the cropland. In this option, emissions from the production of solar power, emission savings from the replacement of fossil fuels, and carbon storage due to natural vegetation growth are considered in the balance.

According to official calculation rules, option a results in net greenhouse gas savings of 32.9 million t, while option b results in net greenhouse gas savings of 107.2 million t CO_2.

3.7 What are the opportunity costs of logging European forests for bioenergy, when these could instead be left growing to sequester more carbon?

Using an average storage balance of 1.28 t CO^2-eq per ton of wood (Fehrenbach et al. 2022), a foregone storage effect of

30.7m t CO_2

is calculated for an estimated pellet use in the EU of

24m tonnes

Source: (UNECE 2022)

In a similar way as in chapter 3.7 the question can be asked what are the opportunity cost of energy wood in the EU27 & UK. The difference lies in the respective production system. While in chapter 3.6 agricultural systems (energy crop production with e.g.: maize, oil palm, soya etc.) are considered, in this chapter forestry systems are investigated. The concept of carbon opportunity costs as applied in chapter 3.6 is not intended for use in forestry systems. However, there are other concepts that are very close to the concept of carbon opportunity costs and that can be used for forest systems.

The **carbon storage balance in forests (CSBF)** is a concept developed by the Öko-Institut[1]. The concept was developed against the background that wood products on the one hand substitute fossil products or CO_2-intensive products, on the other hand wood products reduce the CO_2 sink capacity of forests.

In order to achieve the goal of greenhouse gas neutrality, it is essential to find out what a complete picture of the greenhouse gas balance of energy wood would look like. Or to put it differently: Does it make sense to use energy wood to reduce emissions or not?

To get this more holistic picture of the greenhouse gas balance of wood use, the following components are considered in the balance:

Greenhouse gas emissions from the production of wood products, greenhouse gas emissions from the substitution of fossil products, carbon storage in the forest, and carbon storage in wood products from the forest. A schematic representation on the website of Öko-Institut[1] shows that extensive wood use, i.e. when as little wood as possible is removed from the forest, the carbon storage in the forest rises strongly and thus more CO_2 is stored in the overall balance. In other words: The less wood is removed from the forest, the better the overall balance.

The value of the storage balance tries to combine exactly the combination of wood extraction and the lost storage effect. By integrating the storage balance into the greenhouse gas balance, a more holistic picture of wood use is presented. The storage balance thus represents the extent to which the potential CO_2 storage capacity of the forest is reduced by wood removal. It can be expressed in units of tonnes of CO_2 per cubic meter of wood extracted.

In 2022, a study examined more than 200 scenario combinations of forest management in Europe and outside Europe (Soimakallio et al. 2022). The result of this study is that the storage balance is always positive, which means that the use of wood always leads to a reduction in the CO_2 sink capacity of the forests.

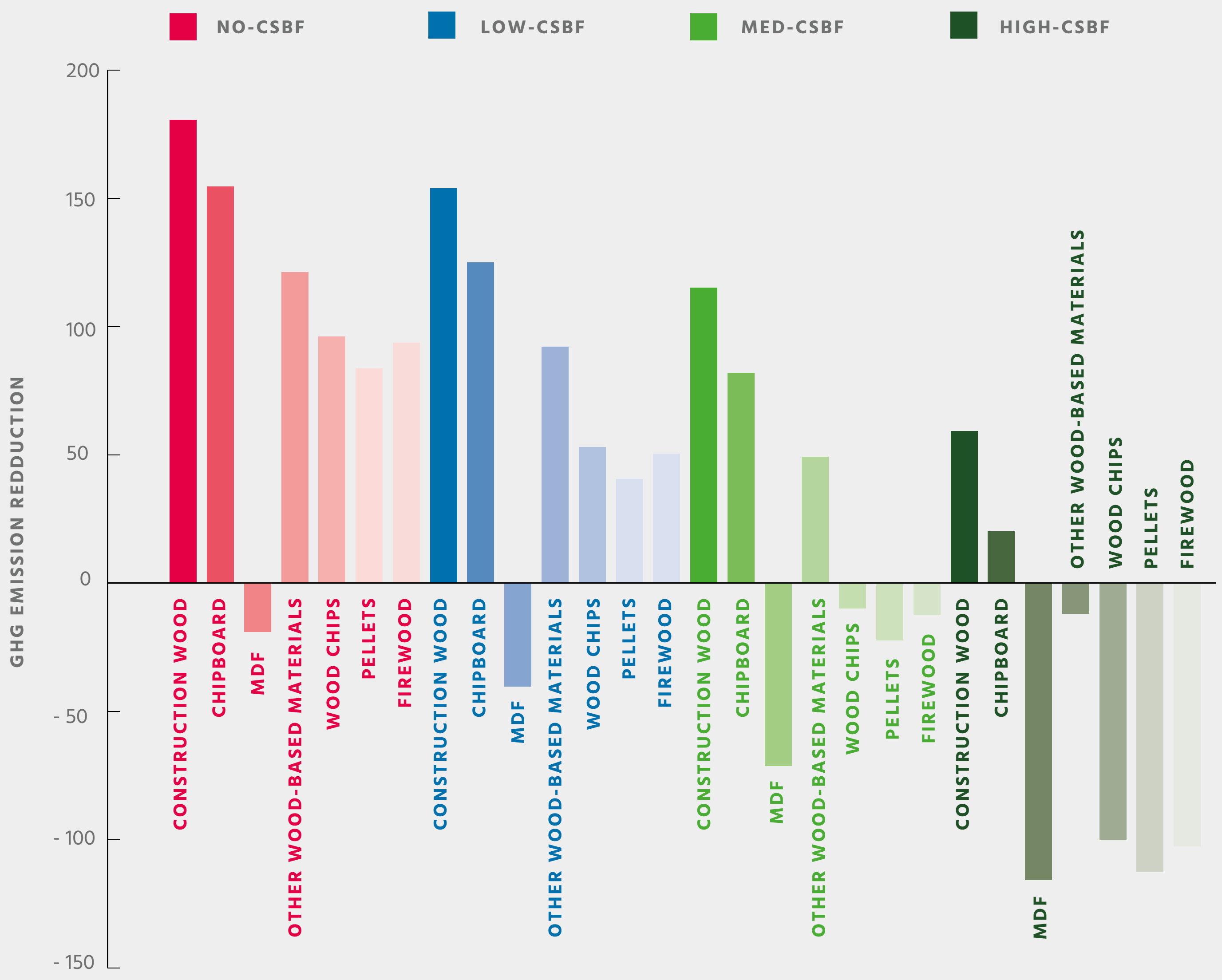
Another study (Fehrenbach et al. 2022) has used the concept of storage balance in the balance of wood products. It was shown that the greenhouse gas emission reduction of wood products compared to their non-wood alternatives are significantly reduced using the storage balance and some wood products even represent a net greenhouse gas source. For example, energy wood performs as a source in this expanded GHG balance. Therefore, from a climate protection perspective, building up the carbon stock in the forest would be the better option.

Figure 3, which is taken from (Fehrenbach et al. 2022), clearly shows that the energy wood products wood chips, pellets and firewood in particular do not result in any greenhouse gas emission savings compared to the fossil alternatives.

The **less wood** is removed from the forest, the **better** the overall **balance.**

[1] https://co2-speichersaldo.de/de/index.html

FIGURE 3: GREENHOUSE GAS EMISSION REDUCTION OF DIFFERENT WOOD PRODUCTS COMPARED TO THEIR FOSSIL ALTERNATIVES UNDER THE ASSUMPTION OF 4 DIFFERENT CARBON STORAGE WITH DIFFERENT CARBON STORAGE (CSBF) VALUES FROM (FEHRENBACH ET AL. 2022)



In a similar way, the storage balance was used in the balancing of energy wood products, namely wood pellets and firewood (Hennenberg et al. 2023). Once again, the balance showed that no greenhouse gas reduction is observed for energy wood products. On the contrary, these products represent sources. The authors emphasize that from a climate protection point of view, especially in climate-sensitive forests with ecological stability, the use of wood should be reduced and the carbon storage in the forest should be built up.

Using an average storage balance of 1.28 t CO_2-eq per ton of wood (Fehrenbach et al. 2022), a foregone storage effect of 30.7 million t CO_2 is calculated for an estimated pellet use in the EU of 24 million tonnes (UNECE 2022).

In addition to using the storage balance, it is also possible to include direct emissions from wood combustion in the balance. As part of a short study on the topic of energy wood in industry, commissioned by NABU (Fehrenbach and Bürck 2022), a balance including combustion emissions was carried out in addition to the balance including the storage balance. Similar to the use of the storage balance, it is clear that the net emissions of the wood for energy use fall within the range of the emissions release.

However, there is scientific and political debate about the role of energy wood in climate protection. Some authors emphasize that old unmanaged forests will become a source of CO_2 in the long term and that only managed forests can make a contribution to climate protection (Irslinger 2023). This is opposed by the argument that old forests are also effective carbon sinks (Luyssaert et al. 2008). In short, there is scientific and political disagreement about which type of management is best from a climate protection perspective.

Conclusion

In the context of this short study, which corresponds to a Q&A, questions were answered in the context of nature-based solutions. The political goal of the EU, which aims to achieve an annual storage of 310 million tonnes of CO_2 through natural sinks by 2030, was addressed.

In addition, the central ecosystems of the EU, to which grassland, forests, heathland and shrubs, sparsely vegetated lands, inland wetlands, rivers and lakes and marine inlets and transitional waters belong, as well as their 11 sub-ecosystems, in which a future carbon sequestration in the vegetation can be assumed, were explained.

Furthermore, the current storage of the selected ecosystems in the EU27 & UK was identified on the basis of area data of the respective sub-ecosystems and corresponding carbon storage values from literature. It results in 48.5 billion t CO_2, which could be somehow over-estimated, considering the reported bad condition in which many of these ecosystems are. This storage potential corresponds exclusively to a potential storage based on the use of the listed storage rates.

Moreover, the future annual sequestration potential of these ecosystems was estimated. Assuming that these ecosystems are in an optimal state, an annual storage rate of 378 million t CO_2 could be possible. Considering the current degraded state of the ecosystems, the current amount is estimated significantly lower at possibly 75.7 million t CO_2. This may be true if the degradation of ecosystems in Europe continues and, in particular, if the use of forests tends to intensify.

In addition, the sequestration potential was estimated assuming different wilderness developments in the EU. Provided that wilderness areas continue to exist on only a small percentage of land, 28.3 million t CO_2 could potentially be sequestered annually. However, to reach the target of **10%** wilderness areas in the EU, the area share would have to increase strongly, and the annual sequestration rate would increase accordingly.

Assuming that this target is met, 335 million t CO_2 could potentially be removed from the atmosphere by 2030 in cumulative terms.

After a description of the main threats to ecosystems, which are largely due to climate change and associated impacts, as well as anthropogenic influences, the carbon opportunity costs of crop-based biofuels (based on cultivated biomass) consumed in Europe are described. The central results of a recently published study in this context are presented. According to these results, the carbon opportunity costs of biofuel consumption in the EU amount to 66.3 million t of CO_2. With regard to bioenergy from forest wood (wood pellets), the so-called storage balance, a counterpart to the carbon opportunity costs, would be 30.7 million tonnes of CO_2.

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