Carbon Dioxide Removal options in the National Long-term Strategies of EU Member States

A Climate Recon 2050 report

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Final report

15th December.2022

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

European Climate Initiative EUKI

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Suggested citation

Walke, P., Tool, B., Tamm, K. (2022): Carbon Dioxide Removal options in the National Long-term Strategies of EU Member States. Stockholm Environment Institute. Tallinn.

This report is part of the project

Climate Recon 2050 - Dialogue on Pathways and Policies for a climate-neutral EU

For further details, please visit the project website www.climatedialogue.eu

Acknowledgements

The authors would like to thank Isabel Haase, Matthias Duwe, and Ewa Iwaszuk (Ecologic Institute), Kamil Laskowski (WiseEuropa) and the rest of the Climate Recon 2050 project team.

Summary

In accordance with the Paris Agreement, the global community needs to make its best effort of keeping the global average temperature rise to 1.5 ºC compared to the pre-industrial average. In the EU, after reaching climate neutrality, **net negative emissions must be achieved.** To achieve that, each EU Member State is required to adopt and regularly update a **holistic decarbonisation strategy until 2050, known as a long-term strategy (LTS).** While GHG emissions can be removed by natural sequestration in soils, forests and oceans, technological removals like Bioenergy with Carbon Capture and Storage (BECCS) or Direct Air Capture (DAC) are also possible solutions. Further, technological options that avoid additional emissions, Carbon Capture and Storage (CCS) and Carbon Capture and Utilization (CCU) also contribute in some sectors. **In the last 30 years, the carbon sink in the EU has decreased**. Currently, the most ambitious scenario (with additional measures, WAM derived from EEA database of LULUCF emissions), entails a sink of -209 Mt CO_2e by 2030[1], while the EU Reference Scenario foresees a sink of -271.1 Mt CO_2e in 2050 and the *'Clean planet for all'* communication includes a sink target of around -400 Mt CO_2e by 2050 as well. **In this report we analysed how EU Member States addressed the Land Use, Land Use Change and Forestry (LULUCF) sector as well as other carbon removal options in their national LTS's.**

The structure and requirements as well as the need to include projected emissions reductions and enhancement of sinks by 2050 in the LTSs are set out in Regulation 2018/1999 (Governance Regulation) of the European Parliament and Council[2]. As the guidance regarding content and format set out in Annex IV to this Regulation is rather vague and sparse, the level of detail and structure of the LULUCF sector was found to be highly variable between LTSs. For example, not all countries have specified the level of emissions reductions in their LTS required to reach climate neutrality. Therefore, in this report **minimum boundaries were established for total necessary sequestration based on the stated or implied maximum level of reduction each country has proposed** (on average 87% compared to 1990), **the so-called sink requirements, and then compared to the EU reference scenario**. If no clear emission reduction target was given, a value of 85% from 1990 levels (excluding LULUCF) was used. The same procedure was used for countries who had yet to publish their strategy (Bulgaria, Cyprus, Ireland, Poland, and Romania) as of August 31st, 2022. **The analysis highlighted that the assistance natural sink enhancements can play in reaching climate neutrality are not uniformly distributed across Member States**.

Natural emission and sequestration processes are found across six different land-categories: **forest land, cropland, grassland, wetlands, settlements, other land**. We analysed to which extent these were covered in the strategies (inclusion of description, measures, and targets). Forestry was separated from other land categories as by far the most information was provided on this. As agriculture will soon be combined with LULUCF in the EU and the Governance Regulation also treats them together, agricultural measures were sometimes included in the analysis from the land use emissions perspective. **LULUCF and natural removals cannot be viewed with tunnel**

[1] LULUCF sector emissions and removals in the EU, by main land use category. EEA. https://www.eea.europa.eu/data-and-maps/daviz/eu-emissions-and-removals-of-1#tab-chart_2 (Accessed: 10.12.2022)

[2] The European Parliament and the European Council. (2018). Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action.

vision, which is why overlaps with using bioresources, biodiversity and adaptation are also included in the analysis. **As the countries do not always distinguish CCS/CCU from actual carbon removal technologies (BECCS and DAC),** future updates could state more clearly which of these technologies is targeted. CCS and CCU are referenced far more often than BECCS/DAC. **No country is currently putting much emphasis on direct air capture** as a potential solution within the lifetime of the current long-term strategies.

General conclusions

- **Countries vastly differ in sink/emissions sizes. For example, Sweden, Spain, and Italy have LULUCF sectors that are currently net sinks and are projected to remain so until 2050. On the other hand, Denmark, the Netherlands, and the Republic of Ireland** are projected to have net emissions expected across the period up to 2050, consistent with the situation since 1990.
- Out of the countries with projected sinks, only three countries were found to have sinks of the necessary magnitude in 2050 based on the 'EU Reference Scenario' – **Spain, Finland, and Sweden.**
- **There were countries with significant trends of change, for example, Estonia and Latvia have seen recent decreases in their sink sizes**, and the **LULUCF sector has become a source of net emissions.** These sinks are not expected to fully recover by 2050 according to the reference scenario.
- The issue of land planning and reducing land conversions was included into the LTS **by 12 of the countries.** Several included targets to reach net zero land conversions by 2050. This was included by both small and big countries.
- Attempts to enhance **afforestation or reforestation were included in most of the strategies.** Issues around monitoring and measuring the LULUCF sector and its emissions were also commonly mentioned. **Only two countries – Austria and France –** out of the 22 countries that have submitted their LTS **addressed sink stability, which is an important related issue.**
- **Countries mostly focused on forest land,** discussion on other land use categories was predominately focused on **wetlands and permanent grasslands.** Cropland, settlements, and other land were rarely discussed. Six countries integrated agriculture with LULUCF.
- **Several countries focus mainly on emissions in the sector. However, there were some exceptions. Spain and Slovenia had thorough discussion on climate adaptation** in relation to natural sinks. **The latter put by far the most focus on biodiversity together with Belgium.** Overall, **Belgium and Croatia had the most comprehensive strategies in terms of overlaps** between agriculture, biodiversity, bioresources and adaptation.
- **Almost all countries plan to increase the use of bioresources**, some to a bigger share than others. Most countries see **increasing the share of wooden long-lived products** as an alternative to reducing carbon intensive products, less focus is given to energy use. However, some countries have conflicting targets for using bioresources and enhancing natural sinks (*e.g.,* Denmark and Italy).

- Based on the mitigation pledges included in the LTS's and expected required sinks in the 'EU Reference Scenario', **most countries cannot reach climate neutrality only through natural sinks.** The **pan-EU scenarios that reach climate neutrality foresee technological removals or avoided emissions of at least 300-600 Mt CO_2 in 2050.** Inter-nation trading in the form of flexibility mechanisms could help achieve union-wide goals.
- Regarding technological solutions, more focus is clearly **put on CCS/CCU rather than BECCS/DAC.** However, the distinctions are not always clear from the strategies.
- **Views on CCS/CCU vary greatly**. 10 of the 20 countries that included CCS and CCU appear to view it positively and have some plans for its deployment in the future, however all assert that more research is needed. Countries like France focus more on storage and Hungary, for example, on utilization. Industrial processes such as cement production are the most common areas for which these technologies are targeted.

Recommendations

- While updating the strategies, all countries should **specify the total reductions and targeted sink size** (in absolute terms) in their LTS's to reach climate neutrality.
- **Sink stability is one key topic missing from the LTS's** that has a great influence on the sink and emissions size, which should be included by all countries in the future as many countries (e.g., Estonia and Latvia) already struggle with this (their LULUCF sector has recently turned into an emitting one).
- **Better integration with biodiversity is necessary.** Currently, only Belgium and Slovenia discuss the importance of the topic comprehensibly and describe the overlaps with other sectors. For example, **the environmental impact of BECCS and intersections with agriculture, bioresources, and biodiversity could be better described in the strategies.**
- Countries could **elaborate more on their proposed measures** and how the goals set in the LTS's will be achieved. Sustainability criteria should be strict enough to effectively incentivise the drive towards policies contributing to carbon sinks.
- Countries should **put more focus on other land use categories besides forests** as well, as currently the LULUCF sector on the EU level without forests is an emitting one.
- After the countries revise their strategies, **agriculture and LULUCF should be combined** rather than viewed separately as they have great overlaps and interaction and at the same time significant challenges exist. This also applied to== to adaptation and use of bioresources – the topic cannot be viewed with 'tunnel vision' only in terms of sink size.
- **Better distinction between CCS/CCU and DAC/BECCS is necessary**. Currently, it is unclear from some of the LTS's what kind of technologies the countries plan to

integrate and what not. For example, Sweden states 'negative emissions technologies' could be a potential option. The French LTS is a good example where distinctions are clearly made between the technologies.

- While emphasis should be on ambitious mitigation and enhancement of carbon sinks, countries still could make better use of **collaboration** (trading scheme) to reach the common goals, *e.g.,* Sweden has enough resources to meet requirements of Malta as well. The only country who already mentioned this in their LTS were the Netherlands.
- Collaboration can also be useful for other activities, such as better digital monitoring systems. Hungary and Luxembourg state in their LTS's that they wish to develop maps of ecosystem services and forest biotypes, respectively. As this has already been developed in Estonia[3], good practises could be shared.

[3] ELME kaardikihtide kataloog. Keskkonnaagentuur. https://kaur.maps.arcgis.com/apps/MapSeries/index.html?appid=9db1c0379be24a13a94c5ad6e4829320 (Accessed: 02.12.2022)

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Abbreviations

BECCS	Bioenergy with carbon capture and storage
CC	Climate change
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
CDR	Carbon Dioxide removal
CN	Climate Neutrality
DAC	Direct air capture
DH	District heating
EEA	European Environment Agency
HWP	Harvested wood product
IPCC	Intergovernmental Panel on Climate Change
LTS	Long term strategy
NECP	National Energy and Climate plan
RES	Renewable energy sources
WAM	With Additional Measures
WEM	With Existing Measures

1. Introduction

In the Paris Agreement, of which the European Union (EU) is a signatory, the global community has laid down the goal of holding the global average temperature rise to 2ºC over the pre-industrial average and make best efforts for 1.5ºC[4]. More recent evidence has stressed the dangers inherent in allowing permanent emissions to rise over this lower limit[5]. This is associated with a remaining 'carbon budget' that can still be released into the atmosphere[6] and it is now understood that to have a **reasonable chance of staying within the 1.5ºC limit, societies must rapidly approach the point of climate neutrality by 2050**[7]. In the EU an even more ambitious target has been set – the EU Climate Law states that after climate neutrality **net negative emissions must be achieved**[8]. The goal of climate neutrality has increasingly been set by **individual Member States as well and sometimes even earlier than 2050** – Sweden and Germany have pledged to achieve carbon neutrality by 2045, Austria by 2040 and Finland is determined to reach it already in 2035[9].

Climate neutrality is defined as the point at which **total greenhouse gas emissions within a given boundary are equal to total carbon sequestration**, the processes through which carbon is removed from the atmosphere. The principle of carbon neutrality should also extend over all sectors. It is widely understood that reducing emissions is not equally difficult in all areas of a national or global economy. Envisioning pathways by which emissions can be reduced from the power sector, for example, are clear, if not precisely straightforward. For other sectors it is expected to be more difficult, and so methods and techniques are required to counteract these emissions.

Given that many countries around the world have now committed to the target of climate neutrality, it is necessary to examine the emerging plans that they will use to achieve this goal. **The national long-term strategies (LTSs) are the key documents meant to describe this in Member States of the European Union**[10]. With a time-horizon of 30 years up to 2050, the national LTSs provide a guideline for decarbonisation across the whole economy and supplement the more short-term National Energy and Climate Plans (NECPs). The structure and requirements for both NECPs and LTSs are set out in Regulation 2018/1999 (Governance Regulation hereafter) of the European Parliament and Council,[11] as well as the need to include projected emissions reductions and enhancement of sinks by 2050 in the LTSs. The Paris Agreement sets the goal for global net zero emissions as a recommended pathway to be pursued, and also foresees an important role in achieving this in the EU for the national long-term strategies.

[4] The Paris Agreement. What is the Paris Agreement? UNFCCC. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (Accessed: 17.10.2022)
[5] Special report: Global warming of 1.5 °C. IPCC. https://www.ipcc.ch/sr15/chapter/spm/ (Accessed: 23.11.2022)
[6] That's how fast the Carbon Clock is ticking. MCC Berlin. https://www.mcc-berlin.net/en/research/co2-budget.html (Accessed: 23.11.2022)
[7] IPCC says limiting global warming to 1.5 °C will require drastic action. Nature. https://www.nature.com/articles/d41586-018-06876-2 (Accessed: 6.09.2022)
[8] European Climate Law. EC. https://climate.ec.europa.eu/eu-action/european-green-deal/european-climate-law_en (Accessed: 23.11.2022)
[9] Race to Net Zero: Carbon Neutral Goals by Country. https://www.visualcapitalist.com/sp/race-to-net-zero-carbon-neutral-goals-by-country/ (Accessed: 23.11.2022)
[10] The Paris Agreement. What is the Paris Agreement? UNFCCC. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (Accessed: 17.10.2022)
[11] The European Parliament and the European Council. (2018). Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action.

Under IPCC guidelines **land-use, land-use change, and forestry (LULUCF) sector plays a major role for emission removals**. This describes natural emission and sequestration processes across six different land-categories: **forest land, cropland, grassland, wetlands, settlements, other land**[12]. The framework for the LTSs in the Governance Regulation also stipulates that LULUCF should be described in more detail in the strategies, including net emissions by source, reduction options envisaged, and how this links to agriculture and rural development policies. **As the LULUCF sector has great overlaps with the agricultural sector**, the countries also need to report to the UNFCCC on direct and indirect nitrous oxide (N2O) emissions from managed soils and land use or management change in mineral soils, biomass burning and harvested wood products etc.

In addition to natural sinks of greenhouse gases, there are several potential technologies that could be used to remove emissions from the atmosphere by other means. Examples include instances in which carbon is taken from air (**direct air capture, DAC**). The concentration of CO_2 present in the atmosphere is low (currently standing at 413 parts per million (ppm) or around 0.04% of the composition of the atmosphere during the northern hemisphere summer of 2022). An example of this is found in Iceland, with the 'Orca' plant targeting to achieve removals from the atmosphere of 4000 tonnes a year[13]. Another example of net negative technologies is **bioenergy with carbon-capture and storage (BECCS)** where carbon is removed by natural processes to generate fuels or electricity, and where the carbon is then captured. However, carbon capture and storage (CCS) and carbon capture and utilization (CCU) are by far more commonly known measures, despite not being permanent or additional carbon-dioxide removal options. Whether and to what extent countries propose to rely on technology – of whatever form – is a pressing key question.

This report seeks to highlight the role played by both natural and technological removals in the national LTSs of the 22 EU member states who had submitted their LTSs by 31st of August, 2022. Further, it also seeks to **highlight the practices and measures in the LULUCF sector** more generally, **and the intersections that exist therein in relation to bioeconomy and agriculture, alongside the effects of the climate crisis**. It also attempts to **draw out comparisons and critical issues across the plans of the Member States as a whole and, in doing so, establish an overarching picture of the role negative emissions can play in tackling the climate crisis in Europe.**

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[12] Towards common GHG inventory reporting tables for Biennial Transparency Reports Experiences with tools for generating and using reporting tables under the UNFCCC. OECD. https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=COM/ENV/EPOC/IEA/SLT(2021)1&docLanguage=En (Accessed: 17.10.2022)

[13] World's largest plant capturing carbon from air starts in Iceland. Reuters. https://www.reuters.com/business/environment/worlds-largest-plant-capturing-carbon-air-starts-iceland-2021-09-08/ (Accessed: 01.12.2022)

2. Report scope and background

It is critical to have a disclaimer at the beginning of any report on this topic that emissions removals must not be used as an alternative to rapid mitigation. It is simply not possible to feasibly remove all the greenhouse gases emitted since the industrial revolution within the required timeframe. For example, a review of available scientific literature in 2002 indicated that maximising reforestation and afforestation across the globe would remove enough carbon to account for ten years of emissions at current levels.[14] Many other forms of natural carbon sinks like sequestration in soils (peat) are simply not accessible on human timescales[15]. Moreover, the emissions and sink size of the LULUCF sector is regarded as the most difficult to measure[16]. There is also a risk when using CCS or similar methods of 'locking-in' carbon from certain industries or practices when widespread alternatives exist. Nevertheless, sequestration in one form or another is needed and the role it will play in a climate neutral world warrants discussion. To put it simply, if some economy-wide emissions persist, then removals must also exist.

2.1. Three different categories

Herein, we group greenhouse gas removals into three distinct categories we discuss in this report. The first of these is **natural removals associated with the LULUCF sector**. Besides forests, this accounts for removals by other land categories, such as wetlands, grass- and croplands, settlements and other land and the conversions between them. It also includes carbon that is removed from the atmosphere and stored in manufactured goods through the category harvested wood products. The different land types can either cause a net removal or emission of greenhouse gases, and the balance of importance between them can vary based on a range of factors, *e.g.*, in some cases grasslands can be more effective in carbon capture and more resilient to the effects of climate change than forests.[17] This is also something that may not be static in a changing climate.

We consider the **technological options, which emanate from point sources as a second category.** Carbon Capture and Storage (CCS) and Carbon Capture and Utilization (CCU) are based on similar principles but differ in what happens with the captured carbon. CCS refers to means by which the removed carbon is stored, for example in geological sites or empty mine shafts[18]. In contrast, CCU is used when the carbon becomes a feedstock for subsequent industrial processes. Examples could be in the production of synthetic natural gas**. It is important to stress that technologies in this group do not cause a reduction in atmospheric GHG concentration.** Instead, they eliminate carbon before it is released. What is measured then when these techniques are referred to in terms of removals is not a reduction in total GHG from the air, but the net amount by which the level of these gases would be higher in the absence of CCS/CCU. Furthermore, such removal can never be 100% effective, although most of these technologies already avoid at least

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[14] https://onlinelibrary.wiley.com/doi/abs/10.1046/j.1365-2486.2002.00536.x
[15] Can Soil Help Combat Climate Change? https://news.climate.columbia.edu/2018/02/21/can-soil-help-combat-climate-change/ (Accessed: 24.11.2022)
[16] LULUCF. European Commission. https://forest.jrc.ec.europa.eu/en/activities/lulucf/ (Accessed: 24.11.2022)
[17] https://iopscience.iop.org/article/10.1088/1748-9326/aacb39/meta
[18] What is Carbon Capture and Storage? National Grid. https://www.nationalgrid.com/stories/energy-explained/what-is-ccs-how-does-it-work (Accessed: 17.10.2022)

90%[19]. An emissive process that includes CCS and CCU will however cause higher emissions than if CCS/CCU had not taken place.

The third category includes technologies and processes where the original source of carbon is diffuse (the actual technical carbon dioxide removal)**.** Here, there are two main subcategories. The first refers to processes where machines remove the carbon from the air, under the name Direct Air Capture (DAC)[20]. The second is based on the removal of carbon by natural processes and carbon storage in biomass. This biomass is then used to generate fuels or electricity, while carbon from his process is being captured. This is known as Bioenergy with Carbon Capture and Storage (BECCS)[21]. These processes differ from the above category in that they can in principle lower the level of carbon in the atmosphere: DAC through direct carbon capture from the atmosphere and BECCS through preventing carbon dioxide extracted from the atmosphere by the biomass when it grows from being released to the atmosphere. This difference between the two technologies translates into different environmental implications. BECCS and DAC are both energy intensive, given the electricity needed by carbon capture facilities, but BECCS is also land intensive, as it requires a large amount of area to be set aside for the carbon to be absorbed and it is only considered sustainable if specific fast-growing species are used for this on areas for this specific land use.[22] This contrasts with DAC, which is energy intensive, but with a smaller land footprint.

2.2. Background for natural removals

The sink type used to store carbon is also of great importance. Certain storage processes can be long or short lasting. For example, the level of carbon dioxide in the atmosphere fluctuates each year, a result of greater removals by vegetation during the northern hemisphere summer[23]. Within forestry, the size of net annual sequestration can vary depending on the age of the forest and what management practices are used, if any. Eventually, natural sinks saturate and can turn emissive. The changing climate and its effects are also important here as they influence the state of natural ecosystems, for example, by increasing the risk of wildfires or soil erosion. A second influence is on the rate of growth. Higher temperatures and greater CO_2 concentrations are associated with faster growth of plants and therefore sequestration. However, research has pointed towards such sinks being less stable,[24] obstructing their ability to store carbon in the long-term. Furthermore, utilisation in products is also transient. The storage of carbon in buildings typically only has a lifetime equal to that of the building, unless building materials consisting of captured CO_2 are reused.

Natural sinks are also unique in their overlaps with other sectors. A clear example of this is agriculture, with the soil balance and carbon levels, and the choice of vegetation (forests, crops, pasture or mixed) clearly influencing food production. A second example is in the bioeconomy and

[19] How efficient is carbon capture and storage? MIT Climate Portal. https://climate.mit.edu/ask-mit/how-efficient-carbon-capture-and-storage (Accessed: 02.12.2022)
[20] Direct Air Capture. IEA. https://www.iea.org/reports/direct-air-capture (Accessed: 17.10.2022)
[21] What is bioenergy with carbon capture and storage (BECCS)? Drax. https://www.drax.com/carbon-capture/what-is-bioenergy-with-carbon-capture-and-storage-beccs/ (Accessed: 17.10.2022
[22] Kato, E., Yamagata, Y. 2014. BECCS capability of dedicated bioenergy crops under a future land-use scenario targeting net negative carbon emissions. Advanced Earth and Space Science. https://doi.org/10.1002/2014EF000249 (Accessed: 17.10.2022)
[23] Climate Change: Atmospheric Carbon Dioxide. Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide (Accessed: 25.11.2022)
[24] Brienen, R. J. W., Caldwell, L., Duchesne, L., Voelker, S., Barichivich, J., Baliva, M., Ceccantini, G., Di Filippo, A., Helama, S., Locosselli, G. M., Lopez, L., Piovesan, G., Schöngart, J., Villalba, R & Gloor, E. 2020. Forest carbon sink neutralized by pervasive growth-lifespan trade-offs. https://www.nature.com/articles/s41467-020-17966-z (Accessed: 17.10.2022)

bio-resources sector which can, in some instances, be at odds with carbon sinks. Products derived from the natural environment are found in both traditional and emerging industries, where they are used to replace advanced chemical products derived from fossil fuels[25]. These aspects must also be considered within the context of the natural environment as a carbon sink. They are, moreover, to some extent interdependent and can be competitive. For example, a meta-analysis conducted in 2021 indicated that agroforestry practices (despite its many benefits) had a net detrimental effect on crop yields, at least in northern Europe.[26] It is not possible, under any normal circumstances, to increase the total land stock. Therefore, if total food production is to remain constant, more land will be needed for agricultural production, with the potential that conventional forest stock could be lost. Another similar analysis found similar results in organic agriculture,[27] despite its many known benefits. Such a discussion should not be seen as a criticism of such practices. The aim is to to highlight the trade-offs that can be found throughout any national choices regarding land management. However, implementing measures that help reduce food waste and improve the global food distribution imbalances would enable us to reduce overall food production and perhaps use more sustainable agricultural practises mentioned above, leaving more land to enhancing carbon stocks by afforestation, BECCS or sustainable grazing. But considering that currently agriculture is not yet combined with LULUCF[28], a full analysis of agriculture will remain out of scope for this analysis, and it is only discussed in terms of intersections with LULUCF. **However, in the future, we suggest that agriculture and the current LULUCF sector should not be viewed separately.** Finally, the issue of net carbon removals cannot be tackled in isolation from other environmental issues, such as biodiversity and water availability.

[25] Upcatalyst. https://upcatalyst.com/technology#co2 (Accessed: 28.11.2022)

[26]Ivezic, V., Yu, Y., van der Werf, W. 2021. Crop Yields in European Agroforestry Systems: A Meta-Analysis. https://www.frontiersin.org/articles/10.3389/fsufs.2021.606631/full (Accessed: 17.10.2022)

[27] https://www.nature.com/articles/s41467-018-05956-1

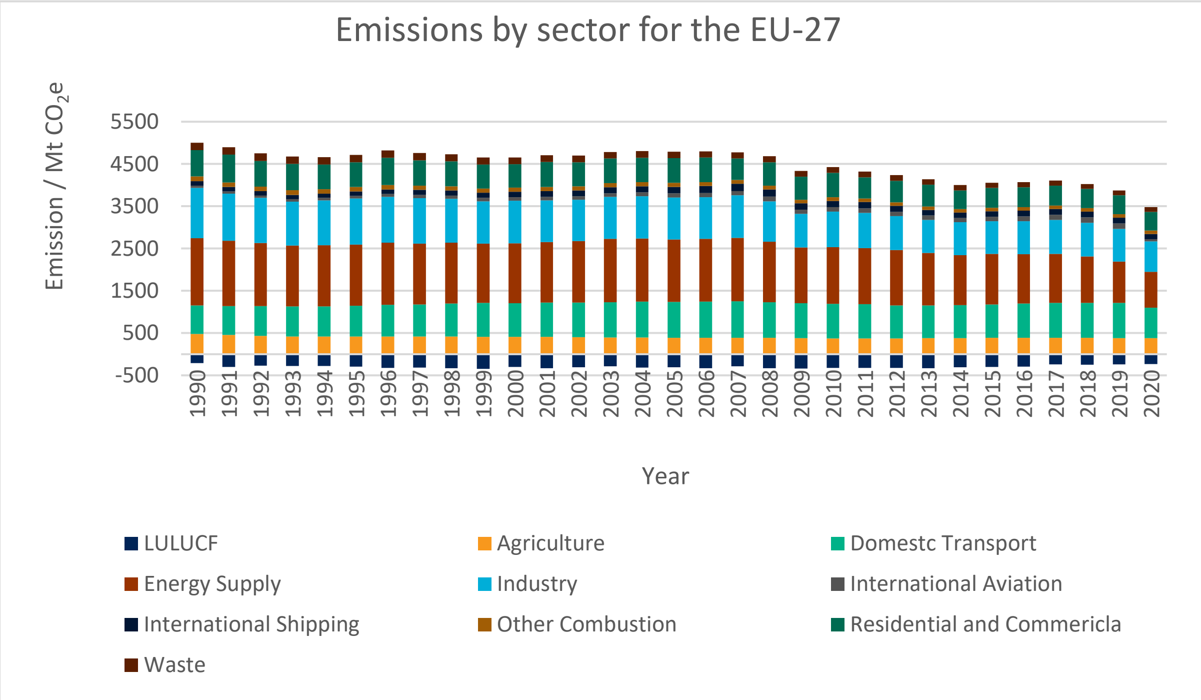
[28] Land Use, Forestry and Agriculture. EC. https://climate.ec.europa.eu/eu-action/european-green-deal/delivering-european-green-deal/land-use-forestry-and-agriculture_en (Accessed: 25.11.2022)

3. Overview of carbon sinks at EU-level

3.1. Natural sinks

Before discussing the regulatory landscape in the EU, we briefly discuss the nature and extent of current emissions across Europe. Figure 1 shows the time series of emissions within the EU, broken down into sectors. The LULUCF sector in the EU is a moderate carbon sink. However, the removals of LULUCF are only equal to a minor share of total emissions from other sectors. Net emissions in the EU-27 stood at just under 3500 Mt CO_2e in 2020, including international transport. However, emissions have been decreasing for some time and the 2020 value amounted to a reduction of around 30 and 27% compared to 1990 and 2005 levels, respectively[29]. It can also be seen that there is a significant decrease in emissions between 2019 and 2020, which is a legacy of the Covid-19 pandemic. Emissions subsequently rebounded in 2021,[30] although this year has yet to be included in the European Environment Agency database (EEA).

Figure 1. Emissions by sector for the EU-27

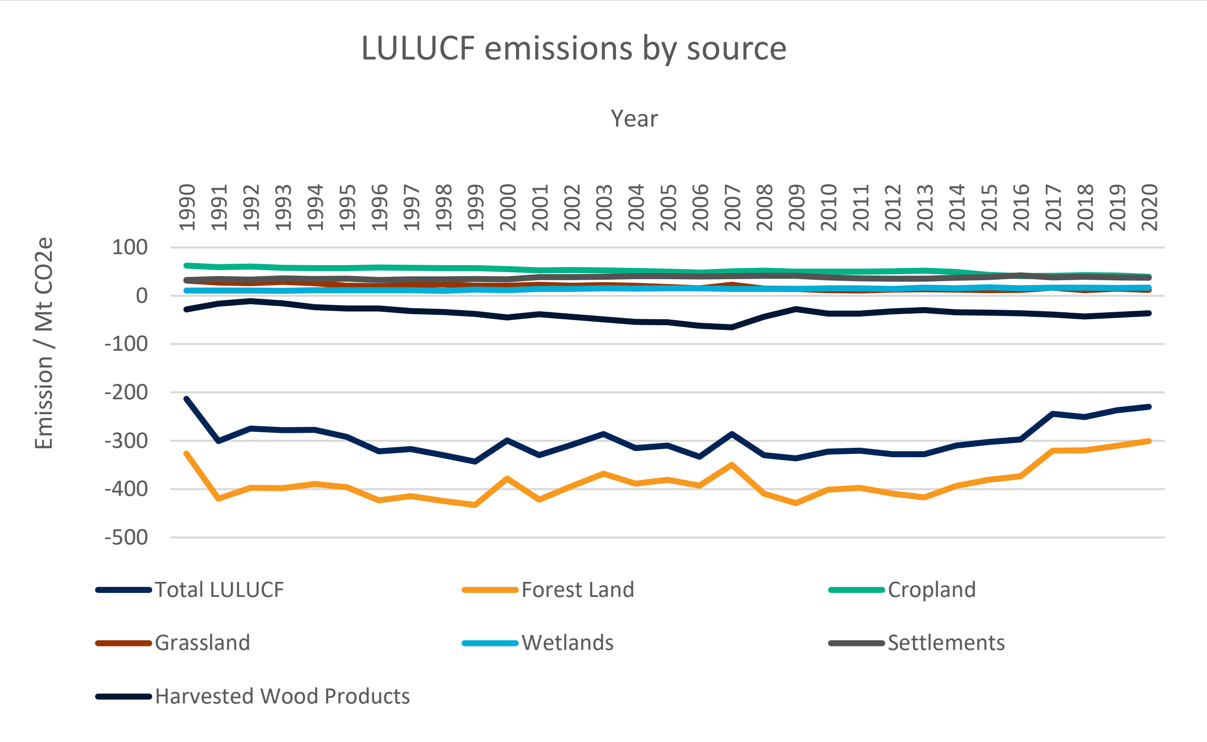


Source: Author's compilation based on EEA data

However, whilst total emissions have been decreasing across the Union for the last 30 years, so has the size of the natural sink. Figure 2 shows the breakdown of emissions by source, as well as total emissions for the whole sector. The size of the sink has been decreasing since around 2009. Total LULUCF removals amounted to -230 Mt CO_2e in 2020. The corresponding value from 2009 was -336 Mt CO_2e. Moreover, the size of removals from forest land is larger than the sector as a whole, meaning that total net emissions are positive from the remaining sub-sectors.

[29] Note that for subsequent calculations of required national sink sizes international transport was discounted.
[30] EU Emissions, International Energy Agency (IEA). Available here.

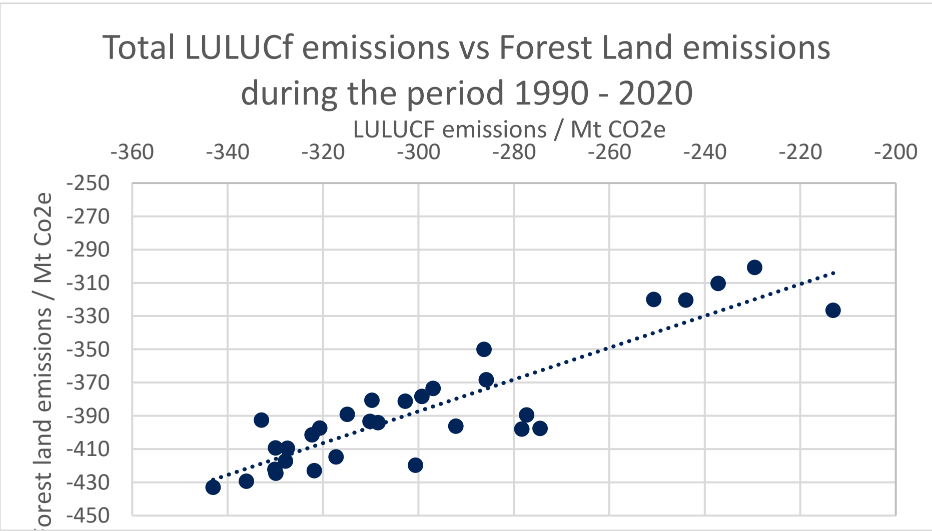
Figure 2. LULUCF emissions by source



Source: Author's compilation based on EEA data

Indeed, the size of the sink in any given year closely follows sequestration from forests. The only other category that has yielded a net removal across the entire range from 1990 to 2020 is *"harvested wood products"* (Figure 2). All other categories showed net positive emissions. In turn, Figure 3 displays a scatter plot of total emissions from the LULUCF sector against those from forest land. The two values have been significantly correlated, at least over the last 30 years. The trendline yields an R^2 value of 0.79 which refers to a quite strong correlation between LULUCF and Forest Land emissions, which means that total LULUCF net emissions to a large extent depend on the net emissions from forests.

Figure 3. Total LULUCF emissions vs Forest land emissions in the period 1990-2020



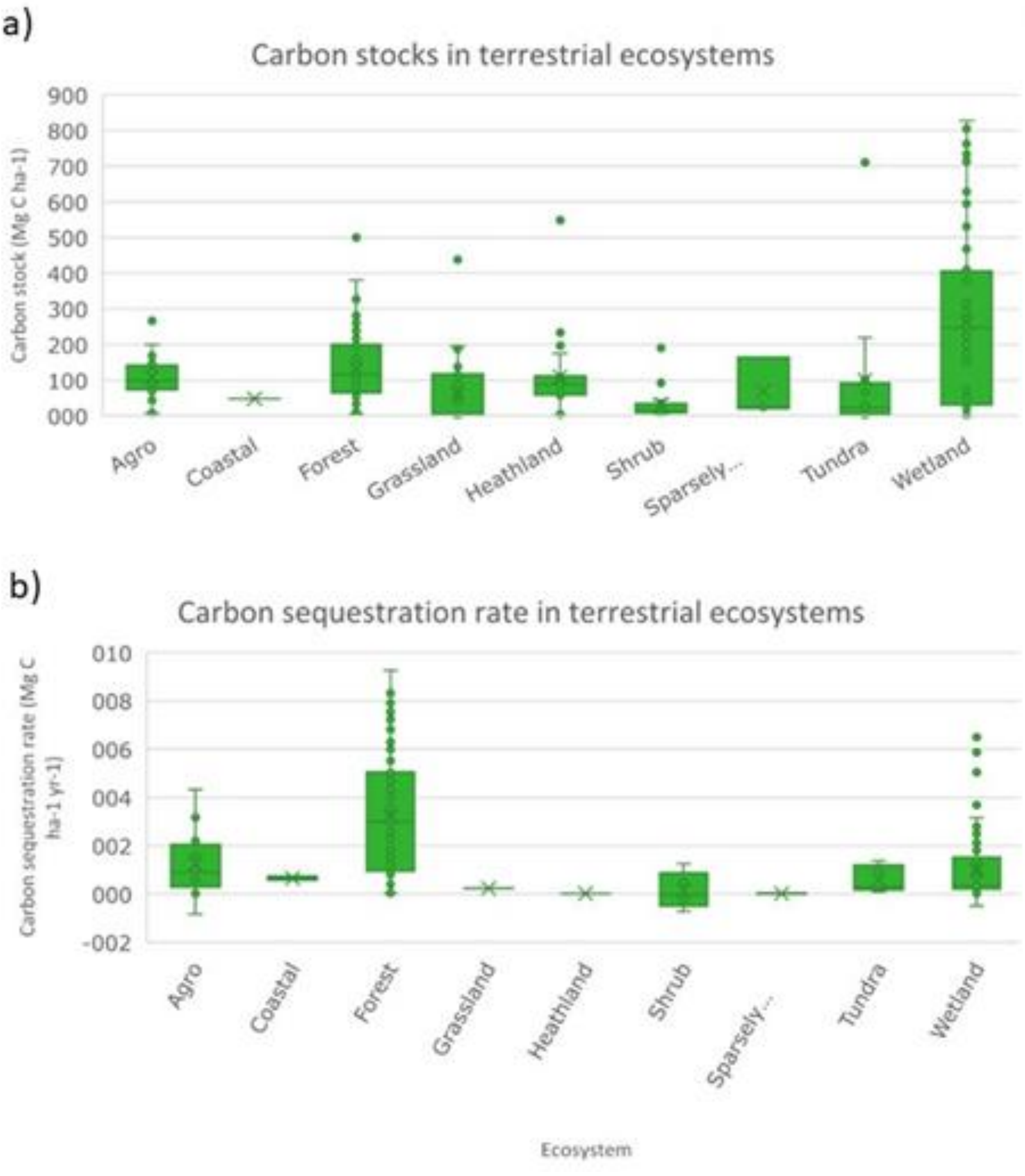
Source: Author's compilation based on EEA data

Without further intervention, the size of the LULUCF sink is projected to decrease further. Projections by Member States on the EEA database of LULUCF emissions under current policies (with existing measures scenario, WEM) point to a total LULUCF sink of only around 190 Mt CO_2e in 2030 (compared to -237.2 Mt CO_2e in 2019).[31] When potential additional measures (WAM) are factored in, this only increases the size of the sink to around 209 Mt CO_2e, although this data was not provided by all countries. The equivalent values for 2040 are 181.3 and 209.6 Mt CO_2e, respectively. A slightly more positive picture is painted by a separate projection, this time from the EU reference scenario for 2020.[32] Here, net emissions from the sector are expected to be -258.3 Mt CO_2e in 2030 and -250.7 Mt CO_2e in 2040, with this increasing to -271.1 Mt CO_2e in 2050. However, these values are still significantly smaller than sink sizes in the decade prior to 2010.

It is also widely understood that accounting for emissions from LULUCF is not straightforward. Recently, the EU released a report summarising data on sequestration rates of different forms of land-use.[33] A clear conclusion was the high degree of variety that exists within the same land-type. Furthermore, a distinction must be drawn between carbon stocks and sequestration rates. Figure 4 was taken directly from this report and shows box plots of carbon stocks and sequestration rates, respectively, for each land type. It can be seen that wetlands are a clear example of a land type with extremely high carbon stocks but with sequestration rates similar to other land types. Indeed, this underlines the importance of protecting existing wetlands in order to protect the stored carbon. Forests were found to have by far the highest sequestration rates of terrestrial ecosystems. But even here, the variance in the rates was pronounced.

[31] LULUCF sector emissions and removals in the EU, by main land use category. EEA. https://www.eea.europa.eu/data-and-maps/daviz/eu-emissions-and-removals-of-1#tab-chart_2 (Accessed: 10.12.2022)
[32] EU Reference Scenario 2020, European Commission. Available here.
[33] https://www.eea.europa.eu/publications/carbon-stocks-and-sequestration-rates/carbon-stocks-and-sequestration-in/carbon-stocks/view

Figure 4. Carbon stocks and sequestration rate in terrestrial ecosystems



Source: Carbon stocks and sequestration in terrestrial and marine ecosystems: a lever for nature restoration? (2020). European Environment Agency.

There is a clear need, regardless of the uncertainties, for natural sinks to be strengthened and the EU has shown some further ambition to strengthen removals. The initial regulatory framework was covered in Regulation 2018/841 as part of the package of measures seeking to reduce pan-European emissions by 40% in 2030, compared to 2005 levels.[34] This defined forest reference

[34] Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in

levels for each country and stated that the sum of total emissions in the sector should not exceed total removals during the 2020s. That is, the size of the LULUCF sink should not decrease. This also accounted for methane (CH_4) and nitrous oxide (N_2O) on top of carbon dioxide.

This further links into the EU's climate neutrality target by 2050. When this was introduced in 2019 through the *'Clean planet for all'* documentation[35], the corresponding impact analysis highlighted three main problems associated with natural carbon sinks. These were the decreasing carbon removals in the land sector, the insufficient integration of the land sector into climate policies, for example through the separation between the agricultural and LULUCF sectors, and challenges in the implementation of current LULUCF rules, such as in establishing appropriate forest reference levels. Reasons given for the decrease in carbon stock included greater wood demand along with a larger share of forests stands reaching maturity. An additional reason given was an increase in disturbances, such as insect infestations, droughts and fires. The documentation also shows that the majority of residual emissions originating from agriculture in 2050, underlining the importance of the combined land use sector in achieving climate neutrality.

The *'Clean planet for all'* documentation further calls for a total of around 400 Mt CO_2e of removals by natural sinks in 2050 to reach climate neutrality[36]. However, many stakeholders have emphasized that total removals will have to be around 600 Mt CO_2e already by 2030[37]. Although not of that magnitude, strengthened legislative proposals are found in the *'Fit for 55'* package of measures[38]. This includes a target sink value of 310 Mt CO_2e from 2030, with specific values assigned to different member states from 2025. The targeted values for each country are listed below in Table 1 (chapter 4.1.) and targeted sink sizes illustrated in Figure 5.

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the 2030 climate and energy framework and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU (Text with EEA relevance). EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0001.01.ENG (Accessed: 18.10.2022)

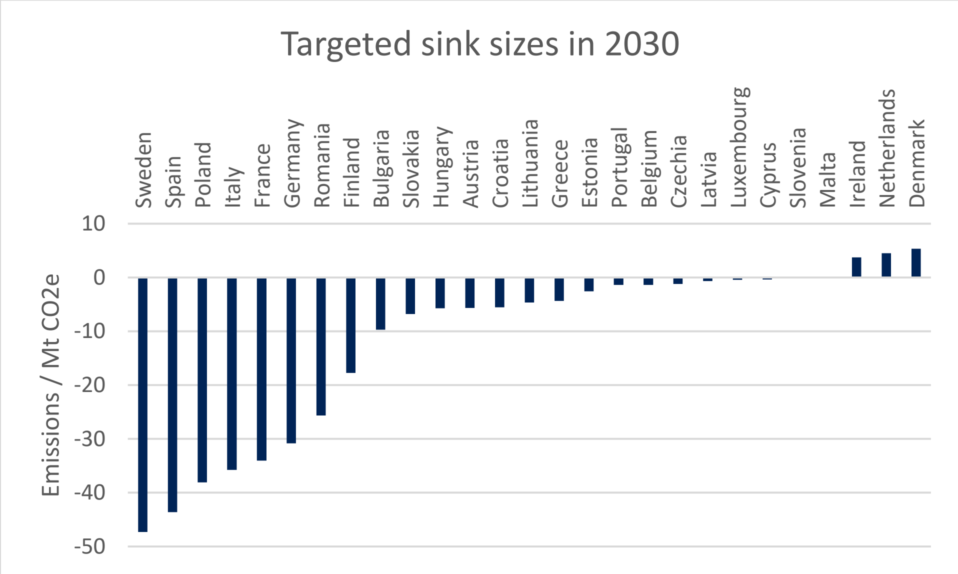
[35] A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773 (Accesssed: 18.10.2022)

[36] IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM (2018) 773 A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. European Commission. https://climate.ec.europa.eu/system/files/2018-11/com_2018_733_analysis_in_support_en.pdf (Accessed: 18.10.2022)

[37] Fit for 55: Reform of the EU LULUCF Regulation. WWF. https://wwfeu.awsassets.panda.org/downloads/wwf_position_paper_on_reform_of_the_eu_lulucf_regulation__july_2021_.pdf (Accessed: 6.09.2022)

[38] Proposal for LULUCF. Fit for 55. European Commission. https://eur-lex.europa.eu/resource.html?uri=cellar:ea67fbc9-e4ec-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF (Accessed: 17.10.2022)

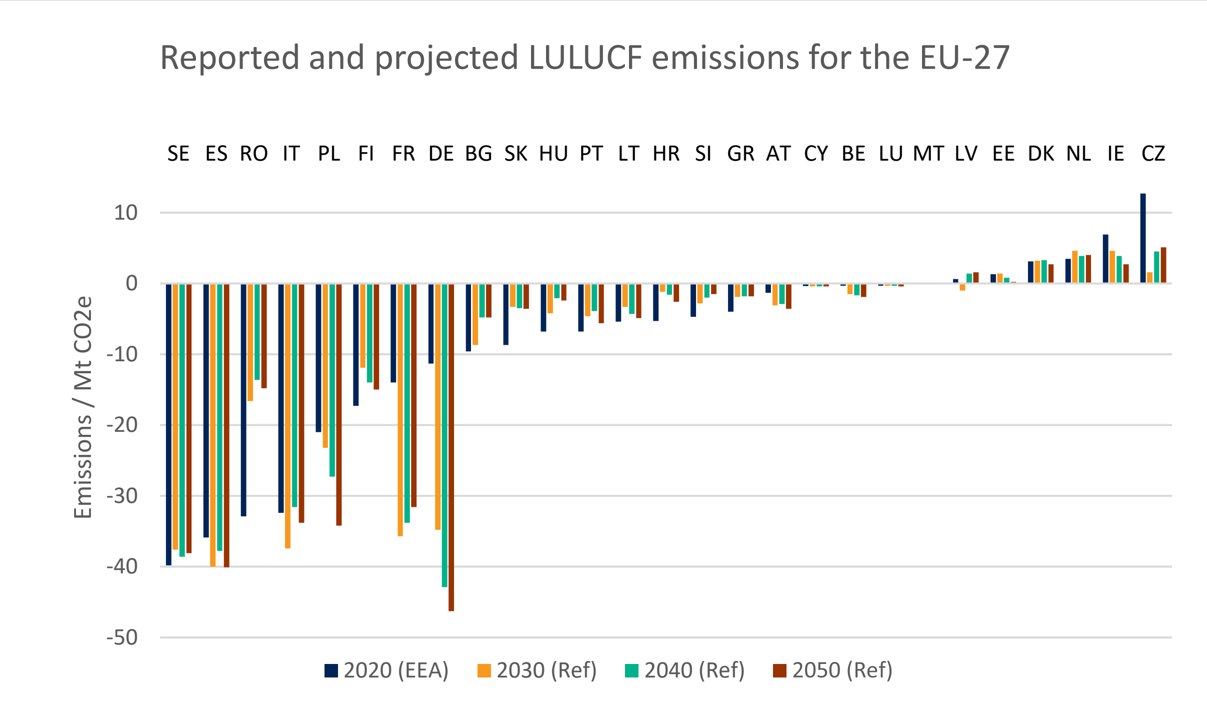
Figure 5. Targeted sink sizes in 2030



Source: Author's compilation based on data from the LULUCF proposal in Fit for 55

The values in Figure 5 show large differences between countries and reflect the differing capacities of each to remove carbon. A further reflection of this is shown in Figure 6. Here, the reported values of emissions for each member state are shown, along with the projections of the EU reference scenario for the years 2030, 2040 and 2050. Whilst some countries, such as Sweden, Spain and Italy have LULUCF sectors that are net sinks, and are projected to remain so until 2050, others, such as Denmark, the Netherlands or the Republic of Ireland belong to the opposite category, with net emissions expected across the period up to 2050, consistent with the situation since 1990. Other countries have seen recent decreases in the size of their sink, and this trend is not expected to reverse by 2050 according to the Reference scenario. The clearest examples here are Estonia and Latvia, for both of whom the LULUCF sector recently became a net emissions source. The Czech Republic is another notable example in this group, with net emissions projected to increase during this period.

Figure 6. Reported and projected LULUCF emissions for the EU-27



Source: Author's compilation based on the LTSs from EU Member States and EU Reference Scenario

Perhaps considering this heterogeneity, the proposals also support inter-nation trading in the form of flexibility mechanisms. Somewhat more long-term is a call for a combined land sector, combining LULUCF and non-CO_2 agricultural sector to be carbon neutral by 2035, as found in the *'Stepping up Europe's 2030 climate ambition'* document that accompanies the *'Fit for 55'* measures. Finally, recent documents have highlighted the need for sustainable carbon cycles decoupled from fossil fuels.[39] Within the *'Sustainable carbon cycles'* communication, the interlinkages between agriculture and carbon sinks are further strengthened through calls to establish a system of carbon farming credits at the individual level that can be traded within the bioeconomy. The latest Commission proposal within the Green Deal puts forward a plan for certification of carbon removals[40]. The regulation aims to significantly improve the EU's capacity to quantify, monitor and verify carbon removals, which will ensure higher transparency, by setting rules for independent verifications, and help fight greenwashing. These high-quality carbon removals need to be correctly quantified, deliver additional climate benefits, strive to store carbon for a long time, prevent carbon leaks, and contribute to sustainability[41]. Moreover, according to the document, carbon removals (both natural and technological) must be in accordance with biodiversity goals.

[39] Sustainable Carbon Cycles. European Commission. https://ec.europa.eu/clima/system/files/2021-12/com_2021_800_en_0.pdf (Accessed: 29.09.2022)
[40] European Green Deal: Commission proposes certification of carbon removals to help reach net zero emissions. European Commission. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7156 (Accessed: 01.12.2022)
[41] Carbon Removal Certification. European Commission. https://climate.ec.europa.eu/carbon-removal-certification_en (Accessed: 01.12.2022)

3.2. Technological options

The call for sustainable carbon cycles also overlaps with discussions on means for technological removals and emission avoidant technologies. The *'Clean planet for all'* communication states that the EU sees the potential for CCS in the power and energy sectors[42]. Although it stipulates that the rapid progression of renewables has lowered this somewhat, it may still be needed for energy intensive industries and the transition phase of hydrogen production before sufficient green hydrogen becomes widely available. BECCS is also based on the same fundamental technology, and therefore similar technological developments will also be needed for this and an associated bio-based (or bioenergy based) industry to be developed.

Since these technologies have yet to reach commercialisation, the document also calls for larger research and demonstration projects, with EU support. The report then shows these technologies coming online after 2035.

The larger impact analysis on the transition to climate neutrality[43], found alongside the *'Clean planet for all'* documentation, also shows the degree of carbon capture, storage, and reuse in 2050 under a variety of different scenarios, out of which two achieved carbon neutrality. As shown in Figure 7, both scenarios that reached climate neutrality include very significant levels of technological solutions that remove or avoid further emissions of at least 300-600 Mt CO_2 in 2050. This includes the use of carbon as a feedstock in short-lived products, along with 200 Mt of industrial removals by 2050 in long-lived products or storage.

More immediately, the EU has an aspirational target to remove 5 Mt CO_2 with technological removals by 2030. It additionally calls for 20% of carbon in chemical/plastic products to be non-fossil by 2030. But it is further stated that this must be part of a three-action approach: to reduce emissions as quickly as possible, to recycle those emissions that do occur through the capturing of point sources, and finally to remove through solutions that take carbon from the air directly. A list of pilot projects in the EU can be found online.[44]

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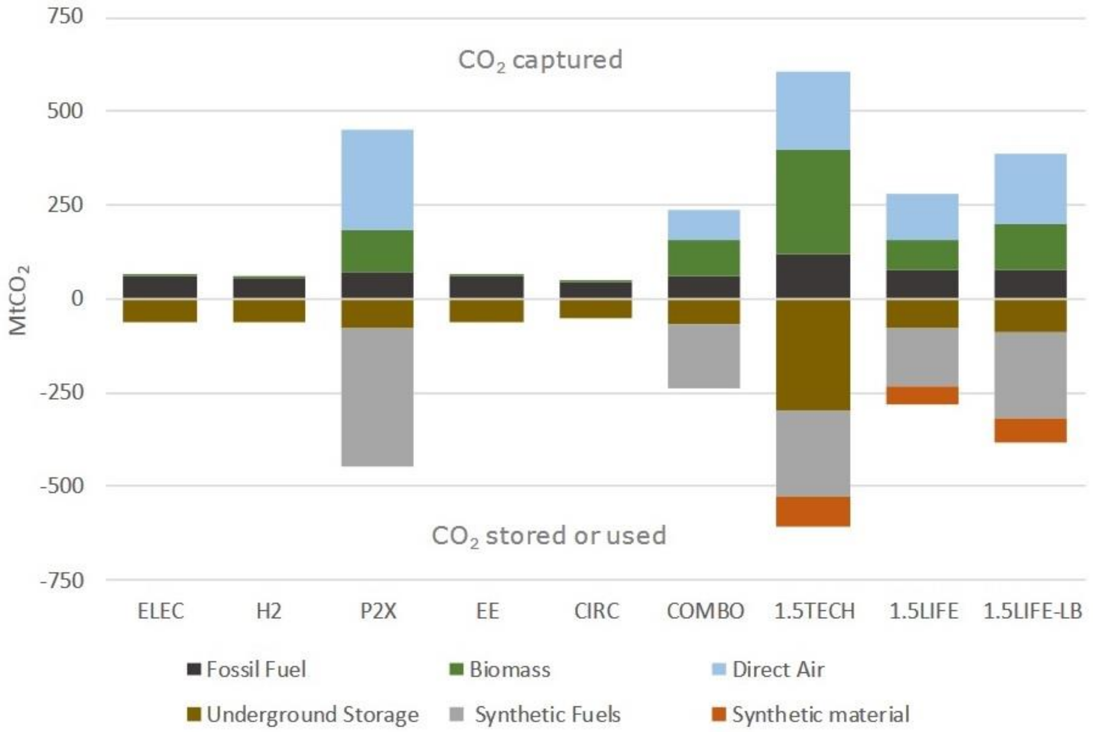
[42] A Clean Planet for All. European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN (Accessed: 01.12.2022)

[43] IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM (2018) 773 A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. European Commission. https://climate.ec.europa.eu/system/files/2018-11/com_2018_733_analysis_in_support_en.pdf (Accessed: 18.10.2022)

[44] CCS/CCU projects. Zero-emissions platform. https://zeroemissionsplatform.eu/about-ccs-ccu/css-ccu-projects/ (Accessed: 18.10.2022)

Figure 7. CO2 captured vs stored/used



Source: PRIMES.

Source: In depth analysis in support of the Commission Communication COM (2018) 773. A Clean Planet for All. (2018). European Commission.

4. Comparative analysis

4.1. Modelling and Targets

The analysis starts by assessing the modelling and targets provided by each country, and what indication they give in terms of the necessary magnitude of the carbon sink to reach climate neutrality. **The aim is not to determine rigorous or precise values for each country.** Instead, the evaluation aims to establish minimum boundaries for total necessary sequestration based on the stated or implied maximum level of reduction each country has proposed, the so-called sink requirements. This can then be compared to projections of natural sequestration for each country in 2050.

The strategies differ substantially in many aspects. This includes length, structure, and the degree of quantitative detail. As of August 31st, 2022, several countries (Bulgaria, Cyprus, Ireland, Poland and Romania) had yet to publish their LTS. Some include only limited, typically qualitative information (*e.g.,* Estonia, The Netherlands) with others still including detailed modelling of emission pathways at the sectoral or sub-sectoral level (*e.g.,* Portugal, Italy). Some strategies act essentially as reports on modelled scenarios, whilst others are situated as higher-level documents to guide policy. Where targets or goals for reductions are included, the level of ambition can vary depending on the date of adoption. Additionally, no assessment of the likelihood or validity of any modelled emission reductions was made. The aim was only to establish boundaries for the level of removals for climate neutrality under the other assumptions of the respective LTS. This always started from the information provided in the LTS, irrespective of ambition. A secondary aim was to assess the likelihood of this being achieved by natural sinks, without having to make use of technological solutions.

Here, we determined the sink requirements using a standardised approach:

- If the LTS states the size of the sink needed for climate neutrality, then this was used. If several options exist (under different modelling scenarios, for example) then the most ambitious was used (*i.e.,* the one requiring the smallest level of sequestration).
- If no modelling was included, the targeted emission reduction (excluding LULUCF) to reach climate neutrality was used.
- If the target was less ambitious than climate neutrality by 2050, any outstanding emissions were added on to the size of the sink.
- If no clear emission reduction target was given, a value of 85% from 1990 levels (excluding LULUCF) was used. The same procedure was used for countries yet to publish their strategy.
- If unspecified, the size of the required sink was then based on the level of remaining emissions in 2050. For example, 15% of emissions in 1990 (excluding LULUCF) for an 85% reduction.
- If the LTS included and specified the size of technological removals that were included in the emission reduction, then this was added on to the size of the required carbon sink. Often, a country only stated that such technologies would be used without specifying the amount of carbon that was sequestered. No adjustments were made in such cases.

The size of emission reductions and chosen method for each country are briefly summarised in Table 1. Further details can be found in 66Annex II: Country details. Countries that clearly state that technological options (in any form) are needed to reach climate neutrality are marked with an asterisk (*). Several other countries appeared to view technological removals positively, but only those that stated its necessity were included. Amongst countries with either direct targets or modelling, the mean size of reductions is around 87% of 1990 levels.

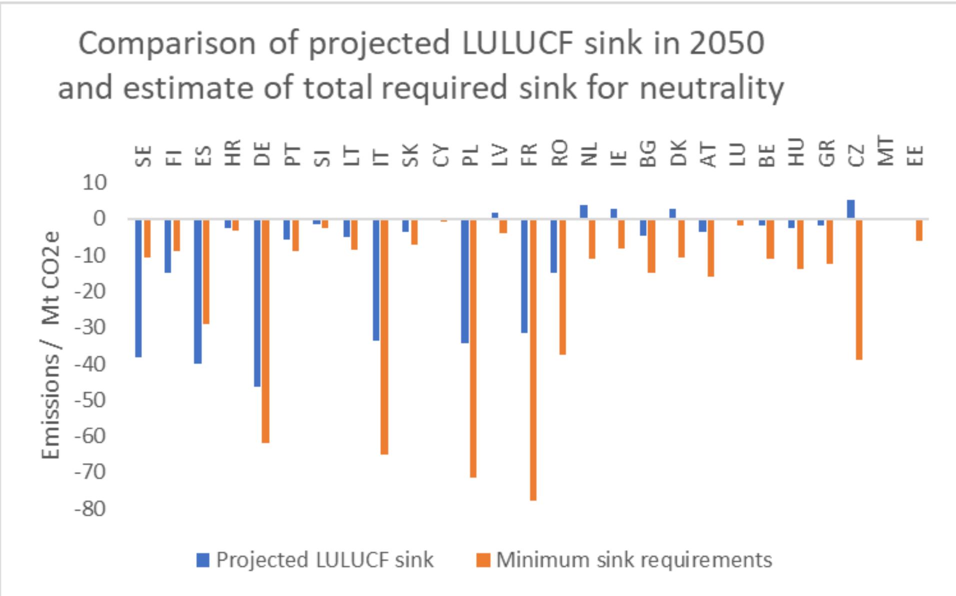
Table 1. Target emission reduction and determined method by country

Country	Reduction target compared to (year)	Method	Country	Reduction target compared to (year)	Method
Austria	80% (1990)	Modelling	Belgium	85% (2005)	Target
Bulgaria	85% (1990)	Assumption (no LTS)	Croatia	89.4% (1990)	Modelling
Cyprus	85% (1990)	Assumption (No LTS)	Czech Republic	80% (1990)	Target
Denmark	85% (1990)	Assumption	Estonia	85% (1990)	Assumption
Finland	87.5% (1990)	Modelling	France (*)	83% (2015)	Modelling
Germany	95% (1990)	Target	Greece (*)	95% (1990)	Modelling
Hungary (*)	88% (1990)	Modelling	Ireland	85% (1990)	Assumption (no LTS)
Italy (*)	87.5% (1990)	Modelling	Latvia	85% (1990)	Assumption
Lithuania	≥80% (1990)	Target[45]	Luxembourg	85% (1990)	Assumption
Malta	80% (1990)	Target	The Netherlands	95% (1990)	Target[46]
Poland	85% (1990)	Assumption (no LTS)	Portugal	90% (2005)	Modelling
Romania	85% (1990)	Assumption (No LTS)	Slovakia	90% (1990)	Modelling
Slovenia (*)	90% (2005)	Modelling	Spain (*)	91% (1990)	Modelling
Sweden	85% (1990)	Target			

[45] Lithuania gave a target that included a maximum permissible value for sequestration, which is used here.
[46] It is unclear if the Dutch target includes LULUCF

Having established the size of the minimum required sink, the values were then compared to the projected LULUCF values for each country in 2050. Here, the results of the 2020 EU reference scenario for the LULUCF sector were used, to allow for a full and equal coverage of each country. No efforts were made to establish the validity of the projections for each country and no additional details were sought for any country. The results of this comparison are presented in Figure 8, which shows a bar chart with the two values for each country. Here, the countries have been ordered based on the difference between the projected and required sinks. Note that the absolute magnitude of the ratio was used in the ordering, since the projected sink is positive for certain countries.

Figure 8. Comparison of projected LULUCF sink in 2050 and estimate of total required sink for neutrality



Source: Author's compilation based on the EU Reference Scenario and the LTSs from EU Member States

Based on the values shown in Figure 8, the countries can then be grouped into three categories:

- Those where the projected LULUCF sink is greater than the required sequestration level (Sweden, Finland, Spain). The sequestration levels for such countries are labelled 'on track'
- Those countries in which the projected sink is within a factor of two of the required sequestration level (Croatia, Germany, Portugal, Slovenia, Lithuania, Italy, Slovakia, and Cyprus). The sequestration levels for these countries are labelled 'within reach'.
- The remaining 16 countries in the EU-27 were found to require sequestration levels greater than 2x the size of the projected LULUCF sink in 2050. The sequestration levels for such countries are labelled 'off track'

Looking more closely at the individual values, the difference between required and projected sinks ranged greatly between the countries. Sweden is predicted to have a sink roughly four times the size it states is required for climate neutrality in 2050. On the other hand, the value for Estonia was 30. This means that for Sweden natural sinks are projected to be roughly 4 times the size the country implies is needed to reach climate neutrality; for Estonia, it is projected to be around 30 times smaller, although in this case it is noted that the value is also high due to the very small (0.2 Mt CO_2e) sink in the denominator. Countries from the former Soviet bloc – and especially the Baltic states – have seen large decreases in emissions since 1990. As such, they suffer in our analysis if no target for direct emission reductions is included in the LTS (using an 85% reduction from 2005 would change the respective ratios would more than half half the ratios for Estonia, Lithuania, and Latvia, respectively). This would make the sink requirements for Estonia 2.9 Mt CO_2e (compared to 2005) instead of 6 Mt CO_2e (1990) and for Latvia 1.6 Mt CO_2e (2005) instead of 3.9 Mt CO_2e (1990). Lithuania included a sink target of 20% by natural removals in 2050 in their LTS, equal to 8.5 Mt CO_2e. However, when taking the same approach as with the other Baltic countries, it would mean -9.6 Mt CO_2e (compared to 1990) and -3.4 Mt CO_2e (based on 2005 levels).

Turning to the other end of the scale, the three countries for whom the projected LULUCF value exceeds that needed for climate neutrality are notable in having some of the largest current levels of sequestration in the EU (Sweden, Spain and Finland had the 1st, 2nd and 6th largest carbon sinks in 2020, respectively). Natural removals in all three countries are also projected to stay at similar levels and, as emissions from other sources successively decline, the size of the sink corresponds to greater proportions of total emissions. However, amongst these three countries, Spain also plans to use avoided emissions technologies (and Finland includes this in one climate neutrality scenario). Although the level of these removals is not specified in the LTS, the document does state that 45 Mt CO_2e can only be removed with the help of so-called 'disruptive' technologies, including CCS/CCU. As such, the sink requirements will necessarily be larger than those shown in Figure 9. Both Finland and Sweden state that technological removals will not be needed to reach carbon neutrality. Finland includes CCS in one of the scenarios that reach neutrality by 2035 (its stated goal), but that was not the scenario use to calculate the sink requirements.

Alternatively, the results bring to light that the majority of countries will have outstanding emissions that are much larger than projected natural removals in 2050, at least under current plans. This is only based on what is currently stated in the LTS's and may change significantly following enhanced ambition at the EU level. Some of these, such as Malta or Belgium, are small and densely populated and will suffer from significant constraints in raising natural removals to the levels required. Estonia and Latvia provide a different example in the sense that these are countries with significant potential but suffer in the analysis from having a sink that is projected to be positive in 2050. In 2010, the LULUCF sector removed 4.8 Mt CO_2e in Estonia, close to the potential value required for climate neutrality in our brief analysis. This suggests that efforts to reverse the recent trend of increasing net emissions hold more potential. Countries such as the Republic of Ireland or Denmark fall into a third category. Both have had net emissions from the LULUCF sector throughout the period of reporting (since 1990), with both also projected to stay as net emitters in 2050. The land sector therefore appears to actively hinder progress towards the neutrality targets, whilst at the same time being the only reliable form of sequestration currently available. It is consequently clear that countries in the first and third category will require extremely high levels of mitigation to approach climate neutrality. Those in the third category will also need to see significant changes in the structure of their LULUCF sector.

The countries in the 'within reach' section are more difficult to assess. Clearly, the EU reference scenario presents results with significant uncertainty, such that the nations in this group could also have natural sequestration levels close to those needed. The values also represent a baseline and policies implemented between now and 2050 could yield significant differences from the projections. Of the countries included here, at least Slovenia and Italy have also stated that technological removals will be required to reach climate neutrality.

The analysis in this section sought to compare estimates of the required levels of sequestration to reach climate neutrality, derived from each country's LTS, against the projected removals from the

LULUCF sector in 2050. In many cases, the level of removals targeted in 2050 was difficult to determine and so a series of assumptions had to be made. A high level of uncertainty is then inherent to the results. For example, the classification for Germany would be very different if the minimum reductions in the LTS (80%) were used instead of the most aggressive (95%). Certain countries may be presented in a more or less positive light simply from not including enough quantitative information in their long-term strategies. An example here is Lithuania, which states that the maximum level of sequestration is 20% of emissions, without ruling out the possibility that a smaller sink being needed in reality. In response, an important first conclusion is then for the LTSs to state more clearly what level of direct reduction and sequestration are being targeted in 2050. Once this has been included, a better picture of which countries have presented sufficient reduction targets can be ascertained. Nevertheless, even such a simple analysis underlines the difficulties some countries may face in reaching climate neutrality within their territorial boundaries.

Modelling and targets

- Not all countries have specified the level of emissions reductions (excluding LULUCF) required to reach climate neutrality. But the average amongst countries that had such detail, either as a direct target or from modelling, was an 87% reduction on 1990 levels.
- A simple comparison of the level of reduction (assumed to be 85% of 1990 levels if not included in the LTS) to the EU reference scenario of the LULUCF sector indicates the assistance natural sink enhancements can play in reaching climate neutrality are not uniformly distributed across Member States.
- Out of the countries with projected sinks, only three countries were found to have sinks of the necessary magnitude in 2050 based on the ‘EU Reference Scenario’ – Spain, Finland, and Sweden
- Several countries will encounter significant additional difficulties in reaching climate neutrality, either because the size of the net LULUCF sink is very small and enhancements encounter spatial constraints, or because the sector has consistently been a net emitter since 1990. Indeed, net emissions from LULUCF precludes climate neutrality, unless technologies for diffuse emission reduction are utilised.

4.2. Land Use, Land Use Change and Forestry, LULUCF

4.2.1. General guidelines for LULUCF

We start this section by considering the general coverage of the LULUCF sector within each of the LTSs. The level of detail and structure of the sector was found to be highly variable between countries. For example, how the sector is included within the strategies varies, with some countries including it as a separate category and others integrating it with agriculture. The guidance given in article IV of the Governance regulation lists agriculture and LULUCF together and as discussed in the introduction, efforts shall be made to combine the two sectors for future accounting. However, most LTSs still contain a separate section on LULUCF. Two of the published LTSs lack any information on the LULUCF sector. How and whether each country has included the sector is documented below in Table 2. The countries in the 'not included' section still made some references to LULUCF throughout the document.

Table 2. Inclusion of the LULUCF sector in the LTS's

Separate section	Integrated with agriculture	Not included
Belgium, Croatia, Estonia, Finland, France, Germany, Hungary, Italy, Lithuania, Luxembourg, Slovakia, Slovenia, Spain, Sweden	Austria, Czechia, Latvia, Malta, Portugal, The Netherlands	Denmark, Greece

Source: Author's compilation based on the LTSs from EU Member States

Several similarities can be drawn out on a first evaluation of these sections, for example, in land planning (or land-use change). Twelve strategies discuss this issue and propose goals for limiting conversions to settlements (the specific terminology changes depending on the LTS). This is not limited to small countries, in which competition for land-use could be higher – large countries like France and Germany also discuss the issue. Secondly, as discussed in the introduction, the complications in accounting for emissions in the LULUCF sector are well-known. Several countries also include targets and goals around improved monitoring of land and habitat-types and in the determination of carbon stocks. Finally, the typical measures to increase sequestration rates are afforestation and reforestation. Many of the strategies hence include this. The inclusion of each of these targets is collated and reported in Table 3 below.

Table 3. Inclusion of targets on land-planning, afforestation/reforestation and monitoring

Land-Planning	Afforestation / Reforestation	Monitoring
Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Italy, Luxembourg, Portugal, Slovenia, Spain	Croatia, Czechia, Denmark, Finland, France, Germany, Hungary, Lithuania, The Netherlands[47], Portugal, Slovakia, Spain	Belgium, Croatia, France, Hungary, Luxembourg

[47] The Netherlands discuss afforestation/reforestation in light of collaboration with other countries with less land scarcity issues.

Source: Author's compilation based on the LTSs from EU Member States

However, despite many countries including these elements in the strategies, the level of detail and ambition is not always the same. For example, on the issue of land planning, Austria states that land consumption should be 'drastically reduced' and emphasizes sensible spatial planning. This is also stated in in the LTSs of Luxembourg and Portugal. Other countries back up this qualitative goal with quantitative targets. Belgium has different targets for its two large regions, with Flanders saying that land conversions ('land take') should be limited to 3 ha/day by 2030 and Wallonia giving a limit of 600 ha/year. The level of net conversions should reach zero by 2040 and 2050 for Flanders and Wallonia, respectively. Similarly, Germany states levels of 30/ha a day by 2030, again with net zero by 2050. Slovenia formulates the target differently, stating that emissions from expanding settlements should be zero by 2050. Finally, France states that land take should be 'limited immediately', specifying a long-term goal of net zero conversions. Denmark also discusses the issue of land planning, though what is meant in their strategy – pilot multifunctional land distribution to inform a future land reform plan – is not entirely clear. Similarly, Estonia states that trends should be monitored and considered in planning, though the meaning of this could be further elaborated upon for more clarity and precision.

Such variations are also seen with the goal of increasing tree cover. As discussed below, this remains qualitative for all but a few countries (although several others may have formulated specific targets to include in modelling but have not specified this in the LTS). Finally, regarding the issues of monitoring and calculations, Croatia states that these should be improved by 2030. France also references improving the monitoring of carbon content in natural environments, whilst also stating the desire to develop a regional tool for assessing climate impacts on forests and wood production. Hungary and Luxembourg wish to develop maps of ecosystem services and forest biotypes, respectively. The Belgian regions also target something similar to Luxembourg. Still other countries underline the uncertainties in accounting for emissions from the LULUCF sector. For example, this is also the case for both Sweden and Finland, the two countries judged to have purely natural sequestration levels 'on track' for climate neutrality. These methodological difficulties could easily jeopardize them being on track. In fact, the Finnish LTS states that climate neutrality is fundamentally influenced by these uncertainties in forest sinks and their development is a key issue up to 2050. Difficulties in quantification is also mentioned in the Slovakian document.

4.2.2. Forestry

Most of the strategies reserve a large proportion of the LULUCF sector for forestry, which reflects that that forestry makes up by far the biggest (or the only) part of the sink size. As stated, nearly all countries reference afforestation/reforestation and improved forest management as means to increase the size of the natural carbon sink. However, the level of detail varies, and few countries give quantitative detail for the expected increase in tree cover. For example, Hungary has the target of achieving 27% forest coverage by 2050. Other countries with specific targets are Portugal, Spain, and Sweden. On the issue of tree cover, a few countries, such as Malta, Luxembourg, and the Netherlands state that this is difficult due to space constraints. The Netherlands raises the interesting option of entering into agreements with other countries to host afforestation outside its national borders. However, tree cover is not the only factor responsible of carbon binding in forests. For example, over half of Estonia's territory is considered forest land, but the LULUCF sector in the country has recently become an emitting one. Forest management practises, the age structure and quality of the forest may be of greater importance. Croatia is one country that clearly states that the value (quality) of forests must be increased as well, and the current forest land has to be maintained or improved.

Beyond the issue of directly increasing sequestration, only a few countries comment on the stabilities of their respective sinks, *e.g.,* Austria, in the case of which it is seen most notably. The Austrian LTS includes an annex showing the level of annual sequestration expected by forestry under a range of different policy options, which align with some of the different directions the country states are possible for reducing emissions, principally in the level of exploitation. Of note is the headline conclusion that sink sizes are predicted to decrease heading into the middle part of the 21st century. For the options where exploitation increases or follows the current trend, the sub-sector is predicted to be a net source from around 2040. In their modelling, the level of sequestration also notably reduces under a scenario where harvesting is reduced, as the sequestration rate is bigger for younger forests than older ones, and the share of non-commercial forests increases. In this case, the sector remains a sink by 2100, but at a very low level. Another country that discusses this issue is France. Here the role of afforestation and forest protection is referenced alongside the issue of development, particularly in French Guyana. Beyond this, the LTS states that the country places more emphasis on storage in durable wood products because of the difficulties and uncertainties inherent to the forest sink.

The issue of sink stability is also one that strongly intersects with management practice and climatic changes. This is underlined in the Hungarian strategy, for example, where without intervention significant parts of the country are expected to transition to 'Forest-Steppe', a mixture of grassland and low-density forest, due to global heating. This will also have a notable impact on the size of the forest sink. Under a climate neutrality scenario, this is mitigated by more aggressive afforestation and the use of more drought-tolerant native trees. Aligned to adaptation or not, the issue of improved management practices is also highlighted by many countries (this topic is discussed further in the section about intersections). A further policy objective is the transition from felling to so-called perennial forest management. For example, Croatia highlights a forest management plan to help with the establishment of good practices and appropriate stand structures. Many countries also call for the development of mixed forests of native species. One example here is Luxembourg, which states that monocultures should be converted into mixed forests to preserve, improve, or restore the functions of forest soil. A series of legislative and financial measures are then listed and the LTS also states that the proportion of old-growth forests should also be increased.

But how these issues intersect with targeted harvesting levels is in general not elaborated upon. Italy states a desire to raise harvests through improved management practices. But it is not entirely clear what such management practices are and how they may differ from the perennial forest management of Hungary or the sustainable management of Lithuania. Therefore, more specificity would be welcomed in the case of Italy. Reductions in burned areas through improved management is another aspect included in 5 of the LTS's, particularly by those countries with known vulnerabilities in this area. Again, Italy discusses this, stating that the size of the burned area could double compared to the long-term average, partly explaining a predicted decrease in the forest sink under the baseline scenario. Hungary, Portugal, Spain and Croatia also discuss management or monitoring in the context of reducing fire risk or burned areas. Spain states that unmanaged forests constitute a missed opportunity for the wood products sector and represent a threat in fire defence and adaptation and Finland sees active forest management as a way of ensuring forest health, then Luxembourg sees the opposite: they see potential in climate adaptation and conservating biodiversity in increasing the area of protected old-growth forests. Finland, however, emphasizes that land that will be freed-up from reduced agricultural use or peat production will be used for afforestation. However, only Portugal gives a quantitative target for reducing the size of the annual burned area, aiming for a value of 70,000 ha/year by 2050 in contrast to the 20-year average of

164,000 ha/year. Measures to achieve this are greater investment in the management of stands, especially regarding fire prevention and fighting. The LTS also states that new afforestation should be with production species or protection / conservation species. Overall, a review of the documents highlights both the similarities (afforestation with native species) and differences or lack of detail (management practices) across the countries.

Further information on what is included by each country is given in Table 4. Note that this table is not intended to be exhaustive. More details can be found in Annex II: Country details. For brevity, the measures were grouped by keyword:

Management change – if the LTS references some change to management or planting practice

Forestation – if the LTS discusses increased tree cover (either via reforestation or afforestation)

Reduced deforestation – if the LTS references reducing the level of deforestation

Other () – other options are grouped here with additional details in brackets.

Table 4. Forestry measures described in the LTS's

Country	Forestry measures
Austria	Management change
Belgium	Management change, Other (monitoring)
Croatia	Other (regulations, research), Forestation, Management change
Czechia	Forestation
Denmark	Forestation, Management change
Estonia	Management change
Finland	Forestation, Management change, Other (regulations, financing)
France	Forestation, Management change, Other (funding, research)
Germany	Management change, Forestation, Other (international collaboration)
Greece	-
Hungary	Forestation, Management change
Italy	Management change
Latvia	Forestation, Management change
Lithuania	Forestation, Management change
Luxembourg	Management change, Other (funding, advice)
Malta	Forestation
The Netherlands	Reduced deforestation, Other (international collaboration)

Portugal	Forestation, Management change, Other (funding)
Slovakia	Forestation, Management change
Slovenia	Management change, Other (advice)
Spain	Forestation, Management change
Sweden	Forestation, Management change

Source: Author's compilation based on the LTSs from EU Member States

We also supplement this general description with examples of greater detail from three countries (Table 5), covering a range of interpretations with regards to the LULUCF sector. The chosen countries represent the diversity of measures proposed and different approaches taken.

Table 5. Detailed forestry measures for Austria, Spain, and Luxembourg

Country	Management change	Afforestation	Other
Austria	Approach should encompass sustainable management and adaptation to increase the resilience and stability of the forest stock. A response to an online consultation, included in the main text, states that forests should be converted into potential 'natural forest communities' with trees adapted to climate change.	Small growth in the size of the forest sink anticipated according to modelling. But no detail in the text.	Several different projections included corresponding to different levels of wood demand/ management. Each point to a reduction in the sink size later in the 21st century.
Spain	Unmanaged forests represent a loss of opportunities for wood products, forest fire defence and adaption to climate change. A management objective is set to reach an additional 3M ha/year by 2050.	Climate neutrality scenario incudes a reforestation rate of 20,000 ha/year until 2050. This would increase absorption by 7 Mt CO_2e a year. Signs of saturation in forest sinks had previously been observed.	
Luxembourg	The wood volume of forests can be increased	Afforestation is limited by spatial constraints.	A complete map of forest biotypes should be

	through increasing the area of protected old-growth forests, conservation of dead wood, and promotion of resilient, mixed and diversified forests. Forests increasingly under threat due to bark beetle infestations. Over 50% of trees show sign of stress. Measures for viable forests under climate change are to convert monocultures to mixed forests and preserve, improve or restore functions of the forest soil.	Increasing sink sizes therefore requires the volume of wood in existing forests being increased.	developed. Decision making tools for the choice of species. Legislative measures to further protect forests and studies into the potential for sustainable wood harvesting. An aid scheme and advisory services for forest owners / managers should be strengthened and diversified. A premium for ecosystem services in forests could also be introduced.

Source: Author's compilation based on the LTSs from EU Member States

4.2.3. Other Land use

Although forestry holds a pivotal role in the LULUCF sector, it is also important to consider how the LTSs incorporate efforts across other land use categories. Here, significantly less detail was provided, and the type of information also varied. For some countries (*e.g.,* Portugal, Slovenia), a description of emissions (such as which categories were net sinks/sources) or change in land area was included. At times, this also extended to a projection by 2050 (*e.g.,* Spain, Germany). In certain cases, general ambitions or measures were given. Finally, a few countries gave more detailed targets or indicated more specific measures. However, these were not necessarily inclusive of one another; an LTS that provided more specific measures may not have included detail on which land use categories were net sinks and which net sources (*e.g.,* Latvia). Whether a particular landscape was included may reflect the particularities of the country in question.

In general, wetlands and peatlands were included most often in the strategies. Where this was the case, the desire to restore or protect remaining areas (or otherwise limit peat extraction) was universal. Permanent grasslands and croplands were also discussed in some cases, but to a lesser extent (e.g., Belgium, Luxembourg).

This was based on efforts to increase the size (through changes or reductions in agricultural practices) or carbon content (such as through reduced ploughing) of these land categories. The intersection of the sector with agriculture is thus made clear in this latter case. Croatia for example, states that only considering one type of storage can lead to an increase in emissions overall and gives the example of grasslands, since the soil carbon stock of grassland is higher than in forest land. They also state that new management practices in certain LULUCF categories can reduce the sink size, *e.g.,* removing wood for energy purposes was found to lead to long-term decrease in storage in soil.

A summary table of the coverage of these factors in each country is provided below (Table 6). For simplicity, the table makes a distinction between targets, where a specific, quantitative value is given, and more qualitative measures (*e.g.,* peatland restoration). Measures are called prescriptive if more detail is given, for example on specific policy instruments. It also highlights whether details on current or future emissions from individual land categories are given.

Target – some quantitative value to increase / limit degradation / etc

Description - this was source, etc. (quantitative) if numbers

Description (projection) – expected values in 2050

Measures (description) – general details (e.g., increase peatland)

Measures (prescriptive) – details of specific policies or instruments

Table 6. Other land use measures described in the LTS's

Country	Land category	Details
Austria		
Belgium	Wetlands, grasslands	Measures (descriptive)
Croatia	Grassland, cropland, wetland	Description
Czechia	Wetlands	Measures (descriptive)
Denmark		
Estonia	Wetlands	Measures (descriptive)
Finland	Wetlands	Description (projection)
France		
Germany	Wetlands, grasslands	Measures (prescriptive), Target
Greece		
Hungary	All	Description (projection)
Italy		
Latvia	Grassland, cropland, wetland	Description (projection)
Lithuania	Wetlands, grasslands	Target
Luxembourg	Wetlands, grasslands	Measures (descriptive)
Malta		
The Netherlands	Wetlands	Description, measures (descriptive)
Portugal	All	Description (quantitative)

Slovakia	All	Description (projection)
Slovenia	All	Description (quantitative), measures (descriptive)
Spain	Wetlands	Description (projection), target
Sweden	All	Description, measures (prescriptive)

Source: Author's compilation based on the LTSs from EU Member States

The distinctions between different countries are further illuminated in Table 7, which summarises the full details from Germany, Slovenia and Slovakia as these are countries with very different approaches in covering the topic. Whilst Germany lacks quantitative detail, it includes a series of measures to reduce emissions from peatland and grassland, although focussing on the period prior to 2030. Slovakia, on the other hand largely describes the results of the modelling conducted as part of the LTS but does not include policy measures. Finally, Slovenia includes some detail on the current state of emissions and a general description of measures, but with less specific detail than found in the German LTS.

Overall, the coverage of other land use categories varies substantially between the different countries. This may reflect differences in interpretation between those countries that focus on more qualitative descriptions of measures and the general situation under climate neutrality, and those that take a more quantitative approach that leans on modelling, but with perhaps less detail on policies.

Table 7. Detailed other land use measures for Germany, Slovakia, and Slovenia

Country	Details
Germany	By 2050, peatland extraction should be reduced (and eventually shut down) with no further conversion of peatland or ploughing of permanent grassland. Progress is needed by 2030 and most detail refers to this period. Conversion of permanent grassland is prohibited without official approval and cannot be reduced by more than 5% in any region. Efforts are made to increase protection at the EU-level. Attempts to create agreements with regions to conserve peatlands and create incentives for investment are underway. Peat use should also be reduced as a growing medium and there are guidelines regarding this in public procurements. The protection of carbon-rich soils for energy use is in national legislation and should be broadened to other uses.
Slovakia	Removals from grassland and cropland are projected to decrease and emissions from settlements and other land are set to increase under a WEM scenario. A table showing the projected values is included in the annex. Wetlands were not included in the modelling due to a lack of data. For the WAM scenario, afforestation of grassland and conversion of cropland into permanent grassland are considered. A number of additional measures are further suggested under a climate neutrality scenario. However, this was performed without any modelling.

	In 2018, forest land, settlements, other land, and wetlands generated emissions of 0.9 Mt CO_2e. Grasslands, cropland and harvested wood products were net sinks on the order of -0.6 Mt CO_2e.
Slovenia	Within agriculture, grassland (reduced ploughing) and wetland (preservation) sinks should be preserved. Unmanaged wetlands should be protected. The 'status' of wetlands is being increased with respect to biodiversity.

Source: Author's compilation based on the LTSs from EU Member States

LULUCF

- Whether and how LULUCF was included in the LTS's varied between countries. Although the sector was most commonly included in a separate section, discussing it in relation to agriculture was also common (six countries). Two strategies (Greece and Denmark) made no mention of LULUCF, whereas the Greek strategy was otherwise very detailed. As with other sectors, the coverage and detail varied substantially amongst those that did include the sector.
- The issue of land planning and reducing land conversions was included by twelve countries. Several included targets to reach net zero land conversions by 2050. This was seen in both small and big countries' LTS's.
- Attempts to enhance afforestation or reforestation were included in most of the strategies. However, only a few provided quantitative targets for forest cover (such as Hungary and Spain). A few countries, such as Malta, Luxembourg, and the Netherlands highlighted the difficulties in increasing tree coverage due to space constraints.
- Issues around monitoring and measuring the LULUCF sector and its emissions were also commonly covered. But an important related issue, that of sink stability, was hardly included at all. Notable exceptions were the Austrian and French LTSs. This is a critical issue for long-term climate neutrality targets post-2050.
- The idea of improved or expanded management and protection of forests was also discussed frequently. However, the exact practice varied significantly. For example, Luxembourg aims to increase the amount of protected old-growth forest and reduce the removals of dead wood. On the other hand, Spain sees advantages in increasing the amount of forest under active management. These differences could be due to the different environments found across the continent – one reason given by Spain is to reduce fire risk. However, in general the type of management is not widely explained beyond a few keywords (*e.g.,* sustainable management).
- Discussion on other land use categories besides forests predominately focuses on wetlands and permanent grasslands, reflecting their relative importance in

the sector. Where wetlands were included, ambitions to halt degradation or enhance restoration were universally included. The intersection with agriculture in the latter case is clear. References to increasing the carbon content of soils are discussed by reduced ploughing, for example, but numerical details are rarely included.

4.3. Intersections – agriculture, biodiversity, and adaptation

As previously mentioned, LULUCF has significant overlap and intersections with the agricultural sector as well as the topics of biodiversity and adaptation. Further details on what intersections are included and to what extent by each country is given in Table 8. However, this table is not intended to be exhaustive. More details can be found in Annex II: Country details and the surrounding text.

Table 8. LULUCF intersections with agriculture, biodiversity, and adaptation in the LTS's

Country	Agriculture	Biodiversity	Adaptation
Austria	Competition for land; bioenergy	Competition between resource use and mitigation	Climate change (CC) resilient tree species
Belgium	Public training on sustainable agricultural practises (mainly for farmers); agricultural sequestration and its' synergies with adaptation	Equal focus on biodiversity and carbon stock (building resilience); green/blue network	CC resilient tree species (obligation); public and private gardens/parks/roofs, urban agricultural areas; creation of an expert group
Croatia	Monitoring changes in carbon stocks in agricultural soils and pastures; agroforestry; competition between biomass and food production	Measures need to be harmonised with biodiversity goals	No direct mention
Czechia	Measures for sustaining carbon sequestration in soils; up to 8% of the total area for biomass production	No direct mention	No direct mention, but restauration of wetlands and dried peatlands can be seen as an adaptation measure
Denmark	Pilot scheme for multifunctional land distribution (major land reform)	Goal to increase biodiversity (untouched woodland, nature parks etc)	No direct mention
Estonia	Increasing carbon sequestration in soils, legislation to reduce agricultural land falling out of use; increased R&D	No direct mention, but avoiding further draining of wetlands has an influence	CC long-term impacts included in land use planning; optimal adaptation of natural species, habitats, and ecosystems targeted
Finland	CC impact not considered in modelling the effects on agriculture; agricultural biproducts used for bioenergy; declining livestock numbers limit biogas from manure	Impacts of land-use change on biodiversity; creating new conservation areas	Not described in the LTS, mention national adaptation plan
France	Greatest source of emissions in 2050 (by far);	No direct mention	Mention national adaptation plan (complements the

Country	Agriculture	Biodiversity	Adaptation
	agroforestry; limited land take; soil conservation; bioenergy from waste; preserving permanent pastures etc.		LTS). Urban planning measures like multiple land use, reducing heat islands, rainwater runoff; sustainable forest management; atmospheric carbon storing building materials
Germany	Conservation of peatlands and permanent grasslands (no more than 5% decrease), funding for paludiculture[48]	No direct mention	CC resilient tree species, coastal protection by planting, forest climate fund
Greece	Energy crop cultivation (land requirements set to increase 4x	No direct mention	No direct mention
Hungary	'Main direction for intervention' together with LULUCF; precision fermentation; adaptive soil and water management	Dissemination of natural water replenishment and conservation-friendly irrigation; preserving and restoring natural ecosystems; developing green infrastructure; mapping ecosystem services	Healthy and climate resilient forests and grasslands; CC is a boundary condition in forest policy (perennial forest management, fire prevention, revenue compensation for loss of production to forest owners). Land use incentives to reduce extreme weather impacts and ensure soil fertility
Italy	Agricultural land use growing until 2040; increasing carbon sequestration in soils; technological innovation; changes in consumption habits and production methods	No direct mention	Mention national adaptation plan; adaptation measures for extreme weather events, forest, agriculture, transport, hazardous industries and infrastructures, energy, health and water resources described
Latvia	Good overview of emissions in the sector, including crop- and grassland emissions in organic soils, management methods to increase carbon stock in mineral soils. 1st generation biofuels are not manufactured	No direct mention	No direct mention

[48] crop production on wet soils

Country	Agriculture	Biodiversity	Adaptation
Lithuania	Change in consumption; sustainability training and financial measures to farmers; farm-level accounting system; reducing food waste; manure use for biogas production	Restoring wetlands and other ecosystems, protection of forests, grasslands, wetlands	General and agricultural adaptation methods described, accelerated implementation needed. Accounting system for losses/damage of CC on national/sectoral levels, lack of knowledge on societal and municipal levels; CC impacts on health and ecosystems; nature-based solutions.
Luxembourg	Agroenvironmental technologies; soil carbon sequestration (through crop diversification); agroforestry. Circular economy strategy where agriculture, food, bioresources are key aspects; healthy/sustainable diets, reducing food loss and livestock numbers; conservation plowing. Agriculture impacts/is impacted by CC and has a key role in energy production (biogas, solar)	Wetlands restoration, creating a green infrastructure	Strategy and action plan for adaptation. Complete map of forest biotopes and measures for viable forests under CC; convert monocultures to mixed forests; preserve/improve/restore functions of forest soil; increase the wood volume of existing forests (land limitations)
Malta	Sequestration in soils, loss of economically viable farmland, competition for water use	Loss of biodiversity, native species, habitats, difficulties in pollination mentioned	Ecological and adaptational value of forests; adaptation needed in several sectors, land use management to be adapted to CC (not many details)
The Netherlands	Capturing CO_2 in farmland (smart solutions); coherent use of biomass, nuclear and CCS/CCU is a 'known trilemma'	Pilot projects for wetland and landscape restoration	Being adaptive without 'hanging back'
Portugal	Regenerative agriculture, increasing the organic matter in pasture.	Plant native species; reinforce the distribution of support for ecosystem services and maintenance of forest biodiversity; increasing biodiverse pastures and conservation areas	Costs of CC effects in Portugal described. Improvements in land management/planning; investments in fire prevention; combating desertification; nature-based solutions. Decarbonisation,

Country	Agriculture	Biodiversity	Adaptation
			adaptation and mitigation measures' synergies described. Mention Climate Change Adaptation Action Programme.
Slovakia	Agricultural emissions have not been studied in detail, lots of potential for biomass production (animal and wood waste, increased support)	Analyse different crops' influence on carbon stock and biodiversity	LULUCF vulnerability to CC effects and its' impact on removal potential. Mention national adaptation plan (underway).
Slovenia	Increase efficiency of animal husbandry, nitrogen circulation and the share of extensive grazing (social acceptability); efficient knowledge transfer between generations of sustainable agricultural practises. Change in behaviour, measuring food products footprint, health aspects of excessive meat consumption; micro-biogas devices (food waste and methane from livestock)	Reducing invasive alien species; improvement and restoration of ecosystems; nature conservation; increasing forest soil carbon stock, leaf litter and deadwood. Preservation of traditional methods (late mowing); green infrastructure	Salvage felling to tackle windstorms and bark beetle attacks. Adaptation action plan on the way, agriculture and forestry adaptation strategies already in 2008. Implementation of cost-effective biodiversity supporting adaptation measures available to all; vulnerability assessments; lag on the topic in the country; long-term spatial planning with environmental protection as a priority; support and knowledge to local communities for the preparation or implementation of adaptation measures
Spain	Agroforestry; conservation agriculture; soil sequestration, promotion of rotations in dryland herbaceous crops	Wetland restoration, regeneration of meadows; emphasis on ecosystem services (including carbon capture), state of ecosystems monitored to not worsen the state with other decisions; no negative effect on biodiversity and ecosystem services (everyone must contribute)	Defence against forest fires; CC resilient species; carbon fixation in woody crops and soil; Mediterranean diet. CC effects already visible (influence on RES); adaptation relation to ecosystems functionality. Urgency, social equity, Just Transition. Comprehensive adaptation systems (sectors' overlap). Mention national adaptation plan.
Sweden	Support for organic farming; biomass harvest in	Considering to compensate the landowners for the	Mitigation/adaptation e-services to forest owners/

Country	Agriculture	Biodiversity	Adaptation
	accordance with achieving other goals	protection of forest land; biodiversity overlaps with circular economy; sustainable forest management in light of biodiversity, wetland/ peatland restoration; preserving natural grazing	workers/farmers; adaptation in forests (active forestry combined with high environmental requirements; responsibility on local administrative boards; more than 800 measures (flood and shoreline protection, adapting in agriculture, forestry etc). Mention national climate adaptation strategy

Source: Author's compilation based on the LTSs from EU Member States

As it was briefly mentioned in the LULUCF chapter above, six countries (Austria, Czechia, Latvia, Malta, Portugal, The Netherlands) integrate agriculture with LULUCF in their LTS's. Spain for example treats the subject as "natural sinks of carbon", meaning in the descriptive part they do not differentiate between LULUCF and agriculture. They also emphasize the interaction between mitigation and adaptation very clearly *"Without adequate mitigation action, adaptive capacities will be inevitably overwhelmed and on the contrary, without adequate adaptation, mitigation action will not allow the objectives to be met."* Further, they state that adaptation helps maintain the good state of ecosystems and vice-versa.

Luxembourg, Slovakia and Slovenia had the most comprehensive LTS's in terms of overlaps with agriculture. Slovenia went so far as to discuss the social acceptability of different livestock production methods (free-range hens vs intensive poultry production) and health aspects of excessive meat consumption in the country. They also covered by far the most biodiversity topics, alongside with Belgium. Many countries mention 'organic soil management' under agricultural measures and Latvia describes its high emissions in the sector by giving an example of the difference between managing organic and mineral soils: 1 ha of unused agricultural organic soil generates on average as much GHG emissions as 10 ha of mineral soil. Another measure proposed by several countries is agroforestry, which could have its conflicts with food production goals and greater land-use, but these could be mitigated by reducing waste and overall consumption. Estonia plans to reduce land use and emissions per unit of output in the agricultural sector, which will increase productivity and efficiency. However, intensifying agricultural production has negative impacts on biodiversity. Sweden, similarly to Belgium and Lithuania, offers digital information and e-services to forest owners, workers and farmers on mitigation and adaptation.

Austrian LTS highlights the need to ensure balance between competing goals (biodiversity, mitigation, resources), however the authors feel in some cases these could be developed simultaneously. For example, instead of using 1st generation biofuels, focus could be put on 2nd (*e.g.*, agro-residues, non-edible plant mass), 3rd (algae) and 4th generation biofuels (genetically modified algae) that do not compete with agricultural land use. 2nd generation biofuels are discussed in the LTS to some extent, but not third and fourth. Moreover, we find if soil regenerative species are used, it could even have a positive impact on agriculture and increasing the overall plant cover would benefit climate adaptation, so there are ways how these areas could support one another. Further, Austria mentions the importance of having a holistic approach which includes adaptation and sustainable forest management which would help ensure the stability of forest stock, which is a bit contradictory with seeing competition between biodiversity, resource use and mitigation measures.

The Belgian LTS is one good example of a comprehensive strategy in terms of that it equally describes different sectors (agriculture, biodiversity, bioresources, adaption etc.) and the overlaps between them. Moreover, it is very detailed as it describes the regions in the country separately. Belgium (as well as Austria, Germany, Hungary for example) see potential in planting more climate change tolerant species (obligation in the future) and putting more focus on research into tree stress to help with management. Considering the changes in the climatic conditions they stress that CO_2 should be stored sustainably in public and private gardens and parks, urban agricultural areas and green roofs. As such a transformation requires the engagement of stakeholders, they suggest creating an expert group for adaptation and special training of sustainable agricultural practises is offered to the public (mainly farmers). Moreover, there’s a separate section in the LTS about adaption in the agricultural sector.

Belgium as a small country emphasizes in its LTS that in one of its regions, Flanders, there is a need to preserve and expand solid open space, including releasing space for water. Risks like increased flooding and soil erosion are described and measures to compact these are given. The Belgian LTS puts focus both on increasing the carbon stock and biodiversity, which also helps them build resilience. While most countries only reference the 2050 climate goals, Belgium also emphasizes the importance of meeting European conservation goals by 2050. Further, Belgium expresses the need of designing a well-functioning green/blue network and areas for biodiversity. Belgium is one of the countries that recognizes the potential of agricultural sequestration and discusses synergies with adaptation, although they also state that there is a lack of knowledge of the exact potential to store carbon in soils. Currently, soils in the country store about 1000 kt CO_2e per year, even though they cover 80% of the territory.

Another example of an LTS that includes LULUCF in a comprehensive manner is Croatia, whose LTS clearly illustrates the overlaps with agriculture by stating that by 2050, measures of agricultural practices should include contribution to carbon sinks within LULUCF. The Croatian LTS also states a need to create a system to monitor the changes in the carbon stock of the agricultural soils and pasture. They propose conducting surveys about fertilizer use and soil type as a possible solution for this. Croatia plans to improve and harmonise regulations in forestry, agriculture and environmental protection as well as analyse the effectiveness of current measures for agriculture and forestry sectors.

Intersections

- Six countries (Austria, Czechia, Latvia, Malta, Portugal, The Netherlands) integrate agriculture with LULUCF in their LTS.
- Spain describes adaptation measures the most comprehensively in their LTS, Portugal, Slovakia, Slovenia and Sweden also have quite extensive discussion on adaptation.
- Luxembourg, Slovakia, and Slovenia had the most comprehensive LTSs in terms of overlaps with agriculture.
- Slovenia and Belgium put the most focus on biodiversity in their strategies.
- The Belgium and Croatian LTS's are good examples of a comprehensive strategy, that equally describe the different sectors (agriculture, biodiversity, bioresources, adaption etc.) and overlaps between them. Austria sees the three sectors (biodiversity, mitigation, resources) as competitors and highlights a need to find a balance between them.

4.4. Bioresources

One sector that is tightly intertwined with LULUCF is bioeconomy and the use of bioresources. Wood and other bioresources are often seen as a good alternative to fossil-based materials, which play a role in reducing emissions from extracting these resource-intensive materials, but on the other hand developing bioeconomy results in greater land use. Many countries (*e.g.,* Croatia, Latvia) state they want to develop their bioeconomy sustainably while not compromising other goals like food sufficiency, biodiversity etc. Table 9 gives an overview of the plans in the sector for each of the Member States.

Table 9. Description of bioresources in the LTS's

Country	Plans to increase the use of bio-resources	Sector(s)	Details
Austria	yes	Energy transition, industry and buildings	High potential, but competition for land use. Bioeconomy strategy. 4/5 scenarios for wood use (expect *reduced wood use*) lead to a reduction in forest growth, with all four being a net source by 2040.
Belgium	yes	Biofuels, wood products	Flanders and Wallonia: biomass use based on hierarchy of sustainability (priority to long lived and high value products). Limits on extraction rates in both regions. However, both see biomass as a fuel source as well.
Croatia	yes	Biofuels (including heavy transport, district heating), wood products	Wood use in new and traditional products, support for wood residues and production (carbon storage). Biofuels as the most promising output (help achieve sustainability requirements); biomass and -gas as renewable energy sources (RES) for electricity, use in district heating (DH) systems, less in households. After 2030, replacement by heat pumps and solar thermal heating. In the reference scenario, solid biomass and biogas were predicted to decrease, other biofuels increase. In the strong transition scenario, biogas use significantly increases after 2040. No info for the climate neutrality scenario.
Czechia	yes	Energy, wood products	Biomass for energy, increase up to 2040; potential for 680 000 ha of arable land and 400 000 hectares of permanent grassland for biomass. Increasing competitiveness of forest-based value chain (higher domestic use of wood (products), research into new low-emission products).
Denmark	yes (or remains similar)	Heating, electricity generation	Significant use for heating (2017 made up 2/3 of renewable energy), projected to decrease by 2040 (particularly in heating and cooling), but will remain a significant source (10% of electricity demand), whilst the share of forests is targeted to increase.
Estonia	yes	Energy transition (electricity generation, heating, biofuels, biogas)	Widespread use of domestic bioresources and other RES for electricity production, thermal energy and transport fuels encouraged; combined use of manure from intensive farms and previously unused grassland resources for biogas. Low-quality wood and by-products as fuels.
Finland	yes (modest)	Biogas, transport, fuel oil for buildings,	Modest increase in bioenergy compared to 2020 in all scenarios, but in 2050 bioenergy provides significantly more energy than wind and solar. Biogas production from manure is limited by declining livestock numbers. Timber harvesting increases in the *savings* scenario but will limit the use of bioenergy

Country	Plans to increase the use of bio-resources	Sector(s)	Details
			resources. The *continuous growth* scenario decreases the amount of harvested timber and increases the size of the carbon sink.
France	yes	Wood products and buildings, transport, energy, industry, agriculture	Circular wood economy, main use in buildings and long-lived products (production triples from 2015-2050). Increasing the carbon efficiency of wood products (carbon stored per m^2 of floor area, the volume of wood sent to landfill). Biomass helps with energy transition, it will provide between 400-450 TWh of energy in 2050. Highest expected use of bioenergy in transport. Consumption is likely slightly above production potential, tensions that could arise from this are highlighted. Food is a priority.
Germany	Not clearly stated, but we can presume	Buildings, wood products, energy	Hierarchy of wood use (buildings and other durable products first), barriers need reducing. Wood use in a cascade, cycles should be closed through optimised recycling. Incentives for R&D can promote this (new products as well). Bioenergy from cultivated crops will be limited by 2050, importance to waste and residues.
Greece	yes	Energy, transport (aviation etc), power and industry, biomethane	Bioeconomy development is a priority, large increase in using biomass expected, mainly from non-edible plants (woody biomass, agricultural and logging waste, less from forests). 2nd generation biomass (not food) available after 2030 (*e.g.,* willow and poplar). Abandoned land used for large-scale cultivation to achieve this growth. Primarily for energy, especially in the sectors transport (aviation, shipping, heavy goods vehicles) and electricity. In the *1.5ºC scenario* biofuels account for 41% of final energy consumption (20% when new energy carriers are included); biomass for energy increases by a factor of 4-5 in the scenarios; biomethane provides 20-30% of the gas distribution network in all scenarios (regulations on mandatory mixing). Large-scale pellet industry could be developed (competition with advanced biofuels). The competition for biomass is great, but biofuels have greater added value than other uses.
Hungary	No info	Heating, transport, wood products	Firewood use in households greatly declines (BAU), in the CN scenario it is reduced to a minimum to use the resources in other sectors. Biofuels quite heavily in the transport sector (28 PJ in 2050), but there are no further details beyond this. Forest biomass can substitute forest fuels and sequester carbon in wood products. The importance of R&D emphasized.
Italy	yes	Wood products, energy, heating, agriculture, transport (shipping, aviation, road)	Mention that the potential of biomass must be “fully exploited” as well as the value of wood and sustainable forest management. Biogas and -methane have a significant role in thermal end uses but also in the generation sector. Huge energy potential generated by agricultural activities (wastewater, other by-products, PV on rural buildings) and advanced biorefineries. Regenerative bioeconomy (protection and regeneration of soils, atmospheric CO_2 absorption). Advanced biofuels (as well as electrification, hydrogen, and synthetic fuels) are the most viable options for short sea shipping and inland waterways, while biofuels are an option for aviation.
Latvia	yes	Energy, wood products, transport (aviation, railway)	Electricity produced in biomass cogeneration plants has increased from 215 to 525 GWh and from 288 to 405 GWh in biogas cogeneration plants (the usage of solid biomass in combustion installations spiked when Latvia joined the EU). Promotion of bioeconomy (wide-scale solution) as well as climate objectives by using wood resources for manufacturing products with high added value, sufficient extensive use of liquid biological heating fuel in energy generation, use of bio-oils in equipment in the agricultural and forestry sectors (one solution in achieving CN). Biofuels for aviation and non-electrified train lines. In 2050

Country	Plans to increase the use of bio-resources	Sector(s)	Details
			newest generation biofuels will reduce the risks of edible crops and valuable soil being used for the acquisition of bioenergy.
Lithuania	yes	Wood products, buildings, biofuels, biogas, (district) heating, transport	Currently, biofuels are used relatively extensively in DH (besides gas). Increase in the number of dangerous pollutants from heating equipment in households, (inefficiency of solid (bio)fuels and heat production facilities). Preconditions to promote the consumption of fuels from RES and advanced biofuels by imposing obligations on fuel suppliers. 2024: Adapt the existing natural gas network infrastructure to H2 and biogas transport; all public buildings built at least 50% organic and wood materials. 2030: Bioeconomy focused on high added value moving towards a circular transition, while increasing its contribution to the country's GDP; a minimum of 3.5% of biofuels in the final energy consumption in transport by promoting the production of advanced biofuels; 50% of pig and cattle manure in biogas production. 2045: Exit from using fossil fuels in industries participating in the EU ETS, replacing them with RES (green hydrogen, sustainable biomass, secondary raw materials etc).
Luxembourg	Not clearly stated, but we can presume	Wood products, buildings, energy, agriculture, (heavy) transport, industry	Hierarchical use of wood; increased use of long-lived wood products and construction; support the cascading use of wood, import of unsustainable wood is avoided (should be in public procurements). Also using biomass for energy purposes (*e.g.,* heavy transport). Bioenergy from agriculture should focus on biogas from slurry, and dedicated crops kept to a minimum (increasing the share of 2nd generation biofuels instead of 1st (agro-food)). Without new options, the use of biomass will be limited due to the availability of raw materials. Sustainable biomass is an option in hard to decarbonise processes.
Malta	No info	-	Bioresources are not discussed in the LTS
The Netherlands	No info	Energy, transport (aviation, shipping), industry, wood products	Bioenergy needed for the transition (framework to guarantee all biomass is sustainable and is only used in sectors where no cost-effective alternative is available, such as aviation and shipping). Biomass as base loading power. Hierarchy of use that are as high-grade as possible (storing carbon in wood products).
Portugal	yes (until 2030 at least)	Biofuels, industry, heating, transport (aviation, heavy)	Use of advanced biofuels, biomass consumption will grow up to 2030/2035, before decreasing below current levels. Most clearly seen in the industrial sector (contributes to reductions of 80%), for example by replacing coke. Most cost-effective in decentralised cogeneration and heat production sites near to collection sites, with this also contributing to sustainable forest management. Biofuels for heavy long-distance passenger and freight (for the first may become irrelevant long-term due to the greater cost-effectiveness of other technologies, in aviation the role could be maintained). But biomass for combustion is a trade off with air quality, with a possible increase in non-methane volatile organic compounds (NMVOC) and fine particles (PM2.5).
Slovakia	yes	Heating, energy, biogas	Biomass consumption was 3.6 times higher in 2015 than in 1990. Carbon stock in living biomass has been growing in recent years and is expected to do so in the next decades. Biomass has the largest energy potential among RES in Slovakia (theoretical potential of 120 PJ). Slight growth for biomass in 2020-2030, mainly for energy (cogeneration plants, heating and cooling). The increase in wood chips is expected to grow by 12%. WAM scenario: support scheme for

Country	Plans to increase the use of bio-resources	Sector(s)	Details
			electricity generation with RES, biogas/biomethane and biomass, advanced biofuels from 0.5% in 2022 to 3.5% in 2030. Climate neutrality *NEUTRAL* scenario proposes to increase the support for bioeconomy by using biogas mainly as a local source and processing animal waste more efficiently, but excessive support for direct biomass combustion leads to increased PM emissions and deterioration of the air quality.
Slovenia	yes	Wood products, biogas, transport, (district) heating, cooling, energy	Many mentions of the NECP in light of bioresources. Further exploitation of wood biomass by 2050 where the economic aspect is significant (low-quality wood for energy improves the economics of wood processing chains and energy systems); principles of circular bioeconomy, forest conservation and sustainable forest development are observed and adjusted to CC effects and ensuring CO_2 sinks in forests. Cascading use of wood and energy exploitation of wood products at the end of their lifespan increases the amount of biomass suitable for energy production. By 2050 the promotion of wood biomass use in individual heating systems directed at the areas where the use of other RES is not practical. Support for pilot projects for synthetic fuels development from wood biomass and other lignocellulosic sources. The share of wood biomass in DH and cooling systems will increase intensively, especially through the installation of larger shallow geothermal heat pumps. Increasing the proportion of biofuels in liquid fuels for road transport, while reducing biofuel production from raw materials that are also used as food. Diesel in agricultural machinery will be reduced by 58% (from 100%) by 2050 (replaced by biodiesel, -methane, and compressed natural gas.
Spain	yes	Biogas, transport, buildings, industry,	Biogas production is one of the main lines of work to achieve emission reductions. Biogas, biomethane and renewable hydrogen are important in a just transition by contributing to job creation and socioeconomic development. Biofuels for transport (28% of energy consumption should be renewable by 2030 due to electrification and biofuels). Biomass for replacing fossil boilers in the building sector. Industrial options like cement production and a source of hydrogen through biogas or biomethane steam reforming. The potential of biogas in the circular economy is low; use of waste streams from the pulp, paper and food sectors emphasised. Production and transportation processes can lead to emissions from biomass, in addition to particle emissions. Research and innovation needed. Production models that minimise methane emissions and increase soil carbon uptake: a limit of raw materials or the level of technological maturity is low. Waste recovery and research into new processes for advanced biofuel manufacturing. Resource potential in Spain is such that savings in CO_2 emissions and sustainability should both be guaranteed.
Sweden	yes	Energy, biofuels, industry, heating, transport (aviation and shipping)	The country is well-placed to combine active forestry with high environmental requirements whilst maintaining the size of the LULUCF sink. Bioenergy use is increasing in CHP plants. Biofuels have the highest share of the total RES and are used most extensively in industry, heating, and increasingly transport. Road transport is likely mainly electrified, but aviation and shipping could benefit from biofuels (the extent to which biofuels can contribute depends on opportunities to produce them sustainably at reasonable price). Policy instruments include various charges for emissions that can be discounted or neglected with using biofuels, as well as obligations for fuel suppliers to reduce emissions each year. By 2030, these obligations are a 66% and 28% reduction for diesel and petrol. Large refilling stations must include renewable options. Bio-based alternatives are highlighted in industries as potential replacements for chemicals derived from

Country	Plans to increase the use of bio-resources	Sector(s)	Details
			fossil-fuels (bioenergy use has managed to cut emissions in several industrial sectors). Bioenergy in electricity production and district heating are expected to continue. Potential for construction and clothing. Discussion on synergies and conflicts with sequestration and other issues. Biomass harvests must be done in a way that is compatible with other goals and within sustainability parameters.

Source: Author's compilation based on the LTSs from EU Member States

Almost all countries plan to increase the use of bioresources, although some to a bigger extent (Greece) than others (Germany, Finland). Portugal plans to increase the share at least until 2030, Luxembourg and Germany have not clearly stated this goal of increasing bioeconomy in their LTS's, but from the context of the strategies we can presume it is so. For the Netherlands, Malta, and Hungary no information is given. Finnish and Danish strategies foresee a modest increase or a stagnation until 2050.

Many countries see increasing the share of wooden long-lived products as an alternative to carbon intensive products (*e.g.,* France, Belgium, Croatia, Czechia). Greece, for example, states that although the competition for biomass is great, biofuels have greater added value than other uses, therefore they are focusing on energy production. For Austria increasing the value of bioresources per hectare is important because total replacement of fossil fuels with bioresources has significant land requirements. Croatia brings out the important point about producing biofuels without compromising food production. Estonia foresees a widespread use of domestic bio- and other RES in the production of electricity, thermal energy, and transport fuels instead of energy intensive non-renewables, whereas low-quality wood products should be used for this. Additionally, Latvia states that in 2050 biofuels of the newest generation (genetically modified algae) have been developed which reduce the risks that edible crops and soil fit for growing food is being used for the acquisition of bioenergy. However, further details on how they plan to achieve this are not given. In Czechia, there is potential for 680 000 ha of arable land and 400 000 hectares of permanent grassland for biomass.

Good examples of conflicting targets can be shown in the case of Denmark and Italy. Denmark plans to simultaneously increase the share of forests and bioenergy-based electricity production. Further, Italy states that the potential of biomass must be "fully exploited" while also emphasizing the importance of sustainable forest management. How these goals will be achieved simultaneously is not clear from the LTS.

Bioresources

- Almost all countries plan to increase the use of bioresources, although some to a bigger share (Greece) than others (Germany, Finland).
- Finland and Denmark are the only two countries who foresee a modest increase or a stagnation of using bioresources until 2050.
- Many countries see increasing the share of wooden long-lived products as an alternative to the use of carbon intensive products (*e.g.,* France, Belgium, Croatia, Czechia).
- Some countries mainly discuss potential in energy use (*e.g.,* Greece, Portugal, Estonia, Denmark).
- Greece and Luxembourg mention transitioning to using 2^{nd} generation biofuels by 2030, while Latvia brings out that by 2050 only newest generation biofuels will be used.
- Some countries have potentially conflicting targets for use of bioresources and natural sinks, *e.g.,* Denmark plans to simultaneously somewhat increase the share of forests and bioenergy-based electricity production and Italy wants to “fully exploit” the potential of biomass and practise sustainable forest management.

4.5. Technological options

4.5.1. Carbon Capture and Storage (CCS*) and* Carbon Capture and Utilization (CCU)

Although these cannot be considered technological removal options, the strategies bring insights into the differing perspectives towards CCS and CCU relatively often compared to DAC and BECCS. As in other sections, coverage varies significantly between the LTSs. Certain countries, such as Hungary and France, provide details on the expected levels of emissions to be avoided by 2050, whilst others give no information on these technologies. In general, the use of CCS/CCU is anticipated quite widely throughout the EU. Of the 20 countries that have both submitted an LTS and included a discussion of these technologies, half were judged in our assessment to clearly view their use favourably. Only five countries were found to have no plans to use CCS/CCU. Despite a significant number of countries being in favour, more quantitative detail could be provided regarding the level of potential emissions that could be avoided. Exceptions to this include Hungary and Greece, who clearly state the level of reductions expected. In other cases, such as Spain, it is clear from the text that these calculations have been developed but they are not reported in the LTS.

The following table provides a summary of the coverage of CCS/CCU for each country, including details, if provided, on which sectors of the economy its inclusion is planned (Table 10).

Table 10. Description of CCS/CCU in the LTS's

Country	Plans to use CCS/ CCU	Sector(s)	Details
Austria	No		Geological storage is currently banned, though this could change in the future. It is also used in some of the climate neutrality scenarios. CCS is only viable when the long-term storage can be guaranteed but cannot be ruled about before 2050. The bioconversion of CO_2 to methane/biogas is referenced.
Belgium	Yes	Industry	Both Flanders and Wallonia see CCS/CCU as important, but with Wallonia stating that options for enhancing natural sinks due to land limitations are little. Flanders wants to develop storage and transportation infrastructure. The problems (storage locations are random and geographically confined, unprofitability) are highlighted. A regulatory framework is needed.

Country	Plans to use CCS/ CCU	Sector(s)	Details
Croatia	Yes	Energy, industry (cement)	CCS is needed in the 'strong' transition scenario and so likely also in the carbon neutrality scenario. A variety of industries (and all new fossil plants after 2030) should examine the use of CCS / CCU. CCS is seen as transitional so that fossil fuels can be used for the next three to four decades.
Czechia	~		Used in one scenario that achieves an 80% reduction. Storage was banned until 2020 and further analysis is needed before a decision can be made.
Denmark			No significant mention
Estonia			No significant mention
Finland	~		One of the climate neutrality scenarios uses CCS to remove 14 Mt CO_2e. However, it is likely this refers to BECCS and not industrial CCS. The other climate neutrality scenario does not use these technologies.
France	Yes	Industry	CCS is targeted to account for 6 Mt CO_2e in 2050 and is to be exploited as soon as environmental and economic conditions allow. Application should be limited but could be a technology export. Existing infrastructure should be used and deployment slow and incremental. Storage could take place on land or sea. Land storage of 1 – 1.5 Gt CO_2 but storage at sea may be more socially acceptable.
Germany	~	Industry	Only a brief description. Options depends on R&D developments.
Greece	Yes	Energy, Industry	Both climate neutrality scenarios use CCS for natural gas (2.3 TWh and 11.8 TWh of CCS-gas in these scenarios). CO_2 is either stored or used for synthetic fuels, depending on the scenario. Storage could be 140 Mt CO_2 based on current data.
Hungary	Yes	Energy, Industry	Both climate neutrality scenarios use CCS/CCU (as does BAU). The LTS includes a breakdown of use by sectors, with 10 Mt CO_2e removed in 2040 and 2050 (-2 in 2030).

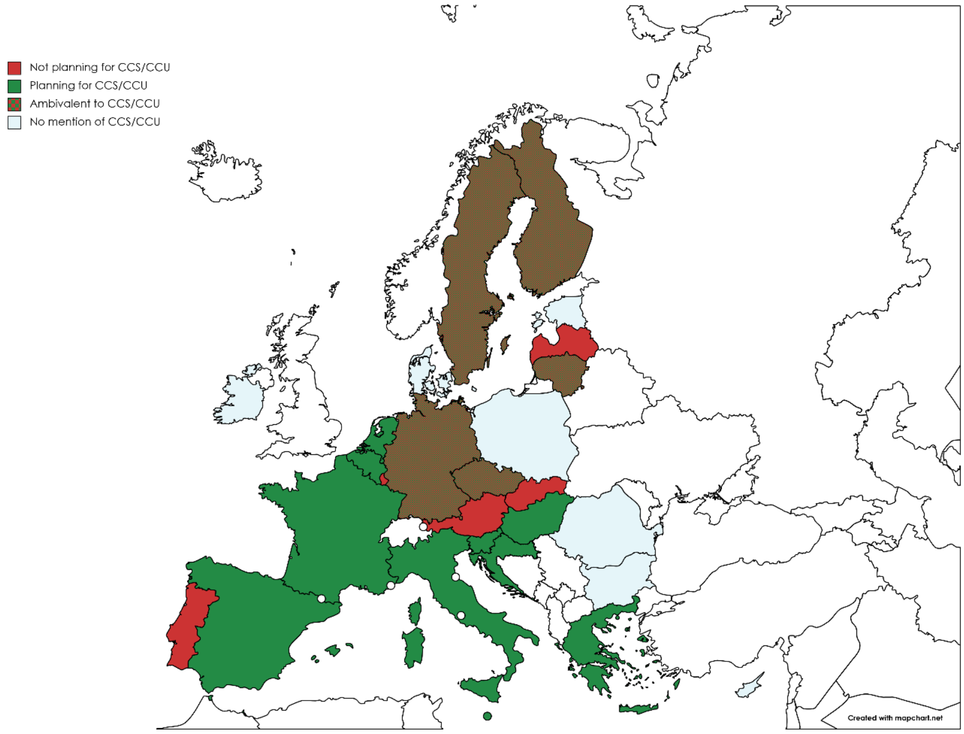
Country	Plans to use CCS/ CCU	Sector(s)	Details
			R&D is emphasised, with technologies only expected after 2030. Utilisation (for hydrogen and fuels) is prioritised due to storage limitations.
Italy	Yes	Industry (Steel and cement)	States that between 10 and 20 Mt CO_2e could be captured from industry
Latvia	No		Mentioned in relation to chemicals and cement but is not economically feasible in Latvia. Further research is needed.
Lithuania	~	Industry	Will consider environmentally safe CCS in sectors without potential for full mitigation by 2050.
Luxembourg	No	Industry	Seen as a last resort for industrial production
Malta	Yes		Within R&D, the country could be a test bed CCS / CCU.
The Netherlands	Yes		It is believed that two of nuclear, CCS and bioenergy are needed to reach climate neutrality. Both utilisation and storage are discussed, with high storage capacity in the North Sea. Carbon from other countries could also be stored.
Portugal	No	Industry (cement)	Seen as only viable in the cement sector but here it may not be justified due to large investments needed. Utilisation for fuel production is also not seen as cost-effective.
Slovakia	No		Excluded from modelling of the energy sector. Research needs are briefly mentioned.
Slovenia	Yes	Industry (cement, metals)	Predicted to be used in industry by 2040 under the most optimistic scenario, with pilot projects by 2030.
Spain	Yes	Industry (cement, petrochemicals, lime, fertiliser)	CCS/CCU are required in the climate neutrality modelling. High costs and storage issues / utilisation options have made commercialisation difficult. Even in cement, 70% of costs would be from carbon capture. Preliminary research on geological storage is being carried out, with storage in durable products not expected within the next two decades.
Sweden	~	Industry (Cement,	Can be used in cases where no alternatives exist. 2 – 5 TWh of electricity could require CCS.

Country	Plans to use CCS/ CCU	Sector(s)	Details
		steel), Energy	There are investment grants for industrial applications and a research budget for technologies (the Industrial Leap programme).

An assessment was made based on our analysis and countries grouped into those planning for CCS/CCU, those that are not currently planning for its development, and those that were CCS/CCU ambivalent. Countries in this final group were those that were open to the technology without actively planning for its use. Typically, this category was applied when carbon capture technologies were only briefly described in the documents or included in one of multiple modelling scenarios that reached the target of the strategy. Note that the distinctions between categories were not rigid. Even amongst the countries most sceptical of such technologies, such as Latvia or Luxembourg, there are no declarations that CCS/CCU will not be used. An overview of the country groups on this issue can be seen on Figure 10.

Similarly, countries planning for CCS/CCU also fall across a spectrum. Some, such as Hungary, France, and Greece, clearly state it is to be used and include it in modelling. Others, such as Italy or Spain are slightly more circumspect, including it amongst a range of options whilst also stating it is likely to be needed for climate neutrality.

Figure 9. Countries' plans for CCS/CCU



Source: Author's compilation based on the LTSs from EU Member States

Overall, a high number of countries are targeting the use of CCS/CCU. But geological storage options are not homogenously distributed throughout Europe. Only a few counties (Austria, France, Greece) give quantitative detail on storage capacity, with some others include qualitative detail. Some countries refer to scientific studies, such as Latvia, for example, derives, where the feasibility is derived from an analysis of storage without quoting details within the LTS, and Spain states that studies are needed or are taking place.

Nearly all countries that include some discussion of CCS/CCU also call for additional research, including sceptical nations, such as Latvia. Where these technologies are included, it is also stated that commercialisation of CCS/CCU is only seen on a significant scale after 2030. This is also in line with the European Union projections. Within the near term, most countries only discuss support and funding for pilot projects, although few countries give specifics on allocated funds. Sweden is an exception as it includes more specifics – with 600 SEK allocated into the 'Industrial Leap' programme in 2021, although this is not only allocated for CCS/CCU.

But these numbers only describe the amount of carbon that is captured in a single year. If the goal is to store carbon, then fewer countries provide detail on total potential storage levels (Table 11). This lack of clear detail on the size of the potential sink complicates any assessment of the feasibility of the plans. Clearly, storage and utilisation limits must exist for all cases. Hungary is an example of a country with a clear preference for utilisation, partly due to the limits in determined storage capacity within the country. In this case, there is still a limit in terms of the processing capacity of any carbon-based industry.

Table 11. Storage capacity of selected countries

Country	Geological storage capacity
Austria	400 – 510 Mt CO_2
France	1 – 1.5 Gt CO_2 (on land)
Greece	140 Mt CO_2
Hungary	Limited
The Netherlands	High

When it comes to the targeted sectors, industry as a whole and the cement sector specifically are referenced most frequently, due to the lack of other options for decarbonisation. For instance, this is seen in the Portuguese LTS, that largely depicts CCS / CCU in a negative light. Although in this case the LTS states that the technology is still unlikely to be used as natural changes in the industry may make it irrelevant. Steel and metal processing are also commonly included as a sector where CCS/CCU could be used, again due to fewer other decarbonisation options[49]. Moreover, energy is another sector with high potential for CCS/CCU, according to the LTSs. For Hungary and Greece this is to allow gas-fired generation to continue until 2050. Croatia and Sweden also see the potential for CCS in energy. Where CCU is targeted, the captured carbon is expected to be used to produce fuels in most cases.

[49] **Kim, J., Sovacool, B. K., Bazilian, M., Griffiths, F., Lee, J., Yang, M., Lee, J.** Decarbonizing the iron and steel industry: A systematic review of sociotechnical systems, technological innovations, and policy options. Energy Research & Social Science. Vol 89. https://www.sciencedirect.com/science/article/abs/pii/S2214629622000706 (Accessed: 25.11.2022)

France sees the potential for CCS/CCU to be a technology export for the country. Additionally, the Netherlands is the only country to explore the possibility of resource sharing, where its storage capacity could be used by other nations.

Discussions about 'locking-in' further fossil fuel developments are generally absent from the long-term strategies. This is despite the emphasis on additional research and the expectation of widespread use only after 2030.

CCS/CCU

- Views on CCS/CCU vary greatly across Europe. Around half of the countries that included detail on these technologies appear to view it positively and have some plans for its deployment in the future.
- Some of these countries, such as Greece, Hungary and France, have included detailed modelling on the expected level of removals
- A few countries report potential storage levels (*e.g.,* Austria, France, Greece). There is also a distinction between countries that focus more on storage, such as France, and others that place more emphasis on utilisation. Hungary provides a good example of the latter case.
- Industrial processes such as cement production are the most common areas for which these technologies are targeted.
- Most countries specify the need for more research, including those that are largely sceptical, such as Latvia. Widespread use of CCS/CCU is only anticipated after 2030. This is also in line with the expectations of the EU.

4.5.2. Bioenergy with carbon capture and storage (BECCS)

When compared to CCS / CCU, there is far less detail in the documents regarding diffuse methods for capturing carbon, with only 11 of the 22 published strategies making any reference (compared to 20 for CCS / CCU). What information is included on technological removal options deals overwhelmingly with BECCS, while DAC is only discussed briefly in a few of the strategies.

In the case of BECCS, the relative sparsity with which it is referenced may also arise from strategies not clearly using the separation or clear terminology applied here. For example, Hungary and Sweden consider capturing the carbon from electricity generation. But the category to which this would fall in our assessment depends on whether the energy source arises from the (current) biosphere, and this is not always made clear. Table 12 lists details included in the strategies on the topic of BECCS.

Table 12. Description of BECCS in the LTS's

Country	Details	Country	Details
Belgium	General statement that BECCS can be considered to remove emissions.	Finland	14 Mt CO_2e are removed in one of the climate neutrality scenarios, likely through BECCS.
France	10 Mt CO_2e is removed by BECCS by 2050. This requires centralised use of biomass. The technology is uncertain but will likely be needed as geological storage is very long-term.	Greece	The climate neutrality scenarios have negative emissions in the industrial sector because of BECCS. It also states that 2.3 TWh and 1.5 TWh of electricity are generated in these two scenarios by BECCS
Hungary	The LTS modelling includes BECCS, including in the BAU scenario.	Italy	The LTS includes BECCS from centralised sources (alongside gas-based CCS). This also states that the captured carbon could be reused in fuels, rather than stored.
The Netherlands	Referenced throughout the document in conjunction with CCS.	Portugal	BECCS is not cost-effective based on current knowledge, but it is a priority research area at European level and should be monitored.
Sweden	BECCS is referenced in the context of the 'industrial Leap' research programme.		

The table demonstrates that where information on BECCS is included in the LTS, it is not done in a consistent way. Most strategies include only a few descriptive elements. This is the case for Belgium, Portugal, and the Netherlands. A few countries include more numerical details. For example, both France and Finland state removal targets through BECCS in at least one scenario. France and Italy consider that BECCS should be centralised to be effective.

But there are few discussions of the intersections and compromises inherent to the technology. For example, as stated in the introduction, BECCS is a land-intensive method of removing carbon and therefore must be considered within the context of agriculture, bioresources, and biodiversity. Where the negatives are considered, it is mainly in terms of the cost of the technology as was the case with carbon capture more generally. The documents do not state clearly whether the source of wood would be via plantation, though this seems likely given the cost issues and the economies of scale.

4.5.3. Direct Air capture, DAC

Direct Air Capture is included less frequently still. Some of the references are also not clear. For example, Slovenia mentions the ‘direct capture of GHG emissions’ and Sweden states that ‘negative emission technologies’ are one of three potential technologies to get to net zero. The Netherlands also states the need to remove carbon from the atmosphere in the future to keep warming to 1.5ºC and the role the country has to play must be determined in a global context. The Belgian LTS states that DAC is an option that can be considered. Hungary includes some discussion, simply saying that the technology must be applied at scale to drive down costs but that it is a potential option to compensate outstanding emissions. France simply states that it is at a very early stage of development.

DAC / BECCS

- Both DAC and BECCS are included less frequently than technological removal of carbon from point sources that do not lead to overall removals. Of the two techniques, BECCS is included more often (by at least 9 countries) than DAC (somewhat mentioned by 6 countries) and discussed in more detail. Furthermore, some of the references to CCS in the strategies may also refer to BECCS, with countries not always making clear which of these two options is being discussed.
- A few countries that specifically include BECCS also give quantitative detail and targets. Examples are France and Greece, countries that also view CCS in a positive light.
- Only a few countries discuss DAC at all. In all cases, it is not viewed as a technology to be included during the time frame of the LTS.
- Several countries highlight the need for further research for both BECCS and DAC.

5. Conclusions

Climate neutrality cannot be achieved without removals from the Land use, Land use change and Forestry (LULUCF) sector due to residue emissions which will be hard to abate. While GHG emissions can be removed by natural sequestration in soils, forests and oceans, technological removals like Bioenergy with Carbon Capture and Storage (BECCS) or Direct Air Capture (DAC) and technologies that avoid further emissions – Carbon Capture and Storage (CCS) and Carbon Capture and Utilization (CCU) – are also increasingly available. **In this report we analysed how EU Member States addressed the LULUCF sector as well as other carbon removal options in their national Long-term Strategies (LTS).** We looked at modelling for LULUCF (if available), measures proposed and description of the technologies the country plans to use. As LULUCF has many overlaps with the agricultural sector as well as bioeconomy, biodiversity and adaptation, these topics were also included in the analysis, but in the interest of limiting the scope, only from the intersections point of view. Further, the report attempts to draw out comparisons and critical issues across the plans of the Member States as a whole and, in doing so, establish an overarching picture of the role negative emissions can play in tackling the climate crisis in Europe.

In the last 30 years, the carbon sink in the EU has decreased. Moreover, the only binding land category has been "forest land", whereas sink size directly follows the trend of carbon binding in forestry. **During the last decade LULUCF removals have decreased roughly by a third** (to -230 Mt CO_2e in 2020). Further, throughout Europe, there is a high degree of variety that exists within the same land-type. By 2030, the currently most ambitious scenario (WAM) derived from EEA database of LULUCF emissions, entails a sink of -209 Mt CO_2e, while 'Fit for 55' foresees a sink of -310 Mt CO_2e in 2030. In 2050 the 'EU Reference Scenario' foresees a sink of -271.1 Mt CO_2e, however, the *'Clean planet for all'* communication includes a sink target for LULUCF of around 400 Mt CO_2e for the same year. Moreover, by 2035, the EU plans to have a carbon-neutral combined land sector, consisting of LULUCF and the non-CO_2 agricultural sector.

Countries vastly differ in sink/emissions sizes. Whilst some, such as **Sweden, Spain and Italy have LULUCF sectors that are currently net sinks, and are projected to remain so until 2050, Denmark, the Netherlands and the Republic of Ireland are on the other side of the scale,** with net emissions expected across the period up to 2050, consistent with the situation since 1990. Some other countries have seen recent decreases in the size of their sink, and this trend is not expected to reverse by 2050 according to the reference scenario. The clearest examples here are **Estonia and Latvia, for whom the LULUCF sector recently became a source of net emissions.**

Not all countries have specified the level of emissions reductions in their LTS (excluding LULUCF) required to reach climate neutrality. However, the average amongst countries that had such detail (either as a direct target or from modelling) was an **87% reduction on 1990 levels**. A simple comparison of the level of reduction (assumed to be 85% of 1990 levels if not included in the LTS) to the 'EU reference scenario' of the LULUCF sector indicates that the assistance natural sinks can play in achieving climate neutrality are not uniform across the countries. Out of the countries with projected sinks, only three countries were found to have sinks of the necessary magnitude in 2050 based on the 'EU Reference Scenario' – **Spain, Finland, and Sweden.** Several countries will encounter significant additional difficulties in reaching climate neutrality, either because the size of the net LULUCF sink is very small and enhancements encounter spatial constraints, or because the sector has consistently been a net emitter since 1990. **In most countries climate neutrality cannot be achieved through only natural sinks, the pan-EU scenarios that reach carbon neutrality foresee technological removals or avoided emissions of at least 300-600 Mt CO_2**

in 2050. Inter-nation trading in the form of flexibility mechanisms could somewhat help achieve union-wide goals.

The level of detail and structure of the LULUCF sector was found to be highly variable between LTSs. The issue of land planning and reducing land conversions was included by twelve of the 22 countries. Several of these included targets to reach net zero land conversions by 2050. This was seen by both small and big countries. Attempts to enhance afforestation or reforestation were included in most of the strategies. **Issues around monitoring and measuring the LULUCF sector and its emissions were also commonly mentioned. But an important related issue, that of sink stability, was not included,** except for the Austrian and French LTSs. This is a critical issue for long-term climate neutrality targets post-2050. Improved or expanded management and protection of different landscapes was also discussed frequently. **Discussion on other land use categories (besides forests) was predominately focused on wetlands and permanent grasslands, reflecting their relative importance in the sector.** Where wetlands were included, they came with ambitions to halt degradation or enhance restoration. Cropland, settlements, and other land were rarely discussed.

Dispute on permanent grasslands and croplands has clear intersections with agriculture. This was mostly based on efforts to increase the size (through changes or reductions in agricultural practices) or carbon content (such as through reduced ploughing) of these land categories, but numerical detail was rarely included. **Six countries integrated agriculture with LULUCF.** The countries that described the overlaps between the two sectors the best were Luxembourg, Slovakia, and Slovenia. The latter together with Belgium, put by far the most focus on biodiversity, which could be significantly strengthened for other analysed countries as well. Spain and Slovenia had great detail on climate adaptation, which is another topic that is intertwined with natural sinks. Overall, throughout these four topics – agriculture, biodiversity, bioresources and adaption – Belgium and Croatia had most thorough description of the overlaps between them. Interestingly, it was found that **almost all countries plan to increase the use of bioresources**, although some to a bigger share than others. Most countries see increasing the share of wooden long-lived products as an alternative to reducing carbon intensive products, whereas less focus is given to energy use. Some countries have potentially conflicting targets for increasing the use of bioresources and enhancing natural sinks.

In terms of technological solutions, the strategies clearly put more emphasis on carbon capture as means of avoiding emissions in combination with fossil sources than in diffuse carbon removal from the air. However, the distinctions were not always clear from the strategies. Future updates could state more clearly which of these technologies is targeted, as well as discussing how the negative aspects are to be mitigated as **CCS/CCU do not contribute to removing emissions that is needed for climate neutrality and going beyond, instead they only avoid further emissions.** Having stated that, views on CCS and CCU varied greatly across Europe. **Around 10 of the 20 countries that included detail on CCS and CCU appear to view it positively and have some plans for its deployment in the future**. Some of these countries, such as Greece, Hungary and France, have included detailed modelling on the level of expected avoided emissions and a few countries report potential storage levels. There is also a distinction between countries that focus more on storage, such as France, and others that place more emphasis on utilisation, such as Hungary. Industrial processes such as cement production are the most common areas for which these technologies are targeted. Most countries specify the need for more research, including those that are largely sceptical, such as Latvia. Further, it is clear that **no country is currently putting much emphasis on direct air capture** as a potential solution within the lifetime of the current long-term strategies. This is not unexpected given that these technologies are still in their infancy, even widespread use of CCS and CCU is only anticipated after 2030.

Annex I: Methodology

The Annex IV framework set out for the LTS is much less detailed than for the NECP. The details in annex IV are also not binding, unlike the equivalent template for the NECPs. This contributes to the differences found in the structures of the strategies submitted by the Member States which somewhat complicates our assessment as the different strategies vary greatly in thoroughness, length and details given. As of August 31st, several countries (Bulgaria, Cyprus, Ireland, Poland, and Romania) had yet to publish their LTS, therefore they were not included in the assessment.

The assessment follows a standardised approach. First, we compiled the general information of the strategies like year of publication, length, and goals for climate neutrality. The analysis then starts by assessing the modelling and targets provided by each country, and what indication they give in terms of the necessary magnitude of the carbon sink to reach climate neutrality. However, the aim was not to determine rigorous or precise values for each country. The evaluation aimed to establish minimum boundaries for total necessary sequestration based on the stated or implied maximum level of reduction each country has proposed, the so-called sink requirements.

The sink requirements were determined using a standardised approach:

- If the LTS stated the size of the sink needed for climate neutrality, then this was used. If several options exist (under different modelling scenarios, for example) then the most ambitious was used (*i.e.,* the one requiring the smallest level of sequestration).
- If no modelling was included, the targeted emission reduction (excluding LULUCF) to reach climate neutrality was used.
- If the target was less ambitious than climate neutrality by 2050, any outstanding emissions were added on to the size of the sink.
- If no clear emission reduction target was given, a value of 85% from 1990 levels (excluding LULUCF) was used. The same procedure was used for countries yet to publish their strategy. It is noted that this could overvalue the sink sizes for some countries, and for these an additional calculation based on 2005 values was also included in the country annex.
- If unspecified, the size of the required sink was then based on the level of remaining emissions in 2050. For example, 15% of emissions in 1990 (excluding LULUCF) for an 85% reduction.
- If the LTS included and specified the size of technological removals or options that were included in the emission reduction, then this was added on to the size of the required carbon sink. Often, a country only stated that such technologies would be used without specifying the amount of carbon that was sequestered. No adjustments were made in such cases.

The sink requirements were then compared to projections of natural sequestration for each country in 2050 based on the modelling done in the EU Reference Scenario as it provided information on all Member States. Besides projected emission reductions and enhancement of removals by 2050 (as well as 2030 and 2040 if information on this was provided), we looked at the current emissions/removals in the LULUCF sector, the description of proposed measures and general coverage of the state of natural sinks.

The guidance given in article IV of the Governance regulation lists agriculture and LULUCF together and efforts shall be made to combine the two sectors for future accounting. Therefore, we distinguished whether countries discuss the sectors separately or have an intertwined approach and to what extent agriculture is included and if it has overlaps with natural removals. Qualitative assessment was done by categorizing information on what kind of land categories, targets and measures were included in the LULUCF section and to which extent (description, target, modelling) they were included. Forestry was separated from other land categories as by far the most information was provided on this. Data was compiled on bioresources, biodiversity and adaptation as well as they are also intertwined with natural removals and should be looked at comprehensively. Description of inclusion and general targets (if available both qualitative and quantitative) were given on these.

As technological solutions also play a role in achieving climate neutrality, removal technologies BECCS and DAC as well as other technological options like CCS and CCU that do not contribute to emissions removals but eliminate additional emissions were included in the analysis. Again, their inclusion, description, qualitative and quantitative targets, and discussion on research were considered in the analysis as well as details, if provided, on which sectors of the economy its inclusion is planned.

In conclusion, we analysed the general structure and content on natural and technological removals in the strategies, which qualitative and quantitative details were included on this, and the overall presentation, comprehensiveness, and readability of the documents.

The structure of the methodology applied for data collection was the following:

1. General information: Publication date, length, goal of climate neutrality
2. Current emissions/removals in the LULUCF sector and future projections
    - *S*ize of current emissions/removals (WEM)
    - Projected emissions/removals based on the EU Reference Scenario
3. Modelling and Targets

    Quantitative metrics on emissions/removals:
    - Sink requirements (targeted removals to reach climate neutrality (if specified) as percentage or value)
    - Inclusion of modelling projections
    - Differentiation by removal type (natural vs technological solutions requirement for carbon neutrality)
4. LULUCF
    - Separate sector or integrated with agriculture
    - Extent of description for agriculture, overlaps with LULUCF, adaptation measures
    - Inclusion and description in the LTS
    - General targets (qualitative and quantitative) and proposed measures
5. Bioresources
    - Inclusion and description in the LTS
    - General targets (qualitative and quantitative)
6. CCS/CCU

- Inclusion and description in the LTS
- General targets (qualitative and quantitative)
- Discussion regarding research, funding and sectors targeted

7. DAC/BECCS
    - Inclusion and description in the LTS
    - General targets (qualitative and quantitative)
    - Discussion regarding research

Annex II: Country details

Austria

1. General information

Published: December 2019

Length: 128 pages

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -1.3 Mt CO_2e

LULUCF emissions in 2030 (projected) = -3.1 Mt CO_2e

LULUCF emissions in 2040 (projected) = -2.9 Mt CO_2e

LULUCF emissions in 2050 (projected) = -3.6 Mt CO_2e

3. Modelling and Targets

Sink requirements: -16 Mt CO_2e (modelling)

Qualitative detail

The LTS includes four scenarios. These are extensions to the transition scenario, conducted in 2017 (updated in 2019), aiming to reach climate neutrality. The transition scenario achieved reductions of 80% thus requiring around 16 Mt CO_2e to be offset. The exact amount varies depending on the scenario.

Two of the four proposed scenarios reach climate neutrality. In these scenarios, the required sinks are even higher. Of these, one heavily invests in CCS/CCU, whilst it is banned in the other, with the sink purely derived from LULUCF (through afforestation).

However, the LTS also states that the sink in this scenario is unstable, and long-term storage is not maintained.

Requires technological solutions for carbon neutrality: yes

4. LULUCF

Separate section in the LTS: integrated with agriculture

The role of LULUCF in emissions removals, whilst also being adaptive to climate change and maintaining biodiversity is discussed. The LTS highlights the competition for land by stating that land consumption should be reduced through limiting urban sprawl and sensible spatial planning policies. Land changes and loss of storage capacity make maintaining the current sink levels difficult. Further policies include developing so-called ‘natural forest communities’ that are adapted to climate change and considering different types of forest management.

5. Bioresources

There is extensive discussion on harvested wood products (HWP), with different scenarios for the use of wood. Four of the five proposed scenarios (except reduced wood use) led to a reduction in forest growth and a net source of emissions by 2040.

The LTS includes the use of bioenergy as part of the energy transition. The bioeconomy is also referenced as part of the industry section, with a need to increase the value of bioresources as a function of land use, and the country has a bio-economy strategy. Moreover, the buildings section states that sustainable raw materials should be used as much as possible. While highlighting the competition for land use, it also states that there is a high potential for bioresources .

Increased use of bioresources: Yes

6. CCS/CCU

CCS is prohibited in Austria! Though this might change in the future

CCS in geological formations is banned until 2023. Studies suggest a domestic storage capacity of 400-510 Mt CO_2e. However, it is stated that CCS is only viable when long-term safety can be guaranteed. However, its use before 2050 cannot be ruled out.

The LTS also refers to the possibility of using bioconversion to obtain methane or biomass from stored CO_2.

Considering CCS/CCU: No (with qualifications)

7. DAC/BECCS

BECCS and DAC are not discussed separately in the LTS. However, the caveats associated with CCS also apply to these two technologies.

Considering DAC/BECCS: No (with qualifications)

Belgium

1. General information

Published: March 2020

Length: 143 pages

Climate Neutrality: by 2050[50]

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -0.3 Mt CO_2e

LULUCF emissions in 2030 (projected) = -1.5 Mt CO_2e

LULUCF emissions in 2040 (projected) = -1.7 Mt CO_2e

[50] The LTS is composed of three separate documents, one for each of the governmental regions of Belgium: Flanders, Wallonia, and Brussels, the capital region. There is no country wide target for climate neutrality, but goals for Wallonia, Flanders and Brussels.

LULUCF emissions in 2050 (projected) = -1.9 Mt CO_2e

3. Modelling and Targets

Sink requirements: -11 Mt CO_2e (target)

Qualitative detail:

The regions have different goals. Wallonia wishes to reduce emissions by 95% and offset the rest (the needed sink stated for Wallonia is 2.8 Mt CO_2e). Flanders hopes to achieve a lowering of 85% in non-ETS sectors, stating that the rest is governed by EU policy. For Brussels, the document only states that climate neutrality should be reached by 2050.

For Belgium, a value of 85 – 87% reduction in non-ETS sectors is targeted based on the individual LTS (from 2005). Although this value is illustrative, it is all that can be used to give an indication of the level of removals needed in Belgium. Total emissions, taken from the LTS without LULUCF were 145.2 Mt CO_2e in 2005, of which 79.0 Mt were from non-ETS sources. Taking the significant assumption of ETS sectors reducing by 100% in 2050, this still leaves around 11 Mt CO_2e to be offset.

Requires technological solutions for carbon neutrality: yes

4. LULUCF

Separate section in LTS: Yes (all the separate strategies discuss LULUCF separately)

Flanders

Flanders states that it is a small and densely populated region, which limits space for additional forests or geological storage. There is, relatedly, a target to reduce net land take to 3 ha / day by 2035, and to reach zero by 2040.

The qualifications regarding removals are further strengthened via stating that the potential of soils to store carbon have yet to be discovered. However, targets include stabilisation of carbon in agricultural soils, maximising natural and forested areas to store carbon and increase biodiversity, and preserving peatlands and riverine forests. The region also recommends better monitoring and mapping of total and potential carbon stocks. It is stated that all storage should be sustainable in light of climatic conditions.

Additionally, the intersection with agriculture is further referenced, through targets to optimise practices to store carbon and increase permanent grasslands and agroforestry (requiring changes to the subsidy system).

Adaptation to climate change in the context of LULUCF and agriculture is also included.

Wallonia

As with Flanders, it is stated that there is a limit to removals. This is because Wallonia is a heavily urbanised area. Again, there is a target to reduce land consumption to 600 ha by 2030 and zero by 2050. Current sinks are absorbing 3% of emissions and can likely only be slightly enhanced. Soils store 1 Mt CO_2e and the forest sink should increase slightly up to 2050. There are further details on sources of emissions in LULUCF.

Thereafter, several measures are discussed. These include the development of a permanent inventory of forest resources and research into forest management and climate adapted species. Another research avenue is into risks, such as from bark beetles.

Agriculture is discussed through attempts to increase the role of sequestration (agroforestry) and strengthening subsidies for the accommodation of forests in agricultural land. There is also some emphasis on adaptation. For example, through the establishment of working expert group and a obligation to plant adapted species. This also discusses risks, which are seen as flooding and soil erosion, as well as loss of biodiversity.

Brussels

As the smallest and most urbanised region, the Brussels LTS does not include as much detail on adaptation. The current sink is estimated to be 0.01 Mt CO_2e. The development plan of the region also includes plans that could grow this. Most measures refer to increasing green spaces (*e.g.,* green roofs) as well urban agriculture – there is a desire to consume 30% of fruit and vegetables from within the region – through voluntary goals.

5. Bioresources

Flanders and Wallonia reference to biomass as a fuel source. However, both regions also discuss sustainable biomass to be used as a hierarchy, starting with long lived and other high value products. Both regions place limits on the extraction rates, stating that they must be 'sustainable' (Flanders) and compatible with absorption and determined by the quantification of mineral exports (Wallonia).

Increased use of bioresources: Yes

6. CCS/CCU

Both Flanders and Wallonia discuss the importance of CCS/CCU to reduce outstanding emissions and both reference this as a strategy for industry, with Flanders wanting to develop a CO_2 'backbone' for storing and transporting captured carbon.

The Walloon strategy says that limits on the size of the natural sink necessitates these technologies but qualifies this with the currently existing problems (geographical confined and currently unprofitable nature of geological storage). Finally, it highlights conflicts that could occur with other land uses, such as gas storage and geothermal energy. This part of the LTS writes that a regulatory framework is needed, and pilot projects should be supported but CCS/CCU should be a last resort.

Considering CCS/CCU: Yes (with qualifications)

7. DAC/BECCS

There is a summary discussion about each region looking for research into negative emission technologies.

Wallonia further elaborates, stating that BECCS is a technology by which remaining emissions can be removed and may be well suited for power sector. It is later stated that DAC (called atmospheric carbon capture) could also be considered for this purpose.

Considering DAC/BECCS: Yes

Bulgaria

1. General information

Published: Bulgaria has yet to publish an LTS.

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -9.6 Mt CO_2e

LULUCF emissions in 2030 (projected) = -8.7 Mt CO_2e

LULUCF emissions in 2040 (projected) = -4.8 Mt CO_2e

LULUCF emissions in 2050 (projected) = -4.8 Mt CO_2e

3. Modelling and Targets

Sink requirements: -14.8 Mt CO_2e (assumption, no LTS)

Qualitative detail

Bulgaria has yet to publish an LTS. However, in order to gain an understanding of the potential necessary sink requirements, it was assumed that mitigation efforts could reduce emissions by 85% on 1990 levels (emissions in 1990 were 98 Mt CO_2e). As such this would set a potential sink requirement as around 14.8 Mt CO_2e.

Requires technological solutions for carbon neutrality: N/A

Croatia

1. General information

Published: June 2021

Length: 125 pages

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -5.3 Mt CO_2e

LULUCF emissions in 2030 (projected) = -1.2 Mt CO_2e

LULUCF emissions in 2040 (projected) = =1.6 Mt CO_2e

LULUCF emissions in 2050 (projected) = -2.6 Mt CO_2e

3. Modelling and Targets

Sink requirements: -3.3 Mt CO_2e (modelling)

Qualitative detail:

Several different scenarios are included in the LTS. These include a reference scenario, as well as gradual and strong transition scenarios. However, only a preliminary final scenario, known as the net zero emission scenario, is designated as reaching climate neutrality. Here, analysis suggests a decrease of 89.4% by 2050, based on 1990 levels. It is stated that the additional reductions should take place through natural sinks or via technological means. This defines the additional sink requirements to be 10.6% of emissions in 1990 (possible to calculate because they state the total emissions without LULUCF, 31.4 Mt CO_2e).

The baseline scenario was estimated to reduce emissions by 46.3% based on 1990 levels for the sectors considered. The gradual and strong transition scenarios would reduce emissions by 56.8 and 73.1%, respectively. However, the strong reduction scenario was targeted to reduce emissions by 80%, with the remaining deficit stated to be somewhat covered by technological options, such as CCS, although it is only capable of removing additional emissions and is not considered to be a removal technology. It is therefore unclear if the net zero emissions scenario has already accounted CCS in the reduction of 89.4%.

Requires technological solutions for carbon neutrality: yes

4. LULUCF

Separate section in LTS: Yes

The LTS states that the sector has consistently been a sink since 1990, but the overall size has been decreasing. It is further noted that the biggest reason for this decline has been the lack of forest management practices since the 1990s. One possibility is that it will continue to decrease in size. Hence, measures should ensure the size of the sink is maintained until 2030 and the sector does not become a net emitter.

Several different policies and measures are then given in the LTS. It is stated that these should be harmonised with other aspects (such as food production and wood products), with certain choices (such as removing wood for energy purposes) found to decrease the size of the carbon sink.

A series of guidelines for 2030 and 2050 are then given in LTS. For 2030, emissions calculations should be improved and management guidelines should be developed to increase the size of the sink. This requires an understanding of the area under each (sub)-category and emissions associated with each type of conversion. Thereafter, improved projections of emissions can be produced. Further guidelines for 2030 need improvement and harmonised regulations in forestry, agriculture, and environmental protection, to analyse the effectiveness of current measures, and to carry out afforestation in line with sustainable management. The effects of this on the fulfilment of RES requirements shall then be ascertained. A further measure is improved forest fire planning.

To develop subsequent guidelines for 2050, measures up to 2030 should be analysed and assessed. Based on these, further guidelines should also be developed for LULUCF development and forest management. Additional funding for research and technical projects should be provided.

Additional emphasis is given to the specific topic of research and development. Here, research is needed into technologies and technical/non-technical measures to reduce net emissions in all sectors. Models and methods for carbon management and to improve sink calculations and projections are also needed, as well as the possibilities to increase carbon storage on agricultural land should be looked into.

The LTS also discusses several points related to agriculture that are relevant for LULUCF. These also refer to improving knowledge. For example, there is a desire to have a system to monitor changes in carbon stocks in agricultural soils and pastures, and to assess the potential by which they can be increased. A list of measures to improve carbon sequestration, such as reduced tillage and agroforestry are then provided.

5. Bioresources

The LTS does highlight some increased use of bioresources however, it also states that wood residues from forests and wood production should be environmentally friendly and sustainable. Wood products in both new and traditional products can be used to store carbon.

However, the LTS most strongly refers to biofuels. For example, solid biomass and biogas are explicitly included as RES for electricity. Refineries should expand their activities towards biofuels and advanced biofuels, which are also highlighted as having a role in heavy transport. It is stated that their use will be subject to sustainability requirements. With regards to energy, guidelines for 2030 discuss biofuels in district heating systems but only via modern techniques to reduce air pollution (it is also needed to replace their direct use in households for this reason). After 2030, these energy needs should further reduce and be replaced by heat pumps and solar thermal heating.

Moreover, some quantitative information is given in the annex. Solid biomass is predicted to decrease in the reference scenario, along with biogas, but other biofuels are projected to increase. However, for the strong transition scenario, biogas significantly increases in use after 2040. No information was available for the climate neutrality scenario.

Increased use of bioresources: Yes

6. CCS/CCU

Within energy use, it is stated that there are the technical and natural preconditions in Croatia for CCS to be used. More research is also needed into CCS and CCU, particularly regarding transport, storage, and possibilities for use. Moreover, CCS is required for power plants and the cement industry in the strong transition scenario (and is therefore likely to also be needed in the climate neutrality scenario). A variety of different industries, such as cement, processing and fertiliser production are requested to examine the feasibility of CCS.

CCS is seen as a transitional solution, allowing the continued use of fossil fuels for the next 3-4 decades. Under the strong transition scenario, it is stated that after 2030, all new fossil fuel plants will need to examine the possibility of CCS.

Considering CCS/CCU: Yes

7. DAC/BECCS

BECCS and DAC are not discussed separately in the LTS.

Cyprus

1. General information

Published: Cyprus has yet to publish an LTS.

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -0.35 Mt CO_2e

LULUCF emissions in 2030 (projected) = -0.4 Mt CO_2e

LULUCF emissions in 2040 (projected) = -0.4 Mt CO_2e

LULUCF emissions in 2050 (projected) = -0.4 Mt CO_2e

3. Modelling and Targets

Sink requirements: -0.8 Mt CO_2e (assumption, no LTS)

Qualitative detail

Cyprus has yet to publish an LTS. However, in order to gain an understanding of the potential necessary sink requirements, it was assumed that mitigation efforts could reduce emissions by 85% on 1990 levels (emissions in 1990 were 5.6 Mt CO_2e). As such this would set a potential sink requirement as around 0.8 Mt CO_2e.

Requires technological solutions for carbon neutrality: N/A

Czechia

1. General information

Published: January 2018

Length: 123 pages

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: 12.7 Mt CO_2e[51]

LULUCF emissions in 2030 (projected) = 1.6 Mt CO_2e

LULUCF emissions in 2040 (projected) = 4.5 Mt CO_2e

LULUCF emissions in 2050 (projected) = 5.1 Mt CO_2e

3. Modelling and Targets

Sink requirements: -39.1 Mt CO_2e (target)

Qualitative detail:

The LTS targets an 80% reduction in emissions compared to 1990 levels (excluding LULUCF). The limit on emissions is then set at 39.1 Mt CO_2e, what they state in the LTS are 'outstanding emissions'. Therefore, based on the target set within the LTS, this level of emissions must be subsequently accounted for in removals to reach climate neutrality. Three different scenarios are found to reach this proposed target, some of which use CCS. These emission projections are intended to be illustrative.

[51] The LULUCF sector was a sink up to 2017 and has increased significantly since then. Further, the projected sink has significant fluxuations throughout the 5 year interval.

Requires technological solutions for carbon neutrality: yes[52]

4. LULUCF

Separate section in LTS: Integrated with agriculture

The main factors influencing the decrease in the LULUCF sink are the age of the forest composition.

It is stated that removals are far from reaching their full potential. There are several measures included to increase the size of the sink, but often related to agriculture: reduced tillage, year-round vegetation, afforestation on agricultural land. Other ways to increase the size of the sink are through sustainable forest management, but little detail is given on what this means.

The LTS also states that the total carbon sink is projected to stay roughly constant (despite the values in the EU reference scenario) and this will be achieved either through increasing forest stocks or by increasing the production of wood products.

There is also a desire for more research into the dynamics of carbon stocks in forest soils.

5. Bioresources

The LTS mainly discusses biomass in relation to energy. It is stated that the use of biomass energy will increase up to 2040. There is a biomass action plan, which states that there is the potential for 680,000 ha of arable land and 400,000 hectares of permanent grassland for biomass.

Moreover, emphasis is given to increasing the competitiveness of the 'forest-based value chain', through higher domestic use and consumption of wood and wood products, and research into new products (especially those with high emissions).

Increased use of bioresources: Yes

6. CCS/CCU

One of the scenarios that achieves an 80% reduction uses CCS and in this case it is used to remove emissions of 35 Mt CO_{2e}. Carbon storage was banned in Czechia until 2020, and further analysis is now needed before a decision on the future of these technologies can be made.

Considering CCS/CCU: yes

7. DAC/BECCS

BECCS and DAC are not discussed separately in the LTS.

Denmark

1. General information

Published: December 2019

[52] Based on the 80% reduction presumption from the LTS, a more ambitious scenario might not need CCS.

Length: 38 pages

Climate Neutrality: by 2050 at the latest

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: 3.1 Mt CO_2e

LULUCF emissions in 2030 (projected) = 3.2 Mt CO_2e

LULUCF emissions in 2040 (projected) = 3.3 Mt CO_2e

LULUCF emissions in 2050 (projected) = 2.7 Mt CO_2e

3. Modelling and Targets

Sink requirements: -10.6 Mt CO_2e (assumption)

Qualitative detail

The LTS does not discuss emissions under a climate neutrality scenario. Only one projection is included, which shows emissions decreasing by 49% on 1990 levels by 2040. No value is provided for 2050. This would require removals to be of a value of 36 Mt CO_2e in 2050 if no further emissions were achieved by this date. However, a more realistic scenario to provide an illustrative example of the required sink would be an 85% reduction in 2050. This would still lead to a requirement for the sink of -10.6 Mt CO_2e in 2050.

Requires technological solutions for carbon neutrality: yes[53]

4. LULUCF

Separate section in LTS: No

It is stated within the Danish plan that the role of LULUCF with regards to climate mitigation has yet to be decided. Perhaps as a result of this, there is limited information on this sector within the current plan. On a section considering agriculture, the plan states that a pilot scheme is needed for multifunctional land distribution that will then inform a subsequent major land reform plan. Thereafter, the LTS states that there will be support for afforestation that will be set out in a climate action plan, which is a goal of the current LTS. A separate goal references creating more diversity and woodlands, including clear targets and initiatives for the proportion of land that should be untouched woodlands and nature parks.

5. Bioresources

Bioenergy is currently utilised significantly for heating and accounted for two thirds of renewable energy in total in 2017. Projections show bioenergy share decreasing by 2040, particularly in heating and cooling but it still remains present. It is also projected to account for 10% of electricity demand, suggesting bioenergy will remain a significant source (around 21% of PEC) whilst the

[53] Reductions over the currently available sink requirements (stated in the LTS) are significant and technological options are likely to be required without significantly enhanced mitigation steps.

share of forests is targeted to increase (by 2040 PEC was projected to be at a similar level to the beginning of the projection).

Increased use of bioresources: yes (or stagnation)

6. CCS/CCU

CCS and CCU are not discussed separately in the LTS.

7. DAC/BECCS

BECCS and DAC are not discussed separately in the LTS.

Estonia

1. General information

Published: 2017 (original), 2021 (EE2035)

Length: 8 pages/31 pages

Climate Neutrality: -80% GHG by 2050 in the original LTS, CN in EE2035

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: 1.3 Mt CO_2e[54]

LULUCF emissions in 2030 (projected) = 1.4 Mt CO_2e

LULUCF emissions in 2040 (projected) = 0.8 Mt CO_2e

LULUCF emissions in 2050 (projected) = 0.2 Mt CO_2e

3. Modelling and Targets

Sink requirements: -6.0 Mt CO_2e (assumption, on 1990 levels), -2.9 Mt CO_2e (assumption, based on 2005 levels)

Qualitative detail

The original document from 2017 states that the carbon sequestration capacity of forests as well as soils must increase and storing more carbon in Estonian wood products is emphasized. The updated document from 2021 (EE35) does not specify how Estonia will reach carbon neutrality. There is no modelling or more specific targets, apart from the the 8 Mt CO_2e goal for GHG net emissions by 2035 (including the LULUCF sector) in EE35. In order to provide an illustrative example of what the size of the sink may have to be in 2050, a value of 85% reduction on 2005 emissions (excluding LULUCF) was chosen as comparing with 1990 levels would be unfair for the Baltic countries. Total emissions in 1990 were 40 Mt CO_2e, that would make 6 Mt sink requirements

[54] In 2020, LULUCF became an emitting sector for the first time, whereas in 2010-2011 it was a sink of 4,8 Mt CO_2e

which is not realistic. However, total emissions in 2005 (19 Mt CO_2e) call for a sink requirement of 2.9 Mt CO_2e.

Requires technological solutions for carbon neutrality: N/A (either in the original LTS or EE35).

4. LULUCF

Separate section in LTS: Yes, 'forestry and land use' and 'agriculture' are separate sections in the original document, although not in EE35.

The original LTS states productive and sustainable forest management (consisting of maintenance felling and timely felling of stands, rapid renewal of the forest with tree species suitable for the growth site type) will preserve or increase the carbon stock in the long term. Use of wood is promoted as it would replace some of the non-renewable resources. In other land categories techniques for increasing carbon sequestration and reducing emissions (which are not described further) are preferred. It's emphasized that trends in the land use sector are monitored and considered in planning.

The carbon stock stored in peat will be maintained or increased. Moreover, further draining of marshes is avoided and natural water regime is restored in disturbed areas, where possible. In R&D, priority is given to research that can help increase carbon sequestration and find alternative ways of using wood.

Both the original document and EE35 read as aspirational. Goals like *"Farmers are motivated to design and maintain permanent grasslands, small wetlands and buffer zones, and to reduce the cultivation of peat soils"* are set, but this is not backed up with measures or further information on what must be done to reach these goals. Falling out of use or reductions in agricultural land with valuable soil, for example by covering the land with buildings or facilities, is said to be limited by legislation. Further, to reduce land use and emissions per unit of output in the agricultural sector, productivity and efficiency will be increased.

5. Bioresources

Both in EE35 and the original LTS widespread use of domestic bio- and other RES in the production of electricity, thermal energy and transport fuels is encouraged instead of energy intensive non-renewables (mainly oil shale), as well as greater efficiency and valorisation of resources. For this climate-aware planning is mentioned. For biogas, the combined use of manure from intensive farms and previously unused grassland resources is preferred. For wood-based fuels, low-quality wood and by-products use from the wood industry are targeted.

Increased use of bioresources: yes

6. CCS/CCU

CCS and CCU are not discussed separately in the LTS.

7. DAC/BECCS

BECCS and DAC are not discussed separately in the LTS.

Finland

1. General information

Published: April 2020

Length: 62 pages

Climate Neutrality: By 2035 at the latest[55]

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -17.3 Mt CO_2e

LULUCF emissions in 2030 (projected) = -11.9 Mt CO_2e

LULUCF emissions in 2040 (projected) = -14.0 Mt CO_2e

LULUCF emissions in 2050 (projected) = -15.0 Mt CO_2e

3. Modelling and Targets

Sink requirements: -8.8 Mt CO_2e (modelling)

Qualitative detail

The climate neutrality goal is achieved in two of the three scenarios described in the LTS. The third scenario achieves climate neutrality by 2050 and is stated to need a net sink of 30 Mt CO_2e. The two scenarios that reach carbon neutrality by 2035, the continuous growth and savings scenarios, reduce emissions by 87.5 and 90%, respectively. These results are with removals excluded, but the savings scenario says it would make use of CCS, whilst the continuous growth scenario does not. The amount of removals from CCS in the savings scenario is uncertain. Hence, taking the other scenario, the required sink would be 12.5% of 1990 total emissions. This is a value of 8.8 Mt CO_2e and is the value included above. However, it should be noted that this defined the minimum sink size in 2050. For 2035, at which point the degree of direct mitigation would be lower, the size of the required sink would necessarily have to be higher.

The WEM scenario is a reference scenario that takes into account planned developments up to 2030 and then extrapolates for the period beyond this. There is also a description of the key baseline date for this scenario in the text. It therefore does not include any additional detail regarding the LULUCF sector.

The continuous growth scenario is based on emissions reductions through rapid deployment of new technologies. Of relevance to the LULUCF sector, this scenario assumes industrial wood production declines after 2030 (at least compared to the WEM scenario). In turn the savings scenario is based on the circular and sharing economies and significantly increasing energy efficiency. It also includes CCS and agriculture, and forestry are used to promote a circular economy and the introduction of new bioproducts to replace those from fossil fuels. Here the wood for new products is sourced domestically.

Requires technological solutions for carbon neutrality: No (one scenario uses CCS)

[55] The current legally binding reduction (as of 2020) was an 80% reduction by 2050.

4. <u>LULUCF</u>

Separate section in LTS: Yes

The LTS predominately provides further detail on the effects of each of the scenarios on the LULUCF sector and not on policies or measures. The document also states that the scenarios are indicative and require more detail on enabling policies must be developed. The scenarios for this sector were made up of individual scenarios for harvested wood products and each land use category. The document states that the goal of climate neutrality is fundamentally influenced by the uncertainties relating to forest carbon sinks and the development of these sinks is a key issue up to 2050, although all scenarios predict it remaining so. All also predict an increase in the size of the growing stock.

Each scenario is rather similar up to 2030. The larger differences that emerge thereafter are mostly due to changes in the forest sink. The continuous growth scenario has the highest sink value as it corresponds to the lowest level of roundwood removal, with the opposite being the case in the savings scenario.

With regards to the intersection of land-use and agriculture, all of the scenarios predict a decrease in cultivated area by 2050. This is driven by a significant decrease in animal products and is larger in the savings and especially continuous growth scenarios. There is a further discussion about how these changes will affect biodiversity and also localised impacts on society and the economy. Both scenarios achieving carbon neutrality by 2035 see a large decrease in peat production. Afforestation is the main alternative for the freed-up land from cultivation and peat production. But it does not have a substantial impact on the size of the sinks, however, due to the short timeframe up to 2050 and the relatively small area converted relative to the current size of forested land. Tables showing the size of different land use areas are provided for each scenario at five-year intervals. A similar table showing emissions and removals for each LULUCF category and for each scenario is also given in the appendix. This also provides significant further detail on the modelling used to obtain the results.

However, there is less in terms of descriptive detail about policies to be enacted outside of the description of each of the scenarios. Some detail on the direction that the Finnish public would like is given in an appendix that details responses to questions arising from public consultation, one of which deals with the land-use sector. The summarised response states that forest health should be maintained by so-called active forest management and a situation should be reached where sinks are not dependent on wood demand and harvesting levels. Several measures are suggested such as scrubland afforestation, abandoning of peat fields, construction of new conservation areas and reduced harvesting quotas. Here, stronger steering instruments would be needed to cut down on forest clearances. Additionally, fees could be payable for land-use change and wood products could be more focussed on products with greater climate benefits (*i.e.,* establishing a hierarchy of use).

On the topic of adaptation, the LTS refers to an adaptation plan drawn up by the environment and agriculture and forestry ministries. But the detail on this plan is not included in the LTS.

5. <u>Bioresources</u>

The developed scenarios include some targets related to bioresources. These include the halving of peat use by 2030, whilst at the same time biofuels should provide 30% of energy consumption in transport and 10% of light fuel oil for buildings. The 2030 share of biofuels in transport are 16, 35 and 30% for the reference, continuous growth and savings scenarios, respectively. The corresponding values in 2050 are 41, 53 and 53%. Taken collectively, however, the scenarios indicate a modest increase in bioenergy compared to 2020 and the figures show bioenergy provides significantly more energy than wind and solar in 2050. The production of biogas from manure is also limited by declining livestock numbers.

The savings scenario increases the amount of harvested timber, but this eventually is calculated to limit the use of bioenergy resources. In contrast, the continuous growth scenario decreases the amount of harvested timber whilst increasing the size of the carbon sink.

Increased use of bioresources: yes

6. CCS/CCU

The LTS states that CCS is not used in the continuous growth scenario but is used in the savings scenario. However, it further states that this will be bio-CCS (of a value of 14 Mt CO_2e), suggesting that BECCS is targeted, rather than CCS.

Considering CCS/CCU: Yes (in one scenario, subject to the caveat described)

7. DAC/BECCS

The savings scenario includes negative emissions from 'bio-CCS'. However, the document makes no specific mention of DAC or BECCS.

Considering DAC/BECCS: Yes

France

1. General information

Published: March 2020

Length: 176 pages

Climate Neutrality: by 2050 at the latest

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -14 Mt CO_2e

LULUCF emissions in 2030 (projected) = -35.7 Mt CO_2e

LULUCF emissions in 2040 (projected) = -33.8 Mt CO_2e

LULUCF emissions in 2050 (projected) = -31.6 Mt CO_2e

3. Modelling and Targets

Sink requirements: -78 Mt CO_2e (modelling)

Qualitative detail

The LTS targets an emission reduction (excluding LULUCF) of 83% on 2015 levels by 2050. Emissions from other sectors in this year were 458 Mt CO_2e according to the LTS. Therefore, outstanding emissions would amount to 78 Mt CO_2e in this year, and this defines the size of the necessary sink requirements. However, it should further be noted that the French submission to the UNFCCC placed 2005 emissions at 551 Mt CO_2e. Note that the LTS itself presents a similar value on page 18. This includes a breakdown by sink type and suggests that the size of the sink is required to roughly double between now and 2050.

Requires technological solutions for carbon neutrality: yes (it is already accounted for in the projections)

4. LULUCF

Separate section in LTS: Yes

The French LTS and coverage of the LULUCF sector is extensive. Different goals are described by guidelines, with most have one or more associated quantitative indicators by which they can be measured. LULUCF has been a sink since at least 1990. Agriculture, on the other hand, is projected to be the greatest source of emissions in 2050 (accounting for well over half of emissions in the climate neutrality scenario).

Projection: A breakdown of past and projected emissions in the LULUCF sector between 1990 and 2050 is provided. Despite an overall reduction in the forest carbon sink in this period (although forest area will increase), this shows the size of the overall sink increasing rapidly after 2030. This is majorly through an increase in carbon storage in wood products and a net decrease in the emissions associated with artificialized land.

Forest-wood strategy: Forests cover 26 Mha across all French territory (including French Guyana), most being deciduous and under private ownership. There are also values for total mortality, amount of removals and amount of wood reaching market (125, 70 and 38 Mm^3, respectively). The cross-benefits of forests for biodiversity and water quality are highlighted. Moreover, in some areas, such as French Guyana, there is a tension between ensuring development and food independence and maintaining forest stocks. There is a desire to increase the amount of stored carbon in wood products and rely less on the forest sink directly, with better managed and less climate vulnerable forests. A series of guidelines and indicators are then given (as is the case for all sections in the French LTS). Examples include developing afforestation whilst considering environmental implications and improved monitoring of carbon content. Another guideline is to maximise substitution and storage in products.

Within the context of preserving the size of the carbon stock, several measures are included. For example, forest management should be expanded, and costs reduced by encouraging management and harvesting to be grouped together. More broadly, forest management should be incorporated into land management and urban planning, and policies that improve poor quality stands should be implemented. The examples of how to do this are through strategic felling and natural or artificial renewal. Moreover, measures are also given for improving afforestation, such as developing a certification standard for private investment, supporting spontaneous afforestation on old farmland, and removing obstacles for trees in urban settings.

The need for more research is also highlighted. For example, development of a regional-scale tool for monitoring climate impacts on forests and removal of wood and an accounting simulator for French wood.

Land planning: There is also a separate section in the LTS under LULUCF on urban planning and development. Diffuse land take and loss of carbon rich soils are continuing. Projections state that the percentage of artificialized land is set to increase from 10% to 14% in 2050 and 20% in 2100. The plan states that land take (conversion from natural to artificialized land) needs to be limited immediately, especially on land with the largest carbon stocks. The long-term goal is to reach zero net land take, but precise goals will be set in an update to the current LTS (the indicator will be net artificialized land per capita per year). Moreover, the importance of soil carbon, which regenerates slowly, is highlighted, along with the need to balance carbon stocks and carbon efficient landforms with renewable resources.

Measures to address land take include densification, developing multiple land uses in both urban and rural settings, developing urban forms resilient to climate change, and limiting soil sealing and excavation. Problems associated with a constraint on land, such as a feeling of overpopulation and congestion, and increased prices in rural areas.

Separately, within the agriculture section are several further points related to LULUCF. The LTS discusses the potential for offsets in this sector, for example through agroforestry.

5. Bioresources

The LTS also discusses bioresources extensively. This is found both in the LULUCF section and throughout the document in respective sections on energy, industry, and agriculture. The use of wood for buildings and long-lived products is recommended over energy purposes. The production of long-lived wood products should triple between 2015 and 2050. The carbon efficiency of wood products should also be improved, along with a circular wood economy. Indicators for this include the amount of carbon stored per m^2 of floor area and the volume of wood sent to landfill.

The LTS states that developing bioeconomy is considered important to substitute for carbon-intensive products. Within industry and energy, bio-based chemicals and more systematic use are targeted. New industries may arise from bio-resources. As an energy source, biomass resources will be strained by the orientation away from oil and gas. It is expected to be available from a variety of sources (wood, wood waste, crops and crop residues and effluents) and that biomass will provide between 400 and 450 TWh in 2050. Transport is the sector with the highest expected use of bioenergy. The consumption of bioresources is likely to be slightly above the production potential and as such will require revising.

Tensions that could arise from the higher use of bioresources are highlighted. Priority should be given to long-lived products and food.

Increased use of bioresources: yes

6. CCS/CCU

The LTS discusses CCS and CCU explicitly and there is an appendix on CCS. CCS is targeted to account for 6 Mt CO_2e in avoided emissions by 2050, based on the climate neutrality scenario in the LTS.

The use of CCS is targeted within industry and should be considered as soon as environmental and economic conditions allow. Captured carbon could be reused for fuels and goods. The degree of use should be limited, but the LTS considers it to be a technology export for France.

Storage could take place either on land or at sea. On land basins amount to between 1 and 1.5 Gt CO_2 based on initial studies, whereas at sea storage capacity is lower. However, storage at sea may be more socially acceptable. Existing infrastructure should be used and should only be deployed cautiously and incrementally.

Considering CCS/CCU: Yes

7. DAC/BECCS

BECCS is also explicitly considered within the LTS. It is targeted to achieve around 10 Mt CO_2e in emissions removals by 2050.

This will require an adequate and centralised use of biomass in big facilities and not in small scale use. France considers that the technology is uncertain, but it is more likely that such technology will be needed in the future as it allows for very long-term storage.

DAC is also included in the LTS. But it is stated that it is at a very early stage of development.

Considering DAC/BECCS: Yes

Germany

1. General information

Published: November 2016

Length: 92 pages

Climate Neutrality: yes* (The goal is not clearly defined, but the LTS includes a goal of extensive greenhouse gas neutrality by 2050)

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -11.3 Mt CO_2e

LULUCF emissions in 2030 (projected) = -34.8 Mt CO_2e

LULUCF emissions in 2040 (projected) = -42.9 Mt CO_2e

LULUCF emissions in 2050 (projected) = -46.3 Mt CO_2e

3. Modelling and Targets

Sink requirements: -62 Mt CO_2e (target)

Qualitative detail

The LTS quotes 1990 emissions of 1248 Mt CO_2e but does not stipulate whether LULUCF is included. However, this value is close to the 1990 total emissions submitted to the UNFCCC excluding LULUCF (1242 Mt CO_2e) and therefore it is assumed to not include LULUCF. The LTS then gives a range of percentage reductions as the goal of the LTS of between 80 and 95%. A reduction of 80% would leave outstanding emissions of 250 Mt CO_2e, whereas a 95% reduction would leave around 62 Mt CO_2e. As the attempt here is to estimate the minimum sink size that could be needed to achieve carbon neutrality, the more aggressive 95% reduction is used. Note also that an intermediate reduction of 87.5% would leave outstanding emissions of 156 Mt CO_2e to be removed. The plan will be further updated and revised through constant learning and feedback and is not a detailed masterplan for the future.

Requires technological solutions for carbon neutrality: no

4. LULUCF

Separate section in LTS: Yes

The sector is a net sink. There is a breakdown of emissions and removals by source for the year of 2014. There is also a focus within land use and forestry on the preservation and improvement of sinks, largely through afforestation. The LTS also makes a clear statement to reduce the conversion of land to settlements, with targets of no more than 30 ha/day by 2030 and no net conversion by 2050.

Guiding principles for 2020: More detail on this is said to be provided in the Forest strategy 2020[56]. However, additional aspects include efforts to better manage forests and better use wood, to conserve permanent grasslands and peatlands. Within forests, milestones for 2030 include adapting forests to climate change by using mixed, native species appropriate to location. One measure will be a forest climate fund to maintain and expand forests and help adaptation. Emphasis is also placed on reinforcement of international cooperation and supporting wider use of sustainability certification for wood products (including solid fuels). Moreover, under the conservation and sustainable management of forests, it is stated that any forest clearing should be offset and must include reforestation on an area at least the size of that deforested.

More space is also given to peatlands and permanent grasslands. There is a desire in the LTS to progressively reduce and eventually eliminate peat extraction and ploughing of permanent grassland. Remaining permanent grassland can only be converted with official approval and should not decrease by more than 5% in any region. There is also an aim to work at the EU level and expand protections at the national level (currently only for extraction for energy). At the EU level banning ploughing on carbon-rich soils is a priority.

It is stated that the government is working with regions to conserve peatlands and create incentives for water management to protect them. The use of peat as a growing medium should be reduced through requirements on peat substitutes in public procurements, although more research is needed. Forest peatlands should be restored wherever possible and the possibilities of paludiculture are examined.

5. Bioresources

The LTS references a national policy strategy on the bioeconomy. Emphasis is placed on wood use in buildings and other durable products and there should be a hierarchy of wood use. Barriers to the use of wood in these areas should be reduced. Bioenergy from cultivated crops will be limited by 2050, but that coming from waste and residues will be more important (wood use to generate energy should be from these sources wherever possible). Wood should be used in a cascade and cycles should be closed through optimised recycling. This can be promoted through incentives for R&D. Further research should also be conducted into new products.

Increased use of bioresources: Not clearly stated, but we can presume

6. CCS/CCU

CCU is briefly discussed in a section related to industry. The option of using this will be considered in the context of R&D for reducing industrial emissions.

Considering CCS/CCU: Yes

[56] https://www.bmel.de/EN/topics/forests/forests-in-germany/forest-strategy-2020.html

7. DAC/BECCS

The LTS does not mention DAC or BECCS.

Greece

1. General information

Published: January 2020

Length: 79 pages

Climate Neutrality: yes (The goal is not strict but is stated as moving towards a climate neutral economy by 2050).

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -4 Mt CO_2e

LULUCF emissions in 2030 (projected) = -1.9 Mt CO_2e

LULUCF emissions in 2040 (projected) = -1.8 Mt CO_2e

LULUCF emissions in 2050 (projected) = -1.8 Mt CO_2e

3. Modelling and Targets

Sink requirements: -12.4 Mt CO_2e (modelling)

Qualitative detail

The LTS presents scenarios in line with the 2 ºC and 1.5 ºC Paris goals, respectively. In both cases there are two scenarios, with greater emphasis on electricity and energy efficiency improvements and the other including new energy carriers. The modelling for these scenarios was done using PRIMES. The scenarios have not been decided on and are included for comparison. All also follow the same trajectory prior to 2030. There are also two further reference scenarios, one of which includes no further policies after 2030, and the other extends and strengthens the polices leading up to 2050.

The two baseline scenarios achieve emissions reduction of 58 and 75% respectively based on 1990 levels. In turn, the two scenarios in line with the 2 ºC show reduction of around 85%. The two scenarios in line with the 1.5 ºC limit (commonly thought to be equivalent to climate neutrality) see reductions of around 95%. Importantly, the LTS also includes absolute values and a sectoral breakdown that make clear LULUCF is not included. The LTS quotes 1990 emissions as 107.5 Mt CO_2e in 1990. This is similar to the value reported under the UNFCC total emissions of 103.5 Mt CO_2e (LULUCF was a sink of 2 Mt CO_2e in 1990). The two 1.5 ºC scenarios have outstanding emissions of 5.7 and 5.0 Mt CO_2e for the electricity and energy efficiency, and new energy carrier scenarios, respectively. However, the LTS also includes information on the amount of CO_2 that is captured in both of these scenarios The sink requirements for climate neutrality is taken from the lowest of these two scenarios. This is significantly greater in the new energy carrier's scenario, with a value of 18.4 Mt CO_2 compared to 6.7 Mt CO_2 in the electricity and energy efficiency scenario. Summing together, the minimum sink requirements are established as 12.4 Mt CO_2e.

Requires technological solutions for carbon neutrality: yes (it is included in the modelled scenarios for industry)

4. LULUCF

Separate section in LTS: No

LULUCF is not considered in the LTS outside of the context of bioresources. All of the scenarios show a large increase in the land under cultivation for energy crops (by a factor of 4 in the 2 and 1.5 ^{o}C scenarios). The maximum is found in the electricity and energy efficiency scenario, with 480000 ha. This is 4.3% of the land area of Greece (for comparison the built area in Greece equals to 6.1%).

5. Bioresources

Biomass resources are primarily targeted for energy, especially in the transport and power sectors. Priority is given to biofuels in transport, particularly in aviation, shipping, and heavy goods vehicles. The 1.5 ^{o}C that does not use new energy carriers, such as synthetic fuels, has biofuels responsible for 41% of final energy consumption (it is 20% when new energy carriers are included). These scenarios have biomass for energy increasing by a factor of 4-5. Biomass will also be used in industry. It is stated that a large-scale pellet industry could be developed but would suffer competition for use from advanced biofuels. Finally, the scenarios suggest that biomethane will provide between 20 and 30% of the gas distribution network in all scenarios.

Further information is given on the source and use of biomass in a separate section. As stated, a large increase in the use of biomass is expected. It is targeted to use biomass from plants that do not affect the food and feed market. On this point, the LTS includes a graph showing the development of biomass by source, with the largest proportion coming from woody biomass and agricultural waste and logging waste, forests provide a very small contribution. Second generation biomass, which does not come from food, should be available after 2030. A list of crops for 2nd generation includes trees such as willow and poplar. Abandoned land needs to be restored to large-scale cultivation to achieve this growth and the role of land improvement projects is important due to the great irrigation needs of energy crops. These new crops can help to improve agricultural income and productivity. It is noted that the competition for biomass is great, but biofuels have greater added value than other uses.

Regulations on the mandatory mixing of biomethane into the gas distribution network could help the development of this industry.

There is then a section on policies. This states that the development of the bioeconomy is a priority. Industrial organisation with large scale yields is needed and growth can have multiple socioeconomic benefits. Biogas and advanced biofuels have priority in the context of the LTS. The raw material should be woody biomass and energy crops, converted to biofuels in refineries. Policies need to increase the availability of these sources.

Increased use of bioresources: yes

6. CCS/CCU

The LTS makes clear use of carbon capture technologies. These are used in both the 1.5 ºC scenarios, with the LTS stating this allows continued burning of natural gas. In this context, it is only with CCS/CCU that residual emissions in electricity are removed. However, geological storage availability is limited in Greece. Current data suggests 140 Mt CO_2 is available, but this would be enough for small amounts in energy and industry.

The LTS includes a table showing the use of CCS and BECCS in each scenario. CCS gas amounts to 2.3 TWh in the scenario focussed on energy efficiency and 11.8 TWh in the one based on new energy carriers (but is not used in other scenarios). There is another graph showing the breakdown of CCS/CCU by sector. In the energy efficiency scenario, it is stored; in the new energy carriers scenario it is used for synthetic fuels.

Considering CCS/CCU: Yes

7. DAC/BECCS

The LTS also includes BECCS. The 1.5 ºC scenarios have negative emissions in the industrial sector because of BECCS. BECCS use amounts to 2.3 TWh in the energy efficiency scenario and 1.5 TWh in the new energy carrier's scenario.

DAC is also discussed at some points but does not appear to be used as a technology in any of the scenarios.

Considering DAC/BECCS: Yes

Hungary

1. General information

Published: September 2021

Length: 121 pages

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -6.8 Mt CO_2e

LULUCF emissions in 2030 (projected) = -4.2 Mt CO_2e

LULUCF emissions in 2040 (projected) = -2.1 Mt CO_2e

LULUCF emissions in 2050 (projected) = -2.4 Mt CO_2e

3. Modelling and Targets

Sink requirements: -14 Mt CO_2e (modelling)

Qualitative detail

The LTS describes three different scenarios. Of these, one is a BAU scenario, whilst the other two reach climate neutrality by 2050. They different in the speed by which the necessary steps are taken. Investment and socioeconomic analysis determined that the scenario which achieved decreases quicker, the early adoption scenario, had greater net benefits, and as such is analysed in more detail in the LTS. Taking this scenario at face value yields emissions to be 4.2 Mt CO_2e in 2050. This is based on the reductions given in table 3 for each sector.

However, these reductions also appear to factor in CCS/CCU. This is deduced from Figure 19 of the LTS, which shows a total of 10 Mt CO_2e in avoided emissions from CCU and CCS for the industrial and energy sectors, along with 11 Mt CO_2e of emissions (Agricultural emissions appear to be missing). Since the values in table 3 should yield 1.5 Mt CO_2e, this implies that CCS and CCU had already been factored in and their values must be separated to yield the total sink requirements in 2050. Adding these together gives a value of around 14 Mt CO_2e. Note that this represents a reduction in total emissions from 1990 of around 88%.

Requires technological solutions for carbon neutrality: Yes

4. LULUCF

Separate section in LTS: Yes

The LTS has further modelling of the LULUCF sector.

Both climate neutrality scenarios have identical treatments of the LULUCF sector, with targeted sink removals of around 4.5 Mt CO_2e for the sector in 2050. The LTS states this is mainly due to increased forest cover, and there is a breakdown of emissions for different LULUCF sectors in Figure 41 (although the scenario is unclear). Note that the document also states the size of emissions would be 0.14 Mt CO_2e under the BAU scenario (although the EU reference scenario still projects the sector remaining a sink). Socioeconomic analysis is also included, which show that the investment costs in addition to the BAU scenario would be 946 billion HUF to enhance storage after 2030. Moreover, it is later noted that achieving the goals will lead to a loss of income for forest owners and this must be compensated (for instance from revenues from the ETS). This could be a key factor in increasing forest cover. Note also that agricultural emissions are slightly larger than LULUCF removals.

However, doing this would increase the rate of afforestation from 3500 ha/year by a further 13000 ha/year and total forest cover would increase to 27% from 20.8%. Without this, forest cover does not increase significantly and as the age of the forest increases and the effects of climate change are felt, a significant part of the country would transition to ‘forest-steppe’, according to the analysis in the strategy.

Goals: The LTS also has specific goals under each sector. For LULUCF, this states healthy and climate resilient forests and grasslands. GIS (Geographical information system), digitalisation and automatization tools for farming will be important. Thereafter, it is stated that sustainable land use is a guiding principle, but there are no references to limiting overall land conversions.

The above detail is found in addition to the specific section on the LULUCF sector. This starts with a SWOT analysis on the sector in Hungary. Moreover, it states that the sum of emissions notwithstanding forests is positive, and projected to stay so until at least 2040, indicating that the entirety of removals will be generated from forests, with this being driven by afforestation and ‘sustainable forestry’ (although later it is also stated temperate grassland could play a role in sequestration).

Policy objectives are then given to maintain this absorption. Afforestation needs to be more climate conscious, with tree species more resistant to climate change and the transition to so-called perennial forest management supported. This is defined later in the text as composed of mixed, stable, and multi-aged forests. Efforts must also be made to reduce the soil degradation association with monocultures (50% of forests are non-native and many monocultural)

Links with agricultural and rural development policies: This section states that a number of relevant measures were also included in the rural development program, which ended in 2020 but should be extended to 2027. Moreover, there is reference to a national afforestation programme, with the hope to mobilise the population. It further states the importance of adaptation measures in light of the expected increased risks associated with climate change. There are measures related to fire prevention and the development of professional forest management, with the integration of climate change a precondition of forest policy. A later adaptation section also has links to LULUCF, for example through developing land use incentives to reduce extreme weather impacts and ensure soil fertility, but specifics are lacking. In this context it further states that increasing forest area is important, along with preserving (close to) natural ecosystems. This requires mapping of ecosystem services and the development of green infrastructure.

5. Bioresources

Sustainable use of bioenergy (within limits) is stated as one of the eight areas where action is needed to reach climate neutrality.

Within energy use in households, it is stated that under the BAU scenario firewood use greatly declines; within the climate neutrality scenario, it is reduced to a minimum so the resources can be used in other sectors. Biofuels are targeted quite heavily in the transport sector (28 PJ in 2050), but there are no further details beyond this. Finally, the LTS states that forest biomass can substitute forest fuels and sequester carbon in wood products.

The importance of R&D is then referenced through a table showing different technologies in the bioeconomy and their current technology readiness level (TRL).

Increased use of bioresources: N/A

6. CCS/CCU

Both of the climate neutrality scenarios state that CCS/CCU will be viable and used. Within the energy sector, emissions need to fall by 95% (from 40 Mt CO_2e) and CCS/CCU is seen as critical to meeting this. Indeed, the BAU scenario also makes use of carbon capture technologies. However, it is then stated that the technologies will only be used after 2030 or 2040, as cheaper technologies currently exist.

The climate neutrality scenario shown in more detail makes different use of the captured carbon. This is associated with electricity (potentially BECCS), industry, and H_2 production. The values are -2 Mt CO_2e (all electricity) in 2030, -10 in 2040 (-4 electricity, -4 H_2, -2 industry) and - 10 MtCO_2e in 2050 (-7 electricity, -3 industry). However, within the industrial production and processes section, the CCS/CCU that may be needed does not offer a cost-effective solution at present.

The need for R&D is then highlighted, with the TRL of various CCS/CCU technologies shown. Later, the LTS states that Hungary has limited storage capacity, which means that utilisation will be the primary focus (in H_2 generation and industry).

Considering CCS/CCU: Yes (it is required in the carbon neutrality scenarios)

7. DAC/BECCS

The plan includes BECCS and states this can be a source of negative emissions, although it is not always clear whether the distinction has been made between BECCS and CCS. However, due to the high price of CO_2, the BAU scenario also sees the adoption of BECCS.

The importance of R&D is also highlighted here. Finally, DAC is discussed as something to compensate remaining emissions. But it is stated that this is very expensive and needs to be applied at a large scale to reduce costs.

Considering DAC/BECCS: Yes

Ireland

1. General information

Published: Ireland has yet to publish an LTS.

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: 6.9 Mt CO_2e

LULUCF emissions in 2030 (projected) = 4.6 Mt CO_2e

LULUCF emissions in 2040 (projected) = 3.9 Mt CO_2e

LULUCF emissions in 2050 (projected) = 2.7 Mt CO_2e

3. Modelling and Targets

Sink requirements: -8.2 Mt CO_2e (assumption, no LTS)

Qualitative detail

The Republic of Ireland has yet to publish an LTS. However, in order to gain an understanding of the potential necessary sink requirements, it was assumed that mitigation efforts could reduce emissions by 85% on 1990 levels. Emissions in 1990 were 54.4 Mt CO_2e. As such this would set a potential sink requirement as around 8.2 Mt CO_2e

Requires technological solutions for carbon neutrality: N/A

Italy

1. General information

Published: January 2021[57]

Length: 100 pages

Climate Neutrality: by 2050

[57] It is emphasized that the LTS does not consider the impact of Covid-19 outbreak, and should be renewed in light of this

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -32.4 Mt CO_2e

LULUCF emissions in 2030 (projected) = -37.4 Mt CO_2e

LULUCF emissions in 2040 (projected) = -31.6 Mt CO_2e

LULUCF emissions in 2050 (projected) = -33.8 Mt CO_2e

3. Modelling and Targets

Sink requirements: -65 Mt CO_2e (modelling)

Qualitative detail

Italy has had 17% decrease in GHG emissions between 1990 and 2018 (from 516 to 428 Mt CO_2e). It is stated that for carbon neutrality 390 Mt CO_2e removals (including LULUCF) need to be achieved by 2050 compared to 2018. Two scenarios are modelled in the LTS: the reference scenario also known as 'NECP extension to 2050 scenario' and 'Decarbonisation scenario for 2050'. One of the three levers for the decarbonisation scenario is *"increase in CO_2 absorption, by forest land (including forest soils) obtained through sustainable management, the restoration of degraded land and afforestation, possibly supplemented by forms of CCS"*. In total, in the decarbonisation scenario, there are 65-85 Mt CO_2e to compensate in 2050, but LULUCF can provide a sink up to 45 Mt CO_2e. The lowest required value for the sink in 2050 is then taken as 65 Mt CO_2e.

Requires technological solutions for carbon neutrality: Yes, the remaining GHG emissions (20-40 Mt CO_2e) are offset by CO_2 sequestration as well as the eventual use of CCS-CCU. However, it is not stated when CCS/CCU can be used.

4. LULUCF

Separate section in LTS: Yes

LULUCF removals were 36 Mt CO_2e in 2018 and they have been similar over the last 20 years, with a peak in 2015 (45 Mt CO_2e). 45 Mt is also the goal for 2050 which seems rather realistic with adequate policies to combat fires and sustainable soil management.

Land use for agricultural areas is expected to increase until 2040 and then stabilize (increase in cereal areas, decrease in woody and industrial crops). Forage areas and number of grazing animals will decrease. Forest areas will grow until 2030 and then remain the same. It has been hypothesized that forest management in Italy can increase harvesting activities up to a maximum of 40-45% of the annual increase, starting from the current estimated use of 33%. There is concern about the land use of PV plants in the LTS.

The agricultural sector is responsible for about 7% of the total GHG emissions corresponding to about 30 Mt CO_2e in 2018. Overall emissions have decreased by 13% compared to 1990 levels, due to the reduction in the number of livestock, areas and agricultural production, the reduction of fertilizers used, the changes introduced in the management of farming techniques and the implementation of the interventions of the Common Agricultural Policy (CAP). Improvements can be made in the management of livestock farms and innovative virtuous techniques to increase the stock of carbon in the soil.

5. Bioresources

It is stated in the LTS that the potential of biomass must be “fully exploited”, including the valorisation of wood deriving from sustainable forest management.

Change in eating habits is mentioned to reduce CH_4 emissions in the agricultural sector. The contribution of bioenergy (biogas and biomethane) will be significant in thermal end uses but also in the generation sector. Italy sees huge energy potential generated by agricultural activities (wastewater, other by-products, photovoltaics on rural buildings) and advanced biorefineries (to produce biofertilizers, protein feed, bioenergy and biochemical substances), which also offer opportunities for the transition to a climate-neutral European economy and the creation of new jobs.

The benefits of regenerative bioeconomy are mentioned, as it feeds the "biological cycle" or the recovery and enhancement of matter and energy of organic waste from production and consumption processes. It can play a key role in the protection and regeneration of soils, also contributing to the absorption of CO_2 from the atmosphere.

In road transport, in addition to increasing efficiency, there’s a residual need for private mobility and goods, which can be solved by the spread of biofuels, especially biomethane, and the increase of electric vehicles which are promoted in the LTS. Electrification, hydrogen, advanced biofuels and synthetic fuels also appear to be the most viable options for short sea shipping and inland waterways. Biofuels are also one option for aviation. The use of renewables has grown 5 times compared to 2000, which reflects the emergence in the residential sector of the consumption of woody biomass not accounted for in the economic-financial circuits.

Increased use of bioresources: yes

6. CCS/CCU

For CCS/CCU potential is seen mostly for industry (energy and non-energy). In the steel and non-metallic minerals industries (cement in particular) it could be possible to capture 10-20 Mt CO_2e.

However, in order to use it, critical system aspects will have to be resolved, including the transport of CO_2 from generation plants to reuse or geological storage sites. Two options of CCS explained for the energy sector: Power plants with post combustion capture and power plants with capture in oxy combustion. For example, fuel switch to less emissive fuels is one option that can only be considered if coupled with a greater use of CCS.

Alternative methods mentioned to CCS in the LTS: changes in consumption habits, other technologies and production methods (eating less meat, development of technologies that help phase-out F-gases, revision of energy taxation, circular economy in energy intensive sectors).

Considering CCS/CCU: yes

7. DAC/BECCS

The LTS states that the electricity generation system also offers the opportunity to subtract CO_2 from centralized emission sources (CCU and CCS) fuelled by bioenergy and natural gas, both to be stored (which would result in "negative emissions" if the CO_2 comes from biological sources) and for reuse in the production of carbon-free alternative fuels. For example, H_2 derived from renewables combined with captured CO_2 of "bio" origin allows the production of biomethane and fuels like conventional ones but with zero greenhouse gas emissions (e-fuels), thus favouring the reuse of existing infrastructures and vehicles.

BECCS can be used to produce alternative fuels such as synthetic methane or methanol (for the transport sector) or sequestered in underground deposits for hundreds of years.

Moreover, the subtraction of CO_2 from thermoelectric plants makes it possible to eliminate emissions from any production quotas that would still be based on fossil fuels. The negative emissions from plants powered by bioenergy or biomethane can be spent in other sectors, where decarbonisation is considered extremely difficult.

Considering DAC/BECCS: yes

Latvia

1. General information

Published: 2019

Length: 55 pages

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: 0.64 Mt CO_2e

LULUCF emissions in 2030 (projected) = -1 Mt CO_2e

LULUCF emissions in 2040 (projected) = 1.4 Mt CO_2e

LULUCF emissions in 2050 (projected) = 1.6 Mt CO_2e

3. Modelling and Targets

Sink requirements: -3.9 Mt CO_2e (assumption, based on 1990), -1,6 Mt CO_2e (based on 2005)

Qualitative detail

There are two strategic objectives in the LTS, i) reducing GHG emissions in all sectors and ii) increasing CO_2 removals. Compared to 1990 levels (26.3 Mt CO_2e), Latvia aims for -55% emissions reductions by 2020, -65% by 2030 and -85% by 2040 without LULUCF. To put this into perspective the total GHG emissions in the country were 11.3 Mt CO_2e in 2017 (without LULUCF), which corresponds to 57% decrease compared to 1990. With LULUCF, however, the emissions in 2017 were lower (9.6 Mt CO_2e), but the decrease from 1990 was less significant (42%). For 2020 the projection for total emissions reduction with LULUCF was 16%, for 2030 38% and 2040 76%. In order to obtain an estimate of the minimum sink requirements for carbon neutrality, and in the absence of other information, the target reduction of 85% on 1990 levels (excluding LULUCF) could have been chosen. However, as stated above in the Estonia country annex, sink requirements based on 1990 reference year are not realistic. Therefore, comparing to 1990 defines a minimum sink size of 3.9 Mt CO_2e in 2050, but on 2005 levels it would equal to 1.6 Mt CO_2e. This is on the unlikely assumption that no further emission reductions occur between 2040 and 2050.

The LTS gives a great overview of the sectors and situation in the country, which is of help in understanding the historical context, but it lacks in modelling. Two scenarios, WEM and Climate Neutrality are mentioned, but no details are given. It is mentioned that additional investments for achieving the CN scenario are approximately 16 billion euros (in constant prices of 2010) or 1.35%

on average per year from GDP in the time period (2020–2050) but considering the benefits that would arise from implementing these measures the total additional costs would amount to 13.5 billion euros (in constant prices of 2010) or 1.1% on average per year from GDP in the time period (2020–2050).

Requires technological solutions for carbon neutrality: yes (in addition to technological solutions, Latvia also sees potential in lifestyle changes)

4. LULUCF

Separate section in LTS: Yes, for the current situation chapter, but for the main factors influencing GHG emissions and potential solutions land use and agriculture are described together.

The removals in 1990 (-9.8 Mt CO_2e) were similarly sized to the 2017 overall emissions (11.3 Mt CO_2e), meaning relatively close to climate neutrality. However, in 2020 the LULUCF sector was an emitting one (0.64 Mt CO_2e). By 2030, Latvia wants to reach less than 1.047 Mt CO_2e LULUCF emissions and net-zero emissions by 2040. As in 2050 the LULUCF sector should make up for all non-reducible GHG emissions in other sectors, the progress that needs to be made in 2040-2050 seems significant.

The LULUCF sector became an emitting one in 2013 and emissions are expected to increase until 2050. The main cause for this is the increase in the proportion of stands that have attained or surpassed the falling age which has promoted increase in the amount of exploitation of the forest and increase in emissions related to the natural mortality of trees. This explains the carbon sequestration in the live biomass slowing down, which increases the CO_2 emissions in such forest stands upon mineralisation of the carbon accumulated in the dead wood, which results in GHG emissions exceeding carbon removals in biomass of woody plants. However, the LTS states that balance between deforestation and afforestation is ensured as well as Latvian forests having a sustainable age structure.

GHG emissions from cropland and grassland have, however, been decreasing since 1990. This is mainly related to the mineralisation of organic soils, transformation of cropland into grassland, and afforestation. For grassland, the largest amount of emissions originates from organic soil. It's emphasized that substantial CO_2 and N_2O emissions are formed in organic soil regardless of the method of management, whereas the carbon stock in mineral soil is increasing or decreasing as a result of changing the type of land use or the method of management.

Agriculture is the third largest source of GHG emissions in Latvia, generating 24.6% of the total emissions in 2017 and it's projected that by 2050 the emissions in the sector will increase by 15% compared to current levels (2017) and 43% compared to 1990. The emissions from wetlands have increased compared to 1990 and will continue to do so in the future, due to the increase of peat extraction. Overall, the use of mineral fertilisers, high proportion of organic soils and forestry coverage are the main factors influencing the LULUCF sector in Latvia.

5. Bioresources

Over the years 2015-2019, electricity produced in biomass (wood fuel) cogeneration plants and power stations increased from 215 to 525 GWh and in biogas cogeneration plants from 288 to 405 GWh. The usage of solid biomass in combustion installations spiked when Latvia joined the EU. Bioeconomy is seen as a wide-scale solution which ensures integrated approach towards inclusion of knowledge-based economic growth, social welfare, and environmental protection into agriculture, forestry, and fisheries, conforming to the basic principles of circular economy and more efficient use of natural resources. Reduction of the amount of waste in processing and replacement of fossil resources with bioresources are seen as potential development opportunities.

Bioeconomy can be promoted and achieved simultaneously with climate objectives by developing the use of wood resources for the manufacturing of products with high added value, including for export needs. Sufficiently extensive use of liquid biological heating fuel in energy generation and use of bio-oils in equipment in the agricultural and forestry sectors is seen as one solution in achieving climate neutrality. Biofuels are also brought out as an option for aviation and non-electrified train lines.

According to the LTS, in 2050 biofuels of the newest generation have been developed which reduce the risks of crops to be used in food and soil fit for growing food being used for the acquisition of bioenergy.

Increased use of bioresources: yes

6. CCS/CCU

After determining the modelling prices and the potential geological storage sites in Latvia, it was concluded that the efficiency of the creation of CO_2 storage sites (CCS) is too low and such solution would not be economically feasible for now. Further research needed.

Considering CCS/CCU: it is briefly mentioned, mainly for the cement and chemical substances sectors which are hard-to-decarbonise otherwise

7. DAC/BECCS

The LTS does not mention DAC or BECCS.

Lithuania

1. General information

Published: 2021

Length: 35 pages

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -5.4 Mt CO_2e

LULUCF emissions in 2030 (projected) = -3.3 Mt CO_2e

LULUCF emissions in 2040 (projected) = -4.3 Mt CO_2e

LULUCF emissions in 2050 (projected) = -4.9 Mt CO_2e

3. Modelling and Targets

Sink requirements: -8.5 Mt CO_2e (target), 3,4 Mt CO_2e (assumption, based on 2005)

Qualitative detail

Lithuania intends to reduce its emissions by 30% compared to 2005 and 70% compared to 1990. In the first 15 years after regaining independence (1990-2005) Lithuania managed to reduce its emissions by more than half, from 42.7 Mt CO_2e to 18.9 Mt CO_2e and to further reduce it to 15.6 Mt CO_2e in 2019. However, The LTS does not include any projections of emissions up to 2050 under any scenarios. It is stated that 20% of removals in 2050 should be covered by natural sinks, yielding a value of 8.5 Mt CO_2e. However, it is possible that the actual level of removal will be higher than this if technological means are factored in. If we were to use the assumption of 85% removals compared to 1990 (like with some other countries who do not provide targets) or compared to 2005 (which makes it more realistic for the Baltic states) the sink requirements would be -9.6 Mt CO_2e or -3.4 Mt CO_2e, respectively.

Requires technological solutions for carbon neutrality: Yes, by applying environmentally safe CCS, CCU technologies to offset GHG emissions in sectors where no technological potential for full GHG emissions will be discovered

4. LULUCF

Separate section in LTS: No (there's a chapter on Maximum Sustainable Yield that's connected to the sector)

Lithuania aims for a 6.5 Mt CO_2e carbon sink in 2030 although the projected size of the sink with existing measures is only 3.3 Mt CO_2e. They wish to achieve this by sustainable use of agricultural land and forest land, protection and restoration of natural habitats (forests, grasslands, wetlands) accumulating organic carbon and ensuring good ecological status, increasing the use of wood in construction and production of durable products without additional negative impact on ecosystems, increasing absorption potential, and making the most efficient use of it.

Some of the measures Lithuania plans to use to enhance the carbon sinks by 2024 are increasing the country's woodland by at least 35%, while giving priority to areas self-overgrown with trees and shrubs, in accordance with ecological principles; increasing the areas of permanent grassland by at least 8 000 ha and restoring at least 8 000 ha of areas of carbon-rich ecosystems, ensuring their sustainable use, and stopping the exploitation of new natural wetlands as well as promoting changes in consumption patterns by increasing the use of products and energy produced from renewable wood sources.

Agriculture is the third largest emitting sector in the country. The LTS emphasizes that financial support has so far been mainly given to intensive farming and farmers often lack the expertise to switch to new technologies and implement environmentally friendly production practices that reduce GHG emissions. Also, there's no farm-level accounting system for emissions and removals in the sector that would provide an economic incentive to reduce GHG emissions when operators compare their emissions. The main goals in the sector are to reduce emissions by 11% compared to 2005 by 2030 and abandon using fossil fuels by 2040. The LTS also mentions a goal of food waste reduction by 50% by 2030 compared to 2019.

As the agriculture sector is particularly vulnerable towards climate change, adaptation methods like developing the insurance system, activities for self-fund funds and nature-based solutions are mentioned.

5. Bioresources

The goal by 2030 is to develop a bioeconomy focused on high added value and moving towards a circular transition, while increasing its contribution to the country's GDP.

The Law on Alternative Fuels of the Republic of Lithuania creates preconditions to promote the consumption of fuels from RES and advanced biofuels by imposing obligations on fuel suppliers regarding the supply of fuels. Currently, biofuels are used relatively extensively in district heating (gas is the other major source of heat). The amount of pollutants particularly dangerous to health from heating equipment from households is increasing in Lithuania, due to the inefficient use of heat energy production from solid biofuels and other solid fuels and inefficient heat production facilities.

The country has set several goals for 2024, for example they intend to adapt the existing natural gas network infrastructure to hydrogen and biogas transport, giving priority to gas from RES and ensure that all public buildings are built from at least 50% organic and wood construction materials, therefore increasing the use of secondary raw materials, and reducing the generation of construction waste.

For the transport sector, Lithuania wants to achieve a minimum of 3.5% of biofuels in the final energy consumption by 2030 by promoting the production of advanced biofuels and for biogas production they want to achieve the use of 50% of pig and cattle manure by 2030.

By 2045 Lithuania plans to exit from using fossil fuels in industries participating in the EU ETS, replacing them with RES (green hydrogen, sustainable biomass, secondary raw materials, and other high-quality climate-neutral raw materials) and other non-fossil resources.

Increased use of bioresources: Yes

6. CCS/CCU

While the country wants to gain maximum use of natural sinks, they consider CCS on the condition that it's environmentally safe. CCU should offset GHG emissions in sectors where no technological potential for full GHG emissions will be discovered by 2050 (mainly industry). R&D are mentioned throughout the document, but no specific investment values are given.

Considering CCS/CCU: Yes

7. DAC/BECCS

The LTS does not mention DAC or BECCS.

Luxembourg

1. General information

Published: October 2021

Length: 97 pages

Climate Neutrality: by 2050 at the latest

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -0.3 Mt CO_2e

LULUCF emissions in 2030 (projected) = -0.3 Mt CO_2e

LULUCF emissions in 2040 (projected) = -0.3 Mt CO_2e

LULUCF emissions in 2050 (projected) = -0.4 Mt CO_2e

3. Modelling and Targets

Sink requirements: -1.9 Mt CO_2e (assumption)

Qualitative detail

There are no modelling scenarios in the LTS. There are also no specific targets for reductions, either at the nation-wide or sectoral level. However, a 'guiding principle' of the strategy is to reduce emissions as much as possible and offset what cannot be avoided. As an illustrative example of the potential sink sample, an 85% reduction in 1990 emissions (excluding LULUCF) can be taken. In 1990, Luxembourg had emissions of 12.7 Mt CO_2e. 15% of this would be 1.9 Mt CO_2e. This is then used as an example of the potential size of removals needed to reach climate neutrality.

Requires technological solutions for carbon neutrality: N/A

4. LULUCF

Separate section in LTS: Yes

The section in the LTS is known as Forestry and Carbon Sinks. This states that maintaining and increasing carbon sinks of forests, soils and agricultural land are essential to reaching climate neutrality. The average absorption of the LULUCF sector in the decade to the end of 2019 is given as 0.362 Mt CO_2e of removals per year. This is mainly due to forests. However, drought and bark beetle infestations are causing increasing problems and >50% of trees show signs of stress.

The LTS states that discounting sequestration in agricultural land, the available area for afforestation is limited, so measures to increase sink sizes must increase wood volume in existing forests. This will be through increasing the age of protected old forests, conservation of dead wood and promotion of resilient, mixed, and diversified forests. However, this diversification away from spruce monocultures is also stated to limit the potential. Strategies must be developed to minimise soil artificialisation.

Improvements can also be made to the open environment, according to the strategy. For example, restoration of bogs is highlighted, along with planting hedges and trees or the establishment of green agriculture.

Several measures are highlighted to improve resilience, strategy, and an action plan for adaptation. These are, to complete a map of forest biotypes and a catalogue of measures for viable forests under climate change, convert monocultures to mixed forests, and to improve or restore the functions of forest soil. This is accompanied by legislative measures to further protect forests and studies into the potential for sustainable wood harvesting and the development of decision-making tools for the choice of species. An aid scheme and advisor services for forest owners should also be strengthened and diversified, and a premium provided for the provision of ecosystem services in forests.

Agriculture: The separate agriculture section in the LTS also has relevance to LULUCF. For instance, by stating the role agricultural land can play in storing carbon. Agricultural emissions have been increasing, with emissions dominated by methane.

Agricultural measures with relevance to LULUCF include organic farming, which should be on 20% of land by 2025 and 100% by 2050. The role of agricultural demand as a carbon sink must be maintained or strengthened. This is currently achieved through a ban on ploughing of permanent grassland in ecologically sensitive areas, the promotion of cover crops and conservation ploughing. There is a need to extend the surface of permanent grassland. Crop diversification is supported to facilitate carbon formation in farmland, with detailed guidelines to be developed. Agroforestry projects should also be launched, along with increasing the number of hedgerows.

Harnessing the coordinating function of spatial and urban planning: This is found outside the dedicated LULUCF section, but with relevance to it. The LTS states that the form of urbanisation has a major impact; diffuse urbanisation in rural areas contributes to soil sealing and necessitates motorised transport. The country's land use policies are based on three levels – national, local and cross border. The national policy focusses on 'concentrated deconcentration' and focusses on well-balanced urban structure in towns outside the capital. At the more local level, municipalities and regions have to promote rational land use that reconciles urban and economic development with societal benefits and support for the climate transition. At the neighbourhood level, an eco-urbanism guide should play a key role in the rehabilitation of industrial wastelands. Finally, this section discusses on cross-border aspects regarding conurbation and national parks.

Research and development: The LTS also has a general section on R&D, some of which has specific links to LULUCF. For example, there is a desire to develop agro-economical technologies and soil carbon sequestration, whilst another research priority is monitoring the effects of climate change and scenario modelling to aid adaptation. Here particular attention is given to agricultural and forestry activities.

Adaptation is also included as a separate section.

5. Bioresources

Within the LULUCF section it is stated that an important level for carbon sequestration is the increased use of wood products. It is important for carbon to be stored in quality products with a long lifespan, such as construction. The Luxembourg wood cluster has been established to support the cascading use of wood, and the import of unsustainable wood should be avoided. This emphasis should also be included within public procurements. One important criteria should be materials of a renewable nature, preferring materials capable of storing carbon.

The use of biomass for energy purposes will, however, also be developed. The framework will be strengthened to guarantee sustainability, and the supply radius limited to the 'greater region'. However, the hierarchical use of wood is then again highlighted. Bioenergy from agriculture should focus on biogas from slurry, and dedicated crops kept to a minimum. Biofuels are also an option in heavy transport (and have been increasing in recent years). Criteria for use have been introduced and the share of 2nd generation biofuels should increase whilst 1st generation (agro-food) should decline. Finally, it is stated that without new options, the use of biomass will be limited due to the availability of raw materials (the NECP expects 10% blending by 2030)

Separate sections on buildings and industry also have some relevance. New buildings should use RES but should be fitted with heat pumps and the limited biomass spared, district heating networks excepted. Within industry, the circular economy with respect to bioresources is highlighted. Sustainable biomass is also one option in hard to decarbonise processes.

Increased use of bioresources: Yes (own assessment)

6. CCS/CCU

CCS/CCU is referenced but is seen as a last option for industrial production where emissions are difficult to eliminate.

Considering CCS/CCU: No

7. DAC/BECCS

The document does not discuss DAC or BECCS.

Malta

1. General information

Published: October 2021

Length: 120 pages

Climate Neutrality: Not clearly specified[58]

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -0.002 Mt CO_2e

LULUCF emissions in 2030 (projected) = 0.0 Mt CO_2e

LULUCF emissions in 2040 (projected) = 0.0 Mt CO_2e

LULUCF emissions in 2050 (projected) = 0.0 Mt CO_2e

3. Modelling and Targets

Sink requirements: -0.4 Mt CO_2e (target)

Qualitative detail

The LTS describes a BAU and low carbon development scenarios. The mitigation is modelled using marginal abatement cost modelling, such that only the magnitude of the savings is described in the text and not the absolute level of emissions. Figure 2 appears to show emissions in 2050 under a BAU scenario of approximately 2.75 Mt CO_2e, and under the low carbon scenario of around 0.4 Mt CO_2e. If sinks are not included, this would represent a reduction of around 85% on 1990 levels (emissions excluding LULUCF of 2.6 Mt CO_2e). A similar, though slightly larger, reduction can be seen by summing up the individual abatement potentials of the different sectors, which does not include LULUCF. Therefore, in the knowledge of the uncertainties the approximate sink requirements is taken based on this assumption as around 15% of 1990 levels (excluding LULUCF) as around -0.4 Mt CO_2e. Note that there are also indicative targets for the country of an 80% reduction by 2050 based on 1990 levels. Reaching climate neutrality based on this reduction would also require a similarly sized sink.

[58] Climate neutrality is stated as one of the main pillars of government economic policy, and the climate act enshrines international requirements into national law. Also later states that there is a need align with EU climate neutrality commitments.

Requires technological solutions for carbon neutrality: N/A (Based on the size of the current carbon sink, the implications are that such technologies would be needed for Malta to reach climate neutrality within its own territory).

4. LULUCF

Separate section in LTS: Yes (integrated with agriculture)

Note that there is a big shortage of land in Malta, which makes the abatement potential of the LULUCF sector limited. On top of this, The LTS further states that building space will increase by 20% up to 2050.

Further to the high population density and limited space, the lack of rainfall further complicates sequestration in new vegetation. There is a national forestry accounting plan, which gives details on afforestation and the levels of sequestration in new and existing forests. This was only on the order of 0.01 Mt CO_2e per year. Additional land on the required scale is deemed unrealistic, and as such the LTS does not include mitigation and offsetting measures for LULUCF. However, there is ecological and adaption value in afforestation.

Agricultural mitigation options are also seen as limited, with options mainly referring to diet modification of ruminants and waste management. But the LTS does have a separate section on adaptation. For land use and buildings, it is stated that natural erosion of the limited land area will be accelerated by climate change, which must also be taken together with the effects of sea level rises and storm surges. Other effects could be changes in land use patterns due to high temperatures and drought.

The document includes several measures listed in a table. The most relevant of which is adapting land use management to climate change, but without specific detail. A separate section discusses adaptation of natural ecosystems, agriculture, and fisheries. Here, climate change is seen to lead to soil erosion and reduced carbon stocks and sequestration in the soil. Additionally, a loss of biodiversity and habitats is referenced, along with water scarcity, loss of viable farmland and pollination difficulties. Several measures are again listed.

5. Bioresources

Bioresources are not discussed in the LTS

Increased use of bioresources: N/A

6. CCS/CCU

These technologies are included (known as carbontech). This is mostly from the perspective of R&D, with financing from the EU. Malta could play a role as a test bed for such technologies.

Considering CCS/CCU: Yes

7. DAC/BECCS

DAC and BECCS are not discussed separately within the LTS, beyond potentially been included in R&D projects.

Considering DAC/BECCS: No

The Netherlands

1. General information

Published: December 2019

Length: 22 pages

Climate Neutrality: 95% reduction of emissions compared to 1990

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: 3.5 Mt CO_2e

LULUCF emissions in 2030 (projected) = 4.6 Mt CO_2e

LULUCF emissions in 2040 (projected) = 3.9 Mt CO_2e

LULUCF emissions in 2050 (projected) = 4.0 Mt CO_2e

3. Modelling and Targets

Sink requirements: - 11 Mt CO_2e (to reach climate neutrality, target)

Qualitative detail

The strategy states that the NECP covers many of the points required by the LTS. The LTS is therefore structured differently, to set the agenda for the future post-2030, without all the answers being available. There are no targets for 2050 but there are interim targets for 2030 for most sectors and an overall reduction of 49% on 1990 levels. It is unclear if the 95% reduction includes the LULUCF section. However, it should be noted that this sector has been a source of emissions each year since 1990 (although the magnitude is decreasing). If LULUCF is included, then a 95% reduction on 1990 levels would require 11.3 Mt CO_2e of emissions to be offset or removed. The date of the LTS and the lack of a firm commitment to climate neutrality suggests this is the intended meaning of the reduction. However, to understand what reductions would be necessary to reach climate neutrality, the assumption can be made that the LULUCF sector would have to be a sink and to take a 95% reduction on all other sectors, without this being included. This again would require a sink (this time including LULUCF of around 11 Mt CO_2e. The reason these results are similar is because the LULUCF sector only contributes to 2-3% of total emissions.

Requires technological solutions for carbon neutrality: yes

4. LULUCF

Separate section in LTS: No (one paragraph integrated with agriculture)

The specific target for the sector up to 2030 is no net increase in emissions, with the level set at 5.6 Mt CO_2e. However, the EEA database suggests that the UNFCCC submission was somewhat smaller than this, with a value of 3.5 Mt CO_2e in 2020.

Within the LTS, it is also stated that there has been a decision not to focus on the emissions sink-source ratio of land use, but the policies in place are expected to meet the 2030 EU targets for this anyway.

Smart solutions are being sought with regards to land use, including pilot projects to raise the water level in peat meadows. Finally, there is a list of further measures to increase carbon capture, such as to expand the natural area, limit deforestation and restore landscapes, and increase carbon capture in agricultural soils, but there are no specifics beyond this list.

Further emphasis is placed on collaboration, and it is stated that other countries have more opportunities for afforestation. This is not expanded upon for countries within the EU. However, the LTS states that countries outside the EU could form partnerships with the Netherlands with regards to increases in tree and plant areas. It is further stated that these could be resources that the Netherlands could use in a mutually beneficial way.

Next, the document states that there needs to be a global move towards negative emissions. The national policy focusses primarily on sequestration in farmland but finds that remaining capacity is limited and no further details on measures are given. It is also stated that draining of peat meadows has caused very significant emissions. Thereafter, it is again stated that, whilst there is a focus on capture by vegetation, such as trees, and that this could have many benefits, land is still limited. Finally, more potential is found in the storing of carbon in long lived wood-based products.

Although it is referenced, little detail is given regarding adaptation. Measures and policies are said to be in separate documents, the national climate adaptation strategy for 2016 and the corresponding implementation programme.

5. Bioresources

The LTS states that bioenergy will be required for the transition, but only that which is genuinely sustainable can contribute. Biomass is listed as a source of base loading power. Work is proceeding on a uniform framework to guarantee all biomass in the Netherlands is sustainable. This should only be in sectors where no cost-effective alternatives are available, such as aviation and shipping.

The government is working to increase the supply of sustainable biomass and to facilitate a hierarchy of use for applications that are as high-grade as possible. Further to energy, within industry the supply-chain impact of bioresources can be identified and integrated into policy. However, it is not stated for what industry, or whether this is in bioenergy or products. However, it should be noted that the LTS does reference storing carbon in wood products.

Further details are included under the CCS/CCU section.

Increased use of bioresources: N/A (not clear)

6. CCS/CCU

It is stated that the production of renewable fuels and the capture and reuse of CO_2 can contribute to further integration of the energy system. A strategy was being prepared at the time of publication for the transition of the energy market so that choices can be made, with one option being CO_2 infrastructure for public and private parties. This was targeted to be released in the latter half of 2020.

Thereafter, it is stated that the coherent use of biomass, nuclear energy and CCS/CCU is a trilemma. The reductions targeted necessitate that two of these technologies are used. The government is as such giving space for each to develop. The Netherlands is thought to have ample storage capacity for CCS and offers alternative to the use of biomass on a large scale that could cause space and sustainability problems. CCU and BECCS are further listed as potential opportunities based on CCS technology.

Finally, the role of cross-border collaboration is highlighted. The North Sea could be a location to store emissions from other countries.

Considering CCS/CCU: Yes

7. DAC/BECCS

There are some references to BECCS throughout the document. BECCS is seen as a potential opportunity for CCS technology.

It is finally stated that large scale atmospheric capture in one form will be needed in order to limit warming to 1.5°C. The contribution made by the Netherlands needs to be determined in this context.

Considering DAC/BECCS: Yes

Poland

1. General information

Published: Poland has yet to publish an LTS.

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -21.0 Mt CO_2e

LULUCF emissions in 2030 (projected) = -23.2 Mt CO_2e

LULUCF emissions in 2040 (projected) = -27.3 Mt CO_2e

LULUCF emissions in 2050 (projected) = -34.2 Mt CO_2e

3. Modelling and Targets

Sink requirements: -71.4 Mt CO_2e (assumption, no LTS)

Qualitative detail

Poland has yet to publish an LTS. However, in order to gain an understanding of the potential necessary sink requirements, it was assumed that mitigation efforts could reduce emissions by 85% on 1990 levels. Emissions in 1990 were 476 Mt CO_2e. As such this would set a potential sink requirement as around 71.4 Mt CO_2e.

Requires technological solutions for carbon neutrality: N/A

Portugal

1. General information

Published: June 2019

Length: 102 pages

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -6.8 Mt CO_2e

LULUCF emissions in 2030 (projected) = -4.6 Mt CO_2e

LULUCF emissions in 2040 (projected) = -3.9 Mt CO_2e

LULUCF emissions in 2050 (projected) = -5.6 Mt CO_2e

3. Modelling and Targets

Sink requirements: -9 Mt CO_2e (modelling)

Qualitative detail

The LTS includes three scenarios, two of which ('peloton' and 'yellow jersey') reach climate neutrality by 2050. The other scenario is known as 'off-track' and can be considered a WEM scenario that maintains current economic structures and trends. The two scenarios lead to 85 and 90% reductions in emissions by 2050, based on 2005 levels. Emissions in 2005 were larger than 1990 levels by around 44%. To establish a minimum, the 90% reduction level can be taken. The 2005 emissions of the country excluding LULUCF were 85.8 Mt CO_2e, a 90% reduction would leave 8.6 Mt CO_2e to be removed by sinks. Further, the LTS quotes the size of the necessary sink is between 9 and 13 Mt CO_2e. As such, the value of 9 Mt CO_2e is taken as the value for the sink requirement.

The LTS includes a great deal of detail on specific aspects of the three models. The peloton scenario sees developments compatible with climate neutrality but without significant changes to production structures or lifestyles. The circular economy is included to a modest extent and the population remains centred around large metropolitan areas. The yellow jersey scenario includes significant changes to production, stronger incorporation of the circular economy, and an increased role for medium size cities. Both of these two scenarios include options with and without carbon neutrality being added as a constraint. Significant further detail is given in the LTS on changes associated with these scenarios.

Requires technological solutions for carbon neutrality: No

4. LULUCF

Separate section in LTS: Together with agriculture

The LTS includes an illustrated 'narrative' on the necessary changes for the combined sector up to 2050. The LTS states that land use, including forests can significantly increase sequestration levels to around 11-13 Mt CO_2e. In 2015, the value was already 11 Mt CO_2e, but when net emitting land categories are included, the value decreased to 9 Mt CO_2e. However, this is significantly influenced by forest fires, and it is essential for these to be reduced, whilst increasing forest productivity across different species. The strategy calls for a reduction in burnt areas to around 70,000 ha/year in 2050. The average between 1998 and 2017 was 164,000 ha/year, so this represents a 60% reduction in burnt areas.

Methods to decrease the annual burnt area should be given prominence, and options for this include improvements in land management and planning and greater investment in stand management (particularly in fire prevention and firefighting). The LTS additionally states it is important to reinforce how support is distributed for ecosystem services and biodiversity maintenance. Afforestation and reforestation should mostly take place through production species (with cork oak, pine and eucalyptus listed) or with conservation and protected species, such as native hardwoods). The balance between these two depends on the scenario considered. The LTS also includes a breakdown of emissions in LULUCF and agricultural sub-sectors over five-year periods until 2050.

The rate of new afforestation will also have to increase to 8 000 ha/year by 2050 at the same time as reducing the expansion of other land uses, particularly urban and flooded areas (including dams) and scrubland. Forestry is seen as a key sector for the circular economy and the LTS states that increased investments in forests could increase sequestration by 40% compared to a scenario that does not include the circular economy, although it is not clear how this intersects with the names scenarios in the LTS.

Within agriculture, the LTS sees emissions decreasing slower than in other sectors and representing about a third of outstanding emissions in 2050. Emissions have been increasing since 2013, mainly because of cattle numbers (the livestock sector represents 83% of agricultural emissions) and accounted for 10% of national emission in 2015. When the effects of agricultural practices on land are considered, this increases to 11%. Some measures are included to reduce this, of particular relevance is an increase in biodiverse pastures by a factor of 4, leading to a net sequestration of 0.76 Mt CO_2e by 2050. Other measures include changes to fertiliser use. An increase in the organic content of agricultural land could also be achieved through increasing the area under conservation (or regenerative agriculture) to reach 180 000 ha by 2050, increasing the area under biological farming, and greater use of organic fertilisers. These measures could reduce emissions in agriculture by 0.64 Mt CO_2e by 2050.

5. Bioresources

The LTS states that the use of hydrogen and advanced biofuels will be important. It is seen that biomass consumption will grow up to 2030/2035, before decreasing below current levels. This consumption is most clearly seen in the industrial sector (where it can contribute to reductions of 80%), for example by replacing coke. It further states that these resources can be used most cost-effectively in decentralised cogeneration and heat production sites near to collection sites, with this also contributing to sustainable forest management.

Within transport, biofuels are seen to play a role within heavy long-distance passenger and freight. But it further states that such fuels may become irrelevant long-term due to the greater competitiveness and cost-effectiveness of other technologies. The role of biofuels may be maintained in aviation.

However, the LTS notes that the use of biomass for combustion is a trade off with air quality, with a possible increase in non-methane volatile organic compounds (NMVOC) and fine particles (PM2.5).

Increased use of bioresources: Yes (at least until 2030)

6. CCS/CCU

These technologies are seen as an important option for decarbonisation of the energy system. However, within Portugal it is found that they could only be viable in the cement sector. But natural changes in this sector may not lead to a large enough impact to justify investment form an economic perspective. The use of captured carbon for fuel production is currently also not seen as cost-effective, and the strategy notes that such technologies would always have associated emissions.

Considering CCS/CCU: No

7. DAC/BECCS

The LTS states that BECCS is not considered cost-effective based on current knowledge. However, it states that this is a priority area for research and innovation at the European level. As such, the development of such technologies should be monitored.

Considering DAC/BECCS: No

Romania

1. General information

Published: Romania has yet to publish an LTS.

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -32.9 Mt CO_2e

LULUCF emissions in 2030 (projected) = -16.6 Mt CO_2e

LULUCF emissions in 2040 (projected) = -13.6 Mt CO_2e

LULUCF emissions in 2050 (projected) = -14.8 Mt CO_2e

3. Modelling and Targets

Sink requirements: -37.5 Mt CO_2e (assumption, no LTS)

Qualitative detail

Romania has yet to publish an LTS. However, in order to gain an understanding of the potential necessary sink requirements, it was assumed that mitigation efforts could reduce emissions by 85% on 1990 levels. Emissions in 1990 were 250 Mt CO_2e. As such this would set a potential sink requirement at around 37.5 Mt CO_2e.

Requires technological solutions for carbon neutrality: N/A

Slovakia

1. General information

Published: 2020

Length: 93 pages

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -8.7 Mt CO_2e

LULUCF emissions in 2030 (projected) = -3.3 Mt CO_2e

LULUCF emissions in 2040 (projected) = -3.5 Mt CO_2e

LULUCF emissions in 2050 (projected) = -3.6 Mt CO_2e

3. Modelling and Targets

Sink requirements: -7.1 Mt CO_2e (modelling)

Qualitative detail

The main focus is set on the achievement of the 2030 climate and energy targets, a roadmap to 2050 is added as an extension, but modelling for 2040-2050 is still missing. GHG emissions have dropped by almost half since 1990 (with removals). This can be attributed to economic transformation, more efficient production processes and the introduction of new technologies (BAT technologies). Without including LULUCF the total emissions in 1990 were 71 Mt CO_2e, whereas in 2020 they amounted to 41 Mt CO_2e.

The LTS includes modelling of two scenarios, WEM and WAM, but as they were modelled before the agreement of climate neutrality goal (in 2016-2018), it is stated that additional measures are necessary, otherwise Slovakia will not reach climate neutrality by 2050. These measures are marked as NEUTRAL in the LTS, which are to be modelled in future strategy updates. Before the renewal of the LTS (latest at 2025), several analytical tasks need to be solved, including modelling the scope of reductions and the impact of the additional measures identified as NEUTRAL in the strategy.

Although it's mentioned that the total cost for 2031-50 is expected to be near 196 billion euros, the cost of the most ambitious decarbonisation (-90%) would be significantly higher. For the most ambitious scenario that is modelled (WAM), the projected emission gap is likely to be 14 Mt CO_2e, which accounts for an 80% emissions reduction compared to 1990 (not taking into account removals in the LULUCF sector), but a 90% decrease in emissions is necessary. Respectively, for WEM this amounts to 70% reductions and a 23 Mt CO_2e emissions residue in 2050. However, WEM does not include the European Green Deal commitments and the Slovak Government's decision to adopt on the early termination of support for electricity production from domestic coal. The sink requirements are taken based on the target of a 90% reduction by 2050.

Requires technological solutions for carbon neutrality: N/A

4. LULUCF

Separate section in LTS: yes

Considering the maximum possible removals from the LULUCF sector, 90% emission reductions compared to 1990 could be envisaged, however this is not sufficient to achieve climate neutrality. 90% reductions need to be achieved without LULUCF, and the remaining 10% (7 Mt CO_2e) could be taken up by the sector.

Over the period 1990-2017, the carbon sink in the sector has fluctuated significantly, halving from -10.9 Mt CO_2e in 1992 to -5.7 Mt CO_2e in 2005. The temporary decrease in removals is said to be caused by a gradual increase in the average age of forest stands and a resulting lower year-on-year increase in wood mass. In the WEM scenario up until 2035, removals are projected to decrease in the forest land, crop- and grassland categories and increase in settlements and other land. After 2035, removals are expected to increase in forest and grassland categories. For WAM measures like "afforestation of 23 000 ha of grassland by 2040" and "grassing of 50 000 ha of cropland after 2016" are considered. In the NEUTRAL scenario, many recommendations for LULUCF are mentioned, but they lack in detail and quantitative goals.

The LULUCF sector has a significant role in removing emissions in sectors that cannot otherwise be eliminated (industrial processes, agricultural activities, and transport). Additionally, the use of wood in the material and energy sectors will replace the use of fossil-based products and raw materials. However, currently (WEM) there's an opposite trend.

Slovakia has not yet quantified emissions/removals from wetlands as there is no sufficiently accurate input data based on which it is possible to model emission/removal projections in this category. What is more, the sector is vulnerable to damage caused by the effects of climate change (drought, higher temperatures, wind, fires, pathogens, etc.) that reduce CO_2 removals.

Similarly to wetlands, the production and removal of GHG emissions in agriculture has not been studied in detail. Furthermore, some sources are difficult to quantify, while others are hidden. Agricultural production stopped growing in Slovakia at the end of the 1980s, which was followed by a drop in 1990-2002 due to economic and political changes in the country. Since then, the sector has stabilized. The potential for reducing GHG emissions in the sector is related to manure management and a change of animal feed plans. As the emissions in the sector remain the same for both WEM and WAM modelling, it's necessary to adopt additional measures in the future to reverse slightly increasing trend in emissions. Again, the NEUTRAL scenario, which is not yet modelled, includes many recommendations for achieving this.

The first comprehensive document providing basic strategic guidance for Slovakia's adaptation to climate change and giving examples of adaptation measures is the Adaptation Strategy of the Slovak Republic on Adverse Impacts of Climate Change (NAS) created in 2014 and updated 4 years after. The LTS states that adaptation measures will be further assessed and prioritized in the National Adaptation Action Plan, which is currently at the stage of preparation, where short-term measures for 2020-2022 and medium-term ones for 2022-2025 will be identified.

5. Bioresources

It is emphasized in the LTS that biomass has the largest energy potential among RES in Slovakia, with theoretical potential of 120 PJ (according to the approved Energy Policy of the Slovak Republic). There is a slight growth in biomass expected in Slovakia for the period 2020-2030, mainly for energy purposes (cogeneration of electricity and heat and heating/cooling production). The increase in wood chips is expected to grow by 12% (from 3160t to 3540t). However, interestingly an increase in the total annual volume of planned felling is not expected, as the volume of incidental felling is included in the volume of planned felling carried out and the volume of planned felling cannot be exceeded.

In the WAM scenario support scheme is proposed for electricity generation with envisaged RES technologies such as solar PVs, onshore wind turbines, biogas/biomethane and biomass. The scenario assumes the support of 50 MW in 2021-2025, followed by support of an additional 500 MW based on auctions. The scenario also intends to achieve a share of advanced biofuels in fuels to 0.5% in 2022, 1% in 2025 and 3.5% in 2030. For the NEUTRAL scenario, one proposed measure is to increase the support for bioeconomy by using biogas mainly as a local source and processing animal waste more efficiently. Although, it's also brought out in the scenario that excessive support for direct biomass combustion leads to increased PM emissions and deterioration of the air quality.

Overall, the amount of biomass is increasing in Slovakia (exceeding those harvested) and the balance is favourable. At the same time biomass consumption is also increasing, it was 3.6 times higher in 2015 than in 1990. According to the LTS, the carbon stock in living biomass has been growing in recent years and is expected to do so in the next decades.

Increased use of bioresources: yes

6. CCS/CCU

Research needs for CCS/CCU are briefly mentioned under the recommendations for the NEUTRAL scenario. CCS was excluded from the modelling for the WAM scenario in the energy sector.

Considering CCS/CCU: No

7. DAC/BECCS

The LTS does not mention DAC or BECCS.

Considering DAC/BECCS: No

Slovenia

1. General information

Published: July 2021

Length: 98 pages

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -4.7 Mt CO_2e

LULUCF emissions in 2030 (projected) = -2.8 Mt CO_2e

LULUCF emissions in 2040 (projected) = -2 Mt CO_2e

LULUCF emissions in 2050 (projected) = -1.5 Mt CO_2e

3. Modelling and Targets

Sink requirements: -2.5 Mt CO_2e (modelling)

Qualitative detail

In 2005, the total GHG emissions amounted to 13.3 Mt CO_2e (including LULUCF removals –7.2 Mt CO_2e). To reach climate neutrality Slovenia needs to reduce these emissions by 80-90% by 2050, to at least 2.5 Mt CO_2e, the value of the sink in the net zero scenario. However, in 2018 the emissions were 17.7 Mt CO_2e (including the LULUCF sector). While Slovenia has managed to reduce its emissions by 3 Mt CO_2e from 2005 to 2018, the LULUCF sector has become an emitter of 243 kt CO_2e, instead of the previous 7.2 Mt CO_2e binding capacity, which represents a 103% decrease. The sink requirements are taken based on the need to reduce emissions to at least 2.5 Mt CO_2e. However, it is not clear from the emissions table whether technological removals are included in the reductions for different sectors. The value therefore defines a minimum sink requirement under the condition that this is not the case.

Slovenia set binding targets for 2020 for GHG emissions which are not included in the ETS at a time when no broad political consensus on firmer action against the global climate crisis existed. The country will likely meet these goals, but Slovenia is currently not managing the long-term emissions trajectory.

Two scenarios are mentioned in the LTS: the 'ambitious nuclear scenario' (WAM NU) and the 'ambitious scenario with the use of synthetic natural gas' (WAM SNG). However, there's little detail about the modelling itself, it is only mentioned in the impact assessment of the socio-economic aspects section. The LTS emphasises that the WAM scenario (after 2022) and the WEM scenario (throughout) are unfavourable for the 20% of households with the lowest income (and only the WEM scenario for the second quintile group from 2024 onwards), therefore Slovenia will need to adopt mitigation measures for them. The WAM scenario foresees a decrease in the LULUCF sinks for the period 2025-2040 due to increased realisation of possible felling in forests. The sinks in 2040 should amount to –3.1 Mt CO_2e and at least –2.5 Mt CO_2e by 2050 according to the scenario. Additionally, the WAM scenario includes 21 to 27 billion euros worth more investments (from 66 391 to 71 6016) than WEM (from 21 349 to 26 559).

<u>Requires technological solutions for carbon neutrality</u>: yes

4. <u>LULUCF</u>

<u>Separate section in LTS:</u> yes

As the forest cover and growing stock in Slovenian forests are among the largest in the EU, there is little possibility to increase the sink for forests. For other natural resources though, there is a shortage (71% of materials are imported). According to the LTS, felling is planned in the coming decades to balance the development phases due to forest ageing, to achieve forest resilience and to transform deforested forests into more suitable habitats, with forests still providing sinks (e.g., increase in forest floor carbon stock, leaf litter and deadwood). In 2018 emitting land categories were forest land, settlements, other land, and wetlands, which generated 900 kt CO_2e, while grasslands, fields and the obtained timber products generated sinks in the amount of -662 kt CO_2e.

The LTS focuses heavily on biodiversity. For example, improving the status of wetlands and reducing invasive alien species is emphasized and by 2030 improvement and restoration of ecosystems is planned, primarily of those measures which are urgent and scheduled for the respective governmental Natura 2000 Management Programme.

The carbon sink in harvested wood products (sawn timber, wood panels and paper) is increased by 100% or to -370 kt CO_2e and emissions due to expanding settlements or built-up and similar land are to be reduced by 100% or to 0 kt CO_2e in 2050 compared to 2005. The LTS emphasises observing indirect N2O emissions (5 kt CO_2e 2018) due to nitrogen runoff and leaching, which are the result of soil management.

What is more, there has been a significant decline in the sector's sink since 2014 due to increased felling and mortality of forests resulting from different natural disasters (glaze ice, bark beetles and windstorms). This resulted in the share of salvage harvesting making up 45% of the entire felling in 2010-2019. In 2007 there was an accumulation of growing stock and overgrown permanent grassland, after which the sinks have shrunk. The amendment in forestry policy set the planned possible felling to 75% of the increment (by 2030).

The NECP which was developed together with the LTS and is therefore quoted relatively many times throughout the document, sets key instruments in the field of LULUCF. These include the upgrade and implementation of forest inventories, development of the methodology for monitoring of sinks, upgrade of measures in the sectoral policy, forest management plans of forest management areas (2021–2030), state incentives for forest owners for forest care and protection, and education and workshops regarding sustainable forest management for forest owners.

The emissions from agriculture have stayed relatively similar over the period 2005-2018 (1.7 Mt CO_2e). By 2050 5-22% reduction in GHG emissions from the sector are foreseen compared to 2005 levels (1% by 2030 and 8% by 2040). It’s stated in the LTS that Slovenia has implemented measures to increase efficiency of animal husbandry, the share of grazing, and to circulate nitrogen more efficiently in agriculture. Change in consumer behaviour is seen as one option for reducing emissions along with extensive grazing, investments in low emission technologies and assessing the carbon footprint of different food products for example. Food safety is one topic mentioned throughout the chapter.

5. Bioresources

Use of bioresources is described rather comprehensively in the Slovenian NECP, which sets a goal for mindful forest management and improvement of sustainable cascading use of wood, whereas it must be ensured that the LULUCF sector will not produce net emissions by 2030. For this, the NECP foresees measures like improving the system for monitoring carbon stock in all land uses, upgrading the existing measures, felling and accumulation while observing forest adjustment to the expected climate change, provision of state incentives as well as education of forest owners. Slovenia will maintain and improve the exploitation of the production potential of forest sites or agricultural land, while ensuring the capacities for wood processing with an emphasis on Slovenian wood, production of wood products and food safety.

The NECP also emphasises greater processing of Slovenian wood and the use of wood of poorer quality for energy purposes, while putting focus on incorporating it accordingly in the system, sustainable construction indicators and green public procurement. Furthermore, the NECP focuses on agricultural practices which increase carbon stock in the soil. For example, by 2030 Slovenia will intensify the efforts in the field of efficient animal production by construction of microbiogas devices for biogas production from livestock fertilisers and the grazing of cattle, sheep, and goats, and improve nitrogen recovery from livestock and mineral fertilisers. Investments are made in the quantity of food waste in primary production (biogas devices).

Slovenia will further exploit wood biomass by 2050 where the economic aspect is significant as the exploitation of low-quality wood for energy improves the economics of wood processing chains and energy systems. Smaller local systems with a completed wood biomass supply will be particularly promoted. When exploiting wood, the principles of circular bioeconomy, forest coverage conservation and sustainable forest development are observed, which will be adjusted to the consequences of climate change and the objectives of ensuring CO_2 sinks in forests. Long-term policies and measures of the circular economy will be drafted to enable a cascading use of wood and energy exploitation of wood products at the end of their lifespan (at the actual end and by observing the cascading use of wood) with no significant environmental impact. Therefore, the scope of biomass suitable for energy use will also increase. The promotion of wood biomass use in individual heating systems will be further directed at the areas where the use of other RES is not practical (2050).

Slovenia will support pilot projects to become actively involved in the development and use of sustainable technologies to produce synthetic fuels from wood biomass and other lignocellulosic sources. The use of biofuels will concentrate on the development, production and application of advanced sustainable biofuels while observing food safety (by 2050). The share of wood biomass in DH and cooling systems will increase intensively, especially through the installation of larger shallow geothermal heat pumps. Slovenia will increase the proportion of biofuels in liquid fuels for road transport, while the proportion of biofuels produced from raw materials that are also used for food production will be gradually reduced. It is expected that by 2030 the share of biofuels is 11% out of the 21% for RES in transport. Today, in agricultural machinery, diesel fuel represents a 100% share, which will be reduced by 58% by 2050. It will be replaced by biodiesel (30%), biomethane (7%) and compressed natural gas (6%).

Increased use of bioresources: yes

6. CCS/CCU

Support for pilot projects on CCS and CCU in the industry sector is mentioned in the NECP until 2030 and the most optimistic scenario predicts that CCU will be implemented for the sector in Slovenia by 2040. The use of CCU technologies is especially anticipated in the cement industry and for manufacturing metals. For the adaptation to climate change with sustainable solutions, Slovenia will primarily ensure financial resources for the investments which have the largest potential for carbon capture and storage and those which will ensure the improvement of natural habitats and the implementation of sustainable solutions.

Considering CCS/CCU: yes

7. DAC/BECCS

"Direct capture of GHG emissions" is mentioned in the Slovenian goal for climate neutrality in the LTS, but this phrase is not used anywhere else in the document.

Considering DAC/BECCS: N/A (not clearly stated)

Spain

1. General information

Published: November 2020

Length: 73 pages (additional 179 pages in annex)

Climate Neutrality: by 2050

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -35.9 Mt CO_2e

LULUCF emissions in 2030 (projected) = -40.0 Mt CO_2e

LULUCF emissions in 2040 (projected) = -37.8 Mt CO_2e

LULUCF emissions in 2050 (projected) = -40.1 Mt CO_2e

3. Modelling and Targets

Sink requirements: -29 Mt CO_2e (modelling)

Qualitative detail

The Spanish LTS extends the NECP (called PNEIC) up to 2050. It is seen as a more flexible document than the respective NECP, and the specific details for each decade will be set out in the relevant NECP. The document includes two scenarios – the scenario as defined in the NECP but extended up to 2050 (a WEM scenario) and one that reaches climate neutrality. The NECP scenario does not reach the goal of climate neutrality. For the climate neutrality scenario, total outstanding emissions in 2050 amount to 29 Mt CO_2e, with the size of the LULUCF sink being -37 Mt CO_2e. The size of the required sink for climate neutrality is taken from the value of outstanding emissions in this scenario. The value of outstanding emissions represents an approximate reduction of 91% based on 1990 levels. However, the annex to the LTS further states that there is an 'emissions gap' of around 45 Mt CO_2e that can only be closed with the use of 'disruptive' technologies, one of which is CCS/CCU. This makes it clear that the actual sink requirements including CCS/CCU will be necessarily larger than this, but without further detail in the LTS no improved estimate can be derived.

Requires technological solutions for carbon neutrality: Yes (although the size of the sink is greater than outstanding emissions, the level of mitigation is thought to not be feasible without CCS/CCU).

4. LULUCF

Separate section in LTS: Yes (titled as 'natural sinks of carbon')

The LULUCF sector was a net sink of 38.1 Mt CO_2e in 2018 and has slightly increased since 1990 (assigned to reforestation before 2005 and transition to woody agricultural crops). In the WEM scenario there is a decrease in the size of the carbon sink of 38.4% between 2018 and 2050. For the climate neutrality scenario, a reforestation rate of 20 000 ha/year is proposed between 2020 and 2050. This amounts to an increase in forest area of 4% (or 0.6 Mha) and increases the sink from forests by 7 Mt CO_2e in 2050. Moreover, other potential sink increases over the reference scenario are given. Considering the potential for management improvements of the existing forest area leads to an additional 3 Mha of forest under management by 2050. According to the strategy, this leads to an additional net sequestration in 2050 of 4 Mt CO_2e over the WEM scenario. The reasons given for this increase are greater growth, reduced fire risk and the use of forest products.

17% of the forest is currently managed. Additionally, a further 1 Mt CO_2e are found in the climate neutrality scenario due to the restoration of wetlands (50 000 ha by 2050). The LTS includes an estimate that 60% of Spanish wetlands were destroyed in the 20th century. Agroforestry systems and meadow regeneration (leading to forest succession) also increase the size of the sink by 0.5 Mt CO_2e. Finally, the LTS discusses improving the organic content of soil in agroforestry systems, finding that this is likely to be the case, but does not include in the calculations due to a lack of robust methodology. But it is noted that the organic content of agricultural soils tends to be low in the country, and incentives may be required. On top of the projected increases in the magnitude of the LULUCF sink under the climate neutrality scenario, the LTS emphasizes that additional ecosystem services must also be maintained.

Further detail on the changes in land category are provided in the annex. It is noted that whilst forests increase slightly, there are signs that a saturation is being observed, which is causing a decline in total sequestration. This is projected to increase under the effects of climate change without mitigating measures. Cropland and grassland would decrease slightly, on top of the moderate increase in forest area under the climate neutrality scenario. But conversion of agricultural land and pasture to other categories would slow to an average of 1,000 ha/year (the 1990-2016 average was 25 000 ha/year). Settlements would also increase in area by 500 000 ha over the level of today.

It is found, in comparison to other sectors and technologies that can remove emissions, that the LULUCF sector is relatively simple to manage with policies to increase net removals, whilst generating environmental and socioeconomic co-benefits.

Agriculture: Modelling indicates that greater than 50% of outstanding emissions in 2050 will arise from agriculture. As of 2013, an increase in emissions has been observed and two thirds of current emissions are from enteric fermentation. Regarding the intersection of agriculture and LULUCF, the LTS notes that the sector acts as a natural sink through the ability of soil and woody crops to fix carbon, in addition to being an emissive source. Practices that encourage removals should be promoted.

The WEM scenario discusses crop rotation and nitrogen and manure management. On top of this, the climate neutrality scenario proposes pruning of woody crops for biomass (with emissions accounted for in the waste sector) and its incorporation into the soil, the promotion of so-called conservation agriculture, the maintenance of cover crops, amongst others.

Adaptation is also emphasised. This is seen as urgent and essential as the country is already experiencing the effects of climate change. The second national adaptation plan was approved in 2020. Extensive detail is given in the annex, in which soils and desertification, agriculture, livestock fishing and food, and forest planning and management are individual subchapters.

5. Bioresources

In addition to reducing the risk of fires, the LTS finds that forest management represents an opportunity in the energy system. In this context, biogas production is seen as one of the main lines of work to achieve emission reductions. Renewable gases (biogas, biomethane and renewable hydrogen are listed) are important in a just transition by contributing to job creation and socioeconomic development.

Transport is one sector where the use of biofuels is envisioned (28% of energy consumption should be renewable by 2030 due to electrification and biofuels). Biomass is also seen as an option to replace fossil boilers in the building sector. Industrial options include cement production as well as a source of hydrogen through biogas or biomethane steam reforming. The potential of biogas in the circular economy is seen as low. But the use of waste streams from the pulp and paper and food sectors is emphasised. Finally, it is noted that production and transportation processes can lead to emissions from biomass, in addition to particle emissions.

Research and innovation in the bioeconomy, agriculture and forests is also important. Production models that minimise methane emissions and increase soil carbon uptake are important. In some cases, there is currently a limit of raw materials, whilst in others the level of technological maturity is low. It is also seen as a must to implement waste recovery and research into new processed for advanced biofuel manufacturing. However, it is later stated that the resource potential of the country is such that savings in CO_2 emissions and sustainability should both be guaranteed.

Increased use of bioresources: Yes

6. CCS/CCU

The strategy considers CCS/CCU to be important for sectors for which decarbonisation will be difficult. Examples that are given are the cement and petrochemical sectors. It is stated that there is a further 45 Mt CO_2e of additional emissions in 2050 without this and other technologies (hydrogen, synthetic fuels and advanced biofuels/biomass).

The strategy considers that CCS/CCU could be the only options for the cement, lime, and fertiliser industries. High costs and storage issues, as well as long-term and large-scale utilisation options, have made commercialisation difficult. For example, when one of the cheapest options is considered, CCS in the cement sector, the additional energy costs represent 70% of production costs. Alternatives are the storage of CO_2 in durable products, where long-term studies are needed, but no relevant advances are expected in the next two decades. Regarding geological storage, preliminary analyses are being carried out.

Considering CCS/CCU: Yes

7. DAC/BECCS

The LTS does not consider DAC. Technologies that are already advanced should be promoted, such as composting, anaerobic digestion, and biogas capture.

Considering DAC/BECCS: No

Sweden

1. General information

Published: December 2020

Length: 87 pages

Climate Neutrality: By 2045 (and climate negative thereafter)

2. Current emissions/removals in the LULUCF sector and future projections

LULUCF emissions in 2020: -39.8 Mt CO_2e

LULUCF emissions in 2030 (projected) = -37.6 Mt CO_2e

LULUCF emissions in 2040 (projected) = -38.6 Mt CO_2e

LULUCF emissions in 2050 (projected) = -38.1 Mt CO_2e

3. Modelling and Targets

Sink requirements: -10.6 Mt CO_2e (target)

Qualitative detail

The LTS calls for emissions to be reduced by 85% compared to 1990 levels. Total removals should then be at least 15% of 1990 levels, which yields a value of 10.7 Mt CO_2e. Note that the LTS shows 1990 emissions of around 70 Mt CO_2e. As net emissions (*i.e.,* including LULUCF) for this year were approximately half this value, it strongly supports the assumption that the 85% reduction does not include the LULUCF sector.

Requires technological solutions for carbon neutrality: No

4. LULUCF

Separate section in LTS: Yes

The size of net removals from the LULUCF sector is mainly influenced by forest growth, harvesting volumes and natural disruption. The forest shows net growth. There has also been a consistent increase in removals since 1990 and the value closely tracks the forest value – without this, the other subsectors sum to close to zero net emissions. Under a BAU scenario the sector will remain a sink of around 42 Mt CO_2e in 2050. Highest net emissions are in organogenic land.

The LTS also includes potential obstacles and uncertainties to the size of the sink increasing. This states that climate change presents both risks and opportunities with regards to LULUCF. Certain studies have indicated that the associated warmer temperatures would mean higher forest growth, but natural disaster risks would also be likely to increase. In this context, it is important to also adapt forests.

A series of policy instruments are then given. The Swedish forestry act promotes both production and protection. Forests must be used sufficiently for sustainable profit and must manage biodiversity. Owners have freedom under the act, but also a series of obligations to report on the state of the forests and harvesting, whilst special rules apply for certain forest types. A second instrument is to rewet drained wetlands. Rules on drainage are included in the environmental code, with any drainage being only fit for increasing the long-term suitability of the land for a particular purpose. The rewetting of peatlands is also highlighted within the agriculture section. Other measures here that are of relevance include support for organic farming and preserving natural grazing areas.

There is finally a section on adaptation, which highlights the importance of adapting forests and reducing the negative impacts. The country has a national climate adaptation strategy and there are also joint maps of geotechnical risks and tools to assess climate risks. The Rossby centre is making climate scenarios until 2100 and a flood portal is being developed to map flooding risks.

5. Bioresources

The LTS states that Sweden is well-placed to combine active forestry with high environmental requirements whilst maintaining the size of the LULUCF sink. The national forest action plan sets goals and measures for increasing access to bioresources. Bioenergy use is increasing in CHP plants. Biofuels also have the highest contribution to the total RES of the country and are used most extensively in industry, heating, and increasingly transport.

Within transport, the LTS states that road transport is likely to be mainly electrified, but aviation and shipping could benefit from renewable fuels, such as biofuels. The extent to which biofuels can directly contribute depends on opportunities to produce them sustainably at a reasonable price. Policy instruments in transport include various charges for emissions that can be discounted or neglected in the case of biofuels, as well as obligations for fuel suppliers to reduce emissions each year. By 2030, these obligations are a 66% and 28% reduction for diesel and petrol, respectively. Large refilling stations must also include renewable options.

In industry, bio-based alternatives are also highlighted as potential replacements for chemicals derived from fossil-fuel. Bioenergy use has so far managed to cut emissions in several industrial sectors. Bioenergy is also used within electricity and district heating and these roles are expected to continue. Construction and clothing are other areas where bioproducts could be important.

The document also discusses synergies and conflicts with sequestration and other issues. Biomass harvests must be done in a way that is compatible with other goals and within sustainability parameters.

Increased use of bioresources: Yes

6. CCS/CCU

The LTS states that CCS/CCU can be counted as a measure to reduce additional emissions when no other alternatives exist. It then goes on to say that these technologies are one of four ways (along with deployment of biofuels) to decarbonise steel and especially cement. Policy instruments include industrial investment grants for CCS. Electrification is likely to increase energy consumption in energy by 15-20 TWh and large-scale CCS could contribute 2-5 TWh of this. Another government programme, the industrial leap, that runs until 2040 also has money budgeted for technologies to reduce emissions.

Considering CCS/CCU: Yes

7. DAC/BECCS

Negative emission technologies are referenced as one of three potential technologies to get to net zero once emissions are reduced by 85%. BECCS is also referenced in the context of the industrial leap programme.

Considering DAC/BECCS: yes

A report written by **SEI Tallinn**

In collaboration with **Ecologic Institute**

as part of the **Climate Recon 2050** project

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