Renewable Energy and Climate Change Strategy:

Paths away from primary solid biomass

Report

Trinomics

Contract details

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Disclaimer

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CONTENTS

Abbreviations

AFT	Agence France Trésor
BECCS	Bio-Energy Carbon Capture and Storage (see also Box 1 in section 2.3.2)
CAP	Common Agricultural Policy (EU)
CAPEX	Capital Expenditures
CBA	Cost Benefit Analysis
CC(U)S	Carbon Capture (Use) and Storage
CF	Cohesion Fund (EU)
CfD	Contracts for Difference
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
CTP (MIX)	Climate Target Plan (EU) – MIX scenario
DG ENER	Directorate General for Energy (European Commission)
EC	European Commission
EED	Energy Efficiency Directive (EU)
EFC	European Foundation Centre
EIB	European Investment Bank
EPBD	European Performance of Buildings Directive (EU)
ERDF	European Regional Development Fund (EU)
ESIF	European Structural and Investment Funds (EU)
EU	European Union
EU-ETS	EU Emissions Trading System
EUR	Euro
GBP	(Great Britain) Pounds sterling
GHG	Greenhouse Gas
GVA	Gross Value Added – a measure of economic output less intermediate inputs
GWh	Gigawatt hour – a unit of energy (1 000 000 000 watt hours)
H_2	Hydrogen
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre (EU)
JTF	Just Transition Fund
kW	kilowatt – a measure of energy capacity (1 000 watts)
kWh	kilowatt hour – a measure of energy (1 000 watt hours)
LCOE	Levelised cost of energy
LULUCF	Land Use, Land Use Change and Forestry
MACC	Marginal Abatement Cost Curve
MS	Member State (EU)
$MtCO_2e$	Megatonne (million tonnes) Carbon Dioxide Equivalent
MW	Megawatt – a measure of energy capacity (1 000 000 watts)
MWh	Megawatt hour – a measure of energy (1 000 000 watt hours)
NbS	Nature-based Solutions

NREL	National Renewable Energy Laboratory (US)
NZEB	Nearly-Zero Emissions Buildings
OGF	Old growth forest
OPEX	Operational Expenditures
pa	Per annum (year)
PES	Payment for Ecosystem Services
PSB	Primary Solid Biofuels
PV	(solar) Photovoltaics
RD&I	Research Development and Innovation
RECCS	Renewable Energy and Climate Change Strategy
RED (II/III)	Renewable Energy Directive (EU)
RES	Renewable Energy Source
RRF	Recovery and Resilience Fund (EU)
TBtu	Tera British Thermal Unit – a unit of energy (1 000 000 000 000 btu)
TWh	Terawatt hour – a unit of energy (1 000 000 000 000 watt hours)
VAT	Value Added Tax

EU country abbreviations

AT = Austria
BE = Belgium
BG = Bulgaria
CY = Cyprus
CZ = Czechia
DE = Germany
DK = Denmark
EE = Estonia
EL = Greece
ES = Spain
FI = Finland
FR = France
HR = Croatia
HU = Hungary
IE = Ireland
IT = Italy
LT = Lithuania
LU = Luxembourg
LV = Latvia
MT = Malta
NL = Netherlands
PL = Poland
PT = Portugal
RO = Romania
SE = Sweden
SI = Slovenia
SK = Slovakia

Non EU country abbreviations

UK = United Kingdom
US = United States

Glossary

Term	Explanation
Biofuels*	Biofuels are derived directly or indirectly from biomass for energy purposes. Biofuels used for non-energy purposes are excluded (for example wood used for construction or for furniture, biolubricant for engine lubrication and biobitumen used for road surface). Biofuels can be split up into three categories: 1. Solid biofuels (fuelwood, wood residues, wood pellets, animal waste, vegetal material, ...) 2. Liquid biofuels (biogasoline, biodiesel, bio jet kerosene, ...) 3. Biogases (from anaerobic fermentation and from thermal processes)
Solid Biomass or Solid Biofuels*	Covers solid organic, non-fossil material of biological origin (also known as biomass) which may be used as fuel for heat production or electricity generation. In energy statistics, solid biofuels include charcoal, fuelwood, wood residues and by-products, black liquor, bagasse, animal waste, other vegetal materials and residuals and renewable fraction of industrial waste.
(primary) Forest biomass#	The main category of biomass use that is examined in this report and for which the RECCS removes all subsidies for its use in energy production. (Primary) forest biomass includes all roundwood felled or otherwise harvested or removed. This includes all wood obtained from removals, such as the quantities removed from forests, including wood recovered due to natural mortality and from felling and logging. It also includes all wood removed with or without bark, including wood removed in its round form, or spit, roughly squared or in other forms, such as branches roots and stumps, along with wood that is roughly shaped or pointed.

* Explanation based on glossary produced by Eurostat - https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Biofuels

[#] Explanation based on EC definition for primary woody (forest) biomass https://knowledge4policy.ec.europa.eu/glossary-item/primary-woody-biomass_en

Executive Summary

This report provides an analysis prepared for Wild Europe which sets out a positive **Renewable Energy and Climate Change Strategy (RECCS)** whose adoption would bring numerous benefits to the climate, economy, people and environment. It is based on the removal and reallocation of subsidies for the industrial-scale use of primary forest biomass for energy and bio-energy carbon capture and storage (BECCS). This form of energy production emits high volumes of greenhouse gas emissions, but is currently wrongly accounted as carbon neutral[1].

RECCS provides a vision of how, for only a fraction of the same subsidy cost, the energy gap caused by the disappearance of subsidised forest bioenergy could be filled by alternative renewables, and furthermore, how the balance of subsidies could be invested in energy efficiency and nature-based solutions for carbon absorbent ecosystems. This would deliver significantly greater benefits to emissions reduction, improved air quality and health, broader economic development, sounder investment opportunities and avoidance of nature loss.

Current state of play

Use of forest biomass for energy has been rapidly increasing in the EU in the last decade, and EU scenarios to 2030 and 2050 envisage significant further growth, particularly for electricity generation, and with potential adoption of carbon capture and storage (BECCS). This growth in biomass use for electricity generation has been heavily subsidised, with official support in the EU estimated at EUR 6 billion per year, and a further EUR 2 billion per year provided in the UK. This increase is based on flawed assumptions on the carbon neutrality of biomass.

As shown in Figure 0-1 electricity from bioenergy produces higher lifecycle[2] emissions of CO_2 equivalent than fossil fuels, even lignite and coal. Even with adoption of BECCS – hitherto untried at scale and hugely expensive - emissions would remain higher than all other renewable sources. Therefore, it is crucial to stop subsidising high emission forest biomass as a power source, to abandon development of subsidised BECCS, and the fallacy this could deliver negative emissions, and to utilise alternative low emissions energy sources to fill the energy gap this leaves.

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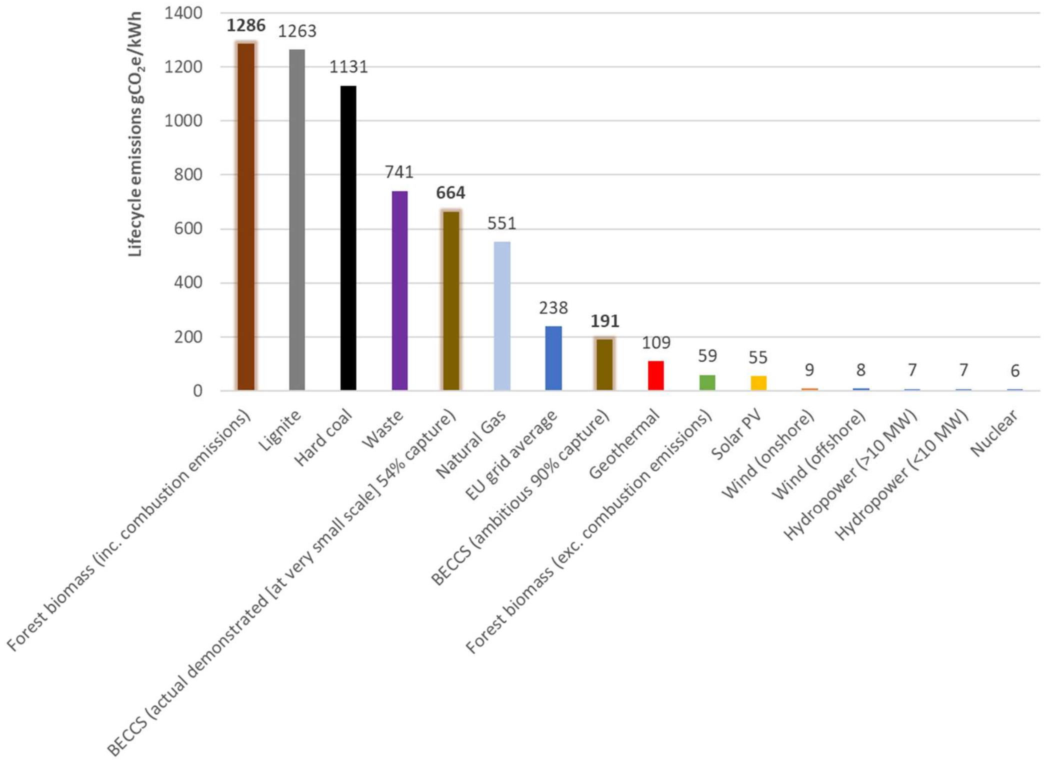
[1] See section 2.3 of the main report for a debunking of this fallacy.

[2] Lifecycle emissions account for all emissions in the manufacturing, construction, operation and decommissioning of a plant and cover CO_2 and all greenhouse gases.

Figure 0-1 Total lifecycle emissions of different energy technologies in the EU [Grams of CO_2 equivalent per kilowatt hour], gCO_2e/kWh



Source: Trinomics based on Trinomics (2020) Study on energy costs, taxes and the impact of government interventions on investments: External costs (study for EC DG Energy); and Umweltbundesamt 2022, Kohlendioxid-Emissionsfaktoren für die deutsche Berichterstattung atmosphärischer Emissionen (for CO_2 content of wood). A 30% thermal efficiency was assumed for the biomass plant including combustion emissions.

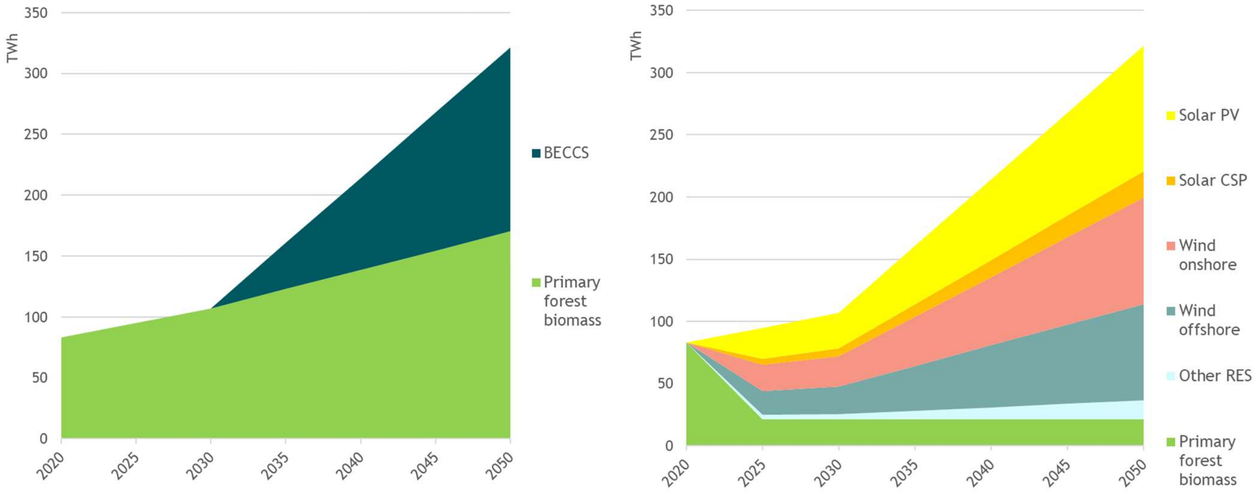
Filling the energy gap

Removing subsidies to industrial-scale forest biomass use for electricity in the EU would lead to a gap of around 74 TWh by 2025, or around 2.5% of projected 2025 demand (in the UK the equivalent share would be around 5% of electricity generation). This gap would increase over time as the projected, heavily subsidised growth in electricity from biomass and BECCS would no longer occur. By 2030 the gap would be 86 TWh (2.8% of total), by 2040 193 TWh (3.9%) and by 2050 300 TWh (4.4%).

The RECCS proposes to fill the gap by re-directing a share of the subsidies to true low carbon renewable energy technologies, i.e. wind, solar and other RES (geothermal, wave, tidal, small/micro hydropower). Wind and solar are far cheaper than biomass thus far fewer subsidies are required to fill the gap in electricity generation. Based on an analysis of which technologies are most suited at a national level a distribution of new electricity generation to fill the gap is estimated. An additional 20% subsidy is added on top of the support for generation from these alternatives, to support investments in grid strengthening and storage technologies.

Even with this addition the volume of subsidies required to support the RECCS is far less than required for the base case support to biomass. For example in 2030 estimated subsidies of around EUR 7.4 billion to support 86 TWh of generation from biomass, can be replaced by EUR 2.7 billion of subsidies to renewables (including EUR 0.6 billion to grid strengthening) to produce the same total 86 TWh, a saving of around EUR 4.6 billion. The alternative renewables already reduce emissions compared to solid bioenergy, and further reinvestment of the savings in energy efficiency and nature-based solutions further increases the emissions reductions and other benefits.

Figure 0-2 Electricity generation sources in base case (left) and RECCS case (right), 2020 (actual) to 2050 (projection), TWh



Source: Trinomics own calculations. For further detail see section 2.1.

Note: The RECCS is based on removing subsidies, however, a small residual share of electricity from forest biomass may remain economically viable without subsidies. In reality, other pressures are quite likely to also push this from the grid, so the negligible remaining biomass share is also likely to be replaced by renewables or other low-carbon power sources.

Costs and Benefits

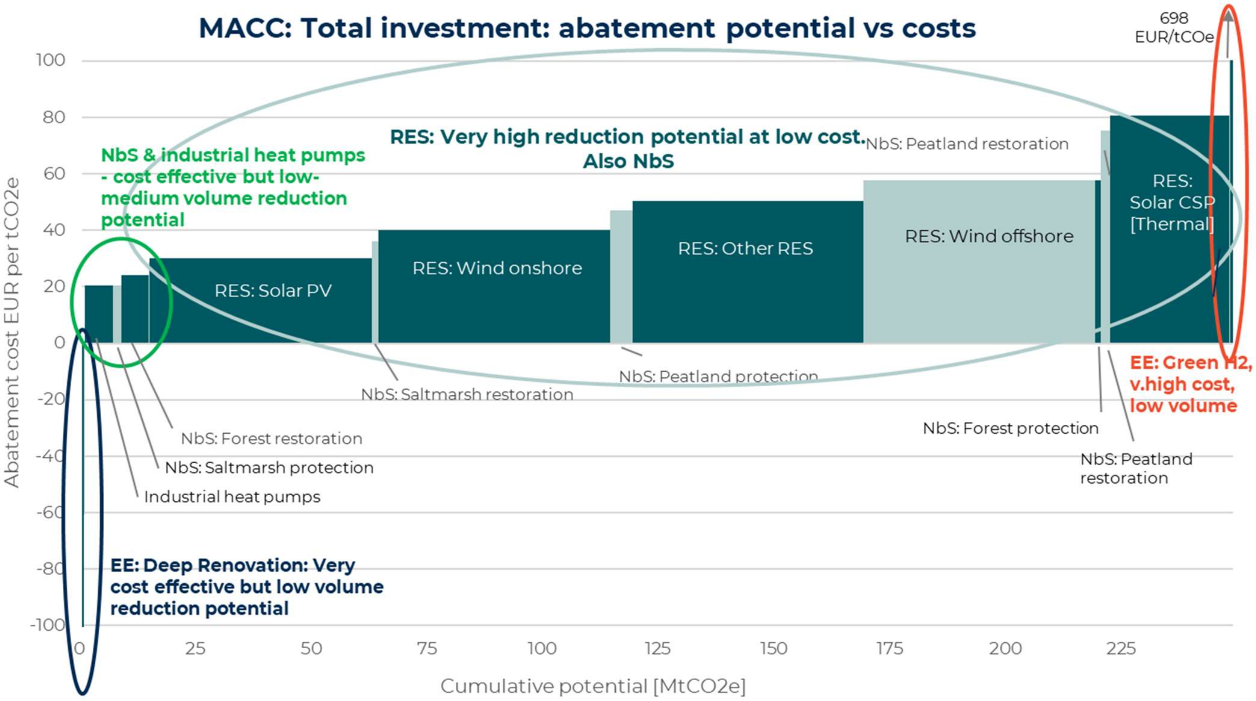
This report considers numerous options consistent with an integrated renewable energy and climate change strategy as alternatives for emissions reduction. Analysis of the cost-effectiveness of the options provided insights into their prioritisation with the RECCS. The following figure presents a marginal abatement cost curve for the options based on a EUR 1 billion investment in each; this shows both annual emissions savings volumes and the total marginal cost of these, averaged over the lifetime of the measure.

The most cost-effective measures for emissions reduction are investments in low-cost deep renovation (which delivers energy cost savings to households through substantial home energy efficiency (EE) renovations) and industrial heat pumps, with marginal costs of 20 EUR/tCO$_2$e or less. However, the volumes of the emissions reduction potential of the renovation measures are relatively small, whilst heat pumps have medium reduction potential.

By far the biggest emissions reductions at cost effective prices are found in the renewable energy and technologies, with marginal costs of 30-80 EUR/tCO$_2$e and emissions reductions volumes of 10-50 MtCO$_2$e each. Therefore for large volume, cost effective emissions reductions renewable energy investments are essential. Nature based solutions provide low-medium volume emissions reductions, at marginal abatement costs comparable to heat pumps and renewables, highlighting that they can be cost effective emissions reduction measures.

At the far end right of the curve are green hydrogen and high cost-low saving deep renovation measures which have very high marginal costs i.e. >440 EUR/tCO_2e and smaller emissions savings potential. Of these two, green hydrogen is likely to become much more cost-effective over time, and investments at this stage in the green hydrogen innovation curve will speed the scaling and innovation in the sector.

Figure 0-3 Marginal abatement cost curve (MACC) for RECCS measures in year 1, total investment cost basis (see section 6.2)



Source: Trinomics. See chapter 6.1 for more detail on the MACC calculation.

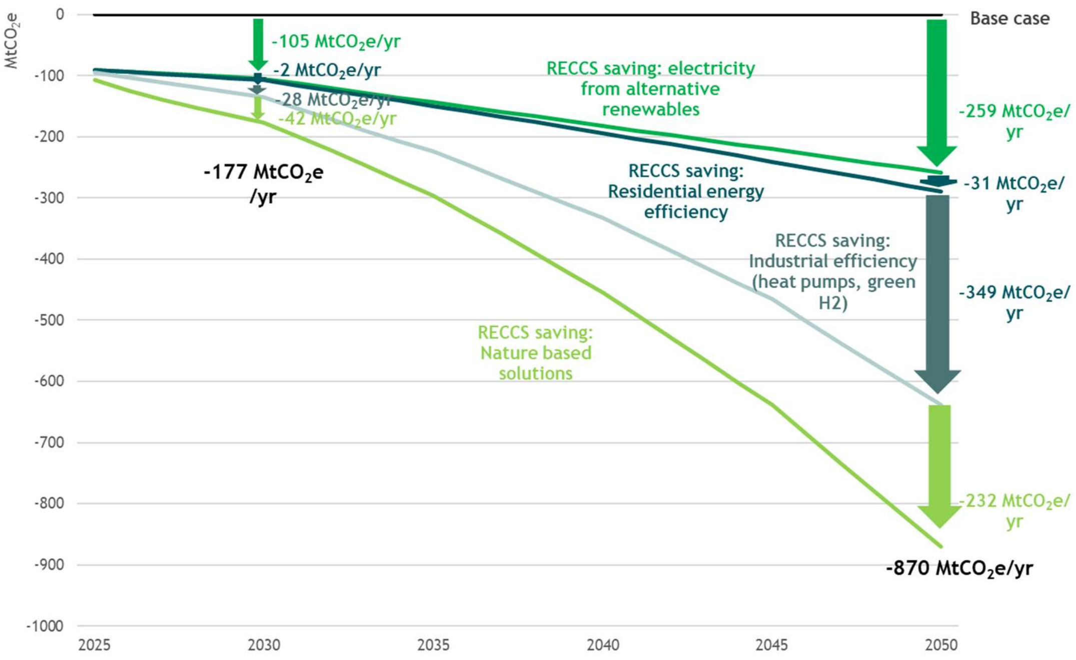
RECCS

Whilst the cost curve provides insight into the cost effectiveness of the different options, it does not account for the numerous other benefits that can be provided by the measures. An integrated RECCS was developed and modelled based on the full re-direction of subsidies intended for biomass and BECCS, which prioritised (1) the filling of the energy gap with alternative renewable energy sources; and (2) the split of any remaining subsidies equally between investments in energy efficiency measures and measures that support nature based solutions for carbon absorbent ecosystems. Within these priorities assumptions were made regarding the split of funding to specific measures and sub-categories, i.e. to residential energy efficiency, industrial heat pumps or green hydrogen in industry; and to nature protection and restoration in forests and inland and coastal wetland ecosystems.

A summary of **RECCS emissions savings** compared to the base case is presented in Figure 0-4 which shows that the RECCS measures deliver emissions savings of 177 MtCO_2e per year by 2030. This is a sizable amount in the context of the EU Fit-for-55 goal for 55% emissions reductions by 2030, with the RECCS saving already contributing the equivalent of 15% of the total required savings[3].

By 2050 with an EU goal of net zero emissions, the cumulative annual impact of the RECCS of 870 MtCO$_2$e per year compares to current EU total emissions of 3 242 MtCO$_2$e per year (2021), and therefore RECCS represents savings equivalent to a contribution of almost 27% towards meeting the EU net zero goals by 2050. In addition to these savings the RECCS would also contribute substantially to protecting EU forest and wetland carbon stocks, protecting around 34.6 GtCO$_2$e of carbon stocks in these ecosystems by 2050.

Figure 0-4 Summary of annual emissions savings possible in a RECCS scenario, compared to the base case, 2025-2050, MtCO$_2$e



Source: Trinomics own calculations

The full economic, social and environmental results of RECCS implementation compared to the base case of the continued expansion of energy from forest biomass are summarised in Table 0-1 below. This shows that not only can the proposed RECCS can generate exactly the same volume of electricity as the base case using a fraction of the volume of subsidies, but furthermore, RECCS could deliver tens of billions in further investment, economic output and GVA than the base case investments in biomass and BECCS. It could also deliver hundreds of thousands of additional jobs. The table also shows that by using these subsidies differently RECCS can also provide significantly higher energy savings, cheaper energy, improved health, cleaner air, reductions in pollution, protection and restoration of ecosystems and biodiversity, and lower greenhouse gas emissions.

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[3] We note this as equivalent to, as the savings from the renewable energy measures in RECCS are based on actual savings from reduced biomass combustion for electricity, whilst the EU emissions inventory and targets do not include these emissions. For directly comparable values the savings from the RES measures in the RECCS could be subtracted from the total RECCS savings.

Table 0-1 Summary comparison of the Base case and RECCS approaches

Indicator	Base case		RECCS	
Description	Continued use and subsidisation of high emission industrial-scale power and heat from forest biomass, plus subsidisation of high cost BECCS technology.		Switch from industrial-scale forest biomass use to subsidies equivalent volume of alternative renewables, complemented through use of remaining subsidies to fund energy efficiency measures for households, industrial efficiency and decarbonisation measures plus investments in nature-based solutions for carbon absorbent ecosystems.	
	2030	2050	2030	2050
Energy system impacts				
Electricity generated by biomass or by alternative renewable energy sources [TWh]	**Electricity:** **107 TWh Total** 107 TWh Biomass	**Electricity:** **321 TWh Total** 170 TWh Biomass 151 TWh BECCS	**Electricity:** **107 TWh Total** 21 TWh Biomass 46 TWh Wind energy 29 TWh Solar PV 6 TWh Solar CSP 5 TWh Other RES	**Electricity:** **321 TWh Total** 21 TWh Biomass 0 TWh BECCS 163 TWh Wind energy 101 TWh Solar PV 21 TWh Solar CSP 15 TWh Other RES
Energy saved [TWh]	**Heat:** 2 141 TWh total **0 TWh saving**	**Heat:** 1 664 TWh total **0 TWh saving**	**Heat:** 2 129 TWh total **12 TWh saving**	**Heat:** 1 508 TWh total **156 TWh saving**
Cost of energy [EUR/MWh]	134	167	67	40
Economic impacts				
Total Investments [EUR bn]	21.0	177.7	101.5	1 160.9
Economic output [EUR bn]	13.8	13.8	29.6	130.9
GVA impact [EUR bn]	12.0	12.0	24.1	105.5
Employment impact ['000 jobs]	176.4	176.4	408.6	1 818.0
Impact on competitiveness and innovation	0	-- Negative due to high cost of BECCS	+	+++ Drives innovation in renewables, industrial decarbonisation and efficiency. Lowers energy prices.
Distributional impact	0	0	-/+ Important for RECCS alternative measures to target regions adversely impacted by cuts to biomass. RECCS can provide benefits to energy poverty, reducing inequality.	-/+ Important for RECCS alternative measures to target regions adversely impacted by cuts to biomass. RECCS can provide benefits to energy poverty, reducing inequality.
Social impacts				
Skills impacts	0	0	+	+
Health impact	- Air pollution causes negative health effects	-- Increased air pollution with expansion of biomass and BECCS leads to increased negative health impacts	+ Reduced air pollution brings health benefits. Better housing improves health outcomes.	++ Significant reductions in air pollution compared to base case, reduces negative health impacts.

				Better housing improves health outcomes.
Environmental impacts				
GHG emissions impact [MtCO$_2$e]	0 savings +31 MtCO$_2$/pa emissions from new biomass (compared to 2020)	0 savings +112 MtCO$_2$/pa from new biomass +76 MtCO$_2$/pa from BECCS	**Total: 177 MtCO$_2$/pa savings** 105 MtCO$_2$/pa alternative renewable power 2 MtCO$_2$/pa residential energy efficiency 28 MtCO$_2$/pa industrial efficiency 42 MtCO$_2$/pa from nature based solutions	**Total: 870 MtCO$_2$/pa savings** 259 MtCO$_2$/pa alternative renewable power 31 MtCO$_2$/pa residential energy efficiency 349 MtCO$_2$/pa industrial efficiency 232 MtCO$_2$/pa from nature based solutions
Marginal abatement cost [EUR RECCS subsidy/tCO$_2$e]	N/A		36.8	
Environmental impact (air, land, water, resources)	- Increasing particular matter pollution, land and water use	-- Increasing particular matter pollution, land and water use	+ Lower air pollution, land and water use compared to base case	++ Lower air pollution, land and water use compared to base case
Biodiversity impact	- Lost forest habitats with attendant dis-benefits - species depletion, sedimentation, flooding, loss of amenity/tourism benefits etc	-- Lost forest habitats with attendant dis-benefits - species depletion, sedimentation, flooding, loss of amenity/tourism benefits etc	+ Reduced destruction of forests. Protection and restoration of ecosystems through NbS conservation measures. **Total 9 million ha protected or restored**	++ Reduced destruction of forests. Protection and restoration of ecosystems through NbS conservation measures. **Total 53 million ha protected or restored**

Recommendations

As a result of this work we bring the following recommendations to policymakers:

- **As a matter of urgency, eliminate subsidies to forest biomass for energy**;
- **To fill the energy gap this creates through redirecting these same subsidies to alternative renewable energy sources and supporting investments in grid and storage infrastructure**;
- Furthermore, given that we believe it is possible to fill the energy gap at a much lower subsidy cost than would otherwise be spent on energy from forest biomass, **policymakers should take the opportunity to use the remainder of the planned subsidies to forest biomass for energy efficiency and nature based solutions**. This has been shown within this report to deliver significant economic, social and environmental benefits.
- **Investments in household energy efficiency can be very cost-effective for households and offer emissions reductions potential, these should be part of a RECCS.**
- **Investments in industrial heat pumps can be crucial in reducing industrial emissions (and costs) and in the short-medium term are highly relevant**. In the medium-longer term other industrial efficiency and decarbonisation measures, such as green hydrogen become much more relevant.
- **Investments in nature-based solutions** require the highest proportional commitment by RECCS, but provide cost-effective emissions reduction potential and offer a range of other co-benefits for nature and society. These **should be a priority within any RECCS action**.
- **Policy should address other bottlenecks that could slow the adoption of RECCS:** the proposed RECCS measures could face challenges to scale up to the desired levels, particularly

for renewables there are supply chain, planning, network capacity and other barriers that can slow down investments. Policymakers should support a RECCS with reforms and support to alleviate these barriers and speed the adoption of the measures. RECCS has the advantage of providing incentives in-line with other EU climate and energy policies, such as the EU-ETS, Net Zero Industry Act and the Innovation Fund (e.g. by supporting industrial decarbonisation), achievement of Renewable energy and energy efficiency targets, and by protecting and restoring habitats contributing to achieving policy targets for the environment and natural world, including from the Nature Restoration Law.

- **Policy should avoid biomass emissions leakage:** it would be foolish to eliminate subsidies to biomass in Europe only then to see the European biomass industry continue to cut forests to export to non-European countries where the net-zero emissions fallacy of biomass remains. Policy should also be joined up and adjust accordingly to avoid this. Adjustments to tax and/or tariff policy, or regulations, can help to ensure that it is not economically rational to export forest biomass for industrial scale energy use.

For implementation we recommend:

- **That the public and private sources of finance identified in chapter 7 are fully explored and utilised to boost the implementation of RECCS**. There are a variety of EU-level funds that can be used to complement RECCS funding.
- **To ensure national plans e.g. National Energy and Climate Plans (NECPs) are based on the specificities of particular countries** as each country will have different subsidy re-direction potential, different energy gaps and potentials for renewable energy, different industry and household energy needs, different ecosystems and different financial possibilities.
- **That RECCS implementation progress is reviewed periodically** to monitor and track progress, and to investigate if new technologies and measures should be supported by RECCS and/or if the balance of support to the different measures should be adjusted.
- **Managing impacts in biomass harvesting communities:** the proposed changes may result in reduced economic activity and employment for affected forestry and bioenergy companies and communities. Whilst part of the losses would be of companies outside the EU pursuing destructive practices, part of the losses will be felt by EU communities which rely on forests economically. The overall economic boost from RECCS and generation of new employment should much more than offset the largest part of any impacts, although re-training and other support may be needed for affected workers to access these new opportunities. Targeting RECCS measures to encourage their locating in the most affected communities would be a good way to further manage these impacts and could be important to securing support. There are various ways in which these impacts can be managed including for example, the NbS measures of RECCS subsidising protection and restoration of forest areas and this leading to increased potential for tourism or payments for ecosystem services; or opportunities to locate new renewable energy infrastructure in the affected regions.

1 Introduction

This report presents an analysis prepared for Wild Europe which sets out the reasoning and potential benefits of removing subsidies to industrial-scale use of (primary) forest biomass for energy, and instead using other renewables and energy savings measures to fill the energy gap. It also examines the role that investments in nature-based solutions for carbon absorbent ecosystems could play to achieve the desired emissions reductions. In doing so this report provides the basis of a positive **Renewable Energy and Climate Change Strategy (RECCS)** whose adoption would bring numerous benefits to the climate, economy, people and environment.

1.1 Background

The use of forest biomass as an alternative energy source to fossil fuels saw a rapid increase in the EU in the last 10 to 15 years, following the introduction of the EU Renewable Electricity Directive (2001) and, subsequently, the EU Renewable Energy Directive (2009). Whilst forest biomass is not the largest renewable energy source for electricity, its combined use in electricity and heat production, and in industry, makes it the largest single renewable energy source in the EU. Furthermore, future projections show that bioenergy is planned by its proponents to play a significant role in reaching (EU) renewable energy targets, as part of a broader policy agenda aiming at climate neutrality and the phase out of fossil fuels. In this context, bioenergy, including forest biomass, has been, and is expected to be, the target of policy measures and public finance that incentivise, directly or indirectly, its use.

However, an increasingly significant body of scientific evidence provides arguments against large scale use of forest biomass for energy[4]. In particular, studies point to the fact that the use of forest biomass for energy leads to an immediate increase in greenhouse-gas emissions, an inefficient use of limited natural and capital resources and to negative impacts on both the environment (particularly forests and biodiversity in the EU and globally) and human health (due to increased air pollution). In this context, policy measures – i.e., subsidies – which incentivise the use of forest biomass can be seen as doubly harmful, by both promoting a form of renewable energy that can worsen climate change and destroy forest carbon stores and by diverting resources from environmentally and economically sound alternatives.

Whilst the EU has made certain progress in recognising and addressing some of these issues in the revisions of existing regulation[5], some important fundamental issues remain. Currently, in view of the target to reach climate neutrality by mid-century, a package of climate- and energy policies has been reviewed and updated at the EU level, including the EU Emissions Trading System, the Renewable Energy Directive, the Energy Taxation Directive and the LULUCF Regulation. In combination with the recently adopted REPowerEU plan, and the planned phase out of Russian gas, many of these regulations look set to encourage a substantial further increase in the use of forest biomass for energy in the coming decades.

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[4] See for example: Johnston, C.; Cornelis van Kooten, G. 2015. Back to the past: Burning wood to save the world. Ecological Economics 120, 185-193; Walker, T. et al. 2013. Carbon Accounting for Woody Biomass from Massachusetts Managed Forests: A framework for Determining the Temporal Impacts of Wood Biomass Energy on Atmospheric Greenhouse Gas Levels, Journal of Sustainable Forestry, 32,130-158. Searchinger et al., 2022, Europe's Land Future? Princeton University; Norton M, Baldi A, Buda V, et al. Serious mismatches continue between science and policy in forest bioenergy. GCB Bioenergy. 2019; 11: 1256–1263.

[5] Notably, by agreeing on certain biomass sustainability criteria in the revised Renewable Energy Directive (2018) and the subsequent strengthening of these in recent changes

The updates made to the EU Renewable Energy Directive (known as RED III) have maintained that solid forest biomass can be used to achieve renewable energy targets if certain sustainability criteria are met. Other new measures under RED III include eliminating subsidies for energy from some types of wood (e.g. stumps and roots), eliminating subsidies for use of biomass in dedicated electricity plants, disqualifying energy from forest biomass from primary and old growth forests from counting towards renewable energy targets. However, the restrictions on forest biomass have numerous exemptions, which could encourage its further use and lower sustainability criteria, for example in exemptions from rules for just transition regions and in the case of BECCS (Bio-Energy Carbon Capture and Storage)[6]. The classification of wood type is also left to Member State interpretation, which can lead to lax criteria being applied. Therefore, recent changes in the EU regulatory framework are unlikely to help avoid the large-scale deployment of forest biomass for energy that conflicts with international climate and biodiversity commitments. For many non-EU countries even these limited regulatory safeguards are absent and therefore at greater risk.

In parallel policy developments have also been taking place in the UK, which released its Biomass strategy in August 2023[7]. This focuses on growth in the use of biomass for energy across all sectors. The medium to long-term strategy is focused heavily on developing BECCS to 'deliver negative emissions', although this claim is debunked in Box 1 in section 2.3.2 of this report. Supporting policies and subsidies for BECCS are promised, but not yet in place.

1.2 Objectives

The objectives of this report are to:

1. Quantify how the energy gap arising from the removal of subsidies for industrial scale use of forest biomass for energy could be filled by renewable alternatives.
2. Assess the costs and benefits of renewable alternatives, investments in reductions in energy demand and investments in nature-based solutions.
3. Develop a Renewable Energy and Climate Change Strategy based on a comparison of the costs and benefits of the three categories of alternatives and the impact of the subsidies currently provided to forest bioenergy being retargeted to these measures.
4. Identify potential funding sources to complement the subsidy reallocation and catalyse greater investments in the RECCS measures.

1.3 Scope and definitions

Specific definitions relevant for this work are provided in the glossary at the front of this report. In addition, the focus of the work is on primary solid forest biomass for industrial scale use, which we define as:

- **Solid forest biomass**, includes all roundwood felled or otherwise harvested or removed. This includes all wood obtained from removals, such as the quantities removed from forests, including wood recovered due to natural mortality and from felling and logging. It also includes all wood removed with or without bark, including wood removed in its round form, or spit, roughly squared or in other forms, such as branches roots and stumps, along with wood that is

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[6] BECCS is an approach that applies carbon capture and storage technology to the bioenergy plant, this captures part (50% and upwards) of the CO_2 emissions from biomass combustion. Whilst this reduces the emissions of electricity from biomass they remain higher than other renewables. See Box 1 in chapter 2 for further detail on BECCS.

[7] https://www.gov.uk/government/publications/biomass-strategy

roughly shaped or pointed. In summary, this study is concerned with virgin wood from forestry, arboricultural activities or from wood processing, excluding from the scope the limited supply of genuine forest waste and residues[8].

- **Industrial scale use of bioenergy**, i.e. for large-scale power or heat generation, or in industrial applications. It is not intended that this work focuses on small scale residential heating. Focusing on larger industrial scale biomass use more effectively targets the subsidised share of use. The statistical scope of the work covers all forest biomass used as transformation input (i.e. burnt at power or heat generation facilities, and including large district heating) and also final consumption by industry. It excludes final consumption by individual residential households (although this is responsible for a large share of biomass use), commercial and public services and agriculture and forestry as these uses are either not subsidised and/or small scale.
- **Exclusions:** Biomass used for transport or biofuels is excluded, as is biomass used to produce biogas, and renewable municipal solid waste.

Important Note: unless otherwise specified, when the term biomass is used in this report, it refers to solid forest biomass used within the scope defined above.

The **geographical scope of the work is Europe**, whilst the EU naturally becomes a major focus and often provides the best data for quantifying the most relevant issues, the scope also includes non-EU countries including the UK, Norway, Switzerland and the non-EU Balkan countries. Since data is poor for other European countries (e.g. Belarus, Russia), they were not considered in the scope. However it is reasonable to assume that the broad themes will be similar, and the overarching lessons will also apply to these countries too. Impacts are most often assessed in aggregate, but where possible guidance is also provided on country-level considerations. The quantitative data is based on scenarios and calculations covering only the EU as similar, comparable data is unavailable for the other European countries.

Lessons in this report are assessed by the team to also be strongly applicable to other regions around the world including North America and East Asia. While some of the particular details may differ, a RECCS approach, to cut subsidies for wood pellet production and/or industrial-scale biomass usage for energy, to invest instead in other low carbon energy sources, demand reduction and nature based solutions, would also be expected in other global regions to deliver better economic, social, health, biodiversity, energy and climate outcomes.

The **timescale of the work is focused on impacts by 2030 and 2050**, corresponding to Paris Agreement target dates, although in the development of the report's recommendations it was kept in mind that impacts related to emissions or ecosystems often require longer timescales.

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[8] Genuine residues, assuming that they do not have any significant alternative uses (cascading effect), can provide climate mitigation benefit if used to replace fossil fuel energy. However, genuine forest residues would not be a substantial contributor to the planned growth in biomass use, given the relatively low additional volumes that can be sustainably and economically harvested. However, for producers it is attractive to classify other types of solid biomass as residues to enable their use. There are some serious concerns with the lack of clear definitions and evasion of this type.

1.4 Approach

This work is based primarily on desk review, analysis and modelling. It has drawn upon a wide range of public sources including published work on energy subsidies; scenarios for energy and climate policy; and, scientific and industry work on emissions, efficiency, costs and impacts. Industry stakeholders were contacted during the course of the work and the feedback they provided helped to shape not only the selection and quantification of measures in the demand reduction and energy efficiency section (chp 5) but also to demonstrate interest in engaging with the goals of decarbonisation and measures that support this. In addition the work has been subjected to peer review by an independent technical advisory group of senior experts.

Base case: the analysis is based on a comparison to a 'base case' which represents the current and projected use of biomass up to 2050. The base case is detailed in chapter 2, and is based upon available statistics and policy scenario impact assessments which match the actual (to date) policy outcomes as far as possible. The key characteristic of the base case is that it projects increasing biomass use over time, which, as we clearly set out in the report will result in worse climate, environmental and economic outcomes than the RECCS we propose.

Biomass use is not carbon neutral: this is a key assumption of this work, and is contrary to the existing policy, climate and technical assumptions used in Europe (and globally). For the reasons we set out in section 2.3 the assumption of carbon neutrality for biomass is wrong for the great majority of forest biomass use for energy, particularly in the timeframe of net-zero by 2050, and is leading to high net GHG emissions. Our assumption provides analysis based on the reality of the current period where significant and urgent emissions reductions are required, and where the current assumptions are having a perverse and negative impact.

Limitations

Whilst best efforts and expertise have been applied to undertake the analysis provided in this report it is only possible to go so far with the available resources. Therefore, there are some limitations to the work that should be kept in mind when reviewing the report, including:

- Within the energy system the characteristics of any generation facility can vary significantly due to multiple factors (cost, fuel prices, location). For the estimations and calculations we have used average and representative values, however, these may not represent every case.
- Given the wide-ranging nature of the measures considered the results should be considered more as broad indications of the potential magnitude of impact.
- The further into the future the impacts are estimated then the more uncertain the results are, as there are multiple cost, efficiency and other assumptions that will evolve over time and will deviate from what is assumed in the calculations.
- Country level impacts are provided indicatively but it was not possible in most cases to make country level estimates, the calculated impacts are based on EU averages.
- Economic modelling is simplified and uses input-output based multipliers to calculate quantitative impact. It was not possible to use country specific multipliers, nor to utilise partial or general equilibrium modelling to further calculate the numerous economic interactions of the RECCS. Nevertheless, the results are thought to provide a reasonably robust indication of the direction and magnitude of the potential impact of RECCS and triangulation with sector sources demonstrates a consistency in the outputs with other work.

- There are significant variations in the costs of individual measures, averages are used to enable calculation of quantitative impacts, in reality costs could be higher (or lower) based on location and the specific circumstances. Costs could also increase/decrease in future in different ways to those assumed in the scenarios.
- Emissions reductions for the nature based measures are dependent on assumptions of sequestration per measure and ecosystem type. There can be large variances and uncertainties in the sequestration assumptions, and also their additionality in RECCS compared to the base case. Nevertheless, reasonable variances in the assumptions do not change the overall finding that nature based solutions can offer large volume, low-cost emissions savings with multiple co-benefits. The biggest challenges for these measures will come in large-scale finance and implementation.

1.5 Structure

The rest of this report is structured as follows:

- **Chapter 2: Current state-of-play** – provides a clear overview of the current state of forest biomass use for electricity, heat and industrial purposes, and also details projections of the planned trajectory of forest biomass use. Furthermore, this chapter also details the current and projected level of subsidies provided to forest biomass, and also the associated emissions from forest biomass use. It summarises the energy gap to be filled, the amount of subsidies that could be available and the possible emissions impact.
- **Chapter 3: Filling the energy gap with other renewables** – provides an analysis of the energy gap from removing forest biomass subsidies at country level and identifies, based on country-characteristics and a comparison of energy technologies, the most appropriate renewables to replace forest biomass use. It demonstrates how the energy gap can be filled and considers the various costs and benefits of doing so.
- **Chapter 4: Nature-based solutions** – examines the different types of investments in carbon absorbent ecosystems which could deliver positive climate impacts. It compares different options and their costs and benefits.
- **Chapter 5: Demand reduction and energy efficiency** – presents an analysis of some key measures in the residential and industrial sectors that can reduce energy demand, which could complement the measures highlighted in chapter 3. An analysis of the costs and benefits allows for comparison across the proposed measures.
- **Chapter 6: Renewable Energy and Climate Change Strategy** – brings together the analysis in the previous chapters to compare and select from the available measures (and subsidy funding) to recommend a portfolio of investments that would comprise a positive RECCS for European countries. The analysis first considers how the measures address the energy gap through renewables and energy demand reduction, and how this affects the energy system compared to the base case. It then considers how these measures, and those for nature-based solutions, would affect emissions, and then concludes with a comparison of the multiple co-benefits of the RECCS compared to the base case. It then provides guidance on a plan for the implementation of such a strategy including the necessary actions by public policy, industry and investors within a given timeframe.
- **Chapter 7**: Additional sources of funding and synergies with existing policies – this chapter provides an overview of public and private funding sources in Europe which, complementing

the repurposing of subsidies, could be used to make RECCS a reality. It provides practical and firm recommendations on how these funds can be accessed.

2 Current state-of-play

Key points

- **Overall, a large expansion (+50%) in industrial scale energy from forest biomass is planned in the EU by 2050, particularly after 2030 using BECCS:** from around 500 TWh in 2020 to 550 TWh by 2030 (+10%) and to 750 TWh (+50%) by 2050. This is driven especially by growth in solid forest biomass use for electricity and BECCS.
- **This growth, especially of BECCS, will require tens of billions of new subsidies annually, imposing significant costs on consumer bills:** subsidies are estimated to grow from around EUR 6 billion per year today, to an estimated EUR 35 billion per year by 2050. Between 2025-2050 a cumulative EUR 475 billion could have been paid in subsidies to power from biomass and BECCS, with the majority likely to be financed through consumers bills.
- **CO_2 Emissions from electricity from forest biomass are higher than for coal:** if the false assumption of carbon neutrality over the life-cycle is discarded, then an average biomass plant emits more than 1.2 kg/CO2 per kWh, higher than both lignite and hard coal plant.
- **BECCS would not provide emissions savings, and would be a very expensive and inefficient addition to the energy mix:** analysis shows when emissions from biomass are properly accounted that BECCS emissions are not negative and depending on the actual effectiveness of this unproven technology could have net emissions similar to natural gas. It would be hugely expensive per unit of electricity, with limited learning and scaling opportunities to reduce cost. Also the already low thermal efficiency of power from biomass would be reduced further for BECCS by applying CCS technology.
- **Total EU emissions from these industrial scale uses of biomass (not currently accounted) are estimated at around 630 $MtCO_2$ per year, or around 20% of all EU GHG emissions:** this impact is larger than the whole aviation sector or agriculture, and emissions would increase with planned increases in forest biomass use, in direct contradiction of net zero targets.
- **Removing subsidies for energy from forest biomass could curtail a large part of its use and lead to large emissions savings:** particularly for electricity which is heavily reliant on subsidies for its commercial survival, and especially for BECCS which is not viable without large subsidies (or proven at scale). We estimate that replacing the subsidised energy from forest biomass by renewables could reduce emissions by around 250 $MtCO_2$ per year by 2050, equivalent to the current total GHG emissions of Spain.
- **Projections for energy from forest biomass:**
    - **Electricity from forest biomass projected to significantly increase**: by around 29% between 2020-2030 and by 105% by 2050, almost doubling from its current level.
    - **BECCS is planned to increase from 0 today to match electricity from forest biomass, a massive expansion:** By 2050, electricity production from BECCS is planned to reach 151 TWh per year, around the same volume as forest biomass without CCS, a very significant expansion fuelled by new forest biomass consumption.
    - **Heat from forest biomass is currently the main renewable heat source, although a small decline may be foreseen:** a small decline in biomass consumption is projected by 2030 (-9%), deepening by 2050 (-30%) as heat demand declines and heat pumps expand.
    - **Use of forest biomass for energy by industry is planned to increase:** Forest biomass contributes around 10% of industrial final energy consumption, and this is projected to increase by 2030 (+8%) and further by 2050 (+19%)

- **The overall increase in forest biomass demand will put additional stress on biomass fuel supply, driving further increases in imports and exporting deforestation on a large and rapidly growing scale**

This chapter sets out the current state-of-play for biomass use in Europe, subsidies provided to fuel this use and the emissions associated with the use. This provides the factual basis and context for the measures proposed in the following chapters.

2.1 Current and projected use of forest biomass for energy in Europe

Overview of current use

In the EU27, in 2021, total energy supply from biomass[9] amounted to 1 211 078 GWh, of which 1/3 is used in electricity, heat or CHP (combined heat and power) production facilities, or consumed on site (autoproducers) for heat and power. This represents around 8% of total EU primary energy consumption in 2022. The largest share of biomass use, around 2/3, is for final consumption, where biomass is burnt by households, industry and other sectors, primarily for heat. Table 2-1 highlights the scope of this work, which covers a bit more than 50% of total biomass use for energy. Further statistics are provided in Annex A.

Table 2-1 Overview of biomass use for energy in the EU in 2021

	GWh	As %	In scope of this study?
Transformation input (i.e. combusted at industrial scale in power and heat generation facilities)			
Electricity	63 173	5%	Y
Heat	65 974	5%	Y
CHP	172 594	14%	Y
Autoproducers (electricity and heat)	80 478	7%	Y
Final energy consumption (i.e. combusted on-site by the final users)			
Industry	245 631	20%	Y
Households	525 823	43%	N
Other sectors	57 405	5%	N
Total	**1 211 078**	**100%**	
Total in scope of this study	**627 850**	**52%**	**Y**

2.1.1 Electricity

Recent trends in use of biomass for electricity

Total electricity generation in the EU peaked in 2008 at just under 3 000 TWh and since then has seen two dips, first during the financial crisis 2009-2010 and then during the COVID19 pandemic in 2020. The main story in the last decade has been the growth of renewables with wind and solar power especially leading the growth, with the share of electricity from renewables increasing from 16% to 38% between

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[9] Biomass here refers to the statistical category of Primary solid biofuels (PSB) used by Eurostat. This provides the statistical category that is closest to primary forest biomass that is the focus of this work, however PSB does include some sources of biomass that are not the intended focus of the work, italicised in the following definition. Definition from Eurostat: Primary solid biofuels is a product aggregate equal to the sum of fuelwood, wood residues and *by-products, black liquor, bagasse, animal waste, other vegetal materials and residuals and renewable fraction of industrial waste*.

2000-2021. Electricity from **biomass has increased from less than 20 000 GWh in 2000, to more than 90 000 GWh in 2021, a 370% increase.** It has also increased 29% between 2015 and 2021. This highlights the rapid increase and importance of primary solid biomass for electricity generation. Further details are provided in Annex A.

Projections in use of forest biomass for electricity

A variety of energy scenarios have been developed to explore potential future energy system outcomes. Within Europe the EU reference scenarios are regarded as the most comprehensive and authoritative scenarios for the energy system. However, the latest version of these scenarios, the 2020 reference scenario[10], was released prior to both the new EU climate targets and policies (Green Deal, Fit-for-55, revised Renewable Energy Directive) and also prior to the energy price crisis of 2021-2023 and the Russian invasion of Ukraine, each of which has had dramatic impacts on the energy system and markets, and in turn on future scenarios. For this work we have utilised public data to tailor projections for the European electricity system. The main sources are the scenarios prepared for the EC as part of the Climate Target Plan (CTP) and the associated impact assessment. These scenarios provide significant detail on future outcomes and take into account expected (and now actual) policy developments and targets and some of the energy price crisis impacts[11]. We have made our baseline for this work based on the projections on the MIX scenario from the CTP assessments:

- **CTP MIX – a scenario utilising a mix of carbon pricing and regulatory measures**, which achieves around 55% GHG reductions by 2030, by both expanding carbon pricing to road transport and buildings and moderately increasing the ambition of policies. This scenario most closely matches the actual policy outcomes, although the renewables share at 38.5% in 2030 is lower than the target of 42.5% adopted in the revised Renewable Energy Directive. The higher target in reality is likely to be achieved by a mix led by solar and wind, but may also include to a lesser extent biomass, therefore the scenario is likely to represent a small under-representation of targeted forest biomass use for energy.

Important note: the EC scenarios for 55% emission reductions assume that forest biomass is carbon neutral in combustion. The actual emissions impact of the scenarios, if this assumption is discarded to show real emissions, is explored further in section 2.3 and shows the significant negative impact on emissions of using forest biomass for energy.

The projected scenario for forest biomass use in electricity generation is presented below in Figure 2-1 and Figure 2-2. The main trends that can be observed include:

- Following the update of the climate targets **total electricity generation increases from 2020 levels by 11% by 2030 and by more than 146% by 2050**, a very significant long-term increase.
- **The increase is achieved by a massive expansion in renewable electricity, which should almost double by 2030 (+93%) and increase almost x5 by 2050**. Up to 2030 fossil use should decline by nearly 47%, whilst solar PV (+196%) and wind power (+170%) should nearly treble. Through to 2050 the increase in wind and solar power accelerates even further, more than x8 on 2020 levels. Even larger % increases are forecast for other RES [geothermal and marine energy], but from such low levels these still only make minor contributions by 2050. Electricity

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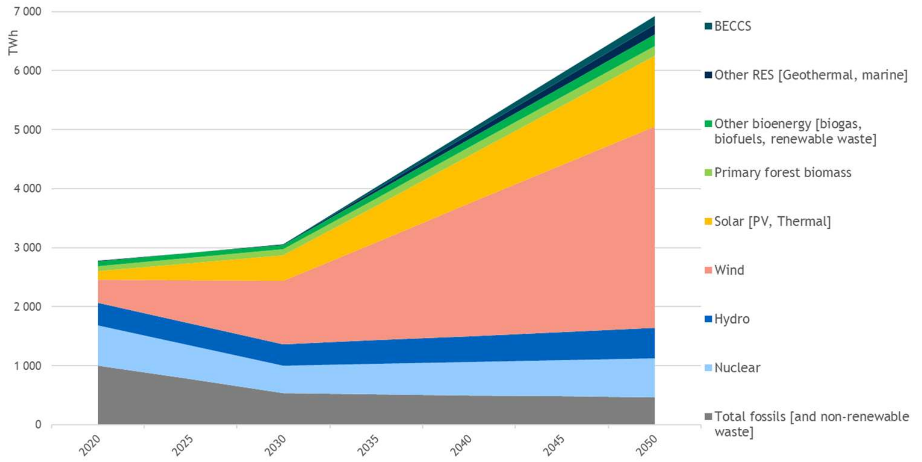
[10] https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

[11] Further details on these scenarios can be found as part of the Impact Assessment of the EU Climate Target Plan (SWD(2020)176 final).

from nuclear is expected to be largely flat between 2020-2050, although a notable dip in nuclear power by 2030 is expected as old plants close, this is filled by new nuclear generation coming online between 2030-2050.

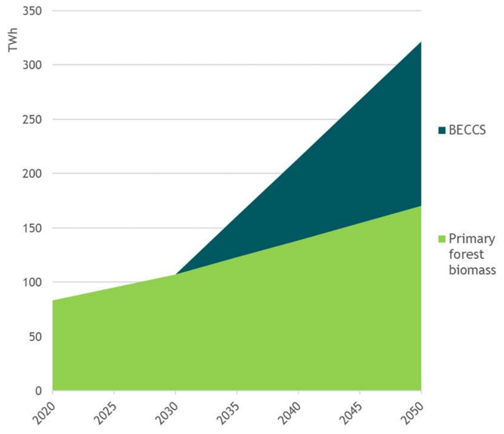
- **Electricity from forest biomass (see Figure 2-2) and BECCS is expected to increase by around 29% (+24 TWh) between 2020-2030 and by almost 290% (+239 TWh) by 2050, therefore almost quadrupling from its current level.**
  - Within this **electricity from forest biomass is expected to increase by around 29% between 2020-2030 and by 105% by 2050, therefore almost doubling from its current level of 83 TWh to 170 TWh per year**.
  - After 2030 BECCS is also expected to play an important role in electricity production, with electricity production from BECCS reaching 151 TWh in 2050 – this is almost as much as the projected share of primary solid biomass without BECCS.
  - While BECCS is not expected to play a major role in the short term (i.e., up to 2030) it is projected in this scenario to account for almost half of the total electricity production from forest biomass by 2050.

Figure 2-1 Forecast scenario (based on CTP MIX scenario) of electricity generation in the EU27, split by fuel, 2020-2050, TWh



Source: Trinomics based on EC Climate Target Plan and other sources

Figure 2-2 Forecast scenario (based on CTP MIX scenario) of electricity generation from forest biomass and BECCS in the EU27, 2020-2050, TWh



Source: Trinomics based on EC Climate Target Plan and other sources

2.1.2 Heat

Recent trends in use of biomass for heat

Total heat generation in the EU peaked in 2010 at around 720 TWh and has largely stabilised since then. **In contrast to electricity, where low carbon sources are in the majority, fossil fuels remain by far the dominant source of heat,** and this highlights this part of the decarbonisation challenge. **Similar to electricity, one of the main stories in the heat sector has been the growth of renewables, but with forest biomass leading the growth over this period, accounting for 153 TWh of the total in 2021.** This has pushed the share of fossil heat down from 90% in 2000 to 70% in 2021, and the share of renewables has increased from 10% to 30% over the same period. Heat pumps are also emerging as a contributor, but statistics do not yet show the major growth in the 2021-2023 period, where it is now estimated around 20 million households (around 10% of the EU total) have heat pumps installed. Further detail on historic trends for heat are provided in Annex A.

Projections in use of biomass for heat

For heat it is less straightforward to make projections of biomass and renewable energy use than for electricity due to variations between data sources and unclear assumptions. We are unable to provide a direct continuation of the heat generation figures in the previous section, therefore the scope of the projection encompasses (non-electricity) final energy consumption in residential and services buildings[12]. The scenarios developed for the Climate Target Plan give an indication on the planned direction of policy makers for the use of renewables and biomass in heating (residential and tertiary). An overview of these is presented below in Figure 2-3 and Figure 2-4.

The main trends that can be observed from the projection of heat consumption is:

- **A reduction in overall heat consumption of -20% (-520 TWh) by 2030 compared to 2020 (2 670 TWh), further declining to -37.5% (-1 000 TWh) by 2050.** This is due to various factors including, improved building insulation requiring less heating, increased temperatures lowering heating demand, increased efficiency of heating as heat pumps are more widely adopted.
- **The reduction in heating is driven by a massive reduction in heat from fossil sources, down -47% by 2030 and -98% by 2050.** The small share of remaining heat from coal (3% of 2020 heat) reduced -95% by 2030 and -100% by 2050; oil (15% of heat in 2020) reduced by -73% by 2030 and almost -100% by 2050; and for natural gas (42% of heat in 2020) reduced by -34% by 2030 and -97% by 2050.
- The **planned reduction in heat from fossils sees a corresponding increase in heat from renewable sources which increase from 40% of the total in 2020 (1 061 TWh) to 60% by 2030 and 98% (1 625 TWh) by 2050.**
- **The decrease in fossil heating poses a risk,** that forest biomass is used instead as it is the current leading renewable heat source. **However, the projection shows that heat from forest biomass is not expected to increase**, and the largest part of the reduction in fossil heat is covered by efficiency/demand reduction, heat pumps and e-gas[13] (after 2030).

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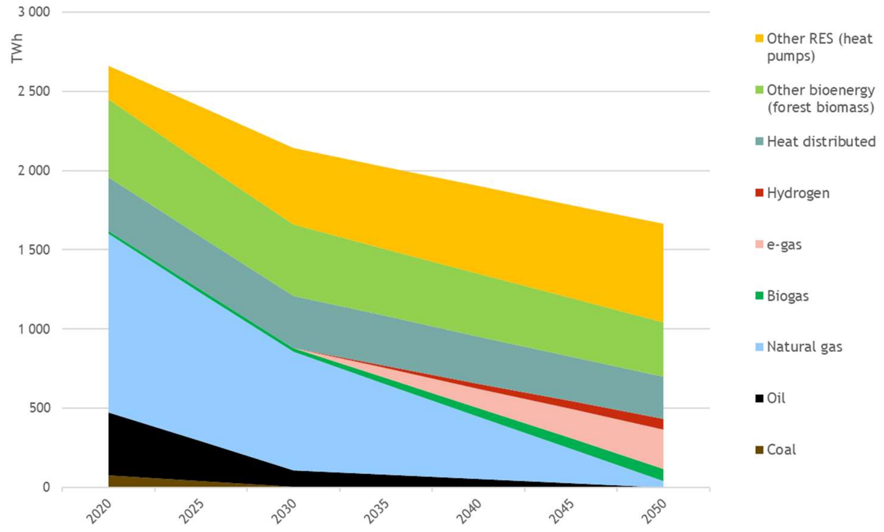
[12] Therefore this includes the heat produced in thermal plants and district heating supplied to residential and service buildings (same as part of previous figure), and also includes heat produced on-site in residential and services buildings e.g. residential gas boilers, residential biomass stoves. Whilst noting that as per 1.3, small, unsubsidised residential solid biomass use is not the primary scope of this work these projections give good insight into the overall technology trends expected for heat.

[13] E-gas refers to synthetic gas manufactured using electricity using one of a number of industrial processes. The processes can be powered by low carbon electricity to make e-gases a low carbon replacement for natural gas.

- **The projection shows that other renewable energy sources (RES) (primarily heat pumps) grows to exceed the share of biomass in heating already by 2030** (to 483 TWh) and to a 37% share of the total by 2050 (625 TWh).
- After 2030 e-gases and hydrogen are planned to start contributing to heat consumption, growing from zero in 2030 to around 20% of consumption by 2050, although hydrogen plays only a relatively small, very niche role as a heating fuel. Biogas is expected to also follow a similar trajectory as hydrogen, resulting in around a 4% share in heating by 2050.
- **For forest biomass[14] for heating (18% or 492 TWh of the 2020 heat total) a decline in consumption is foreseen in the period 2020-2050, a decline of 9% by 2030 to 449 TWh and of 30% by 2050 to 345 TWh.**
    - Heat from biogas is expected to increase from around 16 TWh in 2020 to 80 TWh by 2050 (+390%). The fuel for this biogas is not specified, most likely it would be from anaerobic digestion of agricultural waste, but it is also possibly from forest biomass. However, the additional biogas generation of around 63 TWh is much less than the 148 TWh decline in heat from forest biomass.

Figure 2-3 Projection of heat consumption[15] in the EU27, split by fuel, 2020-2050, TWh



Source: Trinomics based on EC Climate Target Plan and other sources

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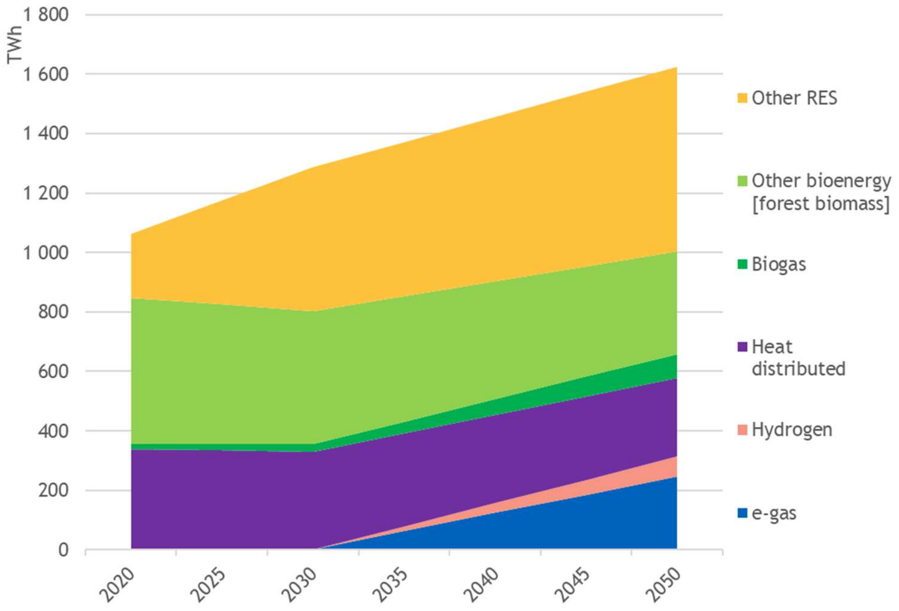
[14] Note forest biomass is aggregated within the category other bioenergy in the statistics, this also includes some other small sources such as renewable municipal solid waste, however, forest biomass is by far the majority in this category.

[15] Non-electricity energy consumption in buildings in the tertiary (services) and residential sectors. The presented values for biomass are on a gross available energy basis, i.e. before combustion, and therefore are not directly comparable to the historical figures – this is one of the reasons why the totals in this figure are much higher than those in the historical data.

Figure 2-4 Scenarios of heat generation in the EU27, from renewable energy, 2020-2050, TWh



Source: Trinomics based on EC Climate Target Plan and other sources

2.1.3 Industry

Recent trends in use of biomass for energy in industry

The industry sector accounts for about a quarter of the EU's final energy consumption, with 2 796 TWh consumed in 2021.[16] During the last decade (2012-2021), the total amount of final energy consumption remained relatively constant. Fossil fuels and non-renewable waste contribute around 51% of this total, a share which has basically remained unchanged over the last decade, with small declines in coal and oil use compensated by increased natural gas and non-renewable waste use.

Primary solid biomass contributes around 9% of the total, providing 245 TWh per year, therefore a significant amount compared to biomass use for electricity and heat as outlined in the previous sections. Primary biomass consumption by industry has increased by 15% over this period, a slow but steady growth trend. Primary biomass use is concentrated in a handful of industrial sectors, with it contributing more than 10% of the energy use within only two sectors the Wood and Wood products sector (57% of total) and the paper, pulp and printing sector (38%)[17]. Together these account for more than 83% of the primary solid biomass use for energy by industry.

Use of genuine biomass residues by industry offers a resource efficient way to generate energy and should be welcomed, however, there is also some evidence that subsidies distort practices so that non-residue forest biomass is also used. For example, a survey of the Finnish sawmill industry[18] showed that all factories surveyed were producing bioenergy, with 61 also selling either electricity or heat to external users. Among the key factors in driving bioenergy use, respondents indicated government subsidies. Removing subsidies for bioenergy could help to avoid non-residue forest biomass being used in this way.

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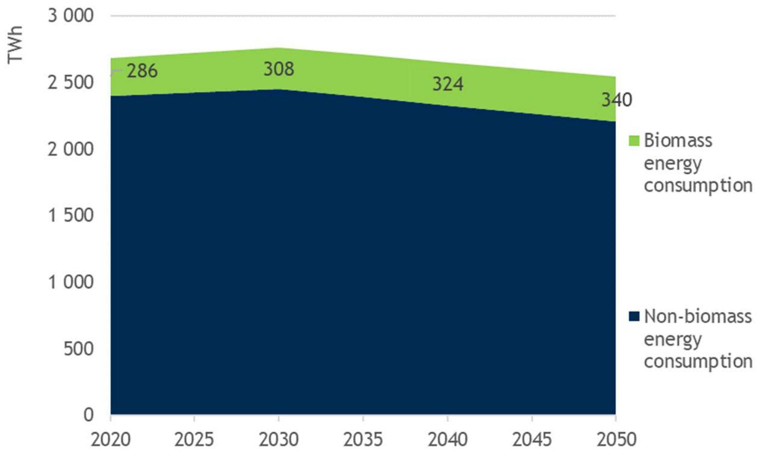
[16] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_industry_-_detailed_statistics#Energy_products_used_in_the_industry_sector
[17] Based on analysis of Eurostat EU27 energy balances.
[18] https://www.tandfonline.com/doi/pdf/10.1080/14942119.2012.10739965?needAccess=true&role=button

Projections in industrial energy use

According to the CTP projection (see Figure 2-5) **total industrial energy consumption is expected to increase up to 2030, but after that a slow downward trend is expected up to 2050**. However, within this decline the relative importance of forest biomass energy use in industry increases. Biomass energy consumption by industry is projected to increase from 286 TWh in 2020 to 340 TWh in 2050 (+19%). This shows that one implication of the fit-for-55 policies and Green Deal is an increase in the amount of energy from biomass in industry. The higher targets for renewables in the RED III revisions could increase the biomass contribution further.

Proportionally, bioenergy use in industry corresponded to 9% out of the total energy use in industry in 2021, and is projected to increase to 13% by 2050 as the absolute volumes of energy from forest biomass increase whilst total industrial energy use falls. This demonstrates how energy from biomass will become more important to industry in future.

Figure 2-5 Projection of EU's industrial energy consumption, including biomass split, TWh/yr, BSL (left), REG (centre), MIX (right) (2020-2050)



Source: Trinomics based on EC Climate Target Plan and Eurostat data

2.1.4 Biomass fuel supply

State of play for forest biomass supply

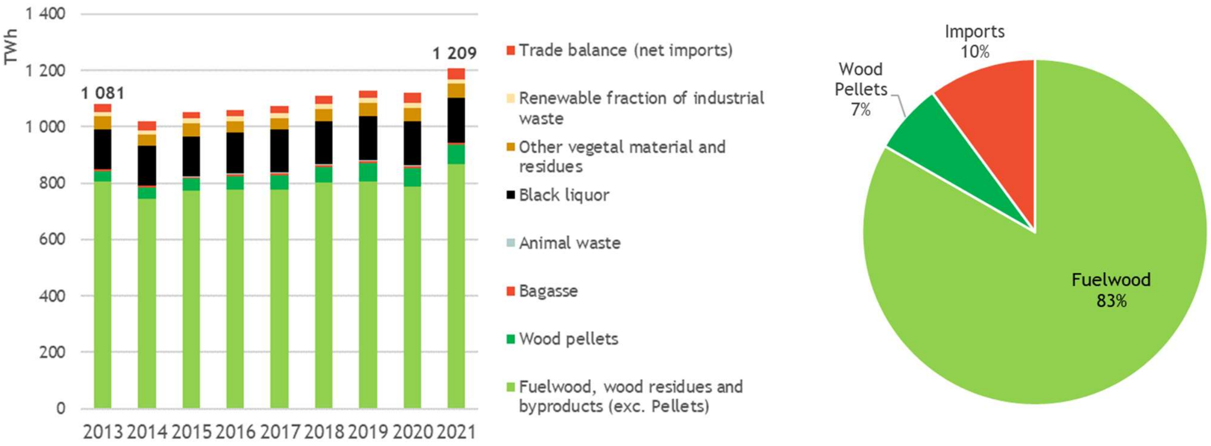
The EU has seen its total biomass output grow by around 117 TWh since 2013 (+11%) to 1 209 TWh per year as biomass use for energy has expanded. The EU produces the largest part of its biomass supply domestically, with indigenous production accounting for around 97% of the supply (by energy content) (Figure 2-6). By far the largest share of biomass supply is classed as fuelwood which accounts for 72% of the total, with black liquor, a by-product of industrial processes (especially in the pulp and paper sector) the next biggest contributor. Fuelwood is a broad category that covers many types of wood and includes both wood that may genuinely be considered suitable for use as a fuel, but also much wood which would have better economic uses, and also ecological value, if not used for energy. Fuelwood plus wood pellets are the closest proxy for the forest biomass of interest in this work.

Wood pellets account for only 6% of the total (69 TWh), but the volumes of this have grown rapidly since 2013, increasing by 78% (+30 TWh) over this period. EU Imports have also increased significantly over this period to 105 TWh, an increase of +33 TWh (+45%) with a value of EUR 300-400 million, as have exports, but overall there is a net negative trade balance of around 3% of EU biomass fuel (in TWh) and around EUR 250-350 million each year. It is likely that the largest part of all imports are wood pellets. Imports are also highly prevalent in the UK which imported around 6.7 million tonnes of wood pellets in 2023, equivalent to around 32 TWh, and contributing more than 1/3 of the forest biomass fuel supply in the UK[19]. With the UK own supply not meeting its needs it is noteworthy that any further expansion of energy from forest biomass, e.g. any planned BECCS expansion, will be met by further imports putting pressure on forests elsewhere, including tropical rainforests.

By excluding the non-relevant biomass categories of Bagasse, Animal waste, Black liquor, Other vegetal materials and renewable industrial waste, then the picture becomes clearer (see right of figure 2.6 below), with **wood pellets and imports are playing a significant and growing role in forest biomass supply.**

Based on assumptions of energy content of the fuel and per hectare an estimate of the equivalent forest area in the EU for used for fuelwood production can be made[20], this estimates that **the equivalent of around 21 million hectares of forest are needed to support the EU own fuelwood supply, or around 13% of total EU forest coverage.** If 13% of forests were harvested in this way each year without replanting then the EU forests would disappear within 8 years. In reality some replanting does take place and parts of the fuelwood and wood pellet supply are from genuine waste wood and residues, or sustainable harvest (e.g. from short rotation coppice) – but clear cutting of forests for biomass fuel supply remains a highly significant issue.

Figure 2-6 EU biomass supply per fuel: left figure 2013-2021 (GWh), right figure, 2021 share of fuelwood, imports and pellets



Source: Eurostat (NRG_CB_BM)

Fuelling the projections – growth in forest bioenergy use

It is important to get further insight into the types of biomass that are intended to satisfy the scenarios for biomass consumption in Europe. Analysis supporting the EU Climate Target Plan shows (see Figure 2-7 below) that between 2015 and 2030 total bioenergy use is intended to grow, from around

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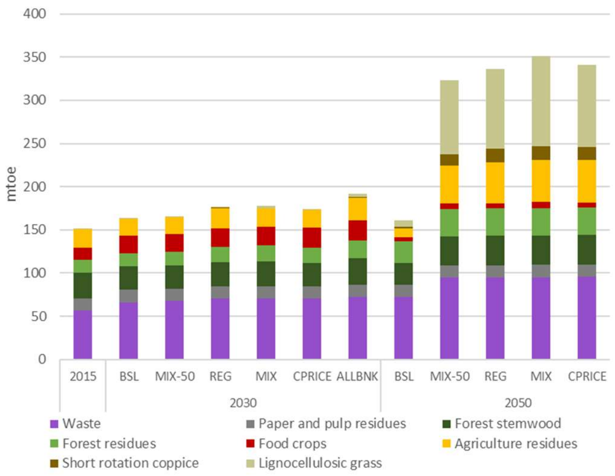
[19] https://www.forestresearch.gov.uk/tools-and-resources/statistics/statistics-by-topic/timber-statistics/uk-wood-production-and-trade-provisional-figures/

[20] See for example Table 2 in IRENA (2019) solid biomass supply for heat and power - technology brief. The estimation is based on energy production of 150 GJ/ha.

151 Mtoe[21] in 2015, to 178 Mtoe (2 070 TWh) (+18%) in the MIX scenario (used as a basis for the projections in earlier sections) in 2030. However the largest growth is anticipated in the 2030-2050 period with bioenergy use increasing from 175 Mtoe to 336 Mtoe (3 908 TWh) by 2050 (+89%). Highlights of these changes include:

- In the 2015-2030 period the increase in forest biomass feedstocks is understood to be sourced primarily from waste wood, although as highlighted above, fuelwood does not typically include a large genuine share of waste wood, and that for the largest part the supply will be sourced from clear-cutting.
- After 2030, growth is more spread across the feedstocks. The growth of lignocellulosic grasses as a feedstock are responsible for the largest part of the changes post-2030. However, there are also notable increases in consumption of Forest residues, Forest stemwood and Short rotation coppice as sources, all of which could have important impacts on forests in the EU and globally. There is also a noticeable reduction in the food crop bioenergy feedstock.
- Lignocellulosic grasses[22] represent an emerging technology and practice for the supply of bioenergy. It is as yet, expensive and not widely used – so substantial further innovation, development and adoption would be necessary to unlock this level of growth in future. There would also be concerns about conflict with food production, as although such crops have energy yields comparable to woody biomass per hectare[23] they still require land and therefore could displace agriculture. Promoters of these resources believe that they can be successful on land of marginal agricultural value. However, supplying 100 Mtoe from this type of fuel could require around 21 million hectares of production, this equates to roughly 13% of current EU farmland, and would be likely therefore to bring significant conflict with food production[24]. There is also a risk that if these grasses were not as productive or cost-efficient as projections that there would be increased pressure on other forest biomass feedstocks to fill the gap.

Figure 2-7 Break down of bioenergy feedstocks, EU climate target plan scenarios, 2015-2050, Mtoe



Source: EU Climate Target Plan (Figure 79)

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[21] Million tonnes of oil equivalent

[22] Lignocellulosic grasses include plants such as miscanthus, switchgrass, giant reed, reed canary grass and cardoon and are typically selected based on their suitability for conversion to energy and their successful growth on marginal or poor land.

[23] See for example Table 2 in IRENA (2019) solid biomass supply for heat and power - technology brief

[24] This is based on the assumption of 200 GJ/ha energy crop production which is consistent with current yields. However, these yields could be lower in reality, or possibly improve with innovation.

2.2 Subsidies for use of forest biomass for energy in Europe

The rationale for the Renewable Energy and Climate Change Strategy presented in this report is strengthened when subsidies given for the use of forest biomass for energy can be re-deployed in support of the proposed actions. In this section we quantify the volume of subsidies provided to the industrial-scale use of forest biomass in Europe.

2.2.1 Definitions, scope and approach

We work with a definition of subsidies based on the commonly used World Trade Organisation definition, and one which has been operationalised in the regular Costs and Subsidies of EU energy studies prepared by the European Commission[25], namely:

> Article 1: Definition of a Subsidy
>
> 1.1 For the purpose of this Agreement, a subsidy shall be deemed to exist if:
>
> (a)(1) there is a financial contribution by a government or any public body within the territory of a Member (referred to in this Agreement as "government"), i.e. where:
>
> (i) a government practice involves a direct transfer of funds (e.g., grants, loans, and equity infusion), potential direct transfers of funds or liabilities (e.g., loan guarantees);
>
> (ii) government revenue that is otherwise due is foregone or not collected (e.g., fiscal incentives such as tax credits);
>
> (iii) a government provides goods or services other than general infrastructure, or purchases goods;
>
> (iv) a government makes payments to a funding mechanism, or entrusts or directs a private body to carry out one or more of the type of functions illustrated in (i) to (iii) above which would normally be vested in the government and the practice, in no real sense, differs from practices normally followed by governments;
>
> or
>
> (a)(2) there is any form of income or price support in the sense of Article XVI of GATT 1994;
>
> and
>
> (b) a benefit is thereby conferred.

This therefore includes the following types of subsidies:

- **Direct transfers:** soft loans, grants, others
- **Tax expenditures:** tax reductions, tax exemptions, tax refunds, tax credits, tax allowances, other
- **Under-pricing of goods/services:** under-pricing of government-owned resources or land, under-pricing of government-owned infrastructure, other
- **Income or price supports:** capacity payments, biofuels blending mandates, RES quotas with tradable certificates, differentiated grid connection charges, energy efficiency obligations, interruptible load schemes, contracts for difference (CfDs), feed-in premiums, feed-in tariffs, consumer price guarantees (cost support), consumer price guarantees (price regulation), producer price guarantees (price regulation), green premiums, others
- **Research Development and Innovation (RD&I):** Research development and innovation

---

[25] Including: the "Study on energy prices costs and subsidies and their impact on industry and households" (2018), "Study on energy costs, taxes and the impact of government interventions on investments" (2020), and "Study on energy subsidies and other government interventions in the EU" (2021).

In the case of biomass particularly the tax expenditures and income and price supports are most relevant. RD&I subsidies can also be relevant for example in the case of Bioenergy Carbon Capture and Storage (BECCS).

The scope of the subsidies covered includes the following:

- Subsidies to forest biomass for electricity and heat production, for the production of forest biomass, and for use by industry
- Subsidies in the EU and UK

The scope excludes:

- Subsidies to waste, biogas and other forms of biomass
- Subsidies for the use of forest biomass in transport – as there is little evidence that forest biomass is being considered over alternatives such as crop-derived ethanol for transport fuels
- Subsidies to small scale uses by households or small apartment buildings, district heating systems (a cut-off of approximate 7.5 MW_{th} is applied, consistent with the EU Renewable Energy Directive revisions)
- Blanket subsidies that apply to multiple fuels, e.g. reduced VAT rates for energy as a whole

Notes on calculation of subsidies

The approach to this work builds on existing subsidy inventories for the EU and UK which provide a comprehensive overview, description and quantification of subsidies to biomass for energy. Further follow-up and new review of subsidy data has been carried out. However, there are complexities to the data that mean that the inventory may not be exhaustive and estimations are sometimes used in the quantification of subsidies. The latter is often necessary for subsidy measures that address multiple types of renewable and/or bioenergy, or energy efficiency investments, and for which the published data does not separate out the specific values for forest biomass. In these cases estimation techniques are applied to provide best estimates of the subsidies.

The existing subsidy inventory provides a snapshot of subsidies at a given moment in time, in this case the years 2020-2021[26]. Values for this moment in time can be considered with high confidence. However, for this work it is important to also estimate how the level of subsidies may evolve in future, to understand what level of finance may be freed if the subsidies were stopped. To do so it is important to note that the subsidy space changes over time as new subsidies are introduced and existing ones closed. This is impossible to predict. Furthermore, many subsidies are time limited in multiple ways e.g. a scheme may only run for a few years then stop, whilst others may grant payments for future periods of 10, 15 or 20 years, and therefore even if no new applicants are accepted they continue to provide support for many years, with possible contractual implications in the case of premature cessation. In the latter case governments would need to take advice, and/or weigh up the costs of honouring existing agreements that worsen climate change along with all other attendant dis-benefits.

Other complications include the fact that some subsidies are capped, or are tied to market prices (e.g. contract for difference type arrangements) which can lead to large variations in the subsidies paid (e.g. in the last years, schemes of this type in the UK and Netherlands have at times not paid subsidies, and in the UK case suppliers have been required to pay money back to the government). Estimating future

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[26] This lag of 2-3 years is a result of the lag in publication of subsidy data

price movements or subscription to subsidies is beyond what is possible here. Furthermore, the policy framework is evolving, with limits to what can be subsidised and how being revised at EU level for example as part of the third revisions to the Renewable Energy Directive (REDIII) which aim to limit some of the least sustainable uses of biomass.

Given these complications this work has taken a somewhat simplified approach to estimating future subsidies, by linking future subsidy estimations to the projected volumes of electricity or heat production from forest biomass as this is the main basis on which subsidies are provided[27]. We acknowledge that the uncertainty surrounding future subsidy levels is high, for the reasons outlined above, therefore the estimations should be treated with caution – but we believe they offer a realistic estimate, and uncertainties do not lessen the argument for their cessation.

One area given special attention for future subsidies is Bio-Energy Carbon Capture and Storage (BECCS) which by its nature requires massive investments, and therefore subsidies, and which can have very large impacts on forest biomass use going forward due to the lock-in effects of such large investments. The potential subsidy policy in the UK and EU is examined specifically to estimate the potential volume of subsidies.

2.2.2 Estimation of subsidies to forest biomass

Based on the data gathering, update and review carried out in this work 75 individual subsidies for forest biomass were identified in the EU and UK. Quantification of these subsidies shows (see Table 2-2) that from **2015 to 2020 subsidies to forest biomass for energy have increased from less than €6 billion to almost €8.2 billion, a 37% increase in just 5 years**. The breakdown also shows that **by far the largest amount of subsidy is provided to biomass use for electricity production**. In 2021 the first grants to BECCS are noted, with a few projects awarded under the EU Innovation Fund now starting up. The electricity generation data shown earlier observed only a 15% increase in the same period, showing that forest biomass subsidy growth is outpacing forest biomass electricity production growth. Overall around 25% of subsidies are financed by the government or other public bodies, **whilst 75% are financed by final consumers through their bills**.

Table 2-2 Total subsidies to forest biomass for energy, split by purpose, million EUR annually (EU + UK)

	2015	2016	2017	2018	2019	2020	2021*
Electricity	5 861	6 112	6 210	6 772	7 330	7 865	6 803
Heat	85	81	78	98	95	117	101
Industry	9	25	41	104	80	115	75
Biomass Production	8	6	5	7	17	16	15
BECCS	0	0	0	0	0	0	69
TOTAL	**5 962**	**6 225**	**6 334**	**6 980**	**7 521**	**8 113**	**7 063**

* Only partial data available

Going forward, subject to the uncertainties highlighted earlier, it is very likely that subsidies will continue to grow alongside the planned expansion in the use of forest biomass for energy. In Table 2-3 estimates of potential subsidy growth for forest biomass are provided. This is based on some important

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[27] Additionally subsidies to investments in production technologies are also provided, but (1) these are typically a small share of the total subsidies to biomass; and (2) by adding to generation of electricity and heat these also, to a large extent, can be expected to scale with generation

assumptions, including assuming a linkage between the estimated LCOE of biomass and the market price, where our assumption is that the subsidy value per MWh would need to be sufficient to bridge the gap to the projected market price. This is consistent with the general move in subsidy provision to contract for difference type arrangements. The price assumption therefore is important, we have assumed a market price of 50 EUR/MWh, this is higher than the pre-crisis average wholesale market prices, and closer to current (Q1 2024) prices, which could represent a rough 'new normal'. Lower actual market prices would increase the subsidy requirement to biomass, and vice-versa. Secondly, we assume a long term levelized cost of energy (LCOE)[28] for biomass of 120 EUR/MWh, this is consistent with work in the UK[29] and Germany[30]. However, we note that a large range of LCOE values is possible depending on assumptions and actual price developments. Lower LCOE values would justify lower subsidy amounts, and vice-versa.

Analysis of the subsidy projections (for the EU only) shows a few key trends, including:

- **For electricity, subsidies to biomass can be anticipated to increase as the volume of electricity from biomass increases**. The average level of subsidy per unit of electricity is estimated to reduce a little over time, as more generous subsidies are phased out, however the difference between the LCOE and market price assumption sets a minimum level of required subsidy for biomass at 70 EUR/MWh. The projected small decline in unit subsidies is not significant enough to offset the increase in volumes of electricity from biomass, which more than double by 2050. This results in **a growth in subsidies to EUR 6 billion by 2030 and to more than EUR 10.4 billion by 2050** (excluding subsidies to BECCS).
- **For other biomass subsidies (heat, industry, production)** it is more difficult to estimate the subsidy trajectory in future. However, there are both few subsidies provided to biomass for these purposes and only very small changes in subsidised forest biomass use anticipated in future. As a result **few changes to subsidies are anticipated with these remaining at around EUR 250 million annually**. However, it should be noted that the introduction of broader renewable heat incentives for biomass could change the picture on this indicator.
- BECCS subsidies, of the type introduced in Sweden and being considered for Drax in the UK, are difficult to estimate. However, by combining scenario BECCS outcomes with an assumption on the LCOE of BECCS an estimate of the subsidy per unit of BECCS can be made and total subsidies then calculated[31]. The estimates demonstrates how large the growth might be this area and of this subsidy type. The tables demonstrate that in the low price scenario **BECCS will soon start to dominate the subsidies given to forest biomass with values increasing from an estimated EUR 1.1 billion in 2030 to more than EUR 24.1 billion by 2050 in the EU, a massive increase, and a hugely substantial increase on current levels.** Subsidies in the UK are not included, but using similar assumptions for the 2.6GW capacity at Drax, then annual

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[28] Levelised cost of energy is a standard approach used in the energy sector to calculate over the full lifetime of a power generation plant the average cost of each unit of energy produced, this allows for a reasonable comparison of energy technologies, albeit with some limitations.

[29] UK GOV – BEIS (2020) ELECTRICITY GENERATION COSTS 2020, available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911817/electricity-generation-cost-report-2020.pdf

[30] Fraunhofer ISE (2021) LEVELIZED COST OF ELECTRICITY RENEWABLE ENERGY TECHNOLOGIES, available at https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/EN2021_Fraunhofer-ISE_LCOE_Renewable_Energy_Technologies.pdf

[31] The estimate of 160-180 EUR/MWh subsidies is consistent with estimated the LCOE of BECCS (around 200-250 EUR/MWh) and market prices, similar to the approach taken for electricity subsidies. It is also in the range of subsidies to BECCS being provided in Sweden, one of the first countries to formalize a subsidy proposal (not yet confirmed) for BECCS with subsidies of around 100-180 EUR/MWh envisaged.

subsidies would total around EUR 0.8-1.0 billion per year. **This highlights the very large potential long term subsidy liability that could arise from supporting BECCS.**

- **Cumulatively, between 2025-2050 in the base case, more than EUR 475 billion in subsidies could be paid out to energy from biomass and BECCS**. This sum would already more than EUR 41 billion for the 2025-2030 period. This demonstrates the substantial amount of potential funding that could be available for alternative sources of renewable energy, energy savings and carbon absorbent ecosystems.

Table 2-3 Projection of estimated total subsidies in EU to forest biomass use 2020-2050 based on MIX scenario and 50 EUR/MWh energy price

	2020	2025	2030	2035	2040	2045	2050
Electricity							
GWh Subsidised electricity forest biomass	61 784	73 783	85 782	101 640	117 497	133 354	149 211
Average subsidy EUR/MWh	91	81	70	70	70	70	70
Subsidy electricity [M EUR]	5 647*	5 954	6 005	7 115	8 225	9 335	10 445
Other biomass subsidies							
GWh subsidised other forest biomass use	41 763	43 113	44 276	44 284	44 291	44 299	44 307
Average subsidy EUR/MWh	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Subsidy other biomass [M EUR]	247	255	262	262	262	262	262
BECCS subsidies							
GWh BECCS	0	0	0	37 750	75 500	113 250	151 000
Subsidy EUR/MWh	0	180	180	175	170	165	160
Subsidy BECCS [M EUR]	69	138	1 106	6 606	12 835	18 686	24 160
Total all subsidies	5 963	6 348	7 373	13 983	21 322	28 283	34 867

Source: Trinomics.

** this value is different to the previous table as it excludes subsidies in the UK (which totalled around EUR 2.2 billion in 2020).*

2.3 Emissions associated with use of forest biomass for energy in Europe

2.3.1 Introduction

The rationale of promoting bioenergy as a form of renewable energy is that by substituting fossil fuels, greenhouse gas emissions from the use of fossil fuels are avoided, while carbon emissions emitted during biomass combustion will be compensated by future plant growth, resulting in net zero carbon emissions. This assumption for biomass is highly questionable, particularly in the timescales relevant to address climate change, and also ignores the multiple other social, environmental and economic benefits of not using forests as fuel.

Despite the questionable carbon neutrality, this assumption still informs the relevant EU policies and underpins subsidies to biomass use. The question of whether and when these emissions will be compensated for (i.e., in a time frame relevant for climate mitigation targets under the Paris Agreement) depends on a wide range of factors, including the conversion efficiency of the power or heat plant, the extent of supply chain emissions, the type of feedstock used and the related initial impact on forest carbon cycles (biogenic emissions), and the time it takes for forests to accumulate additional plant growth to compensate for the initial emissions[32]. Reaching a “carbon emission parity”

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[8] Giuntoli, J., et al., 2016. Climate change impacts of power generation from residual biomass. Biomass and Bioenergy 89, 146–158

time, and carbon reductions afterwards, can take several decades (JRC, 2014). During this period, producing bioenergy from harvested biomass leads to a net carbon debt. This is due to its higher carbon content and lower energy density compared to fossil fuels, higher supply chain emissions, less efficient conversion of combustion heat to electricity, as well as land conversion and the related reduction of carbon stocks.[33]

The actual time to 'recover' the carbon debt of forest can range considerably but is most commonly estimated at 50-100 years or more – this is not compatible with net-zero emissions by 2050. In some cases, biomass facilities burning only wood residues could achieve recovery of the carbon debt within 10 to 30 years.[34] However, there are only very limited supplies of actual residues, and most of these are already utilised. In this regard, it has been determined that utility-scale plants burning harvested forest biomass begin yielding lower GHG levels than fossil alternatives only in a period ranging between 45 years (where the alternative is coal-fired power plants) to more than 90 years (in case of gas-fired power plants). Depending on the calculation assumptions, the carbon debt period could also be considerably longer, for instance lasting for several hundreds of years in the case of conversion of old-growth forest. These large differences highlight the negative impact of forest harvested biomass, which, if not burned, would have remained on site sequestering carbon. It also demonstrates that the concept of carbon neutrality is both uncertain and highly time and context dependent, and therefore in most cases wrong.[35]

In conclusion, biomass combustion in the great majority of cases leads to an increase in emissions compared to the fossil fuels it replaces (see Figure 2-16 below), an increase which can last from decades to hundreds of years. On the other hand, the carbon neutrality assumption accounts future removals of carbon as immediate, with a zero discount rate. For these reasons, **subsidies to biomass uses are inconsistent with the Paris goal and EU GHG emissions reduction targets.**

2.3.2 Estimating GHG emissions from forest biomass

Under EU and IPCC rules

Whilst the IPCC does not accept that biomass use should automatically be deemed climate neutral the revised European Renewable Energy Directive (RED II, 2018)[36] provides detailed GHG emission estimations for different bioenergy sources (g CO_2eq/MJ), distinguishing per biomass fuel production system. Article 31 sets out a methodology to assess the GHG impact of biofuels, bioliquids, and biomass fuels, with the details given in Annex VI for biomass fuels.

Regarding forest solid biomass (woodchips, wood briquettes or pellets), the methodology used by the JRC[37] to provide the values given in Annex VI follows a simplified attributional life cycle assessment approach and accounts only for direct GHG emissions associated with the supply chain of the bioenergy carriers. Three long-lived GHG are considered: CO_2, CH_4, and N_2O. The calculation of default values, for

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[33] ·Johnston, C.; Cornelis van Kooten, G. 2015. Back to the past: Burning wood to save the world. Ecological Economics 120, 185-193; Walker, T. et al. 2013. Carbon Accounting for Woody Biomass from Massachusetts Managed Forests: A framework for Determining the Temporal Impacts of Wood Biomass Energy on Atmospheric Greenhouse Gas Levels, Journal of Sustainable Forestry, 32,130-158. See also JRC, 2014.

[34] Walker, T. et al., *ibidem*

[35] Malcom J.R. et al. 2020. Forest harvesting and the carbon debt in boreal east-central Canada, Climatic Change, 161, 433-449; Norton, M. et al. 2019. Serious mismatches continue between science and policy in forest bioenergy. GCB-Bioenergy, 11, 1256-1263.

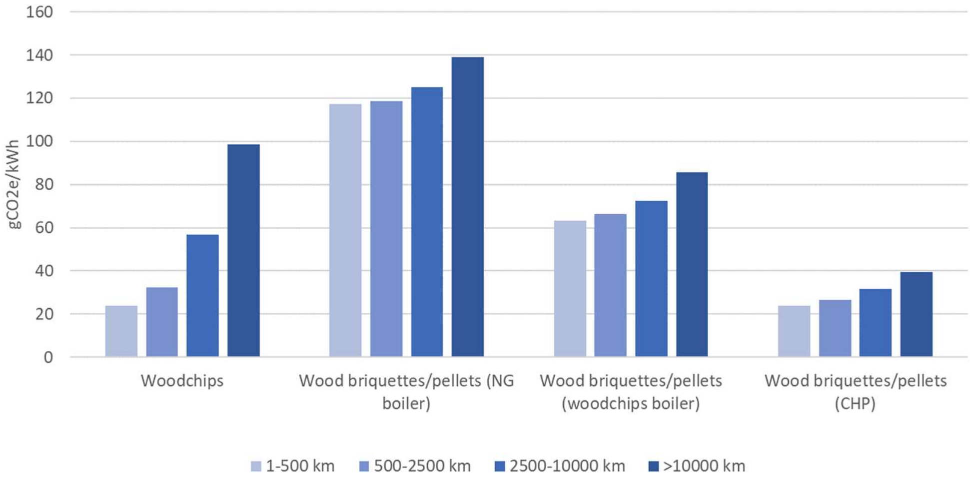
[36] DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources.

[37] https://op.europa.eu/en/publication-detail/-/publication/1893b3a1-3f61-11e7-a08e-01aa75ed71a1/language-en

each pathway, typically includes input values for emissions from plant cultivation (e.g. eucalyptus, poplar), wood chipping, transport to the terminal, seasoning, and truck/ship transport. For pellets, the calculation also includes the input values related to the pellet mill and pellets transport.

Figure 2-8 reports average GHG emissions originating from different biomass fuel production systems with different fuel transport distances, focusing on forest biomass. Woodchips include material from short rotation coppice, stemwood and residues. For wood briquettes or pellets, the RED also provides data on the variation in GHG emissions due to the energy input to the production process, i.e. a natural gas boiler, a boiler fuelled with woodchips, or a CHP fuelled with woodchips which also provides electricity to the process. These show emissions of between 20-140 gCO_2/kWh.

Figure 2-8 Estimated average GHG emissions per biomass fuel production system at plant gate, by transport distance, based on default values provided under Annex VI of the Renewable Energy Directive grams of CO_2 equivalent (gCO_2e)/kWh



Source: Trinomics based on RED II

Two important limitations make these values very conservative and lead to significant underestimations of the total GHG emissions.

First, the default emission values provided under Annex VI, Part D, refer to the emissions produced up to the point that the biomass is delivered to the plant for final energy conversion. This means that the estimation does not include emissions related to biomass combustion or other conversion technology. This is a consequence of considering biomass use as carbon neutral and that in any case emissions would be accounted to the LULUCF balance of the country where the forest biomass is produced. However, since the carbon gain for new plant growth only kicks-in after several decades, and LULUCF statistics are particularly weak, excluding these emissions from the estimate does not seem justified in the context of net-zero goals for 2050.

Second, the default values do not include land use emissions, i.e., they assume a null contribution to GHG emissions from land-use change, defined as "the annualized emissions from carbon stock changes caused by land-use change". When biomass production does involve land-use change, a different methodology applies, as provided under Annex VI, Part B. However, according to the UK

Forest research[38], with this methodology, significant changes in land management (e.g. felling natural forest and replanting) may still take place as part of the production of bioenergy, without an accounted change in land use or with significant underestimations. Even with the sustainability criteria for biomass introduced in the RED, EU rules do not allow full accounting for the cost of losing other land uses. These costs include directly storing carbon in existing or new forests or producing food, which would increase the capacity to preserve or restore forests and other habitats elsewhere while meeting rising food demands, they also exclude soil carbon losses.

The carbon neutral assumption in effects treats land as “free” from a climate perspective even as it reduces land for all these other purposes. As pointed out by recent studies, these opportunity costs should be factored into any accurate analysis of bioenergy. When factoring in these costs, the uses of bioenergy are likely to be adverse at least for decades.[39] Discarding these assumptions an alternative view of emissions can be presented[40].

Emissions including combustion emissions

In Figure 2-9 we present a comparison of different power production technologies and their life-cycle emissions. This is based on a simplified and relatively straightforward estimation of the combustion emissions from biomass, which are based on the CO_2 content and energy content of the wood fuel, and an estimate of the efficiency of the combustion process. All lifecycle emissions are accounted for all technologies (except the EU grid average).

This shows that if combustion emissions are fully accounted to biomass then it has amongst the highest emissions per kWh of all power technologies at 1 286 gCO_2e/kWh[41], on a par with lignite and hard coal. Emissions are significantly higher than for natural gas, than the EU grid average (direct emissions only) and other renewables and nuclear. Even when combustion emissions are excluded it is the worst performing low carbon fuel.

Similarly poor performance is observed for biomass with carbon capture and storage (BECCS), with a range of emissions from worse than natural gas (with 54% capture), to just barely lower than the, rapidly decreasing, EU electricity grid average (at 90% capture). Further examination of BECCS is provided in the following focus box-text.

This is illustrative of the magnitude of the emissions from biomass and the huge difference to emissions accounting the assumption of carbon neutrality makes. It should be noted that actual values per technology can vary considerably per installation, process and fuel, such that range of values can be quite high – including for biomass as partially demonstrated already in Figure 2-8.

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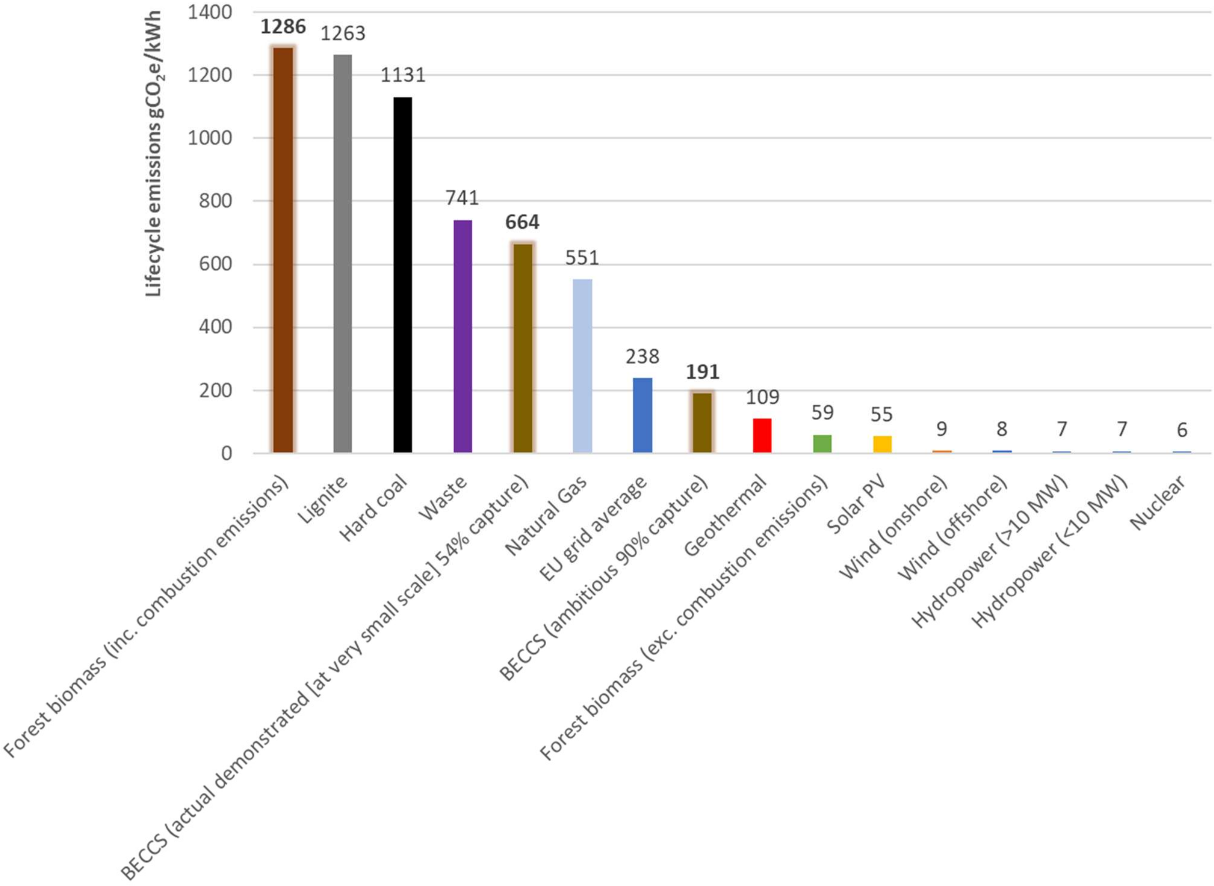
[38] https://europeanclimate.org/wp-content/uploads/2018/05/CIB-Summary-report-for-ECF-v10.5-May-20181.pdf

[39] Searchinger et al., 2022, Europe’s Land Future? Princeton University

[40] A review of guidance on the treatment of biomass emissions by the Greenhouse Gas Protocol is ongoing, this may add further weight to the argument against treating biomass as carbon neutral, https://ghgprotocol.org/land-sector-and-removals-guidance

[41] Note we use CO_2e which stands for CO_2 equivalent, this is a commonly used unit which also converts other GHG emissions to CO_2 to provide a single figure for all emissions, i.e. NO_2, SO_2, CH_4 (methane) and other GHG emissions are included.

Figure 2-9 Total lifecycle emissions of different energy technologies in the EU, gCO_2e/kWh



Source: Trinomics based on Trinomics (2020) Study on energy costs, taxes and the impact of government interventions on investments: External costs (study for EC DG Energy); and Umweltbundesamt 2022, Kohlendioxid-Emissionsfaktoren für die deutsche Berichterstattung atmosphärischer Emissionen (for CO_2 content of wood). A 30% thermal efficiency was assumed for the biomass plant including combustion emissions.

Box 1: Focus on BECCS – Bioenergy Carbon Capture and Storage

BECCS is promoted by some as an important technology in a carbon-neutral future, and one that even allows for negative emissions. The basis of this assumption is that the carbon absorbed by the biomass is captured and stored permanently after combustion, and that new biomass can be regrown, capturing new carbon. However, BECCS faces a number of important criticisms:

1. **The drawdown of carbon in new biomass growth does not occur on a timescale consistent with the Paris goals and carbon neutrality by 2050** – this is an issue common to all biomass use for energy (see also section 2.3).
2. **Reduced efficiency of thermal processes with CCS technologies** fitted to them. This is important as electricity generation from biomass is already not very efficient (~30% thermal efficiency, compared to 40-60% for the most efficient coal and natural gas power plants), and that further reductions in efficiency, although small e.g. to 28%, would increase the amount of fuel needed, and therefore emissions per unit of electricity delivered.

3. **Capture processes are not 100% effective – pilots on power plants have only demonstrated rates of 54%**[42], meaning that a substantial part of the emissions would still reach the atmosphere. Rates of 80-90% are commonly assumed in calculations on BECCS, if these cannot be achieved then emissions will be higher and financial returns (from captured emissions) lower.
4. **No successful demonstrations of BECCS at the required scale**, although there have been BECCS pilots at Drax in the UK and Mikawa in Japan, neither are at a scale or level of effectiveness to yet prove the viability of the technology. For example the two pilots at Drax each captured only 1 tCO_2 or less each day, only dealing with a tiny fraction of the emissions. Whilst the pilot at Mikawa captured 600 tCO_2 per day, but this is still a relatively small unit (50 MW compared to the 645MW units at Drax) and it only demonstrated a 54% capture ratio. Significant technical hurdles therefore still remain. Other hurdles may also become relevant at large scale for example the logistics of dealing with (transport, process, storage) such large volumes of low-density biomass fuel, and potential issues and competition for CO_2 transport and storage facilities.
5. **BECCS will be significantly more expensive than renewable energy technologies and fossil power plants fitted with CCS leading to higher energy system costs which will ultimately be paid by consumers.** As shown below costs of BECCS plants are estimated to come out at around 200 EUR/MWh, far higher than costs of renewables.
6. **BECCS will have higher emissions than renewable energy technologies and fossil power plants fitted with CCS.** Given the high carbon content of forest biomass it is unavoidable for high emissions from its combustion. Even with (not yet achieved) 90% capture ratios the emissions of BECCS will be far higher than renewable energies.

Overall, expanding on the estimates used in section 2.3, additional emissions can result from BECCS due to the lower thermal efficiency, for example a 2% decline in thermal efficiency could lead to an additional 88 gCO_2e/kWh of emissions (+7%) compared to a dedicated biomass plant. Figure 2-10 below presents emissions scenarios for BECCS based on different assumptions. We discard the idealised view of BECCS based on non-accounting of biomass emissions in combustion and present a two more realistic cases of electricity from BECCS. The first (top frame of the figure) shows the emissions from biomass combustion, and additional emissions per kWh of CCS due to lower thermal efficiency in the overall process. After applying a not yet achieved, but hoped for, very high capture efficiency of 90%, net emissions of around 190 gCO_2e/kWh are achieved. Whilst better than natural gas without CCS it has significantly higher emissions than other renewables and would produce higher emissions than a gas plant fitted with CCS and is far from the net negative emissions figure BECCS advocates would paint.

In the bottom frame of the following figure, we present a picture closest to the current proven reality, with the same assumptions applied but this time with the actually demonstrated capture rate of 54%, which leads to net emissions of 664 gCO_2e/kWh, i.e. net emissions higher than natural gas without CCS.

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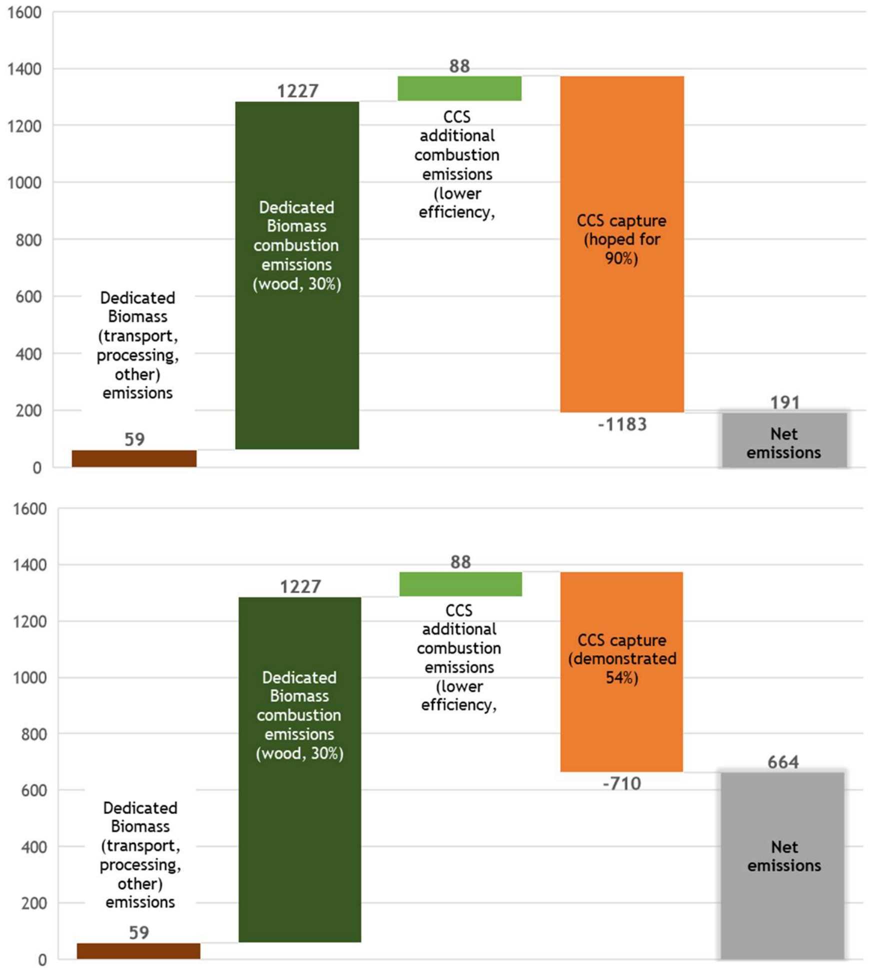
[42] H. Kitamura et al, (2022) CO2 capture project integrated with Mikawa biomass power plant

In summary, whilst it is probable that actual CCS capture rates would be higher than 54%, anything approaching 90% is highly ambitious, therefore net emissions for BECCS in the range of 200-400 gCO_2e/kWh are very likely, making it far from a low-carbon energy source.

Figure 2-10 BECCS emissions waterfall chart[43], accounting combustion emissions and 90% capture rate (top), and accounting combustion emissions and using demonstrated 54% capture rate (bottom)



Source: Trinomics

Financially there are also issues with BECCS. Estimates are clear that it will remain a very expensive power technology, with few savings to be made from learning and comparing poorly on costs to other renewables, and even to other fossil technologies with CCS. Estimates in the UK show an LCOE for a first-of-a-kind BECCS plant in 2030 of 205 GBP[44]$_{2018}$/MWh, comparing to an 87 GBP/MWh estimate for a combined cycle natural gas plant with CCS, an additional 118 GBP/MWh cost, i.e. **more than double the cost**[45]. The BECCS costs are only estimated to decline to 193 GBP/MWh by 2040, when

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[43] A waterfall chart is used to break down an impact or change (for example between years) into the key individual factors that contributed to the overall change. Reading from left to right, the leftmost figure represents either the starting point or first factor in the contribution, and each bar rightwards represents a factor which makes either a positive or negative contribution. The last bar (on the right) represents the net effect of all of the contributions. In this case we use the waterfall chart to break down the key contributors to emissions of electricity generated with BECCS to demonstrate the contribution of the individual steps and compare how different assumptions for example on CCS capture rate can affect the net emissions.

[44] Pounds Sterling (Great Britain), in 2018 constant values

[45] UK BEIS (2020) Electricity generation costs

n^{th}-of-a-kind plants were being built, demonstrating low possibilities for innovation and learning to bring costs down. This compares very poorly to other technologies, many of which, such as solar and wind (costs estimated at 40-50 GBP/MWh in 2030) and batteries, are still getting cheaper as technological innovation continues. Similar per unit cost estimates are made in a report studying the feasibility of BECCS at Drax in the UK[46]. It is the BE of BECCS that especially contributes to its high cost.

BECCS projects only become financially viable with significant and continued subsidies, and a large part of the private business case will rest on the assumption that negative emissions can be monetised and sold on carbon markets. Mechanisms for this are not yet in place. However, assuming capture of around 1 tCO_2 per MWh, and a carbon price of around 100 EUR/tCO_2, this can make a substantial impact on the business case, bringing the >200 EUR/MWh LCOE down. At the same time, a gas CCS plant would also be able to capture around 1/3 tCO_2 per MWh and therefore also reduce its costs, so that it is still highly unlikely that BECCS would ever be cost competitive without subsidy, not without substantially higher CO_2 prices.

From a policy perspective, BECCS is a very expensive way of reducing emissions. Looking at cost-effectiveness, the estimated marginal cost of these emissions reductions is very high, in the order of 500-600 GBP/tCO_2e[47], which would represent very expensive emissions savings at the very high end of any marginal abatement cost curve. Alternative assessments[48], for the application of BECCS in industry, where processes can be more suited to CCS, suggest marginal costs of €150-€200/tCO_2e, therefore still at the high end of the emissions reduction options. As a consequence there is a high opportunity cost of spending subsidies on BECCS to achieve emissions reductions

Countries already estimate their emissions from biomass combustion, but report them as a memo item, not drawing attention to the emissions. For example the Netherlands estimated emissions from biomass combustion of 19.4 $MtCO_2$ in 2020, which equates to around 12% of national emissions; of the biomass combustion emissions 6.2 $MtCO_2$ were from the energy sector, which was the main source of increased emissions since 2016, other major biomass burning sectors were water and waste management, households and agriculture[49].

The results in Table 2-4 present an estimate of current EU emissions from biomass use in electricity and heat generation, and energy use in industry, based on the per unit emissions identified in the previous sections. **These illustrate the very large emissions that would be accountable to forest biomass if the carbon neutral assumption is dismissed.** For current emissions from forest biomass, these are estimated to total 631.6 $MtCO_2e$, and are equivalent to around 19% of EU total GHG emissions of 3 242 $MtCO_2e$ in 2021. This is broadly consistent with other work on the topic, where total emissions from biomass combustion of 600 $MtCO_2$ in 2020 have been estimated[50].

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[46] Keartland & Co (2023) An assessment of the business and commercial risks to Drax's biomass-related business models from a financial perspective

[47] Wood for UK BEIS (2018) Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology: Benchmarking State-of-the-art and Next Generation Technologies

[48] McKinsey (2020) Net-Zero Europe

[49] https://www.cbs.nl/en-gb/news/2021/48/co2-emissions-from-biomass-burning-on-the-rise

[50] See EEA reporting on UNFCCC emissions, category 1.D.3 combustion of biomass. Also https://www.fern.org/publications-insight/red-revision-will-eu-countries-stop-paying-energy-companies-to-burn-forests-2582/

Projecting forward, emissions from forest biomass combustion would be expected to increase as energy from forest biomass increased, which in the context of significant continuing emissions reductions in other sectors would not be compatible with achieving 2050 net-zero emissions targets.

These estimates involve accounting for a variety of variables and thus are best-approximation estimates based on available data. Each case should be calculated separately. The overall message however is clear: emissions from forest biomass burning are huge, and projected to grow further under BAU policy.

Table 2-4 Estimates of EU emissions from biomass when accounting combustion and other life-cycle emissions, current, 2030 and 2050

		Energy generation or use from biomass [GWh]	Emissions [MtCO$_2$e]
Current-2021	Electricity	92 753	119.3
	Heat	152 813	196.5
	Industry	245 631	315.8
	Total	***491 197***	***631.6***
2030 Projection	Electricity	106 957	137.5
	Heat	134 619	173.1
	Industry	308 149	396.2
	Total	***549 725***	***706.8***
2050 Projection	Electricity	170 387	219.1
	Heat	103 350	132.9
	Industry	339 720	436.8
	Total	***613 457***	***788.8***

Source: Trinomics

2.4 Summary of the forest biomass challenge to be addressed

This section has set out to provide key context and background for the proposed Renewable Energy and Climate Change Strategy (RECCS), in doing so it asks three questions.

1. What would the energy gap be if subsidies to biomass were removed?
2. What amount of subsidies could be redirected from biomass to fill this gap?
3. What emissions could be saved?

Answers to these questions are summarised below.

What would the energy gap be if subsidies to biomass were removed?

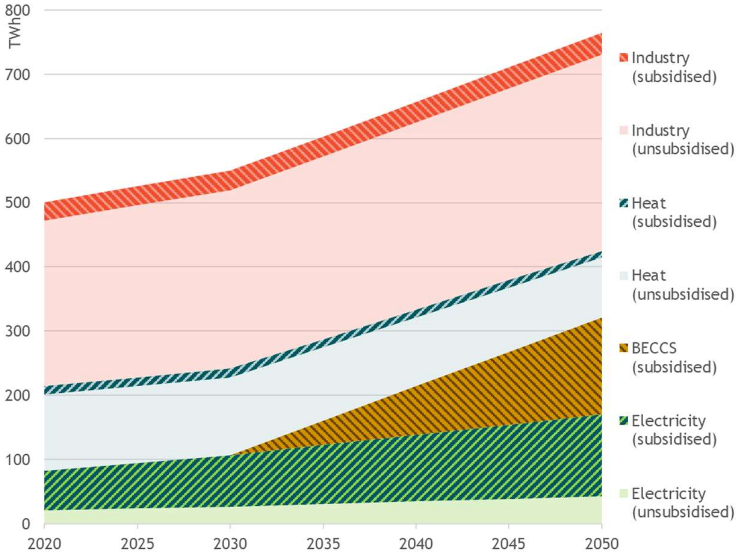
Section 2.1 demonstrated the current and projected future use of forest biomass to be affected if biomass subsidies were to be removed. This is combined and summarised in Figure 2-11 below and shows that in the base case total energy from biomass will grow from around 500 000 GWh in 2020 to around 550 000 GWh in 2030, a 10% increase, and then further to 750 000 GWh by 2050, a roughly 50% increase compared to 2020. The increase is driven by Electricity (+105% between 2020-2050) and BECCS (from zero) and to a lesser extent by industry (+19% between 2020-2050), use for heat is projected to decline (-21%).

The energy gap that would emerge if subsidies were removed is a function of the subsidies received by each source of bioenergy, as some receive more than others. Based on the subsidies data collected and analysed in section 2.2 we are able to make informed assumptions on the proportions of each type which are supported by subsidies. In the case of industry, the proportion is very low (estimated at 1%), with biomass use in industry largely unsubsidised. There are two main reasons for this (1) biomass use in industry is dominated by the paper, pulp and printing and wood manufacturing sectors, which source fuels from their own processes; and (2) energy use in industry is subsidised in other ways, general to all fuels, not directly targeting biomass. However, in the base case industrial use of forest biomass for energy is projected to increase. Whilst much of this use by industry is currently economical and a resource efficient use of waste streams, a part of it is not. For this share of industrial consumption dependent on subsidies we have assumed a value of 10%, this share will be affected by RECCS..

For heat the picture is complicated as subsidies are most typically provided for Combined Heat and Power (CHP) plants, where subsidies are attributed to electricity. A value of 10% has been assumed for CHP. For electricity it was estimated 71% of generation was subsidised in 2020, it is assumed going forward that 75% of electricity (CHP generated to comply with new RED rules) would be subsidised. For BECCS it is assumed that 100% of BECCS will require subsidy.

Therefore, the energy gap if subsidies were removed from biomass is estimated at 104 TWh in 2020, increasing to 124 TWh in 2030 and to 323 TWh in 2050. The energy gap is particularly significant for electricity generation, and after 2030 this includes projected growth in BECCS. In 2020 the electricity gap would be around 60 TWh, increasing to 80 TWh by 2030 and then, including BECCS electricity, to 279 TWh in 2050. This would represent 2.6% of total electricity generation in 2030 and 4.1% of 2050 total electricity generation, therefore a small but significant part of the electricity mix.

Figure 2-11 Energy from biomass 2020 actual and projection to 2050 TWh, highlighting subsidised and unsubsidised volumes, the subsidised share of energy use = the energy gap



Source: Trinomics own calculations.

Note: these figures combine electricity and heat production, with primary consumption by industry

What amount of subsidies could be redirected from biomass to fill this gap?

If biomass were no longer supported in the EU and UK this could free up around EUR 8.1 billion per annum in subsidies based on 2020 estimates, or around EUR 5.9 billion in just the EU.

As biomass use is projected to grow in future so too do subsidies, with total EU subsidies to forest biomass for energy estimated to increase to more than EUR 6.3 billion by 2030. By 2050 the subsidies to BECCS turbocharge total subsidies to an estimated EUR 34.9 billion per annum in the EU. Significant subsidy growth would also be expected in the UK.

Subsidies to electricity from forest biomass are estimated to increase from EUR 5.6 billion in 2020 to EUR 6 billion by 2030 and to EUR 10.4 billion by 2050.

Subsidies to BECCS come to dominate subsidies to biomass from around 2040 onward, with subsidies rapidly increasing post-2030, to EUR 12.8 billion in 2040 and EUR 24.2 billion in 2050.

In reality the ability to reallocate subsidies is more complex, it could take some time for the full amounts to become available for reallocation. With a few exceptions, e.g. solar subsidies in Spain in 2011-2012, governments do not generally cancel existing, signed contracts or agreements to provide subsidies, due to the serious legal implications, costs and trust issues[51]. More typically schemes are closed to new entrants. This means that in practice for longer term contracts for power generation where for example 15 year subsidy agreements are common, that subsidies could not be stopped straight away and that subsidies would taper off slowly as old contracts ran their course. This would mean potential subsidy reallocation would also more slowly ramp-up over time. Whilst each subsidy would need to be reviewed for its termination possibilities, it is still likely a substantial share of the subsidies would be available for reallocation straight away or within a shorter period of time as many of the contracts have already been active many years, for example subsidies to Drax in the UK end in 2027. However, there is also a case to be made that given the seriousness of the flaw in the carbon neutrality assumption and the urgency of addressing climate change that continued subsidies to biomass for energy are unjustified and should be stopped immediately, this could entail subsidy contract buy-outs, negotiations, reallocations within existing mechanisms or further steps..

Certainly with taking what is known now, and was less well understood at the time many of the subsidy contracts were agreed, it would be quite absurd to extend or even continue to subsidise biomass for many years knowing its negative climate impact.

The estimated new subsidies, that would be paid due to current projected growth in forest biomass for energy, are based on the clear case that the projected growth is only feasible with subsidies. Therefore it is also reasonable to assume that similar subsidy amounts could be available to support alternatives if plans change – and we will make the case that they should.

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[51] In Spain the retroactive cancellation of solar subsidies led to numerous (>50) legal challenges, particularly from international investors under investor dispute settlement mechanisms under the Energy Charter treaty. The Spanish government has lost many of these cases, with awards totalling more than $1 billion. However, the Spanish government has not paid these claiming to do so would be against European Law. It is also the case that the EU is leaving the Energy Charter treaty in part because of abuse of settlement mechanisms by fossil fuel firms, as they use the mechanism to challenge renewable energy and climate policies.

What emissions could be saved?

If the subsidised energy from forest biomass, the estimated energy gap, was stopped then this could result in stopping 134 $MtCO_2e$ emissions in 2020 from forest biomass use for energy, 160 $MtCO_2e$ in 2030 and 260 $MtCO_2e$ in 2050[52]. The 2020 value is more than the total 2021 GHG emissions of Czechia, and the 2050 value is equivalent to the total 2021 GHG emissions of Spain. This estimation is based on carbon neutrality not being assumed.

However, any actual emissions savings would depend on how the energy gap was filled. **If the gap were to be filled by wind, solar and other renewables,** as proposed in chapter 3, then the emissions on a life cycle basis would be reduced to around 2-6 $MtCO_2e$ in total, or around 2% of the emissions of the same energy from biomass, meaning **the switch would reduce emissions by 98%.**

Conclusions

Removing subsidies to energy from biomass would create a small but significant gap in future projected electricity supply, but at the same time this could be filled by cleaner, much more cost-effective alternatives. In turn this would: (1) bring benefits in freeing up an increasing amount of subsidies to forest biomass, and in the case of BECCS avoiding spending tens of billions of Euros on this technology annually by 2050; (2) stop emissions from the forest biomass that is no longer burnt as it is not viable without subsidies; and (3) bring substantial co-benefits in climate mitigation, improved air quality and health, biodiversity, economic growth and employment.

Further questions then emerge on how the energy gap could be filled in a way that makes best use of the potentially available reallocated subsidy funding and avoids that the energy gap is filled again with fossil fuels that are almost as polluting as forest biomass. Genuine' low carbon renewable energy sources are the obvious alternative, and could be supported by also reducing energy demand through energy efficiency measures. Other complementary alternatives can also be considered, such as nature based solutions, which can also produce emissions savings.

The following chapters examine each of these alternatives and look at the various possibilities, their costs and benefits and what their impact would be compared to the baseline. By doing so we will make a clear case for a Renewable Energy and Climate Strategy that does not rely on industrial scale use of forest biomass for energy, with all its associated negative impacts on forests, emissions and the economy.

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[52] Compared to current total EU emissions of 3 400 MtCO2e and the net zero goal by 2050. This saving estimation is based on an assumption that BECCS captures 80% of the carbon emitted from biomass combustion. The savings would increase if the capture rate assumption were lower.

3 Filling the energy gap with other renewables

Key points

- **Solar and wind, both onshore and offshore, are the best performing alternatives for low-carbon power generation:** providing advantages in cost, emissions and employment over forest biomass and BECCS. Other technologies also have some advantages, but also significant limitations, e.g. solar CSP and geothermal is more expensive and location specific, wave and tidal power is expensive, and hydropower has broader ecological impact limiting suitable sites.
- **The energy gap from removing subsidies to electricity from forest biomass could be filled for a fraction of the subsidy cost, potentially saving EUR 5.9 billion per year in 2020, and more in future.** Based on the estimated energy gap, best alternatives and required subsidies per MS then the same volume of power as provided in 2020 for EUR 8.1 billion, could be provided for EUR 2.6 billion. These savings would increase in future as more subsidies to forest biomass were avoided.
- **Supporting investments in storage as well as grid stability and modularity would be needed to support additional renewable energy capacity.** Investments in battery or other storage, possibly hydrogen, could be needed to ensure that the lost biomass generation does not significantly impair power system function. The additional costs of this are factored into our calculations of overall subsidies and may decline over time as costs, especially for storage (batteries), are continuing to rapidly decline through innovation and scaling up of production.
- **Switching from biomass to renewable alternatives would bring benefits to energy costs, jobs, growth, air quality, health and the environment.** Alternative renewables tend to bring higher employment per MW installed, for wind especially major parts of the supply chain are European and fewer imports of biomass from the US and elsewhere would be needed. The alternatives are cheaper and could lower overall energy costs, improving competitiveness and reducing households costs. Reduced combustion of wood, would reduce local air pollution and improve air quality and health. The alternatives would also reduce pressure on forests and be beneficial for biodiversity in Europe and other locations from which the EU imports forest biomass fuel.
- **The energy gap from removing subsidies from biomass would be most proportionally significant (13-24% of electricity generation) in Estonia, Denmark, Finland and Luxembourg. The UK and Netherlands** may also face issues due to significant contributions from biomass.

This section aims to estimate what would be the impacts (including costs and benefits) of stopping subsidies to forest biomass. This is done by answering the theoretical question: if subsidies for biomass are stopped tomorrow, and passed onto other renewable energy sources:

- To what extent can these alternative renewables replace the energy from forest biomass, if supported by the same amount of subsidies?
- If they are unable to fully fill the gap - what would be the additional subsidy cost of filling the remaining gap?
- Are there other significant costs (such as system integration and flexibility) and benefits that may stem from this change?

It is important to clarify that this is a theoretical analysis that does not include the practical implications of actually removing subsidies and to support alternatives instead. For example:

- Output-based subsidies are awarded via a contract signed by a public counterpart and the generators. The contract cannot be stopped without incurring in substantial penalties or legal challenges. These contracts typically run for 10-15 years, with varying current 'ages', some coming towards their end, others only recently agreed.
- Newly awarded subsidies tend to be much more focussed on alternative renewables (in particular, solar and wind), rather than biomass. This has created some issues in the supply chains for solar and wind, which are stretched to deliver across all the opportunities, to the point that some auctions for subsidies have gone undersubscribed in recent years. It also creates bottlenecks in the approval process.[53] This means that there could be timing issues in the alternatives coming online.

3.1 The energy gap – country level

The summary in section 2.4 quantified the total energy gap that would need to be filled if subsidies to forest biomass were removed. Based on 2021 consumption a few hot-spot countries, i.e. those with high shares of existing biomass use, can be identified as shown in Table 0-1.

This shows that for electricity at EU level the impact is around 8.4% of renewable electricity generation, and only 3.2% of total electricity generation. However, for Estonia, Denmark, Finland and Luxembourg it constitutes more than 10% of the total electricity generation and therefore could pose a problem to replace. It is also a potential issue in the UK (9%) and Netherlands (6.5%), both countries with large subsidies and a rapid recent expansion in electricity from biomass. It is much less an issue in Germany and France, despite the large subsidies also provided there.

For heat at EU level there is a significant impact as biomass contributes almost 72% of renewable heat production, and 23.5% of total heat production. It is particularly important in Luxembourg, Lithuania, Estonia, Latvia, Finland, Denmark, Sweden and Austria – although the majority of these are well forested and have a history of using biomass for heating. France is amongst the other countries with above average biomass fuelled heat production.

Overall, the previous table suggests the energy gap could be particularly acute for Estonia, Denmark and Finland. However, subsidy data as shown in Table 3-1, paints a more mixed picture, with no biomass specific subsidies in Estonia; and higher total but relatively low unit subsidies in Denmark. Energy gaps are likely to be more acute in other counties such as Czechia, Belgium, Croatia, Germany, France, Italy, Spain, Poland, Netherlands, Portugal and the UK. The UK and Netherlands are notable as funding amongst the largest volumes of biomass but using subsidy instruments that, as of 2020, provide amongst the lowest per unit subsidies as the subsidy amounts vary with market prices, being lower or zero in times of high prices as experienced at times in the last few years.

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[53] For a complete mapping of permissions and administrative procedures across the EU, see the final report of the RES simplify project: *Simplification of permission and administrative procedures for RES installations:* https://op.europa.eu/en/publication-detail/-/publication/949ddae8-0674-11ee-b12e-01aa75ed71a1/language-en/format-PDF/source-search

Table 3-1 Total subsidies [M EUR], Amount biomass energy subsidised [GWh], and average unit subsidy by country (2020)

Country	Total Paid Subsidies in 2020 (M EUR)	Estimated energy from biomass supported [GWh]	Average paid Subsidy (€/MWh)
European Union 27	5 894	61 783	95
Germany	1 827	12 483	146
France	746	7 494	99
Sweden	25	258	96
Finland	248	1 565	159
Poland	233	4 177	56
Italy	703	6 398	110
Spain	335	3 593	93
Austria	143	975	146
Czechia	124	1 241	100
Denmark	181	4 302	42
Romania	29	980	29
Netherlands	600	10 864	55
Portugal	228	1 916	119
Hungary	11	110	96
Belgium	178	1 915	93
Bulgaria	31	625	49
Latvia	5	54	96
Slovakia	83	1 114	74
Croatia	93	967	96
Lithuania	33	347	96
Estonia	0	0	-
Greece	0	0	-
Slovenia	0	0	-
Ireland	34	351	96
Luxembourg	5	55	96
Cyprus	0	0	-
Malta	0	0	-
Non EU countries			
United Kingdom	2 219	24 925	89
Total	**8 113**	**86 709**	**94**

Source: Trinomics own calculations

* The largest subsidy in Finland provides a tax exemption to wood fuels, it is unclear how many GWh are actually supported by this.

3.2 Most appropriate renewable alternatives

In this section, we explore the costs and characteristics of alternative generation technologies for biomass. In order to simplify the analysis, the assumption used in this section is that the gap left by biomass would be filled by alternative electricity generation, even though the gap refers to electricity, heat and industrial biomass use. We take this assumption for three main reasons: (1) the vast majority of subsidies directly target electricity generation, not heat or industrial biomass use (see Table 2-2); (2) the major growth trend in biomass is concentrated on the expansion of use for electricity generation; (3) overarching trends in energy use are towards the electrification of heat and industrial processes.

3.2.1 The most promising alternatives

Based on the current renewable electricity deployment in Europe, in this section we elaborate on the most viable renewable electricity alternatives, in particular:

1. Wind (onshore and offshore)
2. Solar photovoltaic (PV)
3. Solar CSP (Concentrated Solar Power)
4. Hydropower (micro/small)
5. Geothermal
6. Waste (municipal solid waste[54])

Other renewables such as wave and tidal power could also be supported in future, as potentially could other low carbon energy sources (fusion, nuclear) or storage technologies, but this analysis focuses on the currently most viable technologies. The aim of this analysis is to understand which technologies can be successfully deployed across Europe to replace biomass, and what are the costs and benefits that this change may generate. To that end, the costs indicators we are focusing on are Capital expenditure (CAPEX)[55], Operational expenditure (OPEX)[56] and the levelized cost of electricity (LCOE)[57] , while the climate impact is measured by the emissions of CO_2 equivalent per year, and the socio-economic impact is measured by the number of jobs plus other measures as outlined in the specific sector per GWh. Due to limited and homogeneous data availability for the specific technologies, it should be taken into account that there are typically large ranges in actual values per installation. In reality the actual costs, capacity, emissions and impact can vary considerably per specific facility. The intention of the table is to provide a simple, clear guide to the broad magnitude and order of impacts when comparing across alternative renewable energy technologies.

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[54] The analysis was focused on municipal solid waste due to data availability of the specific sector compared to the others

[55] The investment a company makes to acquire and maintain an asset

[56] Expenses included in the operation phase of a business, such as salaries, insurance, R&D funds etc.

[57] Levelized costs of energy.

Table 3-2 Overview of cost and benefits for biomass and seven alternative renewable electricity technologies

Technology	Biomass	BECCS	Onshore wind	Offshore wind	Solar PV	Solar CSP	Hydropower (micro/small)	Geothermal	Waste (renewable MSW)
CAPEX [EUR/kW installed capacity]	4 194	6 000	1 388	3 446	1 266	6 443	2 445	6 413	4 523
OPEX [EUR/MWh/yr]	143 257	182 700	40 836	105 858	21 485	62 678	61 164	101 984	53 181
LCOE [EUR/MWh]	137	241	50	72	36	96	63	45	133
Capacity factor [%]	87%	87%*	35%	45%	17%	49%	40%	85%	77%
Emissions [gCO_2e/kWh]	1 256 (with combustion) 59 (excluding combustion)	239 (with combustion) 59 (without combustion) -1 017 (stored)	6	8	55	67	7	109	741
Direct employment [jobs years/GWh]	0.21	0.18	0.26	0.26	0.87	0.26	0.27	0.25	0.32
Advantages	•Dispatchable power •Reliable •Relatively high capacity factor	•Dispatchable power •May store CO2	•Cost-competitive •Reliable •Scalable •Allow for mixed use (e.g., can be installed in productive land and brownsites)	•Reliable •Scalable •Becoming more cost-competitive	•Cost-competitive •Reliable •Scalable •Significant continuing innovation and cost-reduction potential	•Can utilise storage to boost capacity factor •Scalable •Continuing innovation and cost-reduction potential	•The only mainstream technology that can act both as generation and as storage •Economically competitive	• Reliable • Small footprint of land • Usable for large and small scale installations • Low maintenance requirement • Long life span	• Reduces commercial and residential waste

Technology	Biomass	BECCS	Onshore wind	Offshore wind	Solar PV	Solar CSP	Hydropower (micro/small)	Geothermal	Waste (renewable MSW)
Disadvantages	•Low innovation potential •Expensive •Environmental damage to forests •High emissions	•Very expensive •Low innovation and learning potential •Requires expensive CCS infrastructure •Unproven technology •Lower efficiency than biomass due to energy use in capture process •Environmental damage to forests	•Low generation predictability at plant level •Social acceptance is a common issue across Europe, due to landscape protection • May have impact on natural habitats and areas of high natural values (brownfield sites should be prioritised)	•Relatively expensive currently •Low generation predictability at plant level •Requires suitable locations	•Ground-mounted PV may compete with other productive use of rural land •Rigid output profiles means that short-term storage is necessary for intra-day consumption, while summer-winter difference requires spare capacity to be available	•Requires sunny locations, restricted primarily to southern Europe •Seasonal production, lower availability in winter	•Geography is a key limiting factor, limited sites and trend away from large projects •Conservation best practice is to avoid large hydro and trend is, where possible, to remove from rivers •Capacity increase could have substantial environmental impacts •High seasonal variations and risk of lower production with climate change	• Location dependent, limited number of suitable sites in Europe, many already exploited • High initial cost • Possible surface instability	• Expensive technology compared to the other RES alternatives (high LCOE and investment costs) • High climate impact due to the significant CO2eq emissions • Can generate significant air pollution

Source: Trinomics own representation. Sources include: CAPEX (IRENA Power Generation Costs 2021 & 2022, NREL Annual Technology Baseline), OPEX & LCOE (NREL Annual Technology Baseline), Capacity Factor (IRENA 2021), Emissions (Trinomics 2020 Cost and Taxes of EU energy – External Costs), Employment (Wei, M. et al, 2010, Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?, Energy Policy 38 (2010) 919-931). For BECCS (UK BEIS 2020 Electricity Generation Costs 2020), also assumes an 85% carbon capture efficiency.

* Actual capacity factor may be lower than for dedicated biomass plant as BECCS increases technical complexity and therefore also potential for failures and maintenance

Top alternatives based on current generation

In the previous section, we provided a comparative overview of the most promising renewable technologies that could be deployed to replace biomass across Europe. However, each Member State has different environmental conditions and potentials, which means some technologies may be more suitable than others to be deployed at scale.

Table 3-3 shows the alternative renewable energy sources proposed for support in each country, focusing on those most suited to the climate and with the highest potential for scalability. In almost every country the basis of alternatives are **solar PV** and **wind energy**, as shown already in the comparative overview these provide cost-effective alternatives to biomass.

Other renewables will only play smaller roles, amongst them **Concentrated solar power (CSP)** is currently deployed in Spain at medium scale, but is also plausible in all Southern European or sunnier countries (Italy, Spain, Greece, Portugal, Romania, Croatia). With support and innovation this is a complementary alternative.

Hydropower is currently the second-largest renewable generation source in Europe, but it is highly dependent on the geography of a country, and significant increases in capacity have negative impacts on habitats and protected areas. For this reason further deployment of large-scale hydropower is excluded in RECCS, with a trends towards removing dams where possible. Within RECCS only limited amounts of **small and micro-hydro** are forecast, and would be subject to appropriate and strict environmental impact assessment.

Geothermal is less commonly seen as an option as until now it has been limited to a small number of selected sites (i.e. in Italy, Portugal and Austria), however developments in drilling are opening possibilities for deep geothermal power to become a more widespread future alternative. **Wave and tidal power** may also play a small role in member states with accessible coasts.

A few potential energy technologies are excluded as they have limited potential to scale to large volumes. These include **non-renewable waste** which has limited potential for scalability in the long term, due to efforts to reduce waste generation and increase recycling and circularity, rather than using waste for energy recovery, and because of the environmental drawbacks (mostly, air pollution) of the technology.

Table 3-3 Top three generating alternatives and generation as share of PSB generation

Country	First alternative renewable	Second alternative renewable	Third alternative renewable
Germany	Wind	Solar photovoltaic	
France	Wind	Solar photovoltaic	Solar CSP
Sweden	Wind	Micro-Hydro	Solar photovoltaic
Finland	Wind	Solar photovoltaic	Micro-Hydro
Poland	Wind	Solar photovoltaic	Micro-Hydro
Italy	Wind	Solar photovoltaic	Solar CSP
Spain	Wind	Solar photovoltaic	Solar CSP
Austria	Wind	Solar photovoltaic	
Czechia	Wind	Solar photovoltaic	Micro-Hydro

Country	First alternative renewable	Second alternative renewable	Third alternative renewable
Denmark	Wind	Solar photovoltaic	Micro-Hydro
Romania	Wind	Solar photovoltaic	Solar CSP
Netherlands	Wind	Solar photovoltaic	
Portugal	Wind	Solar photovoltaic	Solar CSP
Hungary	Wind	Solar photovoltaic	
Belgium	Wind	Solar photovoltaic	Micro-Hydro
Bulgaria	Wind	Solar photovoltaic	Solar CSP
Latvia	Wind	Solar photovoltaic	Micro-Hydro
Slovakia	Solar photovoltaic	Micro-Hydro	
Croatia	Wind	Solar photovoltaic	Solar CSP
Lithuania	Wind	Solar photovoltaic	
Estonia	Wind	Solar photovoltaic	
Greece	Wind	Solar photovoltaic	Solar CSP
Slovenia	Wind	Solar photovoltaic	Micro-Hydro
Ireland	Wind	Solar photovoltaic	
Luxembourg	Wind	Micro-Hydro	Solar photovoltaic
Cyprus	Wind	Solar photovoltaic	Solar CSP
Malta	Wind	Solar photovoltaic	Solar CSP
Non EU countries			
United Kingdom	Wind	Solar photovoltaic	

3.3 Filling the energy gap

In the previous section we identified alternative technologies that could be deployed to replace biomass in EU Member States and in the UK. This section attempts to estimate to what extent the subsidies provided to biomass (quantified in section 2.2) can support the deployment of these technologies, and whether there is still an energy gap left after these have been deployed.

Providing this estimate is a theoretical exercise that could be attempted using different assumptions and methods. In this analysis, we assume that the subsidies currently provided to biomass each year (generally provided in different forms, such as Feed-in Tariffs, Feed-in Premiums) are substituted by other output-based subsidies in the form of Contracts for Difference (CfD), as this is the current approach adopted by most countries and recommended by the European Commission. The cost of a CfD support scheme is based on market price and technology costs, which means different assumptions will have to be introduced in terms of costs and in terms of technology distribution.

To arrive at the estimate, we follow a number of sequential steps:

1. Estimate the support needed by different technologies
    a. Identify the Levelised Cost of Electricity (LCOE) for the alternative technologies.
    b. Identify a relevant wholesale long-term market price, expected during the lifetime of the support measure (assumed to be 15 years). A value of 50 EUR/MWh was used, a little higher than the EU average pre-pandemic and energy crisis, and around the levels of prices in early 2024.

    c. calculated the subsidy required by the alternative technologies. This is assumed to be equal to the LCOE minus market price

2. Estimate the amount of alternative technologies that could be supported based on the subsidies currently given to biomass in every country considered
3. Calculate the gap, i.e., the difference between the energy currently subsidised and the energy produced by the newly supported alternatives. If the alternatives require lower support than biomass, then the gap will be negative. This means that there will be some funds left that could be invested in further actions. Given the nature of the alternatives, the remaining amount should be dedicated to actions that compensate for the non-dispatchability of some technologies (compared to the full flexibility offered by biomass plants).

The levelized costs (LCOE) of the alternative energy technologies were presented in Table 3-2 and can be compared with support effectively awarded to these projects in Europe in recent years to validate the approach. Table 3-4 shows the average support given per technology in several European countries, for the most recent year with available data. PV support range starts at 24 €/MWh (Denmark, 2019) up to 132 €/MWh (Malta, 2021), while for onshore wind the support ranges from 20 €/MWh (Denmark, 2019) to 67 €/MWh (Italy, 2020). Data on offshore wind suggests subsidies at similar or slightly higher levels than for onshore wind. Subsidies for biomass are amongst the highest for all technologies, highlighting how this technology requires subsidy support to be financially viable in many cases.

Table 3-4 Support in RES projects across Europe (€/MWh)

Country	Year	Biomass	Solar PV	Wind Onshore	Wind Offshore	Hydropower
Croatia	2020	161	75			137
Denmark	2019		24	20	52	
Estonia	2020		54	63		
Finland	2018			25		
France	2020		80	61	60	104
Germany	2020		52	61	47	
Greece	2020		51	55		
Hungary	2020		56			
Ireland	2020		73			
Italy	2020	134	84	67		150
Lithuania	2015	102		57		73
Netherlands	2020		81	52	42	91
Poland	2020		59	45		90
Portugal	2020		11			
Slovakia	2019					
Slovenia	2020		72	67		86
Spain	2021		30	27		
UK	2019	98	87	46	54	
Average		**124**	**59**	**50**	**51**	**104**

Sources: EU countries AURES auction database 2022, UK: Contracts for Difference Allocation

Based on the above, the support for different technologies is estimated as presented in Table 3-5. For some technologies, and according to the assumed market price, the support level is negative. This is based on the how CfDs work: generators receive a subsidy only when market price is below the strike price (the price that they bid for in the CFD auction), and pay back the difference between market price and strike price when the latter is lower than the former. This trend is leading to some subsidy auctions being undersubscribed as project developers choose to agree long term contracts with private parties or take their chances with markets, hoping, unsubsidised, for their projects to still be profitable. Some generators are still opting for a CfD because of the reduced risks that come with a CfD. However, in our analysis we will assume that these generators will require a nominal minimum level of support, which we have assumed 25 EUR/MWh. The premium could be implemented as part of a contract for difference approach, aiming to guarantee at least a 25 EUR/MWh return above the LCOE of a technology. Strike prices for the contract for difference would be set at a level which over the lifetime of the contract would aim to provide such an average premium.

Table 3-5 Estimate support needed

	Effective subsidy if average market price over support period is €50/MWh
Biomass	87
BECCS	150-200
Solar photovoltaic	-14
Solar CSP	46
Onshore wind	0
Offshore wind	22
Micro-Hydro	13

The analysis presented in Table 3-3 distinguishes between onshore and offshore wind, as the two technologies have different costs and different deployment potential. Assumptions concerning the potential deployment at country level have been made according to Table 3-6.

Table 3-6 Assumed split between onshore and offshore wind by country

Offshore wind	Onshore wind	Country
0%	**100%**	AT, CZ, LU, HU, AT, SK
20%	**80%**	RO, SI,
50%	**50%**	BE, BG, DK, DE, EE, IE, EL, ES, FR, HR, IT, CY, LV, MT, NL, PO, PT, FI, SE, UK

Furthermore, as it was not feasible in the scope of this work to form detailed assumptions per country, a simplifying assumption is made that the countries considered will not invest in a single technology, but would redistribute generation from biomass among the ones considered in Table 3-5 according to a 50%-30%-20% split based on the priority set in Table 3-3. Essentially, 50% of the generation will come from the no.1 alternative in each country, 30% from the no.2 and 20% from the no. 3. In the case of wind, the percentage is further allocated to onshore and offshore as per Table 3-6, which means that, for most countries, the generation gap will be distributed among four technologies.

Across the EU and UK, replacing electricity generation from biomass with alternatives sources that deliver the same amount of power each year could save a total of almost 5.9 EUR billion per year as shown in Table 3-7. This is due to the net difference in subsidies required for the renewable alternatives to deliver the same amount of electricity (see previous tables). This proportion of savings, e.g. around 70% of the total subsidies, can also be assumed looking forward.

Table 3-7 Total subsidy requirement to fill the biomass electricity energy gap in 2020 with renewable alternatives, and remaining funds, if average market price is 50 EUR/MWh

Country	Subsidised biomass use (electricity gap to filled)	Value of current subsidies	Estimated subsidy Onshore wind	Estimated subsidy to Offshore wind	Estimated subsidy to Solar PV	Estimated subsidy to Solar CSP	Estimated subsidy to Other RES	Total subsidy cost	Funds remaining
	[GWh]	[M EUR]	[M EUR]	[M EUR]	[M EUR]	[M EUR]	[M EUR]	[M EUR]	[M EUR]
EU27 total	61 783	5 894	439	398	519	202	79	1 637	4 257
Germany	12 483	1 827	98	98	117	-	-	312	1 515
France	7 494	746	47	47	56	69	-	219	527
Sweden	258	25	2	2	1	-	2	6	18
Finland	1 565	248	10	10	12	-	8	39	209
Poland	4 177	233	26	26	31	-	21	104	128
Italy	6 398	703	40	40	48	59	-	187	516
Spain	3 593	335	22	22	27	33	-	105	230
Austria	975	143	15	-	9	-	-	24	118
Czechia	1 241	124	16	-	9	-	6	31	93
Denmark	4 302	181	27	27	32	-	22	108	74
Romania	980	29	10	2	7	9	-	29	0
Netherlands	10 864	600	85	85	102	-	-	272	329
Portugal	1 916	228	12	12	14	18	-	56	172
Hungary	110	11	2	-	1	-	-	3	8
Belgium	1 915	178	12	12	14	-	10	48	130
Bulgaria	625	31	4	4	5	6	-	18	12
Latvia	54	5	0	0	0	-	0	1	4
Slovakia	1 114	83	-	-	17	-	10	28	55
Croatia	967	93	6	6	7	9	-	28	65
Lithuania	347	33	3	3	3	-	-	9	25
Estonia	0	0	-	-	-	-	-	-	-
Greece	0	0	-	-	-	-	-	-	-
Slovenia	0	0	-	-	-	-	-	-	-
Ireland	351	34	3	3	3	-	-	9	25
Luxembourg	55	5	1	-	0	-	0	1	4
Cyprus	0	0	-	-	-	-	-	-	-
Malta	0	0	-	-	-	-	-	-	-
Non-EU countries			-	-	-				
United Kingdom	195	195	234	-	-	623	1 595	195	195
Total	**86 709**	**8 113**	**633**	**593**	**752**	**202**	**79**	**2 260**	**5 853**

Source: Trinomics own calculations

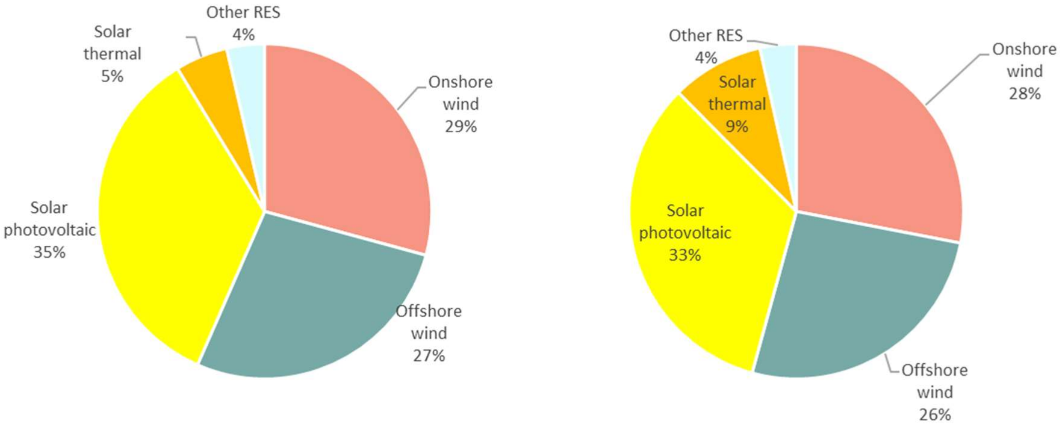
The results presented in Table 3-5 should be considered in light of some practical implications:

- Most countries already have subsidies in place for the alternative technologies identified. Providing more subsidies may not result in additional installations due to limits in the pipeline and planning process. Policies can be developed and agencies supported to help overcome these issues;

- At least some of the €5.9 billion subsidy surplus is likely to be needed to reinforce the grid (for example, to move energy from offshore areas to main consumption centres in the country) and flexibility capability (storage, backup generation) to account for the intermittency of solar and wind compared to biomass. In the RECCS proposal, see chp 6, we reserve an additional 20% on top of the subsidy cost to contribute to this.
- There is a lead time to develop additional energy generation capacity, whilst solar PV can be added in relatively short timescales (1-3 years) it can take longer for onshore wind (2-6 years) and offshore wind (3-8 years).

Finally, Figure 3-1 shows how generation and subsidies are distributed among the alternative technologies considered, showing that these are almost equally proportional. This shows that solar PV provides both the highest generation and would receive the greatest share of the subsidies, followed by Onshore and Offshore wind. Solar CSP (CSP) requires a slightly higher share of subsidies than it provides in generation.

Figure 3-1 Example distribution of alternative electricity generation (left) and subsidies (right) to fill energy gap in 2020 following proposal of alternatives as per tables 3-4 and 3-8



In the medium to long term a few further trends should be taken into account as the projections (see section 2.4) are that the energy gap will grow over time, particularly as the projected growth of BECCS needs to be replaced. In this longer timeframe, a few considerations should be kept in mind:

- The estimated cost, and therefore also the necessity and value of subsidies, for wind and solar power is expected to continue to decrease further in future as technology learning effects continue. Solar PV, Onshore wind and Offshore wind costs are expected to decline respectively to around 25 EUR/MWh, 40 EUR/MWh and 25 EUR/MWh by 2050[58]. Cost declines may also be expected for Solar CSP. Cost declines are primarily driven by increased efficiency and reduced manufacturing costs.
- Similarly costs for storage technologies such as batteries and hydrogen are also expected to decline substantially. So the cost of any additional grid infrastructure required to complement the renewable alternatives and replicate the role of biomass generation would also decline.
- There are other low carbon energy technologies in development that could become competitive and relevant in the timeframe of RECCS, for example deep geothermal, floating

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[58] IEA (2022) Global energy and climate model documentation 2022

wind, marine (wind & tidal) power, possibly nuclear (and small modular reactors), and even, likely after 2040, fusion power. Promoting demonstration and innovation in these technologies could also be a supporting part of a RECCS.

- As a result the amount of subsidies required to fill the energy gap would be expected to decline over time, even as the energy gap grows as projected growth in biomass and BECCS no longer takes place.
- As shown in section 2.2 the amount of subsidies to biomass and especially BECCS are projected to significantly increase, therefore in future greater and greater subsidy budgets may become available for reallocation.

3.4 Cost-benefit analysis

3.4.1 Comparison of impacts per technology

Developing the table in 3.2 further, taking the case of a hypothetical EUR 100 million investment in each technology the following main energy, emissions and cost impacts can be calculated. This shows clearly that biomass (and BECCS) is the most expensive and emissions intensive of the considered power generation technologies. For the alternatives the marginal abatement cost of the emissions reductions is 60 EUR/tCO_2 or less, except in the case of solar CSP (81 EUR/tCO_2e), these prices are comparable to, and in many cases lower than recent EU-ETS carbon prices which have ranged between 60-100 EUR/tCO_2 since 2022.

Table 3-8 Overview of key impacts for biomass and selected alternative renewable electricity technologies on the basis of EUR 100 million investment

Technology	Biomass	BECCS	Solar PV	Solar CSP	Onshore wind	Offshore wind	Other RES (e.g. micro-hydro)
Cost [EUR/kW] or [EUR/m2]	4 194	6 000	1 266	6 443	1 388	3 446	2 445
MW installed [MW]	24	17	79	16	72	29	41
Annual energy generated [GWh]	182	124	118	67	221	114	143
Emissions per kWh [gCO_2/kWh]	1 256	322[#]	55	67	6	8	7
Emissions saving [ktCO2e/yr]	N/A	N/A	141	79	276	143	179
Annual saving for households [m EUR]	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lifetime [years]	20	20	20	20	20	20	50
Marginal abatement cost* [EUR/tCO_2e]	N/A	N/A	30	81	40	58	50

Source: Trinomics own calculations.

* The marginal abatement cost is calculated on the basis of the LCOE multiplied by the estimated lifetime energy production. This implies that all costs (CAPEX and OPEX) are included.

[#] at 80% CCS capture efficiency.

3.4.2 Overall costs and benefits

This section discusses the main practical and cost implications of stopping public support to forest biomass.

Energy prices and markets

Even though subsidies per MWh current paid suggest biomass is expensive (see Table 3-1), its success is due to the fact that it is a rather close replacement for fossil fuels, without the issues of intermittency of other renewables and that it utilises similar technologies (e.g. boilers, steam cycles) to fossils that sometimes fuel switching is possible, e.g. from coal to biomass at the same plant. High subsidies per MWh are mostly due to the fact that they were awarded several years ago, when other renewable technologies were significantly more expensive; since, most other alternative renewable technologies have seen significant cost reductions. Overall, this results in increased generation costs, which are passed onto households and businesses, reducing the competitiveness of the economy. However, there are only limited options to produce heat renewably, and it is now accepted that the main alternative is electrification. This has consequences at system level (see next point).

Based on our analysis, 86.7 TWh of energy from biomass are supported by subsidies. Removing this support (and energy) to support other renewable technologies may have an effect on the price of electricity, but this would be limited due to the current price formation mechanism in the EU electricity market. In EU and in the UK, the market price of electricity is set by the most expensive generator required to fulfil the demand at any point in time, via a mechanism called merit order effect: when different generators put their offer for energy on the market, they would submit an offer for quantity and price (e.g, 100 MWh for €100 to be delivered the following day between 15:00 and 16:00); the offers are then ranked from the cheapest to the most expensive, until the required total generation requested has been met. Usually, the order sees renewables first because they have very low operational costs, and so offer very low prices, while other technologies will generate only when the market price is above their marginal cost. The most expensive generator is often a gas plant, [59] as gas generators have running costs significantly higher than renewables. However, all the offers cheaper than the highest bid that was accepted will receive the same price (pay-as-clear system). Biomass plants have a cost structure similar to a gas plant, which means they would submit relatively high bids and can become price setter (i.e., submit the last accepted bid). Removing biomass as price-setting generator, and replacing it with more zero-marginal generation, means that the price-setting technology will be more often a renewable with zero-marginal costs that would offer lower price than a biomass generator would.

For renewable heating and co-generation, the relationship between alternatives to biomass and costs is likely to be in the opposite direction. Viable renewable alternative to biomass for CHP generation are limited to biogases and biofuels not generated from forest biomass (for example, biomethane from sewage, crop-based biofuels), but these are usually very limited in quantities and are more expensive. Therefore, eliminating biomass subsidies is likely to reduce the number of CHP plants. For heat-only generation, the mainstream solution is electrification (heat pumps), which often also require investment in insulation before it can be successfully applied (these alternatives are explored further in chapter 5). Alternatives to electrification for heat generation have instead a more limited range of

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[59] This is the reason why electricity prices in the EU were significantly high in 2022, independently of how much gas generation different countries had. Because gas was often the most expensive technology required to meet demand, the price was high and renewable generators earned significant profits (windfall profits).

application, such as solar water heaters and geothermal. Essentially, eliminating subsidies for biomass for District Heating may require substantial early investments in large heat pumps and electrification of the heat generator.

System costs

A shift from biomass to other renewable sources for the production of electricity is likely to require some other investments at system level. These include:

- Investments to *reinforce the power grid*, in particular:
    - Increasing transmission capacity in those countries where large renewable generation is located far from where the majority of energy demand comes from. For example, some of the UK's best locations to install large wind capacities are in the North sea, but the majority of the UK demand is located in the midlands and south-east;
    - Reinforcing distribution networks to handle larger power flows in those countries which are more suitable for smaller-scale installations (generally of onshore wind and solar PV).
- Investments to cover the need to expand system capacity, to account for renewables downtime or times where production is low; and
- Investments to deploy larger amounts of storage and flexibility solutions (e.g. batteries, clean hydrogen, pumped-storage, in future potentially gas+CCS in industrial settings);
- Investments by industry in the supply chain to enable more installation of renewables, for example in training qualified personnel, and in installation equipment e.g. ships for offshore wind.

Similarly, alternatives to biomass for the production of heat may also require additional investments, also in the power sector. In particular, an increase in the required speed and extent of electrification, mostly due to commercial-scale heating and CHP switching to heat pumps. In many cases where biomass is currently converted directly to heat, electrification requires first the production of electricity, then the conversion to heat. Although the use of electricity for heat via heat pumps is rather efficient (e.g. 300-400% efficiency, i.e. 3-4 kWh heat for each kWh of electricity input).

In summary, reducing electricity generation from forest biomass may reduce energy costs for final users, but increase other power system costs, such as increasing network investment costs and leading to higher flexibility and storage costs. These costs will flow back to consumers via network costs on their bills and via increased levies. On the other hand, for heating, heating running costs may decrease, but the switch to alternatives to biomass will require high initial investments. The extent of these costs is highly dependent on national circumstances, and on how the power system evolves.

Socio-economic impacts

Finally, reducing support to biomass would have some important economic implications. The majority of biomass subsidies are paid to commercial-scale installations. According to Bioenergy Europe,[60] in 2016 there were over 3 300 biomass plants between 1 MW and 20 MW, and a further 603 above 20 MW. The latter consume the vast majority (74%) of biomass used in commercial plants. Removing subsidies will have two important implications:

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[60] As presented on page 686 of the Commission report supporting the revision of the Renewable energy Directive (2021) https://op.europa.eu/en/publication-detail/-/publication/6fcc38cb-1440-11ec-b4fe-01aa75ed71a1/language-en

- The **turnover** of the vast majority of the 4 000 plants will be significantly affected, as well as part of their supply chain. According to the JRC,[61] the turnover associated to Forest Biomass in EU was €27 billion in 2020, for a value added of €7 billion. According to analysis by Deloitte[62], the total GDP impact from bioenergy at EU level are also estimated to be around €31 billion, of which €8.9 billion of indirect impacts. However, €10.5 billion of direct and indirect impacts are associated with individual heating systems, rather than commercial applications (bioelectricity and district heating). It is reasonable to expect that removing €8.1 billion per year of subsidies will significantly affects the remaining €22 billion of turnover.
- The closure (or reduction in revenues) for a significant number of biomass plants will affect a significant number of **jobs**. According to the JRC, 36 717 people were employed in the production of bio-based electricity in 2020.[63] The JRC estimate is substantially different to the one produced by Deloitte for BioenergyEurope, which puts the estimate of direct jobs at 233 000 for bioelectricity, 109 000 for district heating and 250 000 for individual heating systems. IRENA also reports a similar figure (314 000 jobs in total for power and heat application of forest biomass). However, both the IRENA and Deloitte estimations include large parts of the biomass sector which are not the focus of this work – which is solid forest biomass.

To put the figures above in context, bio-based electricity contributes to less than 1% of the total bioeconomy's turnover in the EU, and less than 1% of the jobs.[64] Deloitte also reported the estimate for 2050, based on the scenarios evaluated by the European Commission during the recast process of the Renewable Energy Directive. According to Deloitte's analysis, in 2050, the economic impact of the bioenergy sector in terms of GDP could account for € 70.1 billion (with €41 billion and €29 billion of direct and indirect impacts, respectively. The impact on employment could reach almost 1.6 million FTE in the same year, around 1 million direct, and 0.6 million indirectly. This estimate is based on a substantial expansion in bioenergy (especially in industry) and it also includes transport biofuels (excluded from the figures presented in the previous paragraph).

To set against these socio-economic impacts in the biomass sector and supply chain are the gains that would take place in other sectors and supply chains. As shown in Table 3-2 the direct jobs associated with biomass are estimated to be a little lower than for wind energy in Europe, and much lower than for solar PV. If we take the estimates for 2020, with 86.7 TWh of biomass being supported by subsidies in the EU and UK, and that this directly employs 18 200 people, then the proposed alternatives in section 3.3 would employ 41 700 people, more than doubling the employment for the same amount of energy. Therefore replacing biomass energy use would be likely to have a positive impact on total direct employment. It is important to consider that:

- The jobs estimated for the Solar PV sector are likely to derive from the high number of micro (rooftop installations). If only commercial scale installations and generation is considered, the number of jobs per TWh is likely to be smaller.
- Based on the estimate presented in Table 3-7, the fact that the same amount of power can be provided for less subsidies, leaves room for the remaining subsidies to be invested in other areas, including the options explored further in this work such as: energy efficiency or nature-based solutions. These additional investments will also deliver economic benefits and

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[61] https://setis.ec.europa.eu/document/download/5003ec51-c46a-452e-a4db-f79eb8ae996d_en

[62] Deloitte (2022) Towards an Integrated Energy System : Assessing Bioenergy's Socio-Economic and Environmental Impact.

[63] https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html

[64] https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html

employment of their own, which will contribute to positive economic impacts on top of the energy switch.

- The estimated impact on energy prices, i.e. that the switch is likely to lead to lower prices, will also have economy-wide benefits as savings are shared by companies and consumers and spent in the broader economy.
- Jobs in renewable technologies alternative to biomass often require a labour force more skilled than that required by the biomass supply chain. This means that each job created is likely to be more skilled and better paid.
- It is also possible to invest in these technologies, or the energy efficiency and nature-based solution alternatives mentioned above, in regions that may lose out from a switch to biomass, for example by locating alternative energy production facilities or the associated value chain activities in these regions. This would help to avoid negative distributional impacts.

Environmental benefits

However, a reduction in forest biomass use in favour of alternatives for heating and power generation will also generate some significant benefits:

- **Reduced forest exploitation for bioenergy, and increase in sustainable use of wood products:** while generally woody biomass use for bioenergy is limited to poor quality trunks and residues (e.g. branches), the availability of subsidies is likely to encourage unsustainable practices, which in practice means using for bioenergy wood that could be utilised in other industries, such as pulp and paper of wood products. The artificially high demand and prices would be reduced if subsidies were removed, whilst there may be some rebound in use from other sectors as prices fall, the net result should be lower usage and prices as bioenergy producers would no longer outbid other users. Lower prices may also make wood extraction from some sites uneconomical, thus reducing total fellings. This will generate an increase in forested area and in the density of forested areas, leading to an improvement in biodiversity of forests in the EU and globally. Expanding on the rough calculations presented in section 2.1.4, the 86 709 GWh of subsidised bioenergy production that would be eliminated requires fuel from around 2 million hectares of forest globally, or to put in context around 1% of the total EU forest area.
- **Increased sink capacity:** reduced fellings will also increase the sink capacity of EU and global forest. Besides the climate benefits, increasing sink capacity in Member States has an important economic implications: in order to meet the EU's decarbonisation targets, the other sectors of the economy will need to reduce their emissions less, if they can count on higher sink capacity in their own forest. This is particularly true for those countries which are major exporter of woody biomass products in the EU. Taking the example above, as a rough contextual calculation, preserving 2 million hectares could preserve carbon sinks of around 30MtCO_2 each year.
- **Reduced air pollution**: the burning of forest biomass, both at commercial and at residential level, is linked to an increase in the emissions of PM10, PM2,5 and VOCs in the EU[65], which worsen air quality in the communities and regions near the power plants. This increases risks to human health. Lowering air pollution will improve health outcomes, lowering medical costs and increasing labour productivity (see also chapter 6 for more on cost of emissions and benefits of reductions).

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[65] https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/renewable-energy-in-europe-2019-recent-growth-and-knock-on-effects

- **Reduced land use**: Solar PV and wind energy take up far less land to deliver the same energy production as forest biomass. For example research estimates that for the same area of land (ha) that solar PV delivers more than 100 times the energy than forest biomass[66].

3.4.3 Considerations at country level

Country	
Germany	**Large users with high subsidised amounts of biomass** These are the countries were biomass subsidies have the largest effect and requires the largest amount of total support. As a consequence, these are the countries where it will be more challenging to move away from subsidised biomass, both in terms of plugging the gap with other technologies, and in terms of economic impacts. However, this is also where the biggest opportunities are. These are the largest countries in the EU, with significant potential for deploying alternatives technologies. In particular, wind in DE, PL, NL, DK and the UK, and solar PV and CSP in ES, IT, as well as FR and DE. The main practical implications of switching away from biomass for power generation are related to the planning process, which often delays large renewable projects. However, some countries have put in place several actions to lower the development time (such as DK, DE and NL), and the others are slowly catching up.
France	
Poland	
Italy	
Spain	
Netherlands	
United Kingdom	
Denmark	
Sweden	**Large users with low subsidised amounts** In these countries, the removal of subsidies is unlikely to significantly affect biomass use, which is driven largely by local availability (and therefore is economically competitive also in the absence of a subsidy).
Finland	
Austria	
Czechia	**Medium users with high subsidies** These countries may be able to replace subsidised biomass with alternative technologies with a limited effort. This is because it is likely few plants will be involved. and all of the countries in the list have significant potential in terms of alternatives.
Romania	
Portugal	
Belgium	
Bulgaria	
Latvia	
Slovakia	
Croatia	
Ireland	
Cyprus	**Medium users with low subsidised amounts and small countries** Removing subsidies in these countries is unlikely to have a significant impact in terms of reduced biomass use. However, this means that replacing biomass is also relatively easy, and would generated limited economic losses. Among these countries, there are countries such as Estonia and Lithuania which are exporters of forest biomass, so their economy may be negatively affected by the removal of subsidies in other countries.
Malta	
Greece	
Luxembourg	
Hungary	
Lithuania	
Estonia	
Latvia	
Slovakia	
Bosnia and Herzegovina	**Other non-EU countries** There is limited information on subsidised amounts of biomass in this group of countries. However, renewable subsidies are expected to be rather low, and the impacts of removing them is also likely to be limited. However, these countries are also where the benefits of removing subsidies may be larger, given that these countries' bioenergy generators do not have to comply with sustainability criteria (EU countries can award subsidies only when sustainability criteria for biomass are respected, as required by the Renewable Energy Directive).
Norway	
Türkiye	
Serbia	
Moldova	
Slovenia	
Kosovo	
Ireland	
Georgia	
North Macedonia	
Montenegro	
Albania	
Iceland	

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[66] Searchinger et al., 2022, Europe's Land Future? Princeton University

4 Nature based solutions

Key points

- **Nature-based solutions (NbS) are increasingly understood and encouraged in strategic policy frameworks as a cost-effective solution for carbon storage and sequestration, and a range of benefits in facing other societal challenges such as adapting to climate change, water and food security, and conserving biodiversity.**
- **Forest and wetland ecosystems**, because of their ability to sequester and store large amounts of carbon over time, **have the greatest potential for nature-based carbon removal in the European region**. Their landscape-scale protection and restoration therefore provide the surest nature-based solution for climate change mitigation. In chaptaer 6 it is demonstrated that a RECCS can protect and/or restore large areas of carbon absorbent ecosystems (millions of hectares) delivering significant carbon sequestration benefits and preserving existing natural carbon stores.
- **NbS are most cost-effective when implemented with natural ecosystems still in a good ecological condition rather than in ecologically degraded ones**. Not only because the former usually have larger carbon stocks, but also because of their self-regenerative capacity. This makes them able to recover from internal and external shocks without costly human intervention, and deliver both storage and sequestration more resiliently over time.
- **Protecting and restoring remaining intact forest ecosystems such as primary- and old growth forests should therefore be prioritised in any RECCS strategy**, followed by investing in protection and restoring more degraded ecosystems. Non-intervention management in the most ecologically healthy forests, by enforcing strict protection, has been shown a highly cost-effective form of conservation supporting resilience and high levels of stable carbon storage over time.
- This chapter analyses costs and benefits of protecting and restoring three ecosystem types with greatest NbS potential in the European region: **Forests, peatlands, and saltmarshes**. For all three ecosystem types, it **shows very favourable benefit:cost ratios of protection and restoration** as an NbS for climate change mitigation.
- **Forest and wetland protection and restoration can be implemented in every European country**, although their relative potential differs between countries due to a combination of factors.
- Significant economic incentives for NbS are already **being implemented** in the European region, both regulatory as well as in terms of public and private investment **, although usage remains fragmented and substantial further development of the market for ecosystem services will be required.** National and regional RECCS could be instrumental to help link them to local needs and opportunities, and herewith scale-up their delivery.

In making the case for reallocation of subsidies for forest bioenergy towards conservation of carbon absorbent ecosystems this chapter analyses the costs and benefits of implementing Nature-based Solutions (NbS) as an alternative public and private investment strategy to energy production from forest biomass. The UN Environment Assembly defined NbS as "*…actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems* *which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human wellbeing, ecosystem services, resilience and biodiversity benefits.*"[67]

Over the past decade, NbS have gained international popularity for their potential to address, in a cost-effective way, climate change adaptation and mitigation challenges in combination with multiple environmental-, social/cultural-, and economic co-benefits[68]. The defining premise of NbS is that encouraging and adopting nature in solutions to society's challenges will prove to be superior due to the multiple benefits that they provide and their potential for lower cost over the long term.

In the case of forests, diverting investment from biomass production for energy to NbS represents a double benefit, as it would not only reduce carbon emissions from forest ecosystems, but also increase sequestration and storage. However, as this chapter will demonstrate, diverting investment towards NbS in other carbon-absorbent ecosystems could be a relevant RECCS pillar too.

4.1 Introduction

4.1.1 Policy context

Growing interest in NbS has resulted in their integration in a wide range of public policy objectives, strategies- and action plans, not least the European Green Deal[69]. While the following section focuses on key initiatives by the EU and its Member States, other European countries have developed policy strategy including NbS, such as the UK's 2023 Environmental Improvement Plan[70] and 2024 National Adaptation Programme (NAP)[71].

The **European Climate Law** for the first time committed the EU to become carbon neutral by 2050, and the Law's Article 4 acknowledged that, to achieve carbon neutrality, the EU should act to enhance its carbon sink by 2030 and beyond[72]. At the time of the Law's adoption, the EU already had a dedicated regulatory instrument to encourage climate mitigation in the land use sectors with the Land Use, Land Use Change, and Forestry regulation since 2018 (hereafter **LULUCF regulation**)[73]. The LULUCF regulation was updated in 2021 to bring it line with the new 2050 objective of carbon neutrality, and it entered into force in May 2023[74].

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[67] Resolution adopted by the United Nations Environment Assembly on 2 March 2022 on Nature-based Solutions for supporting sustainable development (UNEP/EA.5/Res.5), https://www.unep.org/resources/resolutions-treaties-and-decisions/UN-Environment-Assembly-5-2

[68] See e.g. World Economic Forum (2020) The Future of Nature and Business, https://www.weforum.org/agenda/2020/09/how-investing-in-nature-can-help-tackle-the-biodiversity-and-climate-crises and UNEP, WEF & ELD (2022) The State of Finance for Nature in the G20 report, https://www.weforum.org/press/2022/01/g20-countries-can-help-close-climate-finance-gap-by-investing-in-nature-based-solutions/

[69] See for an introduction the Council of the EU webpage on the European Green Deal: https://www.consilium.europa.eu/en/policies/green-deal/

[70] UK Department for Environment, Food and Rural Affairs (2023) Environmental Improvement Plan, https://www.gov.uk/government/publications/environmental-improvement-plan

[71] UK Department for Environment, Food and Rural Affairs (2024) https://www.gov.uk/government/publications/third-national-adaptation-programme-nap3

[72] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119

[73] European Commission's Directorate for Climate Action webpage on the land use sector, https://climate.ec.europa.eu/eu-action/land-use-sector_en

[74] Regulation (EU) 2023/839 of 19 April 2023 amending Regulation (EU) 2018/841 as regards the scope, simplifying the reporting and compliance rules, and setting out the targets of the Member States for 2030, and Regulation (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review https://eur-lex.europa.eu/eli/reg/2023/839/oj

While the revised LULUCF regulation implies little change up to 2025, from 2026 onwards its territorial scope will be broadened to cover all managed land. Moreover, it introduced an EU-wide target of **minus 310 $MtCO_2$ equivalent of net removals per year from 2026 to 2030**. This represents an increase of about 31% in the EU's net removals compared to current levels (-236 $MtCO_2e$ in 2022) and aims to reverse the declining trend in net removals seen in recent years. The revised regulation promotes strong synergies between climate mitigation and environmental protection, including in natural and semi-natural areas, and specifically mentions NbS as an option for capturing and storing CO_2 emissions. Achievement of the updated LULUCF targets represents an enormous challenge considering the current state of European carbon sinks, and would require a drastic reversal of the currently declining trend of forest carbon sinks in Europe and the EU particularly, with forest bioenergy being by far the largest driver[75].

In February 2024, the European Commission presented its assessment for a **2040 climate target** for the EU[76], which recommended reducing the EU's net greenhouse gas emissions by 90% by 2040 relative to 1990. To achieve this target, the Commission estimated that carbon removals should reach up to 400 $MtCO_2$/year from 2031 to 2040. While the Commission in its recommendations mostly focuses on (costly) technical removals, it does recognise NbS both for their carbon removal as well as their resilience-enhancing (and thus risk-reducing) and cost-saving potential.

The co-benefits that NbS provide to biodiversity conservation are widely recognised on public policy too: The Kunming-Montreal Global Biodiversity Framework adopted in December 2022 in the framework of the UN Convention on Biological Diversity (CBD) set 18 targets for 2030, including Target 8 to minimise the impact of climate change on biodiversity and build resilience, under which parties specifically committed on mitigation through nature-based solutions[77]. The **EU Biodiversity Strategy for 2030[78]** recognises that the biodiversity- and climate crises are intrinsically linked, and how nature can be a vital ally in the fight against climate change. It introduces four strategic pillars, three of which focus on the European region and each of which offer large opportunities for climate-relevant NbS: 1) A larger and stronger network of protected areas; 2) A more binding legal framework to encourage nature restoration; and 3) More appropriate governance and finance frameworks too. Each of these three pillars has important potential for nature-based carbon removals:

- **Nature protection:** The EU Biodiversity Strategy sets a target for the EU to increase its network of nature protected areas to 30% of both its land and at sea area. Moreover, it proposes to implement strict protection for at least a third of the 30% protected area, or 10% of the EU's total area, including all remaining EU primary and old-growth forests. In targeted

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[75] LULUCF sinks in the EU ranged between 300 -360 $MtCO_2e$ between 1991-2016, but have declined to the 2022 level of 236 $MtCO_2e$ since 2017. See EU submissions to the UNFCCC and other work, for example: European Commission, Directorate-General for Climate Action, Kowalczewski, T., Gionfra, S., Bellassen, V. et al., Reviewing the contribution of the land use, land-use change and forestry sector to the Green Deal – Final study, Publications Office, 2021, https://data.europa.eu/doi/10.2834/201100

[76] European Commission webpage on a 2040 climate target: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2040-climate-target_en

[77] UN Convention on Biological Diversity (UNCBD) web page on the 2030 targets in the Kunming-Montreal Global Biodiversity Framework (GBF): https://www.cbd.int/gbf/targets

[78] COM(2020) 380 final: EU Biodiversity Strategy for 2030 - Bringing back nature in our lives, which was politically endorsed by the Council of EU Member State ministers in 2020 and European Parliament in 2021: https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

guidance to EU Member States on how to implement these two targets[79], the European Commission recommended to give special attention to the protection of ecosystems that are particularly carbon-rich or have the potential of becoming so with better protection. It also emphasises that strict protection will require areas to be left essentially undisturbed from human pressures, and therefore in most cases will be non-intervention areas, where only limited and well-controlled activities will be allowed that either do not interfere with natural processes or enhance them.

- **Nature restoration:** On 18 August 2024 the **EU Nature Restoration Law**[80] came into effect, a regulation intended to complement existing EU objectives for nature restoration with legally-binding deadlines for 2030/40/50, more detailed national planning, as well as monitoring & reporting on progress. The regulation's more stringent targets include the taking of necessary restoration measures that would enable the recovery of all degraded climate-relevant ecosystems protected under the EU Habitats Directive, such as forests, inland and coastal wetlands, and natural grasslands.

- **Transformative change:** This involves, among other things, actions to improve the implementation and enforcement of existing EU laws requiring nature protection and -restoration, further encouraging private sector action on biodiversity, and enhance financing for biodiversity. Each of these represent substantial opportunities for scaling-up NbS in the European region.

All of these key policy pillars come with **planning and programming of public investment**: The EU has set quantitative targets on the shares of its 2021-2027 long-term budget[81], and ostensibly agreed to dedicate 30% of annual budgets between 2021 and 2027 to climate-relevant expenditure and 10% to protecting and enhancing biodiversity by 2026[82]. Chapter 7 '*Existing and additional sources of funding for RECCS objectives and synergies with existing and potential* policy goals' will provide further information on financing the transition to NbS and other sustainable alternatives to energy production from forest biomass.

4.1.2 Scope & methodology

In order to demonstrate the potential of Nature-based Solutions as an alternative investment strategy to energy production from forest biomass, and encourage their uptake at scale in RECCS, this chapter explores the appropriateness of different NbS options (section 4.2) and for the most promising options provides cost-benefit analyses to help compare their viability against alternative strategies to achieve RECCS objectives (section 4.3). This section first describes the key methodological design and choices made in the overall analysis.

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[79] European Commission (2022) Commission staff working document SWD(2022) 23 final - Criteria and guidance for protected areas designations, https://environment.ec.europa.eu/document/download/12d0d249-0cdc-4af9-bc91-37e011620024_en?filename=SWD_guidance_protected_areas.pdf

[80] Council of the EU press release of 17 June 2024 'Nature restoration law: Council gives final green light', https://www.consilium.europa.eu/en/press/press-releases/2024/06/17/nature-restoration-law-council-gives-final-green-light/

[81] Consisting of the Multiannual Financial Framework (MFF) and NextGenerationEU recovery instrument to support Europe's economic recovery from the coronavirus pandemic and build a greener, more digital and more resilient future.

[82] See European Commission webpage on green budgeting: https://commission.europa.eu/strategy-and-policy/eu-budget/performance-and-reporting/horizontal-priorities/green-budgeting_en

Given the width of NbS as a concept, some decisions were made to narrow down the scope of the options considered for more detailed analysis. These choices are briefly introduced here. The UN definition of NbS introduced previously at the start of this Chapter consists of four broad dimensions:

- The **type of ecosystem** that NbS are implemented in (e.g. terrestrial, freshwater, or marine)
- The broad **type of approach** to NbS taken (protect, conserve, restore, sustainably use)
- The **'effectiveness' and 'adaptiveness'** to which NbS options respond to key **societal challenges**
- **Other benefits** of chosen NbS besides the principal solution to societal challenge(s) targeted

To help understand and explain the importance of these four dimensions, an ecosystem approach was taken[83]. Ecosystems are defined in the context of the UN CBD as '*A dynamic complex of plant, animal and micro-organism communities and their non- living environment interacting as a functional unit.*', and ecosystem approaches are based on the application of appropriate scientific methodologies focussed on levels of biological organisations. Key concepts in ecosystem approaches are:

- **Ecosystem structure:** All of the living and non-living physical components that make up an ecosystem. The more components that make up an ecosystem, the more complex its structure becomes.
- **Ecosystem processes**: The physical, chemical, and biological processes that link organisms and their environment. These are for example biogeochemical/nutrient cycling, energy flow, and food web dynamics.
- **Ecosystem function**: The ability of ecosystems to efficiently maintain structure and essential processes (and herewith their sustained capacity to provide benefits to humans). Biodiversity is a key factor in ecosystem function because diverse communities are more likely to contain a greater range of functional traits and environmental sensitivities. High diversity therefore entails opportunities for more efficient resource use as well as providing stability to ecosystem functions in variable environments and in the face of disturbance. Conversely, systems with species-poor communities are as a rule functionally poorer, less resistant (capacity to resist change) and resilient (capacity to recover from change).
- **Ecological condition or integrity**: Refers to the state of an ecosystem in its entirety, which includes its physical, chemical, and biological characteristics (structure), the processes and interactions that connect them, and function. A related concept is ecological integrity, which is the ability of an ecosystem to support and maintain ecological processes and a diverse community of organisms.
- **Ecosystem services**: The benefits people obtain from ecosystems. Ecosystem services are commonly divided into supporting, regulating, provisioning and cultural services[84]. However different classifications exist, e.g. recent IPBES assessments used a more fine-grained system of "nature's contributions to people"[85].

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[83] See e.g. the UN CBD portal on the ecosystem approach: https://www.cbd.int/ecosystem

[84] Based on the classification popularised in the 2001 Millenium Ecosystem Assessment, https://www.millenniumassessment.org/en/index.html

[85] Mostly as IPBES recognised that many services fit into more than one of the four categories. For example, food is both a provisioning service and also, emphatically, a cultural service in many cultures. See IPBES conceptual framework and 2021 information note on applying "nature's contributions to people", https://www.ipbes.net/conceptual-framework

Type of ecosystem

Given the overarching societal challenge of climate change mitigation that underpins RECCS, a choice was made to narrow down the scope of NbS options to two broad terrestrial ecosystem types that in the European region hold the largest potential for nature-based carbon removal and storage[86]: **Forests** and **wetland ecosystems**. While it should be recognised that certain marine ecosystem types in the European region such as seagrass and mearl beds, cold water coral reefs, and intertidal sediments store and sequester large amounts of carbon, they were excluded from the scope if this study as much remains unknown on their presence, condition, measures required to improve it, and their costs. This makes reliable cost-benefit analysis currently more challenging than for the terrestrial ecosystems that are better known.

Within the two selected ecosystem types of forests and wetlands, the scope of analysis was narrowed further to NbS options in forest- and wetland ecosystems in a good ecological condition, i.e. those ecosystems that still maintain their essential ‘natural’ structure, processes and function. The reason for this choice was threefold:

1. Such ecosystems are usually more mature and as a consequence usually have a relatively higher accumulation of stored carbon (stock);
2. Their maintenance of function allows NbS options in these ecosystems to rely more on these systems’ natural or intrinsic regenerative capacity to recover, and herewith reduce the need for costly technical solutions;
3. Thirdly, since these ecosystems are the most resilient to disturbance over time, and as such provide a greater reliability in carbon capture and storage (and herewith risk of losses).

Types of NbS options

From an ecosystem-perspective, the broad types of NbS options in the UN-definition have a certain hierarchy. For this study it was interpreted, similar to under the UN CBD, that achieving ‘conservation’ usually requires **protection *and* restoration.**

The main vehicle for protection are protected areas, defined by IUCN[87] as ‘*a clearly defined geographical space, recognized, dedicated and managed through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*’. Given the importance of non-intervention management, and the EU’s ambition to strictly-protect 10% of its most valuable ecosystems from a biodiversity and climate point of view (as introduced in section 4.1.1 ‘Policy context’ above), protection in this study refers to strictly protected areas, defined by the European Commission[88] as ‘*…fully and legally protected areas designated to conserve and/or restore the integrity of biodiversity-rich natural areas with their underlying ecological structure and supporting natural environmental processes. Natural processes are therefore left essentially undisturbed from human pressures and threats to the area’s overall ecological structure and functioning, independently of whether those pressures and threats are located inside or outside the strictly protected area*’.

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[86] See e.g. EEA (2022) Carbon stocks and sequestration in terrestrial and marine ecosystems: a lever for nature restoration?, https://www.eea.europa.eu/publications/carbon-stocks-and-sequestration-rates

[87] IUCN (2008, revised 2013) Guidelines for applying protected area management categories, https://portals.iucn.org/library/node/30018

[88] European Commission Staff Working Document SWD(2022) 23 final - Criteria and guidance for protected areas designations, https://environment.ec.europa.eu/publications/criteria-and-guidance-protected-areas-designations-staff-working-document_en

The Society for Ecological Restoration (SER) defines restoration as "*the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed*."[89] Restoration seeks to initiate or accelerate ecosystem recovery through the creation of the necessary conditions rather than carrying out actual work of ecosystem recovery. Within both approaches, a choice was made to **prioritise non-intervention management**, since it ensures both the highest levels of carbon sequestration and most importantly guarantees the surest storage of carbon, especially in ecologically developed and healthy ecosystems.

Section 4.2 below describes in more detail the state of European forest- and wetland ecosystems and what NbS would be required to protect and restore them.

Overall methodology to the CBA

The analysis of costs and benefits in section 4.3 compared 'protection' and 'restoration' costs and benefits per unit area to establish CBA-ratios, and estimated marginal abatement costs that could be compared to alternative RECCS strategies. It should already be noted here that establishing standard protection and restoration costs at a European level is by definition a misrepresentation of most local realities due to variations in, among other things:

- Ecological features of different forest- and wetland ecosystem types across Europe
- Ecological baseline condition of forest- and wetland ecosystems
- The type and magnitude of protection- and restoration measures required
- Different price levels for the same type of measures in different European regions

Developing standard costs for benefits is even more challenging, as ecosystem service valuation studies often assess different combinations of services and different methods to calculate value. While monetising benefits of carbon removal is relatively straightforward, as a tonne of carbon is the same across Europe and has an established market price, for more intangible and less standardised benefits this is more difficult. For this reason, and the specific focus of this study on climate change strategy, only cost-benefit analyses were made for carbon (capture + storage). However it should be kept in mind that if other ecosystem services had been accounted for, benefit-cost ratios would have looked even more favourably.

Representative cost- and benefit data for the European region was obtained from previous studies for the European Commission on the implementation of the EU Nature Directives and the Natura 2000 network of protected areas[90]; the implementation of Target 2 of the EU Biodiversity Strategy to 2020 on restoring ecosystems and their services[91], a European-wide study on the costs of restoration measures in the EU based on an assessment of LIFE projects[92], and the impact assessment study on legally-binding

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[89] SER webpage 'What is Ecological Restoration?', https://ser-rrc.org/what-is-ecological-restoration/ See also: https://www.ser.org/page/SERStandards

[90] Gantioler, et al., (2010) Costs and Socio-Economic Benefits associated with the Natura 2000 Network, Report to the European Commission. Institute for European Environmental Policy (IEEP), London, https://ieep.eu/publications/costs-and-socio-economic-benefits-associated-with-the-natura-2000-network/

[91] Tucker, G. et al., (2013) Estimation of the financing needs to implement Target 2 of the EU Biodiversity Strategy. Report to the European Commission. Institute for European Environmental Policy (IEEP), London, https://ieep.eu/publications/estimation-of-the-financing-needs-to-implement-target-2-of-the-biodiversity-strategy/

[92] Dietzel, A. & Maes, J. (2015) Costs of restoration measures in the EU based on an assessment of LIFE projects. Joint Research Centre. Report EUR 27494 EN

EU nature restoration targets[93]. These more extensive studies collected cost- and benefit data for different measures and from different sources across Europe, and by taking median cost- and benefit data per unit area established CBA's for different broad ecosystem types. To calculate carbon benefits, the analysis drew on a scoping analysis for the European Environment Agency that collected carbon stock- and sequestration data for different natural habitat types in the EU[94].

4.2 Most appropriate Nature-based Solutions with forest and wetland ecosystems

4.2.1 Forest ecosystems

Definition

The official international definition of forest land is "land spanning more than 0.5 hectares with trees higher than five meters and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. Based on this definition, forests cover around 35% of the European and 40% of the EU land surface[95], which makes Europe one of the most forest-rich regions on the planet.

Broadly-speaking, Europe has three main types of forest ecosystems (maps of their distribution are included in Annex C):

- **Deciduous temperate forests**: The most widespread forest type, occurring across Europe from Ireland to the Ural mountain range, and from coastal Norway to Southern Greece. Characterised by predominantly broadleaved trees that are very productive in summer but leafless in winter.
- **Boreal lowland forest, and temperate high montane forests and woodlands,** hereafter 'boreal' and 'mountain' forests, because of snow are dominated by needle-leaf coniferous tree species better adapted to this than broadleaved species. Because of cold these forests have a shorter growing season too, especially in Northern Europe. Boreal forests are most widespread in the Scandinavian and Baltic countries and northwest Russia. Mountain forests occur at higher altitudes in the Alps, Pyrenees, Carpathians, and Dinaric Alps.
- Temperate pyric sclerophyll forests (hereafter '**Mediterranean forests**') that occur in more fire-prone regions in Southern Europe. Because of this, Mediterranean forests have a more open canopy of hard-leaved trees than deciduous temperate forests. Productivity of Mediterranean forests is more limited than temperate deciduous forest because of seasonal drought, hot summers, and often less fertile soils.

Ecosystem services, including climate benefits

Forests can provide a range of important ecosystem services, and primary and old growth forests typically provide these at a higher level. These ecosystem services can bring a range of monetary and non-monetary benefits to society. The most important non-provisioning ecosystem services include[96,97]:

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[93] Trinomics, IEEP, UNEP-WCMC and IUCN (2022) Impact assessment study to support the development of legally binding EU nature restoration targets. The findings of which were presented in EC Staff Working Document (2022) 167 final with the Impact Assessment accompanying the proposal for a Regulation on Nature Restoration. Both can be downloaded from: https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

[94] Hendriks, K., et al., (2020) Carbon storage in European ecosystems; A quick scan for terrestrial and marine EUNIS habitat types. Wageningen, Wageningen Environmental Research, https://www.eea.europa.eu/publications/carbon-stocks-and-sequestration-rates

[95] Eurostat (2023). Data for 2021. Forests, forestry and logging. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Forests,_forestry_and_logging

[96] JRC (2021). Mapping and assessment of primary and old-growth forests in Europe

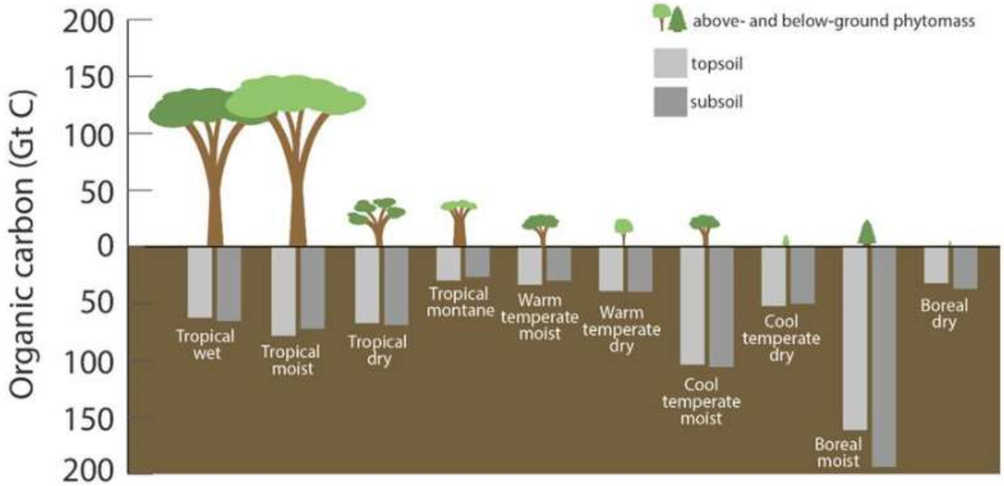
[97] Based on: Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-Being: Synthesis. Island Press

- **Regulating:** Carbon sequestration and storage; Climate regulation; Air quality regulation; Water regulation; Erosion control; Flood control; Pest and disease control; Pollination;
- **Cultural:** Recreation and tourism; Spiritual and religious; Aesthetic values; Educational and scientific values;
- **Supporting:** Soil formation and nutrient cycling; Habitat provision; Primary production;

In terms of carbon sequestration and storage in focus of this study, forests in the European region do not store as much above-ground carbon as tropical forests, however overall carbon storage in European forests is still considerable especially considering the large forest area in Europe. More importantly, forests in the relatively temperate and moist European region are able to store particularly large amounts of below-ground carbon over time (Figure 4-1).

A similar gradient can be seen within the three broad forest types *within* Europe: Forests in warmer regions store relatively higher amounts of organic carbon above-ground, and relatively lower amounts below-ground. Forests in cooler regions store relatively lower amounts of carbon above-ground, but relatively more carbon below-ground, especially under wetter conditions that besides cold limits decomposition of organic matter. Table 4 .3 shows estimates for carbon stock and sequestration rates for common European forest ecosystem types. It shows how both temperate and Mediterranean broadleaved forests generally have larger carbon stocks than coniferous boreal and mountain forests, and that boreal and temperate deciduous forests have significantly higher sequestration rates than Mediterranean and mountain forests. Since temperate deciduous forests are both most common in the European region, and provide the largest climate benefits, they were used as a proxy for forests in the CBA (see section 4.3).

Figure 4-1 Carbon stored in different forest ecosystems[98]



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[98] Taken from: Janowiak, M., et al., (2017) Considering Forest and Grassland Carbon in Land Management. USDA Forest Service, General Technical Report WO-95, https://www.fs.usda.gov/research/treesearch/54316

Table 4-1 Carbon stock and sequestration rates for common European forest ecosystem types

Forest ecosystem type	Carbon stock (tCO_2/ha)			Potential carbon sequestration rate ($tCO_2/ha/year$)
	Min	Mean	Max	Mean
Boreal forests	275	550	825	11.0
Temperate deciduous forests	275	644	1012	12.1
Mediterranean forests	406	638	869	7.7
Mountainous forests	184	434	684	6.9
Average used for this study[99]		**562**		**10.4**

Source: Adapted from Hendriks, 2020, converted from tC to tCO2 and per hectare (ha) values

Ecosystem condition and threats

Over the last centuries, most of Europe's natural forests have been replaced by managed forests. Today, most of the EU's forests (93%) are considered semi-natural and available for wood supply (FAWS). As a result, today more than 70% of the FAWS in Europe is even-aged, and 33% of total forest area consists of a single tree species[100]. As a result, the European Ecosystem Assessment concluded that while provisioning ecosystem services (especially timber production) were maximised, it came at the expense of a wide range of other ecosystem services including the critical regulating service of carbon sequestration and storage, climate regulation and habitat provision[101].

Only 3-4% of forest in the EU is considered 'primary or old-growth' (hereafter OGF) in line with the FAO definition of OGF: "*Naturally regenerated forest of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed*". Given the focus of this study on ecosystems in a relatively healthy ecological condition, this further chapter focusses on:

1) OGF forests
2) Semi-natural forests considered to be in a near-natural state in terms of ecosystem condition.

For the latter, forest habitats protected under the EU Habitats Directive (HD) were taken as a proxy, since they provide the only common EU-wide classification for which both extent/location and condition data is available.

Data on conservation status of HD Annex I forest habitats, reported by the EU's 27 Member States to the European Environment Agency, shows that while forest habitats exhibit the highest proportion of improving trends among the assessments (13%), almost a third of assessments (31%) still show an unfavourable (poor or bad) conservation status. In the boreal and Pannonian biogeographical region, not a single assessment showed a favourable conservation status (Figure 4-2). By far the most-reported high-level negative man-made pressures degrading HD Annex I forest habitats are related to forestry

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[99] Weighted average based on the relative extent of the four broad forest ecosystem types across the wider European region based on national forest inventories collected for the 2020 State of Europe's forest report: Coniferous 46% (mostly boreal coniferous, but also Alpine coniferous), broad-leaved 39% (mostly temperate broad-leaved, and broad-leaved evergreen), and mixed 18% (mostly mountain forest at lower altitude), https://foresteurope.org/state-of-europes-forests/

[100] Forest Europe (2020) The State of Europe's Forest 2020, https://foresteurope.org/state-of-europes-forests/

[101] Maes, J., et al (2020) Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment, EUR 30161 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17833-0, doi:10.2760/757183, JRC120383., Chapter 3.3 'Forest ecosystems (pp 118-147), https://publications.jrc.ec.europa.eu/repository/handle/JRC120383

(one-third of assessments), followed by invasive alien species and agriculture and the modification of water regimes (Figure 4-3).

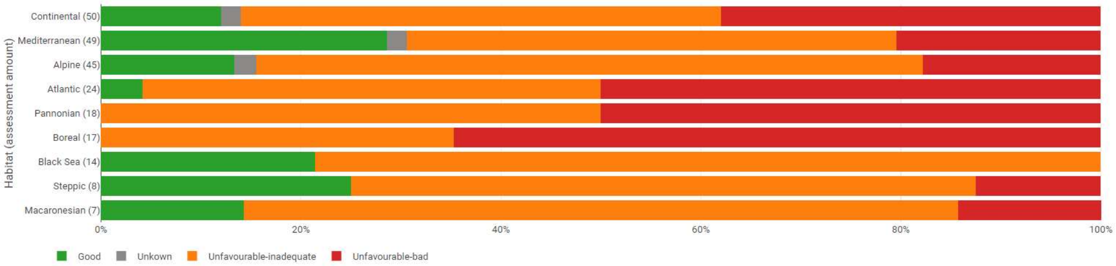
In terms of climate impact, the risk of remaining natural forests including OGF to be put under wood production poses the greatest risk of carbon losses: Commercial forestry would normally take and sell the most commercially interesting oldest trees from newly-exploited stands. After that, trees would be harvested after a growth period required to derive maximum commercial value from their felling (optimal rotation age), which for all species is well-before their natural age. In addition, regular thinning would take place to allow the most commercially-interesting trees to grow faster. As a consequence, the standing carbon stock of forests will be structurally-lower under forest managed for wood supply. In addition, forest management practices will usually accelerate below-ground carbon losses, e.g. because of maintenance of drainage (and herewith enhanced oxidation) and use of heavy machinery on forest soil.

In terms of sequestration, while trees in plantations generally-speaking sequester the highest amount of carbon per hectare because of their enhanced growth rates, a lot of this carbon disappears again through harvesting and above-mentioned management practices, especially under more unsustainable management practices such as large-scale clear cutting. As a consequence net sequestration is reduced, and both above- and below-ground carbon stocks build up much more slowly than they would have under natural conditions (if not resulting in net losses under unsustainable forestry).

Lastly, the impact on forest condition of invasive alien species, and other disruptive changes in species composition and abundance such as pest outbreaks, has been found to be smaller and more short-lived in ecologically healthy forests than in those under productive management.

Therefore protecting remaining OGF and near-natural forests from forestry and other key pressures, and restoring them where needed, represents the most effective strategy to both conserve critical carbon stocks and carbon sequestration at their fullest potential over time. While also improving key other ecosystem services such as habitat preservation.

Figure 4-2 Conservation status of forest habitats for each biogeographical region in EU28 in 2018, in percentage



Source: EU Habitats Directive Article 17 reporting[102]

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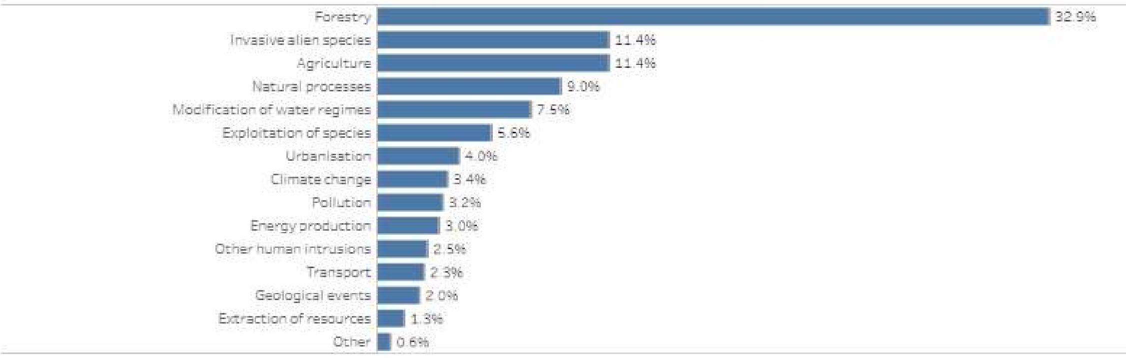
[102] EEA (2020) Reporting from EU Member States under Article 17 of the EU Habitats Directive. Figure taken from the EU's Forest Information System (FISE): https://forest.eea.europa.eu/topics/forest-and-nature/forest-habitats

Figure 4-3 Most-reported high-level pressures on the ecological condition of EU-protected forest habitat types



Source: EU Habitats Directive Article 17 reporting[103]

Key measures required for forest protection and restoration, and the nature of their costs

The healthy, old-growth forests in scope of this analysis would in principle not require conservation management, since they are self-organising and because of their good ecological condition they would be able to regenerate naturally from minor pressures. Moreover, putting these forests under legal protection, or increasing the strictness of existing protection, would only represent a minor administrative cost which was not costed as it can be implemented through regular updates of protection rules.

Nevertheless, some costs will be involved to ensure effective protection. Three broad groups of measures that represent more substantial costs under forest protection were accounted for in this analysis, which are briefly-introduced here:

- **Land acquisition:** Public ownership helps facilitate long-term protection, as private owners who may not have put priority natural forest into productive use may change their mind over time, risking the long-term protection. Since mature natural forest is commercially interesting, land acquisition costs per hectare can be substantial, but are one-off. Since close to 40% of forest in the EU is publicly-owned and close to 50% in the wider European region is publicly-owned[104], large-scale forest acquisition would not be needed everywhere.
- **Compensation for private landowners in and adjacent to protected forest (recurring):** For priority forest under private ownership that cannot be acquired by the state, recurring payments would compensate private landowners (and indirectly any foresters using this land) for income foregone caused by prohibiting harvesting. Compensation would also be available for land owners on the borders of protected forest to help reduce edge effects.
- **Recurring maintenance management:** Ensuring protection will require some recurring management costs for e.g. monitoring, inspections, more up-stream measures to prevent external threats e.g. forest fire, drainage or illegal logging.

For **forest restoration** it was also assumed that the other, slightly-degraded, but still high nature & carbon-value forests in scope of this study can rely for a large part on natural regeneration, or assisted natural regeneration. And that therefore both the width and intensity of measures and their cost would

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[103] EEA (2020) Reporting from EU Member States under Article 17 of the EU Habitats Directive. Figure taken from EEA State of Nature dashboard 'Pressures & threats', https://www.eea.europa.eu/en/topics/at-a-glance/nature/state-of-nature-in-europe-a-health-check/explore-nature-reporting-data

[104] FAO Global Forest Resource Assessment data on the website of the Forest Information System for Europe (FISE): https://forest.eea.europa.eu/topics/forest-basic-data/key-facts

therefore be lower than in more degraded forest ecosystems. The following types of restoration measures were nevertheless accounted for in the analysis of costs:

- **Restoration management (recurring)**: For example local and low-impact measures to enhance structural and functional diversity (e.g. in age classes and/or tree species) and restoration monitoring.
- **Hydrological restoration (one-off):** As highlighted above, the modification of water regimes remains an important pressure on forests, and e.g. removing key obsolete drainage infrastructure rather than simply stop maintaining them can help accelerate recovery.
- **Removal of non-native and invasive species (one-off):** This could be both the removal of historic non-native plantations to enable natural regeneration of native tree species, or the removal of invasive species that could prevent or slow natural regeneration.

For each of these cost items a per unit cost was established representative for the European region (which, as explained in section 4.1.2, is challenging because of differing starting points), and after that an assessment on the percentage of protected forest area the measure would be required. From this, an average cost per unit area was established.

4.2.2 Wetland ecosystems

Wetland ecosystem definition, ecosystem services, and scope of analysis

The most common definition of wetlands is that of the 1971 UN RAMSAR Convention on Wetlands of International Importance, which reads as follows: *'Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.'*

Similar to forests, peatlands and salt marshes provide a wide range of other ecosystem services. Given this study's focus on climate benefits, the scope of analysis was narrowed down to two types of wetland ecosystems of greatest importance from a climate action perspective globally i.e. those with the largest carbon stocks or/and sequestration. These are broadly two groups of ecosystems:

- **Palustrine wetlands:** Those with permanent or frequent saturation of the soil with water, which results in oxygen deprivation below ground, which in turn suppresses microbial activity. In most of these systems, production or organic matter exceeds decomposition, which results in peat accumulation.
- **Intertidal areas**: Ecologically highly productive systems where local sequestration by plants and algae is supplemented by external sources delivered by rivers, currents, and tides. This enables the rapid accumulation and, depending on the ecosystem type, also substantial storage over time.

Within these two still relatively broad biomes, a further selection was made to two more specific functional groups of particular climate-relevance in the European region:

- **Boreal, temperate and montane peat bogs**[105]**:** Peat bogs, while sequestering carbon relatively slowly compared to other ecosystems, can store sequestered carbon in very large quantities and over very long timescales. The intrinsic water retention capability of peat forming mosses mean they create a permanent situation of low decomposition, and as such can grow large layers of organic material, each growing season living vegetation covers that of past years. As

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[105] IUCN Global Ecosystem Typology webpage on boreal, temperate and montane peat bogs (TF1.6, part of Palustrine wetlands biome), https://global-ecosystems.org/explore/biomes/TF1

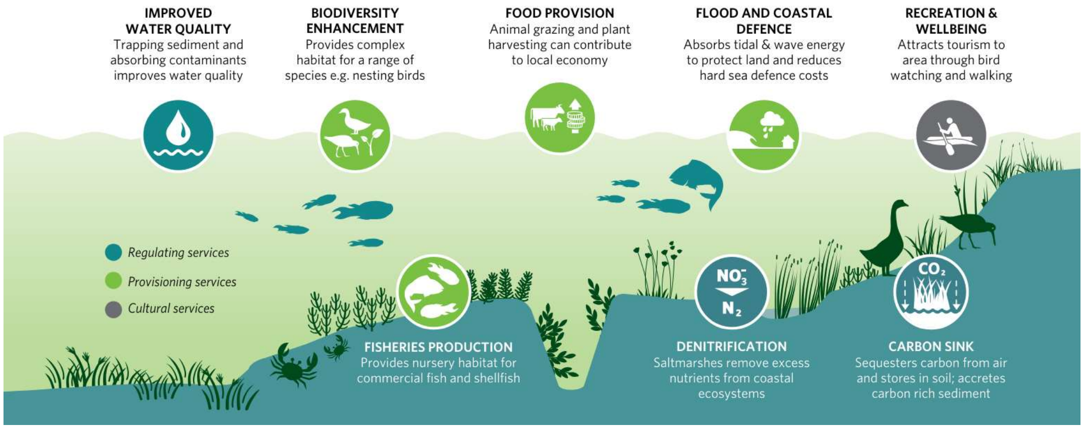
long as water is sufficiently-available, peat mosses can keep storing water at timescales unseen in other ecosystems. As a result, peat bogs in the boreal-subarctic and temperate areas of the world account for up to 40% of the world's soil carbon. Peat bogs are found across the European region, but particularly common in the boreal- and northwest Atlantic regions (see distribution maps in

- **Coastal saltmarshes[106]:** Salt marshes occur in relatively sandy or muddy coastal areas and, especially in ecologically highly-productive river deltas, can sequester relatively quickly large amounts of carbon. Unlike the also highly productive intertidal mud- and sandflats, salt marshes can because of soil formation also store substantial carbon over time. Coastal salt marshes are also relatively fast to respond to re-creation or restoration measures, as they are used to dynamic coastal conditions. As such, they present a powerful solution in nature-based climate change mitigation as absorbing carbon hard and fast.

These two ecosystem types are also of particular importance for European climate change *adaptation* action, which in turn will help reduce risks on nature-based climate change mitigation. Two adaptation benefits should be highlighted in particular:

- **Freshwater quality and -availability services from peatlands**: Because their unique water retaining feature, peat bogs act as landscape-scale sponges and filters, retaining and slowly-releasing high-quality freshwater throughout the year. Especially in mountainous regions, peatlands help them act as 'water towers' that ensure freshwater availably downstream. Especially in agricultural regions where freshwater is scarce in the growing season, e.g. around the central-European mountain ranges, the monetary value of these services is substantial.
- **Storm and flood risk management services from salt marshes**: Salt marshes absorb tidal and wave energy, which can protect inside lands from marine influence in a much more cost-effective way than hard infrastructure, especially if other ecosystem services are accounted for.

Figure 4-4 Ecosystem services provided by saltmarshes[107]



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[106] IUCN Global Ecosystem Typology webpage on Coastal saltmarshes and reedbeds (MFT1.3, part of Brackish tidal biome): https://global-ecosystems.org/explore/groups/MFT1.3

[107] Taken from Hudson, R., Kenworthy, J. and Best, M. (eds) (2021) Saltmarsh Restoration Handbook: UK and Ireland. Environment Agency, Bristol, UK., https://catchmentbasedapproach.org/learn/saltmarsh-restoration-handbook/

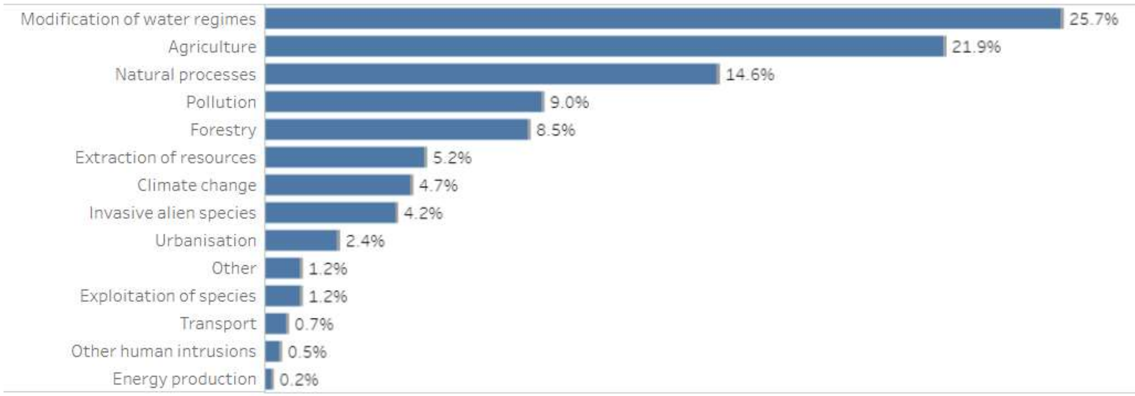
Wetland ecosystem condition

Despite the broad range of services that healthy wetlands provide to human livelihoods, wetlands represent the ecosystem in Europe with the worst condition, with 90% of wetland habitats in poor or bad condition[108]. Historically, wetlands have been suffering from a continued degradation of their habitats from multiple pressures mainly by drainage and conversion into agricultural land and forests. Considering they are already in a poor condition, the wetlands assessed by underpinning data show no improvement in the last two decades, with current trends showing either no changes or yet further degradation.

Moreover, multiple pressures on wetlands are high and do not seem to decrease but rather remain unchanged. Indeed, among the indicators assessed, only nutrient enrichment shows a significant decrease linked to effective regulation. The three most frequently reported high-level pressures on EU protected (and very likely also unprotected) bogs, mires and fens are currently 1) The modification of water regimes; 2) Agriculture (mostly under-grazing, but also overgrazing and other pressures); and 3) Natural succession (Figure 4-5). These three pressures are very interrelated, as drainage on peatlands usually spurs vegetation succession, which without recovery of high-water tables can only be suppressed through unnaturally high levels of grazing.

The historic degradation of **salt marshes** in the European region is similar to that of inland wetlands, and it has been estimated that Europe lost 50% of its salt marsh habitat to coastal development alone[109]. Remaining salt marshes faces multiple pressures, of which infrastructure development, changes in agricultural practices and IAS are the most important both in the Atlantic and Mediterranean region[110].

Figure 4-5 Most-reported high-level pressures on the ecological condition of EU-protected bogs, mires, and fens



Source: EU Habitats Directive Article 17 reporting[111]

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[108] Maes, J., et al (2020) Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment, EUR 30161 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17833-0, doi:10.2760/757183, JRC120383., Chapter 3.3 'Forest ecosystems (pp 118-147), https://publications.jrc.ec.europa.eu/repository/handle/JRC120383

[109] Airoldi, L. & Beck, M. (2007) Loss, Status and Trends for Coastal Marine Habitats of Europe, https://www.researchgate.net/publication/228865959_Loss_Status_and_Trends_for_Coastal_Marine_Habitats_of_Europe

[110] EEA (2020) Reporting from EU Member States under Article 17 of the EU Habitats Directive. Figure taken from EEA State of Nature dashboard 'Pressures & threats', https://www.eea.europa.eu/en/topics/at-a-glance/nature/state-of-nature-in-europe-a-health-check/explore-nature-reporting-data

[111] EEA (2020) Reporting from EU Member States under Article 17 of the EU Habitats Directive. Figure taken from EEA State of Nature dashboard 'Pressures & threats', https://www.eea.europa.eu/en/topics/at-a-glance/nature/state-of-nature-in-europe-a-health-check/explore-nature-reporting-data

Key measures required for wetland protection and restoration, and the nature of their costs

For both peatlands and saltmarshes, the same types of broad cost items were accounted for as under forest protection (land acquisition, compensation payments and recurring maintenance management) however with different costs per hectare. For example, per unit cost for peatland acquisition are substantially lower than for mature forests, and farmland acquisition for coastal wetland restoration is in turn costlier per unit area than for forests.

Similar as for forest ecosystems, for both peatland and saltmarsh restoration the costs for restoration management (recurring), rewetting measures (one-off) and removal of alien species (one-off) were accounted for, however with different types cost levels. Other measures which differed between the two ecosystem types are included in Table 4-2.

Table 4-2 Restoration measures and their costs included in the analysis

Peatland restoration measures	Salt marsh restoration measures
• Rewetting – i.e. The process of returning drained wetlands to their natural hydrological conditions. It involves blocking drainage channels and reprofiling. Has a substantial one-off costs per unit area and applies to all peatland area, and therefore represents a significant share of one-off costs for peatland restoration. • Removal of acidified top soil / reprofiling: Peat soils which have long been drained and overgrown, will have acidified soils which prevent the recovery of peat forming mosses. Top soil removal to help overcome this is costly per unit area, but will not be required on large surfaces. • Reintroducing peat-building vegetation– i.e. Restoring native vegetation, such as peat mosses (for bogs and fens) or reeds and sedges (for mires) can help accelerate recovery of peat formation. It is particularly costly however, will only be required very locally, and therefore impact on overall per hectare costs are limited.	• One-off earth- and grey infra works for rehabilitation of formerly dammed agricultural land (one-off) • Salt marsh restoration management after rehabilitation (both one-off and recurring)

4.3 Cost-benefit analysis

4.3.1 Comparison of impacts per NbS

The following table 4-3 takes the case of a hypothetical EUR 100 million investment in the main NbS discussed in this chapter, to compare the main emissions and cost impacts. This shows that large forest and wetland areas could be conserved for the initial investment and cost effective emissions savings could be achieved. The largest influence on the abatement cost is the ongoing annual costs for protection and restoration, if this could be reduced then the marginal abatement costs would also reduce. The results on emissions savings and the marginal abatement costs can be compared with Table 3-8 in Chapter 3 to contrast with the costs and impact of investments in renewable energy. These show that the measures are very comparable in terms of marginal abatement cost with the renewable energy technologies. It should be noted that the one-off costs are a weighted average based on assumptions described in table 4-4 below, in individual cases the one-off costs can be higher or lower, which would influence the marginal abatement cost.

Table 4-3 Overview of key impacts for selected NbS on the basis of EUR 100 million investment

	Forest protection	Forest restoration	Peatland protection	Peatland restoration	Saltmarsh protection	Saltmarsh restoration
Cost [EUR/ha] - one-off investment (weighted average 2025-2050 costs)	2 276	1 988	711	1 760	5 619	7 347
Cost [EUR/ha] - ongoing annual (incl. Year 1)	141	260	153	237	140	277
Area addressed* [thousand ha]	43.9	50.3	140.6	56.8	17.8	13.6
Per hectare emissions sequestered [tCO2e/ha/yr] *	2.3	9.4	2.8	2.8	8.2	8.2
Emissions sequestered [ktCO2e/yr]	103	472	387	156	146	111
Lifetime [years]	100	100	100	100	100	100
Marginal abatement cost# [EUR/tCO$_2$e]	**58**	**24**	**47**	**75**	**21**	**36**

Source: Own calculations

* By initial EUR 100 Million investment

\# Based on sequestered emissions only. For protection of carbon stocks due to avoided deforestation please refer to Table 4-6.

Note: The specific individual costs included as one-off and ongoing are listed in Table 4-4, as is the average cost of an individual one-off or annual measure contributing to the totals in the table. The values presented are weighted averages over the full lifetime of the RECCS.

4.3.2 Overall cost and benefits

Analysis of costs

Costs data for all measures described in the previous sections for the protection and restoration of forest and wetland ecosystems were collected from existing sources introduced in section 4.1.2 (Scope & methodology), and Table 4-4 shows the main sources of data and which additional sources were used to establish average costs of measures per unit area that can be considered representative for the European region. In case of diverging cost estimates, own estimates were made based on expert judgement.

Costs are presented per unit area (EUR/hectare), and a distinction was made between one-off and recurring costs. One of the key assumptions to be aware of is that related to land acquisition costs. It is assumed that any land protected or restored would either need to be acquired or the landowner compensated. For this reason, within each habitat and option (protection or restoration), the total assumption for land acquisition and compensation sums to 100%. As around 60% of EU forest is privately owned, and compensation requires less upfront investment than land acquisition, the share of compensation in the total is higher than for land acquisition, so that more land can be treated sooner.

The costing per unit area considered that not each protection or restoration measure would need to take place on the entire area under protection/restoration management. For example, inspections would not need to take place in every hectare of forest, but mostly in those places where there is a specific need (e.g. higher risk of illegal logging). Or the removal of invasive alien species, while very costly when considered per hectare, in most cases is only needed in relatively minor shares of the total area under protection or restoration. For such measures the per hectare cost was corrected for the share of area on which the measure was estimated to be applied on (see columns '% of area required' in Table 4-4).

For each cost item an assessment was made whether the cost would be stable or change over time. While most cost items were considered stable, for some an increase was estimated. The main assumption for this was that countries would prioritise 'low-hanging fruit' areas for protection and restoration, with relatively low cost for high climate (and other) benefits, and after that areas where relative costs would be higher for the same environmental outcomes. For example, land acquisition has a high cost per hectare, and therefore it was assumed that countries would firstly prioritise measures on public land (e.g. increasing the strictness of protection of state-owned nature protection areas by introducing non-intervention management) and with private landowners most open to compensation. After these lower cost opportunities become scarcer it is likely that land acquisition becomes more necessary.

The full overview of individual measures, their unit costs and % area applied is provided in Table 4-4 below. In chapter 6 the costs and shares are combined to establish weighted average protection and restoration costs for each ecosystem type.

Table 4-4 Inputs to estimate average per hectare costs for the protection and restoration of forests-, peatlands- and salt marshes

					Share of area on which measure is applied or required			Main source
Ecosystem type	**NbS option**	**Measure**	**Nature of cost**	**Mean cost/ha**	**2025-2030**	**2031-2040**	**2041-2050**	
Forests	Protection	Land acquisition of remaining unprotected high-value forest on private land	One-off (EUR/ha)	4550	20%	40%	60%	NLS, 2023[112]
		Compensation of remaining unprotected high-value forest on private land where land purchase is not possible	Annual (EUR/ha/y)	197	80%	60%	40%	Sarvašová et al., 2017[113]
		Buffer zones: Compensation to surrounding land owners to prevent edge effects	Annual (EUR/ha/y)	130	1%	1%	1%	Sarvašová et al.
		Recurring maintenance management (e.g. monitoring, inspections, preventing external threats e.g. forest fire, illegal logging)	Annual (EUR/ha/y)	46	100%	100%	100%	EC, 2022[114]
	Restoration	Land acquisition of remaining unprotected slightly degraded forests on private land	One-off (EUR/ha)	3000	20%	40%	60%	NLS
		Compensation where land purchase is not possible	Annual (EUR/ha/y)	130	80%	60%	40%	Sarvašová et al.
		Removal of non-native and invasive species	One-off (EUR/ha)	2265	1%	10%	25%	EC
		Hydrological restoration	One-off (EUR/ha)	170	5%	10%	20%	EC
		Buffer zones: Compensation to surrounding land owners to prevent edge effects	Annual (EUR/ha/y)	130	1%	1%	1%	EC
		Restoration forest management (e.g. enabling structural and functional diversity, e.g. in age classes, tree species, restoration monitoring and adaptive management)	Annual (EUR/ha/y)	500	30%	30%	30%	EC
		Recurring maintenance management (e.g. monitoring, inspections, preventing external threats e.g. forest fire, illegal logging)	Annual (EUR/ha/y)	46	100%	100%	100%	EC
Peatlands	Protection	Land acquisition of peatland on private land	One-off (EUR/ha)	1150	20%	40%	60%	NLS
		Compensation where land purchase is not possible	Annual (EUR/ha/y)	197	80%	60%	40%	Sarvašová et al.
		Buffer zones: Regulate drainage in surrounding lands (compensation)	Annual (EUR/ha/y)	130	10%	10%	10%	Sarvašová et al.
		Recurring maintenance management (e.g. monitoring, inspections, preventing external threats e.g. peat fire)	Annual (EUR/ha/y)	46	100%	100%	100%	EC
	Restoration	Land acquisition of peatland on private land	One-off (EUR/ha)	1150	20%	40%	60%	NLS
		Compensation where land purchase is not possible	Annual (EUR/ha/y)	130	80%	60%	40%	Sarvašová et al.
		Buffer zones: Regulate drainage in surrounding lands (compensation)	Annual (EUR/ha/y)	130	10%	10%	10%	Sarvašová et al.
		Rewetting: Ditch blocking, damming	One-off (EUR/ha)	542	100%	100%	100%	EC
		Removal of acidified top soil / reprofiling	One-off (EUR/ha)	859	2%	5%	10%	EC

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[112] NLS (2023) Statistical information. National Land Survey of Finland. Available at: https://khr.maanmittauslaitos.fi/tilastopalvelu/rest/v2023.1/index.html?lang=en#

[113] Sarvašová, Z., et al. (2017). Natura 2000 payments for private forest owners in Rural Development Programmes 2007–2013 – a comparative view. Forest Policy and Economics Forest policy and economics 99 (2019): 123-135

[114] European Commission Directorate-General for Environment (2023) Impact assessment study to support the development of legally binding EU nature restoration targets – Final report. Annex 3, Ecosystem specific assessments, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2779/673007

		Re-introducing peat-building vegetation	One-off (EUR/ha)	2302	1%	2%	3%	EC
		Removal of invasive species	One-off (EUR/ha)	2000	5%	10%	25%	EC
		Recurring restoration management (e.g. follow-up hydrological works, grazing management)	Annual (EUR/ha/y)	116	100%	100%	100%	EC
		Recurring maintenance management (e.g. monitoring, inspections, preventing external threats e.g. peat fire)	Annual (EUR/ha/y)	46	100%	100%	100%	EC
Saltmarsh	Protection	Land acquisition of saltmarsh on private land	One-off (EUR/ha)	11827	20%	40%	60%	Savills, 2023[115]
		Compensation where land purchase is not possible	Annual (EUR/ha/y)	197	80%	60%	40%	Sarvašová et al.
		Recurring maintenance management (e.g. monitoring, inspections, basic grazing management, preventing external threats e.g. recreation)	Annual (EUR/ha/y)	46	100%	100%	100%	EC
	Restoration	Land acquisition of unprotected salt marsh - outside the dike	One-off (EUR/ha)	11827	10%	20%	30%	Savills
		Land acquisition of unprotected salt marsh - inside the dike (e.g. managed realignment)	One-off (EUR/ha)	14995	10%	20%	30%	Savills (2023)[116]
		One-off earth- and grey infra works for rehabilitation of formerly dammed agricultural land	One-off (EUR/ha)	2000	5%	10%	25%	Own estimate based on EC (2022)
		Compensation where land purchase is not possible (outside the dike)	Annual (EUR/ha/y)	130	80%	60%	40%	Sarvašová et al.
		Recurring restoration management (e.g. follow-up works and dams, basic grazing management, preventing external threats e.g. recreation)	Annual (EUR/ha/y)	116	100%	100%	100%	EC
		Recurring maintenance management (e.g. monitoring, inspections, preventing external threats e.g. peat fire)	Annual (EUR/ha/y)	116	100%	100%	100%	EC
		Salt marsh habitat re-creation	One-off (EUR/ha)	1245	10%	20%	40%	Hudson et al., 2015[117]
			Annual (EUR/ha/y)	160	10%	20%	40%	Hudson et al.
		Re-wetting measures (e.g. removal of ditches/drainage)	One-off (EUR/ha)	542	50%	60%	70%	EC

Note: This table provides an overview of the main measures considered necessary across the European region to protect and restore the three broad ecosystem types in scope of this study. However, it does not provide an exhaustive overview of all measures that would be needed in any specific local context. Therefore, for many specific local perspectives, some measures included may be redundant or missing. Due to large variations in the land area on which certain measures would normally be required compared to others, and its impact on costs, a correction was made to account for this by estimating the likely share of land area brought under protection/restoration in each time period for which each measure would be required. This share in some cases can be expected to increase over time. For example land acquisition, which has a high cost per hectare, will initially likely only be needed on a small

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[115] Savills (2023) UK Farmland Values Survey value for most recent price for 'poor livestock' land (lowest price category), converted from GPB/are to EUR/ha: https://www.savills.co.uk/landing-pages/rural-land-values.aspx

[116] UK Farmland Values Survey value for most recent price of 'all land types' (=average farmland value), converted from GPB/are to EUR/ha: https://www.savills.co.uk/landing-pages/rural-land-values.aspx

[117] Synthesis of estimates from Hudson et al. (2015) Cost estimation for managed realignment-summary of evidence. UK, Environment Agency, Report –SC080039/R8, https://assets.publishing.service.gov.uk/media/6034ee49d3bf7f265dbbe305/Cost_estimation_for_managed_realignment.pdf

share of NbS projects because of remaining opportunities on public land. However, given the substantial share of ecosystems on private land, the share of land requiring purchase would grow over time as opportunities on public land become increasingly exhausted. The final column in the table provides the key source on which the per hectare cost was based, although it should be stressed that most of the costings were based on meta-studies taking median cost data of a larger number of studies (e.g. EC, 2022).

These calculated costs were then combined to establish average protection and restoration costs per hectare for each ecosystem type (see Table 4-5 below). This shows increasing average one-off (investment or capital) costs over time as the share of land requiring such costs also increases. Taking the example of the costs for forest protection in 2031-2040, the average one-off cost value of 1 365 EUR/ha is based upon the mean cost per hectare of 4 550 EUR/ha and the assumed 40% of all land brought into protection requiring this cost, i.e. 4 550 * 0.4 = 1 820 EUR/ha[118].

Table 4-5 Average per-hectare cost of protection and restoration of forests and wetlands in Europe

Ecosystem type	NbS option	Cost (€/ha)			
		One-off cost (first year only)			Recurring (annually, including Year 1)
		2025-2030	**2031-2040**	**2041-2050**	
Forests	Protection	910	1 820	2 730	141
	Restoration	631	1 444	2 400	260
Peatlands	Protection	230	460	690	153
	Restoration	912	1 291	1 887	237
Salt marshes	Protection	2 365	4 731	7 096	140
	Restoration	3 178	6 139	9 424	277

Analysis of benefits

Benefit estimates of the ecosystem services offered by forests and wetlands have been made[119]. These estimate for each ecosystem type the monetary values of their ecosystem services. Table 4-6 below summarises the monetary values per hectare per year of the carbon sequestration service and total ecosystem services offered by the three targeted ecosystems, with the monetised values based on a price of 100 EUR/tCO_2. The estimates are median values, noting that the range of benefits can be quite high. The total ecosystem services value includes assumptions to account for biodiversity conservation, regulating services (e.g. water and soil quality, flood prevention, resilience against natural disasters), cultural services (e.g. aesthetic, spiritual, and recreational values), and socio-economic benefits (e.g. employment opportunities, human health).

Table 4-6 Monetised benefits offered by forest, peatland and salt marsh ecosystems at assumed value of 100 EUR/tCO_2

Ecosystems	Carbon storage (tCO_2e/ha)	Carbon stock value (EUR/ha)	Carbon sequestration (tCO_2e/ha/y)	Carbon sequestration value (EUR/ha/y)
Forests	616	61 643	9.4	939
Peatlands	720	72 045	2.8	275
Salt marshes	1 140	114 033	8.2	818

Source: Adapted from Hendriks, 2020, converted from tC to tCO2 and per hectare (ha) values, and carbon price of EUR 100/tCO2.

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[118] This differs from the values in Table 4-3 as the values in Table 4-3 are an average across the full 2025-2050 period.

Recommended hierarchy for prioritising investment in NbS options

Based on the cost-benefit analysis in the previous section, the following hierarchy for prioritising investment in NbS options in EU forests and wetlands was drawn up to inform the RECCS examined in chapter 6:

1. **Full and strict protection of remaining pristine forests (i.e. old-growth and primary) and -wetlands:** NbS options to protect existing pristine high-biodiverse and carbon-rich forests and wetlands should be prioritised as they are the most cost-effective and provide the highest benefits in the immediate future. Most of these areas in the EU are already under some form of protection, but only a modest share is under strict protection[120]. Increasing the area of these critical ecosystems under strict protection will therefore be a first priority. In the case of forests, the strict protection of remaining primary and old-growth forest to protect them from harvesting of woody biomass should be a first priority.
2. **Full and strict protection of managed slightly-degraded natural forests and wetlands of strategic importance:** Only once investment needs for the areas under (1) are covered, should remaining resources be prioritised in strictly-protecting those ecosystems most critical to their long-term health. This concerns mostly mature forests and wetlands of high ecological integrity and high biodiversity and climate value that A) are directly surrounding remaining priority ecosystems under (1), as well as those that (B) are further from remaining hotspots but have a particularly important role in ensuring their ecological coherence at landscape scale which is also important for adaptation. Due to the high regenerative capacity this protection would maintain and enhance, costs would be substantially lower than in younger or heavily-degraded areas and will have a higher success rate. In addition, healthy and resilient ecosystems provide better risk profiles for biodiversity and climate benefits achieved through recovery to be sustained over time. Lastly, opportunity costs will be lower in areas already managed for nature conservation – and legal protection would further guarantee the longer-term maintenance of NbS benefits. Therefore NbS options for restoration should be prioritised in and around already protected core areas.
3. **Restoration of slightly-degraded forests and wetlands of strategic importance under (2):** Once investment needs for the full and strict protection of forests under (1) and (2) are met, remaining resources should be prioritised to the ecological restoration of forest and wetland areas under (2). For lightly-degraded forests of remaining high ecological integrity, protection under (2) could provide sufficient passive restoration benefits to recover naturally. However for the majority of forests some additional active measures will be required. In some cases where local conditions are suitable from both an ecological and socio-economic perspective, restoration measures could also include re-establishment of forest around existing core areas through natural or assisted natural regeneration. In degraded peatlands and other -wetlands ecosystems, a greater share of active restoration measures are usually required, such as rewetting. These may involve substantial one-off costs depending on the location. This should be considered when prioritising restoration measures.
4. **Enhancing protection of other forests and wetlands:** Once investment needs for the full and strict protection and restoration of pristine- and slightly degraded other priority areas are met, remaining resources could be targeted to improving the protection regime of secondary forest and wetlands with potential to recover to primary native ecosystems. This would normally require an increase in the strictness of the legal (statutory) protection regime, either

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[120] Strict protection as in true non-intervention: No extractive use nor other human activity that negatively impacts biodiversity.

through nature protected areas or other effective areas-based conservation measures (OECMs), but could also be supported by relevant supporting interventions to increase the effectiveness of protection in a broader sense such as capacity-building (e.g. for monitoring), leveraging innovative sources of financing, or improve monitoring and enforcement capabilities.

5. **Restoration of other forests and wetlands:** Any remaining resources should be prioritised for restoration measures in the forests and wetlands under (4). These measures could include more land-sharing options, e.g. to increase sustainable forest management practices. The advantage of restorative NbS in existing or new area-based conservation areas is that they usually have good monitoring of ecological condition and management planning with identified restoration needs, objectives and -measures (which are often underfunded). Investing in NbS that restore in these areas therefore have a better risk profile, and therefore be preferable over restoration of degraded areas with higher pressures, or re-creation measures (e.g. afforestation of former agricultural land) which are costly and will only generate benefits after long periods of time – especially with low levels of legal protection of re-created natural ecosystems.

The following two sections briefly reflect on the implications of this hierarchy for policy and investment needs in the European region for forests and wetlands respectively. Because of the significant investment needs required to meet priorities 1 to 3 above, priorities 4 and 5 were not further quantified. Unfortunately no detailed estimations of national costs for saltmarshes could be made in the same way as for forests and peatlands, due to a lack of a similar national-level data on their distribution. The last section of this chapter reflects to what extent these needs could be met through diverted biomass subsidies, combined with other investment already available.

4.3.3 Considerations at country level

The order principles outlined in the previous section is relevant for all European countries and most European countries already have made legally-binding conservation commitments in all three broad ecosystem types considered in this study, where they have such ecosystems on their territories[121]. In this light it is not really appropriate to, as in the previous chapters on renewable energy- or energy efficiency alternatives, prioritise one NbS option over another for individual Member States.

Nevertheless, starting conditions between countries are significantly different, which may require a different emphasis between priorities. Table 4-7 provides an attempt to classify European countries based on their potential in providing cost-effective NbS through the conservation of forest ecosystems, for example based on the baseline condition of remaining forests (which would require lower costs per hectare), or lower price levels (which would protect or restore larger areas). Due to the large diversity and poorer data quality on wetlands, only country-specific considerations for forests are provided. In any case, in each of the countries close cooperation and engagement with state forest agencies will be needed to deliver the targeted RECCS forest protection and restoration benefits.

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[121] For example under the EU Habitats Directive (all three ecosystem types), the EU Water Framework Directive (in case of coastal wetlands), and upcoming EU Nature Restoration Regulation (all three ecosystem types.

Table 4-7 Country specific considerations for NbS in forests

Countries	Profile of countries	Priority emphasis
Bulgaria	**High potential countries, meeting some or all of the following criteria:** • Substantial remaining extent of primary and old-growth forest, or near-primary forest in good ecological condition • Relatively good ecological coherence of remaining primary- or near primary forest areas, and forest area more generally • Relatively high share of primary and near-primary broadleaf forests, which have relatively greater climate- and natural habitat benefits • Relatively high area of primary- or near primary forest under public ownership and/or nature protected areas • Relatively low ecological pressures on forest ecosystems, in particular conversion- and extractive pressures such as timber production • Relatively good condition for land acquisition and other costly protection- and restoration measures, either because of high availability of funding, low input prices (e.g. land prices for acquisition or labour for restoration measures)	Opportunities for large-scale natural recovery through stricter protection as well as acquisition of new areas with high cost-effectiveness. Greater emphasis on protection solutions.
Croatia		
Lithuania		
Romania		
Slovakia		
Slovenia		
Austria	**Medium potential countries, meeting some or all of the following criteria:** • Some remaining extent of primary and old-growth forest, or near-primary forest in moderate ecological condition • Moderate ecological coherence of remaining primary- or near primary forest areas, and forest area more generally • Relatively moderate share of primary and near-primary broadleaf forests, which have relatively greater climate- and natural habitat benefits • Average area of primary- or near primary forest under public ownership and/or nature protected areas • Average levels ecological pressures on forest ecosystems, in particular conversion- and extractive pressures such as timber production • Moderate conditions for land acquisition and other costly protection- and restoration measures, either because of high availability of funding, low input prices (e.g. land prices for acquisition or labour for restoration measures)	Opportunities for large-scale natural recovery are present but will require greater relative investment, either through eliminating or reducing higher levels of pressures (e.g. forestry), relative greater extent to protect/restore for same impact (boreal forests), or higher input costs per ha (e.g. for land acquisition). Balance of emphasis between protection and restoration solutions.
Czech Republic		
Estonia		
Estonia		
Finland		
France		
Germany		
Greece		
Italy		
Latvia		
Poland		
Portugal		
Spain		
Sweden		
Belgium	**Low potential countries, meeting some or all of the following criteria:** • No or very little remaining extent of primary and old-growth forest, or near-primary forest in low ecological condition • Relatively poor ecological coherence of remaining primary- or near primary forest area, and forest area more generally • Relatively low share of primary and near-primary broadleaf forests • Relatively low area of primary- or near primary forest under public ownership and/or nature protected areas • Relatively high ecological pressures on forest ecosystems, in particular conversion- and extractive pressures such as timber production • Relatively poor conditions for land acquisition and other costly protection- and restoration measures, either because of low availability of funding, or high low input prices (e.g. land prices for acquisition or labour for restoration measures)	Little opportunity for large-scale and cost-effective recovery through natural regeneration. Greater focus on restoration solutions, including re-creation of habitat to improve ecological coherence and buffering of few remaining core areas.
Cyprus		
Denmark		
Hungary		
Ireland		
Malta		
The Netherlands		

5 Demand reduction and energy efficiency

Key points

- **Deep renovation of residential buildings and investment in industrial heat pumps offer the most cost-effective emissions reductions amongst various efficiency measures:** Deep renovation provides lifetime cost savings to households in almost every situation, leading to negative marginal abatement costs for reducing emissions. The marginal abatement cost for industrial heat pumps of around EUR 10/tCO2 offers low cost emissions reduction and large energy savings.
- **Industrial heat pumps provide one of the best solutions to reduce industrial energy use:** particularly for industry with low temperature heat demand the use of heat pumps can lead to large energy savings. However, the financial savings depend on a variety of factors, including the tax differential between electricity and gas.
- **Green hydrogen**: Green hydrogen is expected to play an important role in decarbonising sectors that require high temperature heat. It remains a relatively expensive and unproven technology but there are few alternatives and significant political backing to expand its use in industry.
- **Efficiency measures have one-off costs, but can provide savings for 20 years or more:** meaning a programme focused on energy efficiency measures can cumulatively grow its impact over time.
- **Additionally, efficiency measures also bring important co-benefits in employment and to households:** energy efficiency measures are often labour intensive to deploy, generating significant employment. **Deep renovation** can significantly improve the financial situation of households, in addition to the improvements to the home increasing comfort and improving health.

The energy gap caused by the removal of biomass subsidies and scenario of planned (close to) zero industrial scale biomass use for heat and power could also be addressed by demand reduction measures. Demand reduction measures include efficiency measures in buildings such as insulation and onsite generation; and energy efficiency measures in industry (e.g. process improvements, fuel efficiency, recycling, material efficiency). This analysis complements the assessment made in chapter 3, which considered the costs and benefits of replacing heat and power generated with biomass with heat and power generated by alternative genuine renewables.

The aim of this section is to estimate whether the subsidies for forest bioenergy (as estimated in chapter 2) could be cost-effectively targeted to energy efficiency in buildings or in industrial processes. This analysis aims to understand the impacts of these types of measures to show what part they could play in an integrated Renewable Energy and Climate Change Strategy.

The analysis is presented in three parts, section 5.1 addressing efficiency measures in buildings, primarily addressing residential (and services) relevant measures; section 5.2 addressing efficiency measures in industry; and section 5.3 providing a combined summary and indication of costs and benefits.

5.1 Most appropriate efficiency measures in buildings

Energy consumed in buildings for heating and lighting constitutes approximately 40% of final energy consumption and greenhouse gas (GHG) emissions of the EU, and their share in cost-efficient GHG mitigation potentials is estimated to be even higher[122]. Therefore, policies and targets aimed at increasing the energy efficiency of buildings can bring a substantial contribution in lowering energy demand and, by consequence, carbon emissions stemming from that energy.

Improving energy efficiency in buildings would directly reduce the use of a large share of total forest biomass use of 716 TWh per year. Of which the largest part is for residential burning of forest biomass for heating (526 TWh)[123], with contributions also from direct combustion for heating by commercial and public services (37 TWh), and the remainder from commercial heat production (heat only – to supply residential, commercial and/or industrial consumers) amounting to 153 TWh, a share of which is produced from CHP. Improving buildings' energy efficiency reduces the demand for ambient heat.[124]

The energy consumption of buildings depends strongly on the year of construction. According to a BPIE study[125], a building constructed before the 1960s consumes on average 245 kWh/m^2/pa, while the consumption decreases to 130 kWh/m^2/pa for buildings constructed between 1961 and 1990. The consumption is further reduced to 82 kWh/m^2/pa for buildings built between the 1990s and 2010s, while the study suggests that new buildings consume just 27 kWh/m^2/pa. However, the theoretical estimates can differ significantly, i.e. up to 50%, with the actual energy consumption, this is especially true for older buildings or those with low energy efficiency ratings[126].

Non-residential buildings are on average 40% more energy intensive than residential buildings[127], but also require more tailored approaches and are often more expensive to retrofit with energy efficiency measures. These values can vary significantly per country due to variations in climate, culture, building design and standards.

The EU gives high priority to buildings in driving down energy use and help achieving GHG emission reductions, as demonstrated by the current effort in reviewing the Energy Performance of Buildings Directive (EPBD), the Energy Efficiency Directive (EED)[128] and the Renovation wave, a new initiative to support Member States with the significant investments that renovating the building stock entails. The European Commission estimates that, to achieve the proposed 55% climate target by 2030, around €275 billion of additional investment in building renovation is needed every year.[129]

In concrete terms, the top three main options to reduce energy use in buildings are:

1. **Improve insulation** to the building envelope (walls, roof) and apertures (windows and doors);

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[122] https://commission.europa.eu/news/focus-energy-efficiency-buildings-2020-02-17_en

[123] Solid biomass use in households is a very significant share of total biomass use in Europe. This is particularly strong in less developed and more rural regions across Europe, where solid biomass is typically used in the fireplace and in kitchen stoves. However, while this is decreasing significantly over time, the use of wood- and pellet-powered modern heating systems is instead growing across Europe, often supported by energy efficiency policies that promote biomass boilers to replace gas boilers.

[124] Ambient heat is to be intended the heating of buildings, as opposed to water heating

[125] https://www.bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf

[126] https://doi.org/10.1016/j.enbuild.2023.113024

[127] European Alliance to save energy (2021), Review of the Energy Performance of Buildings Directive

[128] The EPBD and EED are the two main directives that drive building energy efficiency in the EU

[129] https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_1836

2. **Improve the energy efficiency of the heating systems**, for example replacing a gas or oil boiler with a heat pump, installing a solar water heater, or connecting the building to district heating. For the majority of Europe, ambient heat is the main energy use in buildings, but in hotter countries and regions water heating and ambient cooling often take up a larger share of energy use.
3. **Install onsite-generation**, such as solar PV, to cover part or all the energy used in the building.

Besides the main options, there are a series of other interventions that are often less expensive but that in some cases may generate substantial savings and with lower installation complexity. These include improvements such as: high efficiency lighting; behavioural change driven by smart controls and smart meters; shading devices; green roofs and green walls.

The next sections explore the different solutions, but it is worth considering that costs vary substantially between countries, while the effectiveness of the measure (e.g., energy savings) depends on the climate and on the current level of efficiency).

5.1.1 Improve insulation

Improving insulation is typically the first step in improving buildings' energy performance, because it can deliver substantial savings and is a prerequisite for the viability of other measures[130]. Insulation measures include:

- **Roof insulation:** it is generally the most cost effective of the insulation measures, as warm air rises the roof is where are large share of heat loss usually occurs. Costs of roof insulation vary according to the roof type, roof size and climate. Insulating an inclined roof from the inside costs around 30-35 €/m^2 in Ireland[131], France[132] and the UK[133], while the cost increases to 40-50 €/m^2 in the Netherlands[134] and Belgium[135]. However, external insulation and flat roofs increase the costs, which can go up to 120€/m^2 [136]. Therefore, insulating a small flat roof (e.g. 30 m^2) may cost between €2,000 and €10,000, while insulating a large slanted roof in a single-storey building (e.g. 200 m^2), without loft may cost over €20,000. For commercial buildings, costs can be significantly larger, but the cost per m^2 are often lower. On average, roof insulation may save between 10 and 50 kWh per year for each m^2 of roof insulated, equivalent to 5-25% of heating needs in homes.[137] In most cases home roof insulation it is a measure with a rather short payback period, i.e., 2 to 5 years.
- **Wall insulation:** the variation in the impact and costs of retrofit wall insulation is much wider than in the case of roof insulation. Some significant savings (10-30%) at low cost can be achieved with cavity wall insulation, while solid wall insulation is significantly more expensive and often encounters technical difficulties. For example, in some cases insulation can be done only inside the building, which is a rather invasive intervention that also reduces the size of rooms where it is applied. Wall cavity insulation is a relatively inexpensive solution, with costs

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[130] For example, in colder climates, heat pumps are a viable solution only if the building is sufficiently insulated

[131] https://insulationcostsireland.com/how-much-does-roof-insulation-cost-in-ireland.html

[132] https://www.quelleenergie.fr/prix-travaux/isolation/isolation-toiture

[133] https://www.mybuilder.com/pricing-guides/insulation-costs/roof-insulation-costs

[134] https://zoofy.nl/en/price-guides/cost-of-installing-roof-insulation/#:~:text=On%20average%2C%20you%20can%20expect,a%20cost%20overview%20for%20you.

[135] https://www.energuide.be/en/questions-answers/how-much-does-it-cost-to-insulate-a-roof/682/

[136] https://www.energuide.be/en/questions-answers/how-much-does-it-cost-to-insulate-a-roof/682/

[137] https://www.bpie.eu/wp-content/uploads/2022/03/Strategy-paper_Solidarity-and-resilience_An-action-plan-to-save-energy-now-1.pdf

starting from 10 €/m^2 (Ireland)[138] to 30 €/m^2 (Italy)[139]. Solid wall insulation is more expensive, with higher costs ranging from 90 €/m^2 of wall insulated (Italy)[140] up to 200 €/m^2 (France)[141] and longer payback periods (>10 years).

- **Glazing and windows:** contrary to roofs and walls, windows are a building element that is more often replaced during the lifetime of a building. The cost can be significant if opting for the best in class, but currently most of the windows sold across Europe offer significant energy savings compared to windows in existing buildings. As an indication, double-glazed windows' costs [142]range between €100-€200 per window (France[143], Italy[144], Belgium[145]), while triple-glazing window start at around €200 (Belgium[146]) up to €600 (UK[147]) per window. Double glazing can result in energy savings of around 10-25% over single glazing, and triple glazing a saving of 5-10% over double glazing.

5.1.2 Heating systems

Buildings' heating systems are one of the key drivers of energy use. In Europe, about 50% of all energy consumed goes to heating and cooling (including water heating). Fossil fuels, mostly natural gas, are the main fuels used for heating and cooling, providing over 70% of energy needs[148]. As shown in section 2.1.2, Biomass is by far the largest non-fossil energy source used in heating. There are a number of options to reduce energy use and carbon emissions from buildings' heating systems:

- **Heat pumps:** these are becoming the mainstream renewable heating choice for residential buildings and are rapidly gaining market share in most European countries. They have flexibility in their applications, scalability, and limited downsides. Heat pumps are also a key emerging technology for some low heat industrial processes and a viable solution for larger heating systems, such as district heating[149]. It is estimated that by 2030, 30 million heat pumps will be deployed across the EU.[150] The main limiting factor for the deployment of heat pumps comes from the need to reach a decent insulation level in buildings before they can be installed. The cost of a heat pump for residential use vary from €5,000 to €20,000 for large and poorly insulated houses, with payback periods ranging from 5-20 years on average[151]. The variation in the payback period is largely dependent on climate, energy efficiency of the building and relative electricity and other fuel (gas, oil, biomass) prices. The former as a colder climate will use more heat offering faster payback compared to alternatives; efficiency as an inefficient building will require a large heat pump, which is more expensive and may cost significantly more to run; and the relative prices, as heat pumps run on electricity, therefore the lower the electricity price compared to the alternative fuels, the more advantageous a heat pump is.

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[138] https://selectra.ie/energy/guides/energy-saving/insulation
[139] https://www.cronoshare.it/quanto-costa/isolare-parete
[140] https://www.pgcasa.it/articoli/esterni/quanto-costa-fare-il-cappotto-termico__27389
[141] https://www.prix-travaux-m2.com/prix-isolation-thermique.php
[142] Excluding the frames
[143] https://www.travaux.com/fenetre-porte/guide-des-prix/prix-du-simple-et-d-double-vitrage
[144] https://www.casa.top/costo-infissi-mq-prezzi-finestre/
[145] https://www.ing.be/en/individuals/my-life/housing/subsidy-high-efficiency-glass#:~:text=How%20much%20does%20high%2Defficiency,HR%2B%2B%2B%20(excluding%20installation)
[146] Ibid.
[147] https://www.homehow.co.uk/costs/double-glazing
[148] https://energy.ec.europa.eu/topics/energy-efficiency/heat-pumps_en
[149] https://energy.ec.europa.eu/topics/energy-efficiency/heat-pumps_en
[150] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0643&qid=1669913060946
[151] For example, McKinsey reports payback periods of between 12 and 17 years, based on the case of a German household https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/refurbishing-europe-igniting-opportunities-in-the-built-environment

- **Waste heat / district heating:** waste heat, for example from some industrial processes, can provide one of the most efficient space heating options, by finding a use for excess heat. The main issue with the technology is the scalability, as this solution is only viable when the heat source and the building to be heated are in close proximity.
- **Geothermal:** Geothermal energy is used mainly for electricity and heating purposes, yet it still has a very limited deployment compared to other renewable energy sources. Currently, the main technologies used across Europe for heating are geothermal heat pumps (2 million geothermal heat pumps were installed in 2019[152]) and geothermal district heating, Both technologies can be used at residential and commercial/industrial level.[153] At residential level, geothermal heat pumps are still rather expensive, ranging from €13,000 to more than €30,000[154], therefore currently they cannot compete with either conventional boilers (gas/oil) or air-sourced heat pumps. When it comes to geothermal district heating, the EU is interested to increase the geothermal capacity from 3.9 GW_{th} to more than 6.2 GW_{th} by 2030, with the investments expected to reach EUR 7.4 billion.[155]
- **Solar thermal:** solar thermal energy is on the rise in Europe, with a cumulative installed capacity reaching 37.8 GW_{th} in 2021,[156] with Italy, Greece and Poland being the countries with the biggest growth rates (83%, 18% and 17% respectively).[157] Solar thermal energy can be used at small scale for water and space heating of residential buildings and public buildings, at large scale for district heating of residential, commercial and public buildings (found in, for example, Denmark, Sweden, Spain, Greece), as well as for industrial purposes (solar thermal systems for industrial processes (SHIP)). Additionally, there is a relatively new a type of collector that combines solar electricity and heat, i.e., Photovoltaic-Thermal (PVT) collectors, with the market growing steadily the last years.[158] The average installation cost of a simple solar thermal collector ranges from €3,800 to €6,600. [159]

5.1.3 Country specific considerations and overall costs

In order to meet the new Nearly Zero Energy Building (NZEB) standards, defined in the EU Energy Performance of Buildings Directive (EPBD), the measures described in the previous section are likely to be needed in all buildings, in different combinations. Deep renovation is aimed not only at the aesthetic and desired improvements of the occupants, but also at deeper building improvements of the energy efficiency type presented above, and additionally also addressing issues like water efficiency, smart controls, etc;.

The cost of these deep renovations vary significantly by climate, building type, location, labour costs and intervention type. For example, the cost of renovating[160] a fully detached house can be substantially higher than the cost of renovating an apartment as part of a renovation project that

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[152] https://www.egec.org/the-geothermal-energy-market-grows-exponentially-but-needs-the-right-market-conditions-to-thrive/
[153] https://www.egec.org/about/#aboutgeot
[154] Based of US prices
[155] https://www.rystadenergy.com/news/full-steam-ahead-europe-to-spend-7-4-billion-on-geothermal-heating-capacity-to-re
[156] EU including Switzerland and the UK. Source: https://solarthermalworld.org/news/historically-high-growth-in-europes-solar-heat-market-in-2021/
[157] Solar Heat Worldwide, Edition 2022
[158] Ibid.
[159] Based on US data. Source: https://modernize.com/solar/solar-heating-costs#:~:text=In%20the%20United%20States%20the,the%20expected%20range%E2%80%94is%20%244%2C750.
[160] Renovating here is used to mean energy renovation, i.e. the upgrade of fixed elements (such as roof and walls) and technical systems (such as the heating system) in order to reduce energy use.

covers the entire building. Enerdata reports wide variation among Member States[161], with the cost of deep renovation varying from less than €100/m^2 in Romania (linked to lower labour costs) to over €350/m^2 in Italy and Germany. However, sources in Italy[162], Greece[163] and Estonia[164] each find higher costs, and a wider range of €200 - €2 000 /m^2. ING quote a cost of between €15 000 and €30 000 for the average house in Germany and the Netherlands, and average of €50 000 for Belgium.[165] Whilst in Italy total average costs of around €100 000 are estimated[166]. Within these costs it is difficult to separate out the part that goes to energy efficiency renovation and the part that addresses the other improvements.

Deep renovation is associated with energy savings ranging between 60% and 90% of consumption before renovation[167], with average improvements of at least 75% according to the Global Buildings Performance Network. With average heating costs of €1 000 - €2 000 per year, then such renovations could save an average household €750 - €1 500 per year, or more in times of high fuel prices.

5.1.4 Overall energy use reduction investments in buildings

In this section we present the results of a high-level analysis of the potential the energy savings that can be achieved via deep renovation of buildings, assuming that EUR 100 million of subsidies currently paid to biomass generation would instead be invested in the residential sector. The analysis provides a range based on renovation costs varying between 300 €/m^2 and 600 €/m^2, and considers the potential energy savings that can be achieved in buildings built in different periods. This is because the savings that can be achieved in houses built before 1960 are significantly higher than savings that can be achieved in newer buildings, when many countries have started introducing energy efficiency requirements for buildings. This section also presents some results at national level for the UK, Germany and Italy.

Table 5-1 presents an overall estimate of energy savings that can be achieved by investing in energy efficiency considering two main sensitivities:

- Renovation costs: (low case: €300/m^2, high case: €600/m^2)
- Subsidies of renovation costs (low case: €100/m^2, high case: €200/m^2) – this is important as it would not be expected that the whole renovation would be subsidised, only part of the energy efficiency upgrade. The subsidy should also leverage private investment in the renovation.
- Savings after renovation: (low case: 50%, high case: 85%)

The analysis assumes that 70% of the renovations will be done in houses built before 1960, and 30% in houses built between 1960 and 1990.

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[161] https://zebra-monitoring.enerdata.net/overall-building-activities/average-cost-of-renovation-in-residential-per-m2.html

[162] https://www.efficienzaenergetica.enea.it/detrazioni-fiscali/superbonus/risultati-superbonus.html

[163] https://energy.ec.europa.eu/system/files/2021-08/el_2020_ltrs_en_version_0.pdf

[164] https://energy.ec.europa.eu/system/files/2020-09/ee_2020_ltrs_official_translation_en_0.pdf

[165] https://think.ing.com/articles/energy-performance-of-buildings-directive-review-how-banks-affected/

[166] https://www.efficienzaenergetica.enea.it/detrazioni-fiscali/superbonus/risultati-superbonus.html

[167] https://e3p.jrc.ec.europa.eu/articles/energy-renovation

Table 5-1 Energy savings from deep renovation at EU level per type of building, example with EUR 100M spent

Costs	Low renovation cost		High renovation cost	
Cost for deep renovation (€/m2)	300		600	
Subsidised cost of deep renovation (€/m2)[168]	100		200	
Total area that can be renovated (m2)	1 000 000		500 000	
Approximate number of households	9 775		4 888	
Current consumption (built before 1960, kWh/m2)	280			
Current consumption (built 1960-1990, kWh/m2)	200			
	High savings	Low savings	High savings	Low savings
Savings from deep renovation (%)	85%	50%	85%	50%
Savings				
Savings for dwellings built before 1960 (kWh/m2)	238	140	238	140
Savings for dwellings built 1960-1990 (kWh/m2)	170	100	170	100
Total energy savings per year (kWh)				
Savings for dwellings built before 1960 (GWh)	167	98	83	49
Savings for dwellings built 1960-1990 (GWh)	51	30	26	15
Total savings per year (GWh)	218	128	109	64
Annual savings total from 10 year programme (GWh)	2 176	1 280	1 088	640

Source: Own elaboration based on data from BPIE (2015) and Few J. et al. (2023)

Based on the analysis presented in Table 5-1, it is possible to estimate that €100 million invested in subsidies to support buildings renovation may allow for the deep renovation of between 0.5 and 1 million m^2 in residential buildings, or approximately 5 000 – 10 000 households. Assuming that each renovation enables savings of between 50% and 85% of the energy use before renovation, the investment will save between 64 – 218 GWh annually. If repeated each year the total annual energy savings would also grow. If such a programme ran for 10 years, then annual savings this could grow to between 640 – 2 176 GWh each year. These savings would also accumulate over the lifetime of the investment, i.e. renovations would contribute these savings benefits for long periods e.g. 20 years or more. This compares to annual consumption of forest biomass for heating projected for 135 000 GWh in 2030, therefore making a positive but small contribution.

5.2 Most appropriate efficiency measures in industry

Introduction to efficiency measures in industry

Energy use and emissions are closely interlinked, for industry energy use is viewed through both the cost and emissions perspective, particularly as emissions lead to costs for industry through mechanisms such as the EU Emissions Trading Scheme (EU-ETS) or UK-ETS equivalent. The emissions perspective shapes most of the analyses of the future of the industrial sector, therefore this is also the starting point for identifying and analysing industrial efficiency measures.

The industrial sector is considered one of the most difficult and expensive sectors to decarbonise by 2050. One of the key difficulties is the very large differences in processes, locations, fuels and inputs

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[168] It is assumed that building owners will contribute €2 for each €1 subsidised.

across the numerous subsectors. This means that each subsector and industry requires tailored solutions.

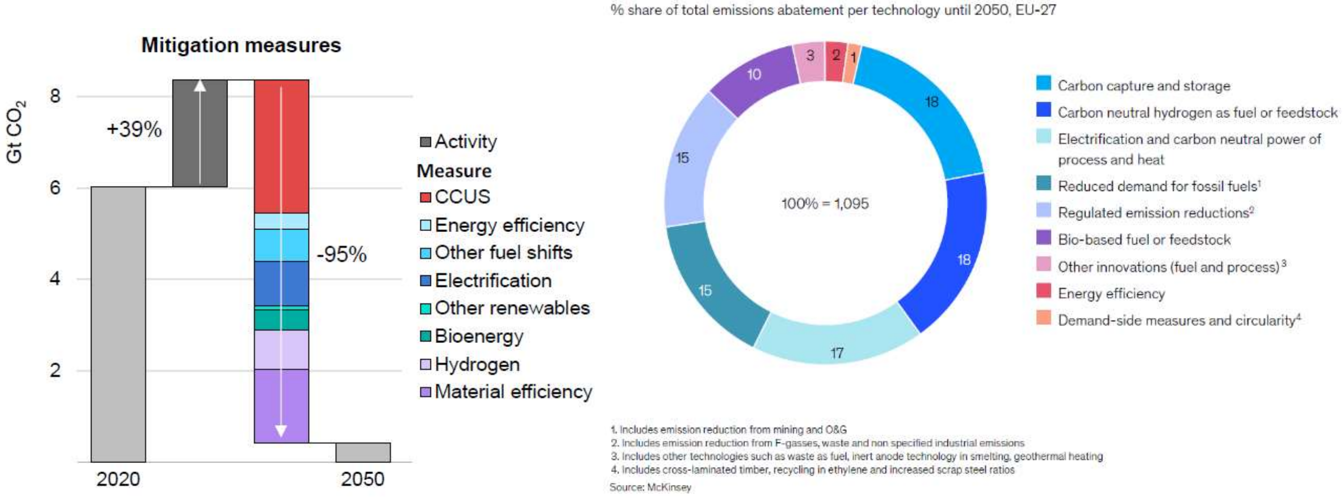
The majority of projections expect the EU industrial sector to still be a net emitter in 2050, although compensated by negative emissions in other sectors and offsets.[169] McKinsey estimates that whilst redirecting future investments would deliver a large part of the required capital spending to achieve net zero in industry, additional funds would also be needed. An estimated additional €410 billion (€13.7 billion per year) should be invested in clean technologies and techniques in the industrial sector. This annual investment is comparable to projected future forest biomass subsidies (see section 2.2).

The following main options to decarbonise industry are identified by leading studies, the role of these measures is summarised below in Figure 5-1:

- Energy efficiency, electrification and fuel switching;
- Innovative low carbon processes;
- Carbon capture and sequestration and or use (CCS and CCU);
- Resource efficiency/Circular Economy;
- Industrial symbiosis;
- Material substitution.

As can be seen in Figure 5-1, standard decarbonisation strategies envisage a growth in the use of biomass in industry, i.e. replacing coal or gas as part of fuel switching; and through the deployment of BECCS. This is contrary to the goals of the RECCS for the reasons set out earlier in this report, particularly on the flawed consideration of carbon neutrality and unproven, expensive case for BECCS. The remainder of section 5.2 details the other, better alternatives for industrial efficiency considered for support in a RECCS, and looks at solutions with common elements that could be widely applied across different sectors.

Figure 5-1 Emissions reduction options for industry, summaries of analysis by IEA and McKinsey[170]



1. Includes emission reduction from mining and O&G
2. Includes emission reduction from F-gasses, waste and non specified industrial emissions
3. Includes other technologies such as waste as fuel, inert anode technology in smelting, geothermal heating
4. Includes cross-laminated timber, recycling in ethylene and increased scrap steel ratios

Source: McKinsey

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[169] https://www.mckinsey.com/capabilities/sustainability/our-insights/how-the-european-union-could-achieve-net-zero-emissions-at-net-zero-cost

[170] Very similar typologies of measures are identified by the European Commission, see EC COM (2018) 733 https://climate.ec.europa.eu/system/files/2018-11/com_2018_733_analysis_in_support_en.pdf

Sources: [left] IEA (2022) Achieving Net Zero Heavy Industry Sectors in G7 Members; [right] McKinsey (2020) Net-Zero Europe: Decarbonization pathways and socioeconomic implications

5.2.1 *Industrial heat – heat pumps*

Recent analysis from the IEA[171] shows that **sectors that utilise low temperature heat** (<100 C) and steam (between 100 C and 400 C) are those that **should be prioritised in the short term**, as this is where **electrification (especially heat pumps[172]) or direct use of renewables (geothermal, solar thermal** and biomass) is possible. Industrial sectors that should prioritised according to the IEA are: food processing; chemicals; paper; machinery; textiles; other sectors. The combined near-term technical potential of these six focus sectors is around 360 TWh, or 13% of industrial energy use.

The IEA analysis shows that the levelized cost[173] of different solutions for industrial users is largely driven by fuel costs, rather than investment costs, therefore high efficiency technologies such as heat pumps are effective in both reducing energy use and costs. The work also assessed E-boilers and hydrogen (H_2), which were much more expensive overall (high initial investment costs), however unlike heat pumps, these are also able to provide high temperature heat, and therefore can be suitable as an alternative to gas for high-temperature industrial processes. Continued innovation for heat pumps, e-boilers and H_2 boilers means thatd both capital and operational costs should fall further in the coming years, further improving their economic case[174].

Heat pumps are a crucial efficiency measure taken forward in the RECCS. The investment cost of installing an industrial heat pump is highly dependent on the sector and on the current production process. In some cases, a heat pump may replace the current equipment used for heating without requiring further changes to the production process, in other cases a large part of the production process will have to be rethought to fit heat pumps[175].

For the analysis presented in this section we make a few simplifying assumptions:

- We assume that industries where heat pumps can be successfully deployed will not require operational support, given that operational costs are competitive with traditional boilers. However, conversion costs may be high, which mean some investment support may be needed.
- We assume that a subsidy covering 50% of the investment cost would stimulate sufficient uptake. This is consistent with existing schemes, for example a German subsidy programme for energy and resource efficiency in commercial enterprises covers up to 55% of the initial cost of the heat pump[176].

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[171] IEA (2022) The Future of Heat Pumps

[172] Technologies include Heat pumps and chillers, Mechanical vapour recompression, Electric boilers, Infrared heaters, Microwave and radio frequency heaters

[173] The levelized cost indicates the total cost of producing one unit of output across the entire life of the installation, including all capital and operational costs. This allows for the comparison of technologies with high CAPEX and low OPEX, such as wind to technologies with low CAPEX and high OPEX, such as gas power plants.

[174] Biomass boilers are not included in the comparison as they are not the main competitor for heat pumps, with their use in industry concentrated in a few sectors. Costs of biomass boilers are likely to be similar to gas, but higher due to both lower efficiency and higher fuel costs.

[175] IEA (2022) The Future of Heat Pumps, available at: https://iea.blob.core.windows.net/assets/4713780d-c0ae-4686-8c9b-29e782452695/TheFutureofHeatPumps.pdf

[176] IEA (2022) The Future of Heat Pumps

Based on a range between €200 and €500 per kW (according to the figures used by the Institute for Sustainable Process Technology[177] and Marina et al. [178]) €100 million of subsidies could support the installation of between 400 – 1 000 MW of industrial heat pumps per year. Contrary to the subsidies paid per unit of output (MWh), as is usually the case for electricity subsidies, subsidies paid towards the purchase of equipment will save energy for years to come and accumulate over time, similar to the investments in insulation presented in section 5.2. Given that operations and maintenance costs are comparable, a grant that supports the switch from gas to electricity would leave the majority of industrial users better off as long as the price of electricity (to power the heat pump) is not multiple times higher than the price of gas.

The amount of energy saved by industrial heat pumps can be substantial, although there are many variables in determining the size of the savings, and it depends heavily on the process it currently replaces. According to a recent report from the American Council for an Energy Efficient Economy[179] industrial heat pumps showed the potential to "*Reduce process heat energy 293-400 TBtus/year (42-57%) of the 704 TBtus/year of process heat energy in the subsegments analyzed*". Based on an utilisation factor of 50% (heat pumps running for 12 hours a day on average), and assuming a saving of 50% would support energy savings of between 880 GWh – 2 190 GWh per year in the 400 MW and 1 000 MW cases respectively. It is clear that these savings could increase significantly over time and if additional funding were provided.

5.2.2 Other industrial efficiency measures

Other measures on **efficiency, process savings and improved circularity** are typically estimated to have relatively low savings potential for industry, although potential is typically cost efficient. Fuel switching in the form of direct on-site generation using renewable energy technologies such as solar PV has characteristics similar to those considered in chapter 3. There is further fuel switching potential highlighted in Figure 5-1, but this focuses on the use of biomass instead of fossil fuels (primarily natural gas), on the basis of the flawed climate neutral assumption, this option is contrary to the premise of this work and not considered further.

Material efficiency or greater circularity (**recycling**, material substitution, ecodesign) is an option in some sectors. Recycling has the highest potential in the steel and metal industries (greater use of scrap) and plastics (increased recycling). Materials efficiency and substitution can be particularly interesting for cement (reducing its share in concrete), where a reduction in demand for concrete through greater efficiency or use of alternative materials such as cross-laminated timber would have the benefit of reducing the need for cement producers to implement CCS[180]. The costs and effectiveness of materials efficiency measures varies substantially across sectors, but there is little specific data on costs. These measures are not included in the RECCS for analysis here but could be considered on a case-by-case basis in actual implementation of a RECCS. However, it should be noted overall that recycling, and greater material efficiency and circularity in general, provides large opportunities for environmental benefits (including climate, but also many other aspects), and can also

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[177] https://ispt.eu/media/UH-20-11_CRUISE_final-report-openbaar_v2.pdf

[178] https://publications.tno.nl/publication/34637767/MueE3v/marina-2021-estimation.pdf

[179] ACEEE (2022) Industrial Heat Pumps: Electrifying Industry's Process Heat Supply, available at https://www.aceee.org/research-report/ie2201

[180] Noting that that substituting for timber would place other pressures on forests that would need to managed are there are risks in using timber where exaggeration of the period of 'carbon lock-up' of wood products can overestimate the benefits. This needs to be carefully assessed.

have similarly large impact on economic development, such as boosting GVA, competitiveness, employment and productivity.

The two major remaining options for industrial decarbonisation and efficiency are **green hydrogen** (H_2) and **CCS**. The former is particularly relevant for sectors which require high temperature heat such as steel making, glass, cement and fertiliser (ammonia) production; and the latter for where there are substantial process emissions such as cement, refineries and fertiliser (ammonia) production. Whilst both of these technologies feature heavily in almost all industrial decarbonisation plans they also both remain at a relatively immature stage of development, still at the demonstration and pilot stages, and not yet widely commercially deployed. For example the Hybrit project in Sweden is piloting the use of green (from renewable electricity) hydrogen in the steel making process to avoid the use of coking coal, to make low-carbon steel, i.e. close to zero emissions compared to around 1.4 tCO_2/t steel with fossil fuels. The project, a global first, has received financial support from the Swedish Energy Agency and EU's Innovation fund and is in the process of scaling up[181].

Given their current stage of development the costs of these technologies also remains quite high and uncertain. For **Green Hydrogen** the CAPEX is estimated around €2 000 - €3 000 per kW capacity, with total investments of €65 - €215 billion estimated as required to meet EU demand[182]. The cost of green hydrogen is higher than hydrogen from fossil fuels and will need to come down to be competitive. It is hoped, that innovation can bring critical technology costs (e.g. for electrolysers) down, and that low cost renewable electricity can also improve the economic feasibility. Some work[183] suggests that much of Europe will only be able to produce green hydrogen at uncompetitive high prices and that it would be better to import it from elsewhere rather than invest in green hydrogen production in Europe.

For **CCS** some estimates put the marginal cost of emissions reduction from CCS at €40-€130 per tCO_2[184], with this wide range of potential costs based on both differences in how CCS might be applied in specific sectors (some easier than others) and also the remaining uncertainties in implementation. The business case for installation improves as the carbon price increases, within the EU-ETS prices since November 2021 have moved within a range of around €50 - €100 /tCO_2. If prices were to stay at the high end of this range then the case for CCS becomes more attractive, with the Norwegian energy company Equinor, who are pioneering CCS at their oil and gas installations, estimating a break-even price starting around €100/tCO_2[185]. Subsidies could be considered to turn these currently marginal business cases into positives and support final investment decisions to invest by industry. CCS in industry can be more efficient and cost-effective than BECCS due to the purity of the emissions streams for capture and the fact that they avoid the additional financial disadvantage of forest biomass energy vs other electricity sources. It is being closely considered in a handful of sectors, especially cement, steel, fertilisers and refineries where other emissions reduction measures are more difficult or expensive to deploy.

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[181] https://www.hybritdevelopment.se/en/a-fossil-free-future/

[182] KPMG (2022) How to evaluate the cost of the green hydrogen business case?

[183] PwC The Green Hydrogen Economy; available at https://www.pwc.com/gx/en/industries/energy-utilities-resources/future-energy/green-hydrogen-cost.html

[184] McKinsey (2020) Net-zero Europe

[185] https://www.reuters.com/markets/commodities/carbon-capture-services-could-break-even-next-10-years-equinor-2021-12-01/

5.3 Cost-benefit analysis

5.3.1 Comparison of impacts per technology

The following table 5-2 takes the case of a hypothetical EUR 100 million investment in the main technologies discussed in this chapter, to compare the main energy, emissions and cost impacts that can be calculated. This shows clearly that the deep renovation measures, whilst addressing only a relatively small number of households, are able to provide significant energy savings, and by generating also financial savings for households the marginal abatement cost can be negative overall, i.e. the investment pays off both in emissions and financially. For industry the industrial heat pumps can deliver significant energy, as they are able to multiply the energy inputs by a factor of 2.5-4.0 e.g. 1 kWh electricity in, 2.5-4.0 kWh of heat out. This provides a significant energy and emissions advantage over natural gas, although the emissions advantage varies with some key factors, with two of the most important being the emissions factor of the grid electricity and the efficiency of the heat pump. Overall, heat pumps provide emissions savings at a low marginal cost. In contrast, and consistent with the still immature level of the technology, green hydrogen (H_2) provides less energy and emissions savings, and consequently much higher marginal costs of emissions reduction. It should be noted that this summary provides an overview of average conditions for each technology, but the circumstances and assumptions for each could change considerably. For example in the case of Green H_2, if this displaced coal instead of natural gas (as it may in sectors such as steel and cement) then the cost effectiveness of emissions reduction can improve significantly as emissions per kWh of industrial heat from coal are more than double that from natural gas.

The results on energy and emissions savings and the marginal abatement costs can be compared with Table 3-8 in Chapter 3 to contrast with the costs and impact of investments in renewable energy.

Table 5-2 Overview of key impacts for selected demand reduction and energy efficiency technologies on the basis of EUR 100 million investment

Technology	EE: Renovation	EE: Renovation	EE: Renovation	EE: Renovation	EE: Industrial	EE: Industrial
	low cost /high savings	low cost / low savings	high cost / high savings	High cost/low savings	Heat pump	Green H2
Cost [EUR/kW] or [EUR/m2]	300	300	600	600	350	1 000
MW installed [MW] or no.of households deep renovation [n]	3 258	3 258	1 629	1 629	286	100
Annual energy generated/saved [GWh]	73	43	36	21	2 503	164
Emissions per kWh [gCO2/kWh]	N/A	N/A	N/A	N/A	79	23
Emissions saving [ktCO2e/yr]*	15	9	7	4	501	33
Annual saving for households [m EUR]	8	5	4	2	N/A	N/A
Lifetime [years]	30	30	30	30	20	10
Marginal abatement cost [EUR/tCO_2e]	-339	-178	-109	213	10	305

Source: Own calculations

* Emissions saving is compared to natural gas which would be the main fuel displaced by each of these innovations.

5.3.2 Overall costs and benefits

This section provides a qualitative overview of the costs and benefits of redirecting subsidies currently paid to forest biomass towards energy efficiency in buildings or towards industrial energy efficiency.

Similarly to the analysis presented in section 3.4, the end of subsidies for forest biomass will have positive impacts on reduced forest exploitation for bioenergy, Increased sink capacity, reduced air pollution and improved health. Furthermore, there are the following additional benefits deriving from the redirection of subsidies:

Investments in buildings energy efficiency

- Improved energy efficiency in homes (from renovation), would create much better and more comfortable living conditions for the treated households. This would have positive health impacts for residents.
- By lowering the total amount of energy needed, Europe will improve its energy security by reducing energy dependency. The vast majority of building energy use in Europe is natural gas, for which Europe is heavily dependent on imports, particularly from a few foreign markets. The dependence on Russian gas prior to the Ukraine war has created severe supply issues and economic costs now this source is sanctioned. These costs could be avoided in the future if dependence on foreign suppliers is reduced because of reduced energy needs.
- The supply issues have also been the cause of a widespread affordability or cost-of-living crisis in Europe, as households suddenly had to face very high gas and electricity costs because of the price spikes in the wholesale cost of gas. This both affected households and government budgets as large temporary subsidies have been provided to reduce the negative impact of the high prices on households and business.
- Investment in energy efficiency in buildings will have a positive impact on jobs. According to the IEA, buildings energy efficiency is the green energy investment that creates the most jobs per million invested (12.8 jobs per million EUR)[186]. This compares very favourably with the employment generated by subsidised electricity production forest biomass presented in section 3.4 where an equivalent value of around 0.4 jobs per million can be calculated.
- Investments in energy efficiency are likely to last significantly longer that what is assumed in the base case of this analysis (20 years). This means that long term benefits will be significant.

Investment in industrial process efficiency

- According to the IEA, investment in industrial processes creates around 9.1 jobs per million EUR invested[187], which is again significantly higher than for biomass power and would accumulate over time if additional annual investments are made. It can also be noted that energy efficiency in industry often requires higher skills than those involved in biomass burning, which would have positive impacts on workers and the economy as a whole.
- Efficiency in industrial processes will increase know-how and support technological innovation in the industries involved, as changes in the source of heat are likely to bring along further

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[186] Converted from 13.9 per million USD https://www.iea.org/reports/energy-efficiency-2020/energy-efficiency-jobs-and-the-recovery

[187] Converted from 9.9 per million USD https://www.iea.org/reports/energy-efficiency-2020/energy-efficiency-jobs-and-the-recovery

improvements in associated processes.[188] Overall, investments in new production processes are likely to improve the international competitiveness and effectiveness of industries involved, and could support the development of new patents.
- As gas is replaced, the exposure to international gas price variation is reduced, even more so for factories that decide to invest in their own generation (for example, solar PV).

Whilst there are practical implications that should be considered in deploying these measures at scale, such as supply chain bottlenecks and staff shortages, these should be surmountable in the medium-long term. What is clear is that there is a strong policy backing for these measures in Europe, with a significant effort to renovate buildings (the Renovation Wave), set to be further increased once a new package of directives is approved as part of the Green Deal (especially the Energy Performance in Buildings Directive and the Energy Efficiency Directive). In the medium-long term reducing the use of forest biomass for energy by adopting the proposed RECCS would have a benefit of reducing demand and therefore prices of wood, freeing up part of the supply for use in other sectors such as construction.

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[188] When a factory invests in a change in the process its uses for the production of goods, it is likely to make further investments to improve other associated processes, for example to better exploit the new heating source and to take advantage of the down time.

6 The Renewable Energy and Climate Change Strategy

Key points

- **A Renewable Energy and Climate Change Strategy (RECCS) would deliver far superior energy, emissions, economic, social and environmental outcomes than a base-case of continuing and expanding the use of forest biomass for energy and BECCS.**
- **The energy gap from biomass could be filled by alternative renewables at significantly lower subsidy cost:** bioenergy and especially BECCS are high cost energy technologies requiring high subsidies. The same amount of energy could be provided much cheaper by alternative renewables such as wind and solar PV, i.e. we estimate that in 2020 the same annual energy outputs could be provided for only 28% of the subsidies required for biomass (see Table 3-7). **This difference saves the energy system and consumers hundreds of billions of euros in the coming decades** (estimated annual savings of more than EUR 40 billion per year by 2050). Even with additional investments in networks and storage, significant subsidy savings could be achieved, freeing up these amounts for further decarbonisation investments.
- **Investments in energy efficiency (including residential deep renovations), industrial decarbonisation (heat pumps and green hydrogen) and conservation (protection and restoration) of carbon-absorbent ecosystems multiply the potential energy and emissions savings and deliver a variety of benefits.**
    - **RECCS measures lead to a reduction in EU annual residential heat demand of more than 156 TWh in 2050**, this represents around 9% of estimated residential heat demand in 2050.
- **It is estimated that full redirection of subsidies intended for biomass and BECCS in the base case, towards the RECCS measures, could contribute savings equivalent to around 27% of all emissions reductions required to achieve EU net zero emissions targets by 2050.**
    - **Annual savings of 177 $MtCO_2e$ are possible by 2030, this saving is equivalent to more than the current (2021) total emissions of the Netherlands.** By 2050 the savings would increase to 870 $MtCO_2e$ per year, equivalent to more than current (2021) total EU emissions from domestic transport.
- **The RECCS delivers far more investment, economic growth and jobs than the base case,** it provides tens of billions more investment, output and GVA, it also delivers hundreds of thousands more jobs over the period.
    - In the short-term, 2025-2030 the RECCS is estimated to unlock more than EUR 101 billion in investments, or EUR 80 billion more than the base case. **This generates significantly higher economic output (+15.8 billion EUR compared to base case), GVA (+12.1 EUR billion) and employment (+232 000 jobs).**
- **The RECCS also provides a range of social and environmental benefits,** to health, energy poverty, energy security, biodiversity, air pollution and skills. **In particular it will bring large areas of carbon and biodiversity rich ecosystems into protection and restoration, an estimated 9 million hectares by 2030, increasing to 53 million hectares by 2050.**

The previous chapters set out the potential alternative uses of subsidies currently spent on energy from forest biomass. This chapter assesses which combination of these alternatives would provide the best basis of an alternative Renewable Energy and Climate Change Strategy (RECCS), with the key objectives of this strategy being to:

- Fill the energy gap that would be created by stopping the subsidised industrial-scale use of forest biomass for energy, by financing: (i) alternative renewables and storage; and/or (ii) technologies that reduce energy demand through energy savings and efficiency.
- Achieve far superior climate benefits compared to forest biomass use in the base case, with emission reductions that significantly improve the chances of achieving 2030 and 2050 targets for the Paris agreement
- Help gain recognition for ecosystem restoration and protection as a key element in climate change strategy, as well as contributing significantly to EU Biodiversity and Forest Strategies – thus meriting a significant proportion of official climate change funding.
- Achieve significantly greater economic, social and environmental co-benefits for people and nature.

6.1 Comparing the measures

In the previous chapters we have analysed various measures for renewable energy, nature-based solutions and energy efficiency. Each measure has a different range of impacts, not all are comparable, but key metrics on the cost of the measures and the emissions reductions that can be achieved are comparable. In the following table we compare the measures side-by-side in a hypothetical, 'If RECCS provided EUR 1 billion of subsidies…' what could be achieved. This gives an idea of the impact that could be achieved as support for RECCS is ramped up, as due to existing subsidy contracts not all of subsidy funding could be re-directed straight away. It also gives a clear picture of the scale and cost of the energy and emissions impacts that can be achieved.

From the table it is the clear that subsidies to **renewable energies** to replace existing generation from forest biomass can achieve very large emissions savings, as emissions from forest biomass (which is replaced) are so high. The overall marginal cost of the measures is between 30 – 80 EUR/tCO_2e. EUR 1 billion subsidy investments are required from other sources to build the power technology. The actual volume of investments required for each renewable energy technology are substantial, totalling between EUR 18-35 billion. However, it is expected that the normal financial markets and renewables developers, who already invest very large amounts in renewables, would be interested to invest given the RECCS subsidies help guarantee a particular level of return, significantly reducing the investment risk. It is also the case, as shown in the following sub-section, that EUR 1 billion of subsidies is not needed per renewable energy technology to fill the energy gap, i.e. EUR 1 billion in each of the five technologies would provide >180 TWh, whilst the energy gap in 2025 is only around 74 TWh.

For the **renovation measures**, the total investment drawn in by a EUR 1 billion RECCS investment subsidy is estimated at EUR 3 billion, i.e. it draws in an additional EUR 2 billion private investment. This is sufficient to renovate approximately 100 thousand homes in the low cost case, and 50 thousand homes in the high cost case. Total energy savings of 640 – 2 180 GWh/year are possible, with resulting emissions savings (based on avoided energy use of a standard gas boiler) of around 130 – 435 ktCO_2/year. Whilst this is significantly less than renewables it is also the case that gas boilers are far less carbon intensive than power from forest biomass i.e. 200gCO_2/kWh for a gas boiler compared to 1 256gCO_2/kWh for electricity from forest biomass. Renovation also generates cost savings to households (of between EUR 70-250 million per year) which results in a negative marginal abatement cost for the low cost renovations. This highlights a high cost efficiency of these measures when subsidies are used to help overcome the barriers to households including energy efficiency measures in their renovations.

For industry, the total investment drawn in by a EUR 1 billion RECCS investment subsidy is estimated at EUR 2 billion, i.e. it draws in an additional EUR 1 billion private investment. This is sufficient to install approximately 5.7 GW of **industrial heat pump capacity** or around 2 GW of **green hydrogen** production capacity. In both cases, and particularly for heat pumps, this investment is able to generate significant volumes of low carbon energy, leading to significant emissions reductions. The reductions are cost-effective for industrial heat pumps with marginal abatement costs lower than the renewable energy technologies at only 20 EUR/tCO_2e. Green hydrogen is much more expensive, at almost 700 EUR/tCO_2e, making it the highest cost measure in RECCS portfolio. However, in both cases there remains significant scope for further innovation in these technologies, particularly green hydrogen, which should reduce costs in the coming years, using estimated future assumptions the marginal cost for green hydrogen could fall to around 100 EUR/tCO_2e in future. RECCS could play an important role in driving this innovation and cost reduction. It is also relevant for RECCS to invest in both industrial heat pumps and green hydrogen to address different energy needs from industry, heat pumps being more appropriate for low temperature heat, green hydrogen for high temperature heat.

Nature-based solutions, do not draw in high levels of total investment compared to the other measures, as they are anticipated to require large public subsidies, assumed at 80% of the investment cost. However, large investments in nature-based solutions lead to large areas of ecosystems being protected or restored. This brings significant carbon benefits from carbon sequestration from these ecosystems. The marginal abatement cost of all NbS measures are low, very comparable to, or lower than, those for renewable energy and industrial heat pumps. Forest protection measures show lower emissions reductions than other measures, this relates to the additionality of the emissions reductions (sequestration) this achieves. However, protection measures remain highly cost-effective for emissions reduction and it should be noted that especially protection measures lead to very high carbon stocks also being protected (these stocks are not counted as emissions savings but are an important benefit – see also section 6.4 for more detail). All nature-based measures provide cost-efficient abatement potential.

Table 6-1 Comparison of EUR 1 billion RECCS support to each measure, showing investment costs, energy and emissions savings, marginal abatement costs

Indicator [unit]	RES:	RES:	RES:	RES:	RES:	EE: Renovation	EE: Renovation	EE: Renovation	EE: Renovation	EE:	EE:	NbS:	NbS:	NbS:	NbS:	NbS:	NbS:
	Solar PV [utility scale]	Solar CSP (thermal)	Wind Onshore	Wind Offshore	Other RES	low cost /high savings	low cost / low savings	high cost / high savings	High cost/low savings	Industrial heat pump	Green Hydrogen	Forest protection	Forest restoration	Peatland protection	Peatland restoration	Saltmarsh protection	Saltmarsh restoration
RECCS subsidy [M EUR]	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
Other finance [M EUR]	34 005	32 631	18 108	34 967	27 911	2 000	2 000	2 000	2 000	1 000	1 000	250	250	250	250	250	250
Total investment* [M EUR]	34 005	32 631	18 108	34 967	27 911	3 000	3 000	3 000	3 000	2 000	2 000	1 250	1 250	1 250	1 250	1 250	1 250
Cost [EUR/kW] or [EUR/m^2] or [EUR/ha]^	1 266	6 443	1 388	3 446	2 445	300	300	600	600	350	1 000	2 276	1 988	711	1 760	5 619	7 347
MW installed [MW] / no.of households deep renovation [n] / thousand ha treated	26 860	5 065	13 046	10 147	11 416	97 752	97 752	48 876	48 876	5 714	2 000	549	629	1 758	710	222	170
Annual energy generated/saved [GWh] / ha treated	40 000	21 739	40 000	40 000	40 000	2 176	1 280	1 088	640	50 057	3 279	549 291	628 666	1 758 011	710 105	222 478	170 141
Emissions per kWh [gCO$_2$e/kWh]	55	67	6	8	7	N/A	N/A	N/A	N/A	79	29	N/A	N/A	N/A	N/A	N/A	N/A
Emissions saving [ktCO$_2$e/yr]	48 040	25 848	50 000	49 920	49 960	435	256	218	128	6 040	562	1 289	5 901	4 838	1 954	1 819	1 391
Annual saving for households [m EUR]	N/A	N/A	N/A	N/A	N/A	247	146	124	73	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual OPEX [EUR/MWh], [EUR/m^2], [EUR/ha]	21	63	41	106	61	3	3	6	6	4	96	141	260	153	237	140	277
Lifetime [years]	20	20	20	20	50	30	30	30	30	20	10	100	100	100	100	100	100
Marginal abatement cost (Total cost) [EUR/tCO$_2$e]	**30**	**81**	**40**	**58**	**50**	**-270**	**-61**	**29**	**447**	**20**	**698**	**58**	**24**	**47**	**75**	**21**	**36**

Source: Own calculations, see earlier chapters for details.

* For the renewable energy technologies the total cost does not include the RECCS subsidy as this is paid for the electricity produced not to fund the initial investment in the construction of the renewable power technology.

The marginal abatement cost (total cost) for renewable energy technologies is based on the LCOE values presented earlier in section 3.4.1. The values for EE Renovation are calculated based on total investments and also include the cost savings for households each year (leading to a negative MAC in some cases).

^ The cost per ha of the NbS is based on a weighted average cost over time, based on the RECCS investment plan. In earlier years between 2025-2030 the actual cost would be lower, e.g. as shown in Table 4-3, and in later years higher, due to an assumed focus on cheaper measures compensating landowners for protection and restoration more at first, as a cost-effective way to large, fast impact, but as opportunities for this become scarcer, the share of more expensive land acquisition increases, and consequently average per hectare costs..

Example calculation: For the case of an industrial heat pump, a 1 billion EUR investment subsidy is provided on the basis of a matching investment of 1 billion EUR by industry, for a total 2 billion EUR investment. At an estimated capital cost of 350 EUR/kw, around 5 714 MW of heat pumps can be installed. This capacity is able to generate 50 057 GWh of heat to industry, based on a capacity factor of 50% (i.e. it runs half of the time) and a coefficient of production of 3 (i.e. for every unit of electricity provided to it, the heat pump produces 3 units of heat), e.g. 5 714 MW * 50% * 8760 hours * 2 (coefficient of 3 minus 1 [used to produce the 3]) = 57 057 000 MWh = 57 057 GWh. With emissions of 79 gCO_2e/kWh over the lifecycle, a kWh from a heat pump will displace emissions of 200 gCO2/kWh from an industrial gas boiler, a saving of around 121 gCO_2e/kWh for annual emissions savings of 121gCO_2e/kWh * 57 057 GWh = 6 040 $ktCO_2e$. To calculate the marginal abatement costs, the costs over the lifetime of the investments are aggregated and divided by the emissions savings. In this case the total investment cost of 2 billion euros plus annual operational and maintenance (OPEX) costs of 4 EUR/MWh (i.e 4 EUR MWh * 57 057 000 MWh = 200 M EUR/year maintenance = * 20 year lifetime = 4 billion euros, therefore 2 billion CAPEX plus 4 billion OPEX = 6 billion total costs. Divided by 6 040 ktCO2e emissions savings for 20 years = 6 040 * 20 = 120 800 ktCO2e lifetime savings. Therefore the marginal abatement cost equals 6 billion EUR / 120 800 ktCO2e = 20 EUR/tCO_2e.

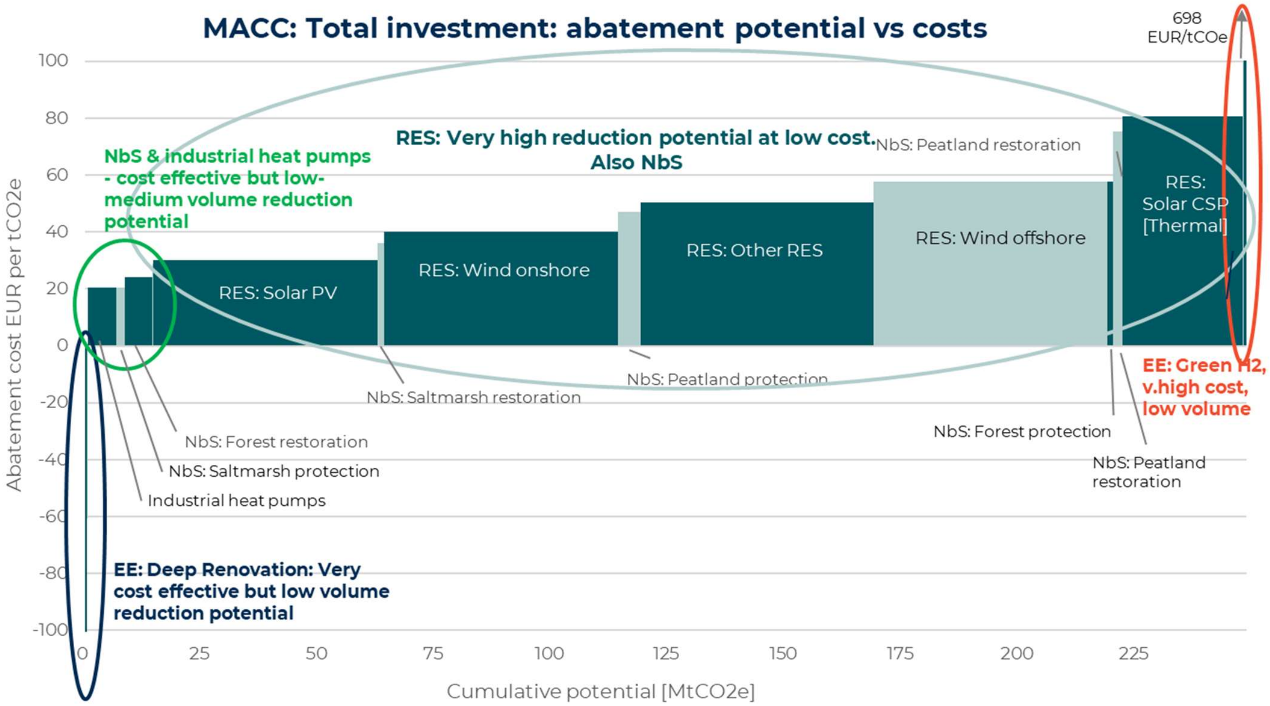
In the following figure 6-1 we show the marginal abatement cost results for the total investment from the previous table using a **Marginal Abatement Cost Curve (MACC),** this gives a clear visual depiction of what can be achieved from EUR 1 billion of RECCS subsidy to each of the measure types. It shows both annual emissions savings volumes (width of the bar on the horizontal axis) and the total marginal cost of these (height of the bar on the vertical axis), averaged over the lifetime of the measure. For example taking solar PV from the previous table, with a marginal abatement cost of 30 EUR/tCO_2e and annual emissions saving of 48 040 ktCO2e (or 48 MtCO2e) it is shown with a relatively wide bar, and is neighboured to the left by the next lowest marginal abatement cost measures of high cost/high saving residential energy efficiency renovation (29 EUR/tCO_2e), and on the right by the next highest marginal abatement cost measure, salt marsh restoration (36 EUR/tCO_2e).

This shows that the low cost deep renovation measures provide the most cost-effective savings potential (with a negative abatement cost resulting from the cost savings to households), however, the volume of emissions savings is very small relative to most of the other measures. The most cost-effective measures for emissions reduction are investments in many of the nature based solutions measures, with marginal costs of 27 EUR/tCO_2e or less. However, the emissions reduction potential volumes are quite small.

By far the biggest emissions reductions at cost effective prices are found in the renewable energy technologies (RES) and industrial heat pumps, with marginal costs of 30-80 EUR/tCO_2e and emissions reductions volumes of 9-50 $MtCO_2e$ each. Therefore for large volume, cost effective emissions reductions renewable energy and heat pump investments are essential. At the far end right of the curve are green hydrogen and high cost-low saving deep renovation measures which have very high marginal costs i.e. almost >440 EUR/tCO_2e and much smaller emissions savings potential. Of these two, green hydrogen is likely to become much more cost-effective over time, and investments at this stage will speed the scaling and innovation in the sector.

Some important things to note from this figure are that for renewable energies the subsidies to generation through RECCS need to be paid again anew each year, whereas the subsidies to energy efficiency (EE) measures are for one-off investments, and therefore over time the volume of emissions reduction will grow as more and more houses are renovated, heat pumps installed or green hydrogen is used. For example, after 10 years the volumes for RES would remain the same, but for energy efficiency would become more sizeable: e.g. for deep renovation, approaching 10 $MtCO_2$ per year; industrial heat pumps 90 $MtCO_2$ per year; and, for Green hydrogen nearly 6 $MtCO_2$ per year; i.e. in total across all three categories almost half of the total volume in the figure. Therefore, whilst renovation, industrial heat pump and green hydrogen measures may be less attractive in delivering large emissions savings, their impact grows over time with continued investment. Similarly for nature based solutions, as more and more land is protected, the total impact over 10 years could also grow to more than 60 $MtCO_2e$/year. As a result, there remains cost-effective emissions reduction value in a RECCS strategy also prioritising these measures for emissions reduction, not only prioritising renewable energy. It is also crucial to note the multiple important co-benefits of the energy efficiency and nature based solutions measures, for the latter particularly the protection of carbon stocks to avoid future emissions is a very important benefit not accounted as abatement.

Figure 6-1 Marginal abatement cost curve for RECCS measures in year 1, total investment cost basis



Source: Trinomics own calculations

6.2 Impact of an integrated RECCS

For this chapter we compare the impact of the base case against the impact of the key components of an implemented RECCS. The RECCS assumes that:

- All subsidies that would be allocated to forest biomass in the base case would be available to support the alternative options[189].
- The subsidies are first used to fund RES alternatives for electricity production to fill the energy gap – spread per technology and value as per chapter 3, i.e. totalling EUR 1 955 million in subsidies in 2025. Subsidies are provided to electricity generation, with the required capital investments coming from existing markets (private and public finance) as already occurs.
- An additional 20% of the subsidy total (EUR 391 million in 2025) is reserved for supporting measures for the RES alternatives, primarily for direct investments for grid strengthening and storage, this helps to ensure that energy system function is maintained.
- The remaining subsidies (EUR 4 002 million in 2025, but increasing over time – see section 2.2) are split equally between energy demand reduction measures and carbon absorbent ecosystems (EUR 2 001 million each in 2025).
- For nature based solutions, based on the analysis in chapter 4, comparison provided in section 4.3.1 and respective volumes of this habitat type, based on expert judgment (considering costs, emissions savings and especially the available hectarage of the habitat types) we assume the following split of funding for the RECCS:
    - 50% of the funds are allocated to forest protection

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[189] We acknowledge that in reality, due to contractual and other constraints not all subsidies could be so quickly redeployed at least in the first period of the RECCS. The previous section provided an indication of what could be achieved through EUR 1 billion subsidy to each measure, giving an idea of how emissions reductions (and other impacts) could scale with increased RECCS subsidies.

  - 32% of the funds are allocated to forest restoration
  - 5% of the funds are allocated to peatland protection
  - 10% of the funds are allocated to peatland restoration
  - 2% of the funds are allocated to saltmarsh protection
  - 1% of the funds are allocated to saltmarsh restoration
  - Sensitivity checks of these splits showed that significant deviations result in RECCS treating more hectares of the ecosystem type than exist in the EU, therefore they are targeted primarily at forest protection and restoration.
  - For each of these activities the RECCS supports 80% of the initial investment costs – taking into account the lower and/or more uncertain returns on investment meaning attracting matching funds is more difficult than for other investments. The remaining 20% of the investment is expected to be sourced from other sources of public or private finance with the RECCS investment leveraging the additional funding (see also Chapter 7).
  - RECCS is also assumed to support 80% of the ongoing operational and maintenance costs of the protected and restored ecosystems.
  - This funding support levels of 80% are broadly consistent with other EU nature funding programmes, and could even be judged generous compared to some programmes i.e. in reality less RECCS funding may be needed and more funding could be secured from other sources. If this were the case then the RECCS impact could be even higher.
- For the demand reduction and energy efficiency measures, based on the analysis in chapter 5 and comparison in 5.4.1, we assume the following split of funding for the RECCS:
  - 70% of the funds are allocated to deep renovation of residential properties, split equally between the four situations modelled, and within each 70% to pre-1960 buildings, and 30% to those from 1960-1990.
  - 30% of the funds are allocated to industry with equal shares of this (50:50) to industrial heat pumps and green H2 up to 2035, from 2036-2050 the split evolves 30:70, with greater focus given to green hydrogen for hard to abate sectors.
  - It is assumed that subsidies are provided for 33% of the cost of the residential renovation measures, and for 50% of the cost of industrial heat pumps and green hydrogen measures.
  - The remainder of the investment cost is expected to be leveraged by the RECCS funding from other public and also private sources (for example from other national or EU schemes, and from the households and businesses receiving the measures, see also Chapter 7);
- No ongoing operations and maintenance costs of any of the RES or EE measures are funded by RECCS, these are expected to be funded by the owner of the measure.
- The volume of the energy gap and subsidies available changes over time, growing as the base case projection for growth in energy from solid forest biomass leads to both higher subsidies and a higher energy gap.

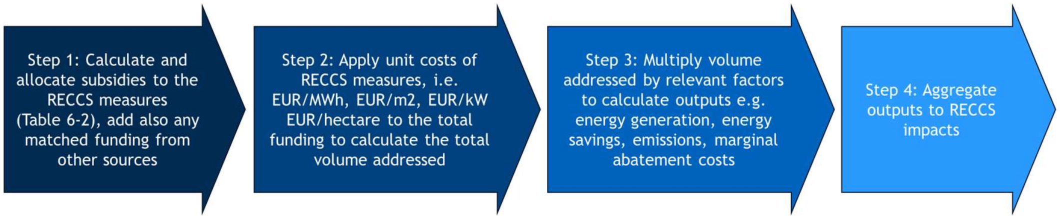
The following table 6-2 summarises the actual subsidy distribution taking into account all the splits described above, comparing the base case and the RECCS case. As explained in section 2.2 the base case for subsidies is based on assumptions in the projected growth over time of the volume of electricity from forest biomass, and especially BECCS, multiplied by an assumed EUR/MWh subsidy rate.

As can be seen, projected growth in subsidies to BECCS, a very expensive form of electricity generation, is the main driver of projected subsidy growth after 2030. The RECCS section in the second half of the table demonstrates how the same total subsidy amount is allocated on the basis of the assumptions set out earlier in this sub-section. These totals do not include the match funding that RECCS will attract from other sources.

Table 6-2 Overview of annual EU forest biomass energy subsidies in the base case and their re-distribution by the RECCS, M EUR

		2020	2025	2030	2035	2040	2045	2050
Base case	Electricity from forest biomass	5 647	5 954	6 005	7 115	8 225	9 335	10 445
	BECCS (Electricity from forest biomass)	69	138	1 106	6 606	12 835	18 686	24 160
	Other energy from forest biomass	247	255	262	262	262	262	262
	Total	**5 963**	**6 348**	**7 373**	**13 983**	**21 322**	**28 283**	**34 867**
RECCS								
RES	Wind onshore		524	609	990	1 371	1 752	2 133
	Wind offshore		476	553	899	1 244	1 590	1 936
	Solar PV		620	720	1 171	1 621	2 072	2 522
	Solar thermal		241	225	274	343	439	534
	Other RES		94	110	178	247	316	384
	RES - sub-total		*1 955*	*2 217*	*3 511*	*4 827*	*6 168*	*7 509*
	Grid improvements		391	443	702	965	1 234	1 502
	Sub-total RES + Grid		***2 346***	***2 660***	***4 214***	***5 792***	***7 401***	***9 011***
NbS	Forest protection		1 000	1 178	2 442	3 882	5 220	6 464
	Forest restoration		640	754	1 563	2 485	3 341	4 137
	Inland wetland (peatland) protection		100	118	244	388	522	646
	Inland wetland (peatland) restoration		200	236	488	776	1 044	1 293
	Coastal wetland (saltmarsh) protection		40	47	98	155	209	259
	Coastal wetland (saltmarsh) restoration		20	24	49	78	104	129
	Sub-total NbS		***2 001***	***2 356***	***4 885***	***7 765***	***10 441***	***12 928***
EE	Buildings renovation		1 401	1 650	3 419	5 435	7 309	9 050
	Industrial heat pumps		300	353	733	699	940	1 164
	Industrial green H2		300	353	733	1 631	2 193	2 715
	Sub-total industry		***2 001***	***2 356***	***4 885***	***7 765***	***10 441***	***12 928***
RECCS: All	Total		6 348	7 373	13 983	21 322	28 283	34 867

On this basis a modelling and comparison of energy production and emissions has been made. Whilst the modelling is quite simplified (see flow figure below for a simple representation of the steps), many of the complex issues are considered and addressed in the calculations. Therefore the estimations provide a good indication of the magnitude and direction of impacts of the RECCS, the following sections present the results of these subsidies.



Step 1: Calculate and allocate subsidies to the RECCS measures (Table 6-2), add also any matched funding from other sources

Step 2: Apply unit costs of RECCS measures, i.e. EUR/MWh, EUR/m2, EUR/kW EUR/hectare to the total funding to calculate the total volume addressed

Step 3: Multiply volume addressed by relevant factors to calculate outputs e.g. energy generation, energy savings, emissions, marginal abatement costs

Step 4: Aggregate outputs to RECCS impacts

6.3 Energy system impacts

The RECCS approach has three key impacts on the energy sector:

1) it drives a switch from forest biomass use for electricity to greater use of alternative renewable energies as described in chapter 3;
2) it reduces heat demand in residential (and services) buildings which are addressed by the deep renovation energy efficiency measures described in chapter 5; and
3) it supports fuel switching in the industrial sector through support for industrial heat pumps and green hydrogen.

The other measures which make up the RECCS, e.g. support for nature-based solutions, do not have a significant direct impact on the energy system. However, RECCS measures in the energy sector can have significant benefits for nature, for example in reduced pollution and land-use per unit of energy output (comparing one hectare forest and one hectare solar PV, the latter requires far less land for the same energy output). These other impacts are addressed later in this chapter.

Impact of alternative renewable energy sources on the electricity mix

In the electricity sector the removal of subsidies leads to a major decline in use of forest biomass, with only a small share of unsubsidised use remaining. It also prevents the development of BECCS which is abandoned as uneconomic without subsidies. Alternative low carbon technologies such as wind (onshore and offshore), solar (PV and thermal [CSP]) and other RES are subsidised to fill the gap. These are deployed alongside investments in the grid and storage options to provide the flexibility the energy system needs. In the base case BECCS and Primary solid biomass together provide around 320 TWh of electricity in 2050 or about 4.7% of the total electricity consumption. In the RECCS case the 151 TWh of BECCS is forestalled, and electricity from forest biomass is reduced to around 20 TWh, a small fraction of its projected level in the base case, and also of the total electricity consumption (0.3%). In reality this small share, of which part would be based on genuine residuals and part on operations that are economically viable without subsidies, is likely to also vanish over time as the case for using forest biomass becomes more and more untenable from a climate perspective. Indeed, this would be the overall goal of the RECCS, to incentivise an entire phase-out of forest biomass use for energy. In the RECCS scenario the electricity gap of around 300 TWh is filled by a mix of wind (+178 TWh), solar PV (+101 TWh), solar CSP (+21 TWh) and Other RES (+15 TWh)[190].

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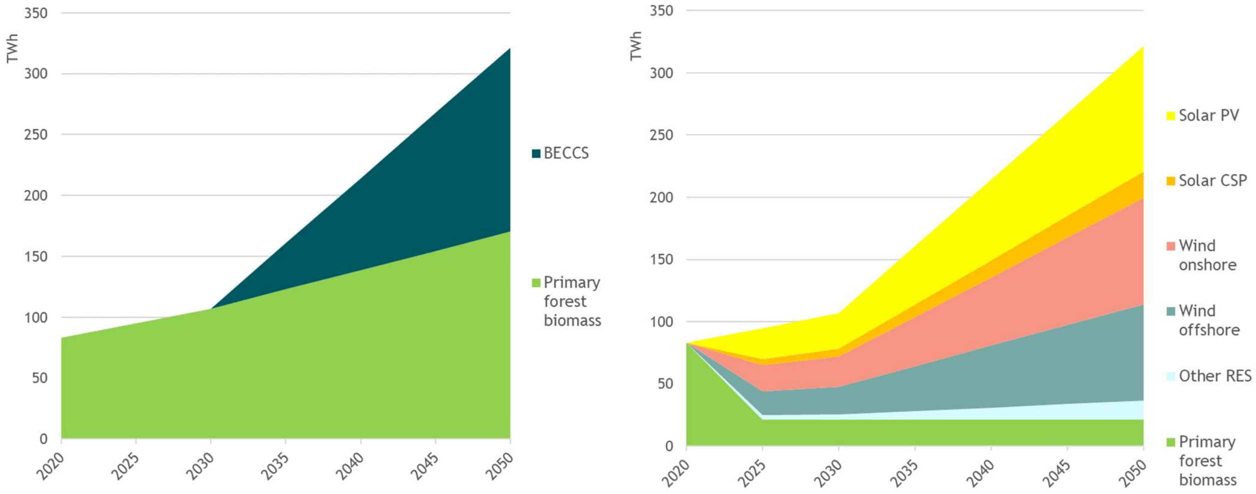
[190] As noted in chapter 3 this category encompasses geothermal, energy from waste, micro-hydro, wave and tidal energy, and in future could include other new low-carbon power sources.

Figure 6-2 Electricity generation sources in base case (left) and RECCS case (right), 2020 (actual) to 2050 (projection), TWh

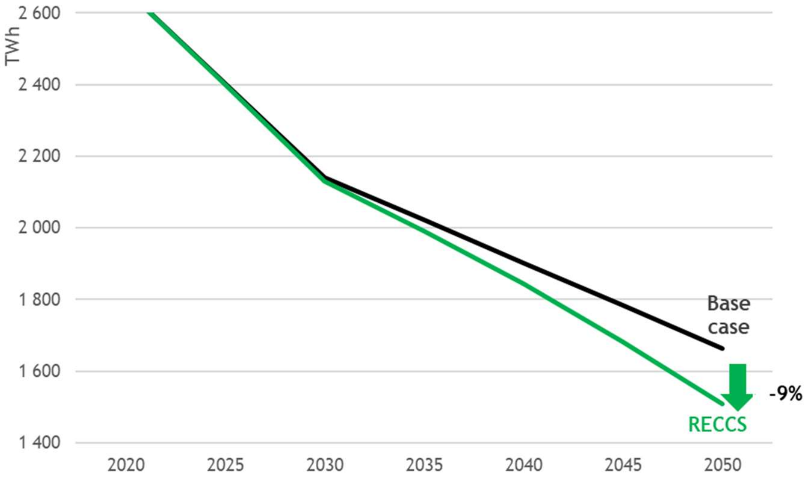


Source: Trinomics own calculations.

Impact of energy efficiency measures on residential (and services sector) heat demand

The RECCS energy efficiency measures outlined in 5.1 can lead to significant energy savings in buildings, and these can also accumulate over time. Starting with subsidy switching in 2025 the programme could fund deep renovation of around 103 000 households across the EU in its first year, as the diverted subsidy totals increase, the number of deep renovations also increases to more than 660 000 households per year by 2050. In total, between 2025-2050 the programme could fund deep renovation of more than 8.8 million EU households, in 2022 there were 198 million households in the EU, **therefore this programme alone could renovate more than 4.4% of all EU households over this period**. The large energy savings that can be achieved at household level, i.e. 50-85% energy savings, lead **to a reduction in EU annual residential heat demand of more than 156 TWh in 2050, this represents around 9% of estimated residential heat demand in 2050.** This reduction in demand would reduce use of a variety of fuels, but would be expected to especially reduce fossil fuel use for heating, especially natural gas. It may also displace forest biomass use for heating in some cases, although in many countries this is used for cultural/traditional reasons and due to the local abundance of fuelwood.

Figure 6-3 Impact of RECCS on annual residential (and services) heat demand in buildings, 2020-2050, TWh

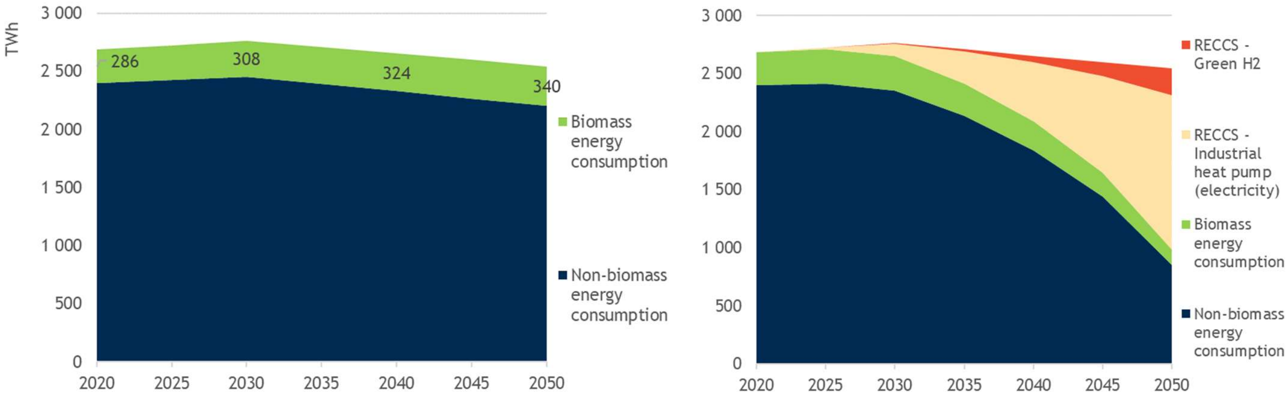


Source: Trinomics own calculations.

Impact of industrial measures on the energy system

The RECCS energy efficiency and decarbonisation measures for industry, detailed in 5.2, also have significant impacts on industrial energy use. The two key measures affecting the energy system directly are industrial heat pumps and green hydrogen. These measures are modelled as a fuel switch within the industrial sector, with the adoption of heat pumps being both more cost and energy efficient than green hydrogen and therefore contributing the biggest impact. **Adopting RECCS could lead to the adoption of industrial heat pumps to meet 53% of industrial final energy consumption by 2050.** This is one of the decarbonisation measures with the biggest impact in the RECCS. Green hydrogen supported under RECCS grows more slowly, accounting for 9% of industrial final energy consumption by 2050. Despite this lower impact it remains desirable to support green hydrogen as this is most applicable to the harder-to-abate industrial sectors that need high-temperature heat. Heat pumps are (with current technologies) only able to address sectors requiring low temperature heat. Sectors needing low-temperature heat constitute between 50-75% of the total energy consumption by the industrial sector, so that by 2050 further opportunities to apply industrial heat pumps may be limited. Funding innovation in high temperature industrial heat pumps and/or an adjustment to RECCS after 2035 to focus more on Green hydrogen would both be good complementary strategies. A review of the situation and technologies in the 2030’s would be advised for those implementing a RECCS in any case and it is likely that the costs of green hydrogen will decrease so that RECCS investments can be increasingly effective.

Figure 6-4 EU industrial energy use: impact of RECCS deployment of industrial heat pumps and green hydrogen (right), compared to base case (left), annual final energy consumption, TWh



Source: Trinomics own calculations

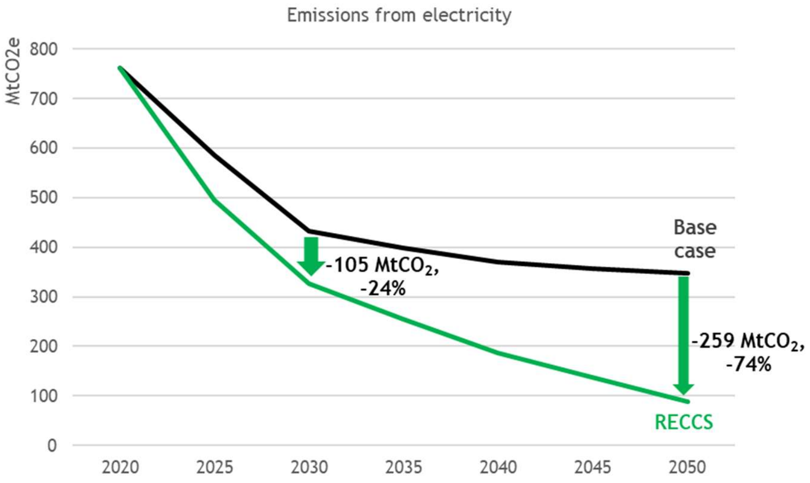
6.4 Emissions impacts

This section provides estimates of the potential GHG emissions savings of RECCS compared to the baseline EU scenario.

Impact on emissions from electricity sector

Substituting electricity generation from subsidised forest biomass for electricity from wind, solar and other RES power could lead to significant emissions savings, as shown in Figure 6-5. Our simple modelling of the energy system emissions based on the emissions factors set out in section 2.3 of the report (excluding life-cycle emissions, but including combustion emissions for forest biomass), shows that **annual savings of 105 MtCO$_2$e are possible by 2030, this saving is equivalent to the current (2021) total emissions of Denmark and Hungary combined. By 2050 the savings would increase to 259 MtCO$_2$e per year, equivalent to more than the current (2021) total emissions of Spain.**

Figure 6-5 Impact of adopting RECCS on direct GHG emissions from electricity, MtCO$_2$e



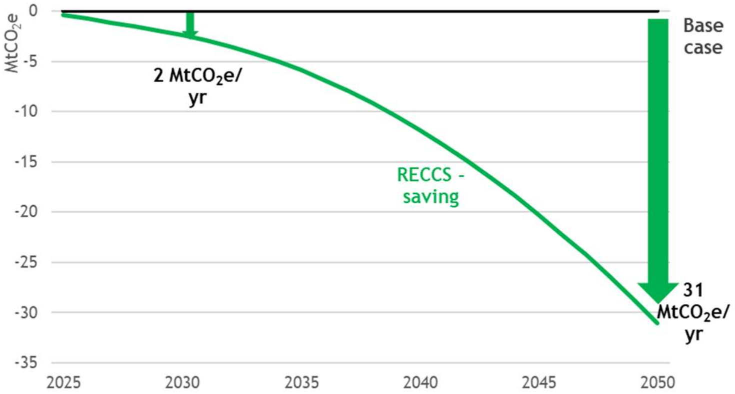
Source: Trinomics own calculations

Note: Emissions in the base case are calculated on the basis of the emissions for biomass and BECCS set out in section 2.3 of this report. Emissions in 2050 are not equal to zero as residual fossil fuel use remains and although fitted with CCS this does not capture all emissions. A very small residual of unsubsidised biomass use, involving genuine residues also contributes to emissions.

Impact on emissions from residential and services heating

The reductions in energy use from the efficiency measures in residential housing also lead to notable emissions savings, with these savings growing over time. As shown in Figure 6-6, **the energy savings in buildings are estimated to generate annual emissions savings of 2.4 MtCO₂e by 2030** as the efficiency measures reduce the use of natural gas. This grows as more and more homes are treated, **and by 2050 annual savings of 31 MtCO₂e are estimated**, this is equivalent to around the current (2021) total emissions of Slovakia. The actual emissions savings could vary depending on the heat system being displaced, for example if more coal, oil or biomass heating systems, each with higher emissions than natural gas, were displaced then emissions reductions would be even higher.

Figure 6-6 Estimated GHG emissions savings of RECCS energy efficiency measures in buildings, compared to baseline, MtCO₂e



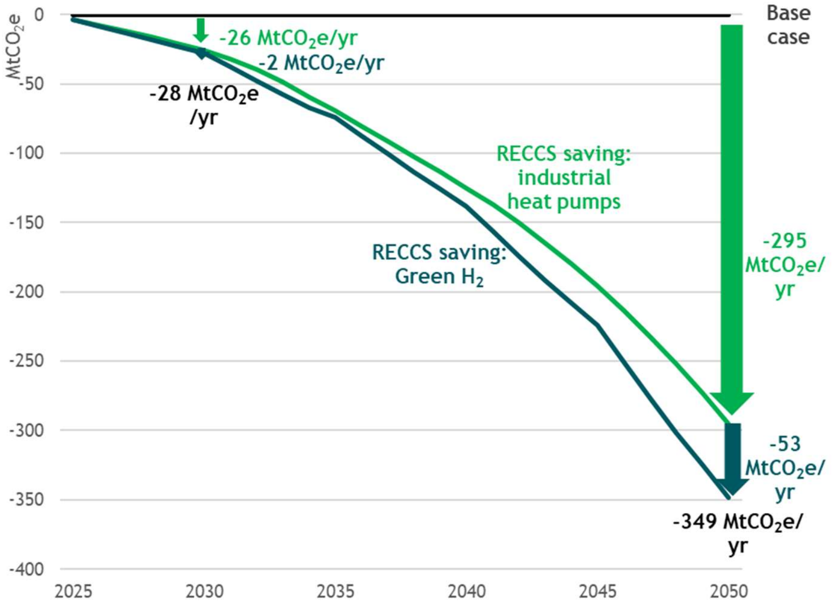
Source: Trinomics own calculations

Note: Emissions savings of the RECCS are calculated on the basis that the energy savings save a unit of energy use from an average gas boiler emitting 0.2kgCO2/kWh of heat delivered.

Impact on emissions from industrial final energy consumption

Reductions in industrial emissions from RECCS are potentially huge. As shown in Figure 6-7 **the adoption of industrial heat pumps by industry can lead to annual emissions savings of 26 MtCO₂e by 2030, with this increasing to 289 MtCO₂e by 2050**. The other branch of the RECCS relevant for industry is **the adoption of green hydrogen which can lead to emissions savings of 2 MtCO₂e by 2030 and 52 MtCO₂e by 2050**. Taken together **the RECCS can lead to annual emissions reductions compared to a baseline of industrial natural gas use of 28 MtCO₂e by 2030, equivalent to the total current (2021) emissions of Estonia and Luxembourg combined, and of 341 MtCO₂e by 2050, almost equivalent to the entire total current emissions of the EU agricultural sector in 2021.** For further context, current industrial emissions in the EU are estimated at 757 MtCO₂e, therefore **these measures on their own could reduce total EU industrial emissions by 3.6% by 2030, and by 45% by 2050.**

Figure 6-7 Estimated GHG emissions savings of RECCS energy efficiency and decarbonisation measures in industry (industrial heat pumps and green H_2), compared to baseline, $MtCO_2e$



Source: Trinomics own calculations

Note: Emissions savings of the RECCS are calculated on the basis that the industrial heat pumps and green hydrogen displace fuels in the same proportions as Figure 6-3. Emissions from non-biomass energy consumption are estimated at 0.27tCO2/MWh in 2025, declining by 0.02tCO2/MWh every 5 years to 2050. Emissions from biomass consumption are held at $0.566tCO_2e/MWh$, based on an assumed 65% efficiency of industrial boilers for heat. Emissions from industrial heat pumps begin at $0.062tCO_2e/MWh$ in 2025, based on a grid emissions factor of $0.18tCO_2e/MWh$ and a heat pump efficiency of 300%, the grid emissions factor is assumed to decline over time to $0.013tCO_2e/MWh$ by 2050. Emissions from green hydrogen are assumed to be zero as these are produced from renewable energy. Actual achievable emissions reductions per investment remain uncertain and could be lower (if success is overestimated) or higher (if learning can reduce costs).

Impact on emissions from nature-based solutions

The nature-based conservation measures set out in chapter 4 can provide significant emissions savings when funded under a RECCS. Based on the costs per hectare presented in chapter 4 and an assumed subsidy of 80% the values allocated under RECCS would be able to fund the conservation of millions of hectares of land each year. Indeed by the end of the period a large share of all forests, wetlands and peatlands in the EU could be conserved under the RECCS assumptions, i.e. by 2030 more than 4.7 million hectares of forest could be protected and 2.7 million hectares restored through the cumulative investment of around EUR 13 billion. The total hectarage represents around 4.7% of the EU total forest area and would represent a significant contribution towards the targets of the EU nature restoration law. For peatlands around 0.65 million hectares would be protected and 0.8 million hectares restored; and for coastal wetlands (salt marshes) the totals are 0.1 million hectares protected, 0.04 million hectares restored[191].

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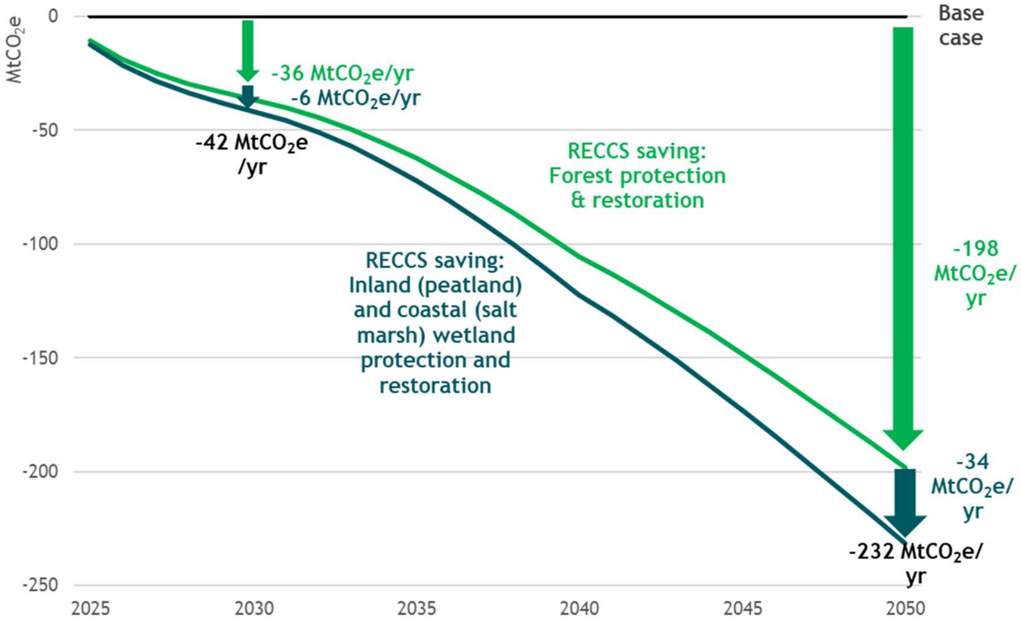
[191] These numbers are based on calculations of the available subsidies multiplied by assumed one-off costs to bring the land under protection or restoration. For example taking the first year of 2025, for forest protection an average investment cost of 1 115 EUR per hectare is assumed. With approximately 1 billion EUR in subsidies allocated to forest protection by the RECCS and an additional 250 million EUR assumed to be leveraged from other sources a total of 1.25 billion EUR can be invested in forest protection. This enables around 1.12 million hectares of forest to be

In reality, achieving such large scale protection and restoration projects would likely be more difficult due to the practicalities of organising such an effort, but the RECCS funding provides the potential for such large scale action. The actual costs per hectare, for example for land acquisition especially, could be higher than our assumption, this would reduce the number of hectares that could be treated (protected or restored). However, as ongoing costs are also funded, fewer hectares would mean lower ongoing costs and more funding available in later years for land acquisition, and vice-versa, this acts as a balancing mechanism so that higher investment costs only lead to relatively small changes in the area that RECCS can treat and the impact it can have. Given this, under the RECCS model, the evidence is clear that large scale protection and restoration activities can achieve significant carbon sequestration benefits (and also carbon storage – see Figure 6-9). The analysis estimates savings would already total 42 $MtCO_2e$ per year by 2030, increasing to 232 $MtCO_2e$ per year by 2050. Forest protection and restoration have by far the largest sequestration impact within the totals, this is reflecting the size of the area that can be protected and restored, which is much higher than the inland or coastal wetlands, and the subsidy allocation which also reflects this.

Figure 6-8 Estimated GHG emissions savings of RECCS nature based solution measures through natural sequestration[192], compared to baseline, $MtCO_2e$



Emissions savings of the RECCS measures are calculated on the basis of assumed average annual sequestration values per hectare of ecosystem protected or restored. For forest protection it is assumed that 25% of the RECCS sequestration is additional to the base case, i.e. the RECCS measure protects forest that would in the base case have lost 25% of its sequestration potential as natural forest became managed, or was converted to farmland or used for other development. Based on our experience we believe this to be quite a conservative estimate, particularly over long management timeframes.

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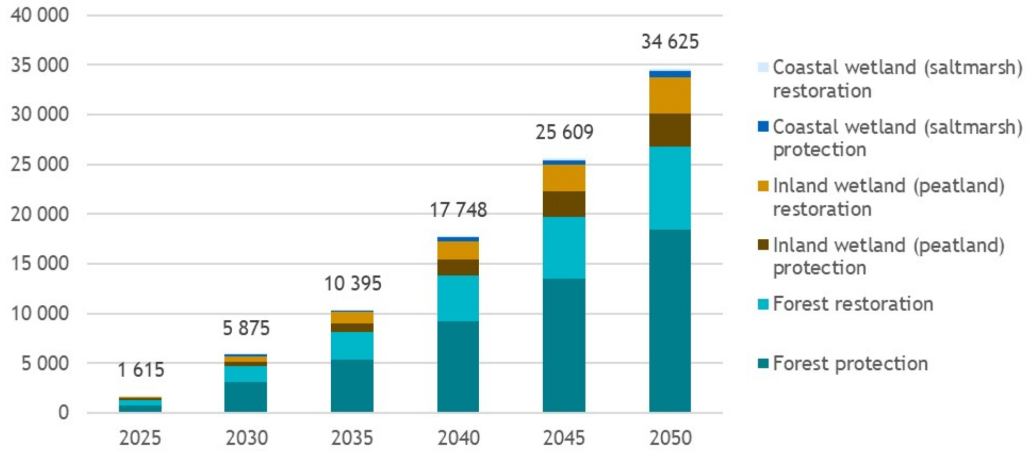
protected (1.25 billion EUR / 1 115 EUR ha). In later years the assumed cost for protection increases, and therefore less land can be protected for the same amount, however, it is also the case that subsidy amounts are projected to increase significantly across this period. As a result high volumes of land can still be brought under protection each year in the RECCS scenario.

[192]

One limitation to the sequestrations calculations presented above relates to the **additionality** of the sequestration savings in the case of protection, where it is relevant to ask the question if protection adds to the LULUCF sink or simply preserves the existing sink, and if gains to sequestration from protection (from regrowth) would persist in the long term. A consideration here is that in the absence of protection a share of the forests would come under more active management (reducing stocks and sequestration) or be lost to development, and this therefore is additional to a baseline of no protection. This issue is dealt with through a, very likely conservative, assumption of 25% additionality of the RECCS measures (see also notes to figure 6-8), however this value could be higher or lower in reality, with significant impacts on the emissions reductions potential, i.e. at 100% additionality emissions reductions from forest protection total 44 $MtCO_2e$/yr in 2030, rather than 11 $MtCO_2e$/yr with the current 25% assumption.

A crucial benefit of nature based solution measures which protect forests and other ecosystems is the carbon stock that they protect. This does not count as an emission reduction per se, but is an important impact from the measure and the scale of the carbon stock protected dwarves that of the sequestration value of the measures. This is shown in Figure 6-9 where around 5 900 $MtCO_2e$ is protected by 2030, increasing to 34 600 $MtCO_2e$ by 2050, for context, total annual EU emissions in 2021 totalled 3 242 $MtCO_2e$, highlighting the high significance of the carbon stocks preserved in forests and wetlands. These estimates are subject to the assumptions on average carbon stocks per ecosystem type, of which there are significant ranges in the scientific literature, but recent macro-level estimations also find carbon stocks of similar volumes possible[193].

Figure 6-9 Estimate of carbon stock protected by RECCS measures for protection and restoration, $MtCO_2e$



Source: Trinomics, own calculations

Note: the values in this chart are calculated on the basis of volume of land treated under RECCS multiplied by the average carbon stock (converted to CO2e) of the ecosystem type – see Table 4-6 for specific assumptions – for example in 2035 an estimated cumulative total of 1.3 million ha of peatland is brought under protection by RECCS, and each ha has an estimated average carbon stock of 720 tCO_2e/ha, then multiplying the two the total carbon stock protected is estimated at 926 $MtCO_2e$.

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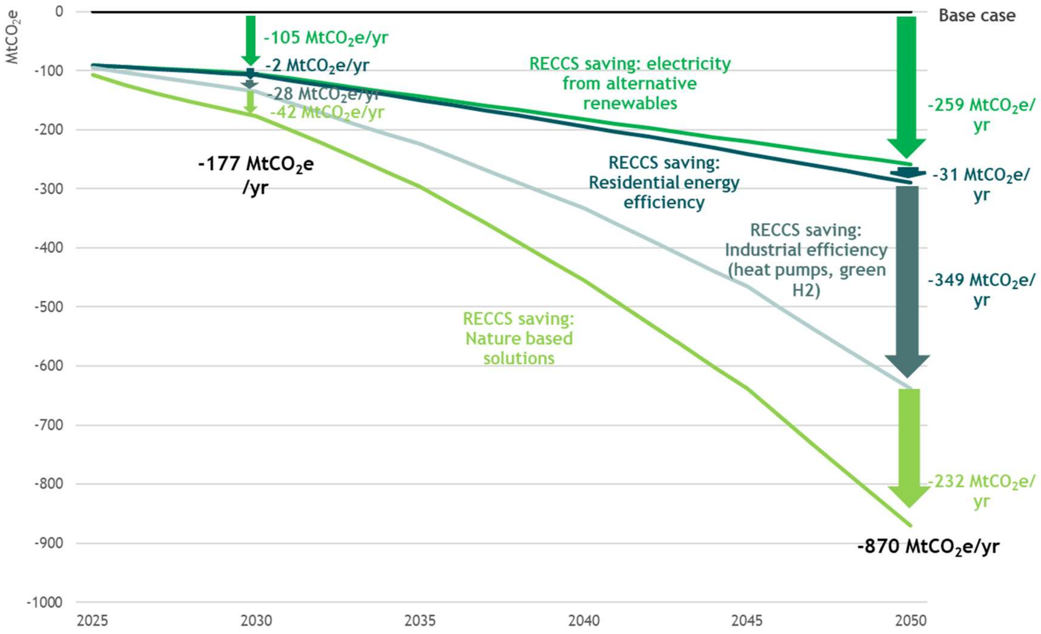
[193] See Keith, H., Kun, Z., Hugh, S. et al. Carbon carrying capacity in primary forests shows potential for mitigation achieving the European Green Deal 2030 target. Commun Earth Environ 5, 256 (2024). https://doi.org/10.1038/s43247-024-01416-5

Summary impact on emissions from RECCS

In total, summing across the active measures we can show **RECCS emissions savings of 177 MtCO$_2$e per year by 2030**. This is a sizable amount in the context of the EU Fit-for-55 goal for 55% emissions reductions by 2030 (compared to 1990 levels), for example compared to the gap from 2021 emissions to the 2030 target of 1 146 MtCO$_2$e, the RECCS saving of 177 MtCO$_2$e would already contribute the equivalent of 15.5% of the total required savings[194]. **By 2050 with a goal of net zero emissions, the cumulative annual impact of the RECCS of 870 MtCO$_2$e per year** compares to current EU total emissions of 3 242 MtCO$_2$e per year (2021), and therefore RECCS represents savings equivalent to a contribution of almost 27% towards meeting the EU net zero goals by 2050. In addition to these savings the RECCS would also contribute substantially to protecting EU forest and wetland carbon stocks, protecting stocks of around 34 GtCO$_2$e by 2050.

Figure 6-10 Summary of annual emissions savings possible in a RECCS scenario, compared to the base case, 2025-2050, MtCO$_2$e



Source: Trinomics own calculations

6.5 Economic, social and environmental impacts

In this section we provide further detail on the key economic, social and environmental impacts of RECCS compared to the base case. These are crucial and further build upon the energy and emissions advantages of the RECCS as set out in the previous sections.

Investments

The allocation of subsidies to either biomass and BECCS in the base case or the range of alternative measures in RECCS has an important impact on investments, which is crucial to understanding the

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[194] We note this as equivalent to, as the savings from the renewable energy measures in RECCS include savings based on savings from reduced biomass combustion for electricity, whilst the EU emissions inventory and targets do not include these emissions. This applies almost exclusively to the estimated savings from alternative renewables. The savings from energy efficiency and nature based solutions measures would be accounted as emissions reductions in a similar manner to these RECCS estimates.

economic impact. The RECCS proposes to use only the same amount of subsidies as the base case but, as shown in Table 6-3, is estimated to unlock significantly higher investments. **In the short-term, 2025-2030 the RECCS is estimated to unlock more than EUR 101 billion in investments, or EUR 80 billion more than the base case. The RECCS delivers almost 2.47 EUR in investment for every 1 EUR spent on subsidies in this period, compared to an estimated 0.51 EUR per 1 EUR subsidy in the base case.** This pattern is repeated across the periods and the RECCS retains a positive ratio of investments to subsidies and significantly outperforms the base-case.

The investments in the RECCS case can only partially be met by redirecting investments intended for bioenergy, indeed the planned bioenergy investments are only around 10-25% of the investments planned in the RECCS case. The RECCS investments are attracted by the subsidies: for electricity this is based on a 25 EUR/MWh (or greater) premium providing a boost to revenues to attract investors. In reality it is likely that the subsidy value would need to be translated into an estimated equivalent in a two-way contract-for-difference system, for example increasing the strike price to provide greater surety for investors of a return on capital. For industrial and household measures, there is often a willingness to invest but insufficient access to investment capital, the subsidy measures would allow many more investment decisions to be taken, as has shown been by existing schemes for example in Italy. For nature-based solutions the investments are heavily subsidised, up to 80% of the investment cost, by RECCS. Consultation with renewables and energy intensive industry during the project highlighted that they would welcome further investment or income subsidies, also as part of a package of measures that addressed other barriers to investment.

Table 6-3 Subsidies and investments, cumulative for the stated period, comparing base case with RECCS, [M EUR]

Indicator	Base Case	RECCS	Comparison
2025-2030			
Subsidies paid	41 162	41 162	-
Investments: Biomass & BECCS	21 042	0	-21 042
Investments: Other renewables	0	51 220	51 220
Investments: Energy efficiency & industrial decarbonisation	0	35 296	35 296
Investments: Nature-based solutions	0	14 968	14 968
Total investments	**21 042**	**101 483**	**80 442**
Leverage (subsidies:investments)	**0.51**	**2.47**	**1.95**
2031-2040			
Subsidies paid [cumulative]	148 627	148 627	-
Investments: Biomass & BECCS	78 351	0	-78 351
Investments: Other renewables	0	182 127	182 127
Investments: Energy efficiency & industrial decarbonisation	0	141 564	141 564
Investments: Nature-based solutions	0	58 997	58 997
Total investments	**78 351**	**382 688**	**304 337**
Leverage (subsidies:investments)	**0.53**	**2.57**	**2.05**
2041-2050			
Subsidies paid [cumulative]	288 661	288 661	-
Investments: Biomass & BECCS	58 997	0	-58 997
Investments: Other renewables	0	269 059	269 059
Investments: Energy efficiency & industrial decarbonisation	0	287 600	287 600
Investments: Nature-based solutions	0	120 052	120 052
Total investments	**58 997**	**676 711**	**617 714**

Leverage (subsidies:investments)	**0.20**	**2.34**	**2.14**
2025-2050			
Subsidies paid [cumulative]	478 450	478 450	-
Investments: Biomass & BECCS	177 743	0	-177 743
Investments: Other renewables	0	502 407	502 407
Investments: Energy efficiency & industrial decarbonisation	0	464 460	464 460
Investments: Nature-based solutions	0	194 016	194 016
Total investments	**177 743**	**1 160 883**	**983 140**
Leverage (subsidies:investments)	**0.37**	**2.43**	**2.05**

Source: Own calculations

Note: The investments for each line are calculated on the basis of the capital investment costs in the new biomass, RES, EE or NbS brought forward by the subsidies (see chapter tables for these values). For renewables as the subsidy is to the produced electricity the entire capital investment is leveraged, and equates to the capacity required to generate the required contribution (in GWh) to the energy gap – with standard assumptions on capacity factors, cost reduction and efficiency improvements over time. Whilst for the energy efficiency and nature-based measures the RECCS provides an investment subsidy, therefore the leverage of these investments is determined by the assumption of how much matching investment RECCS requires. The assumption on the RECCS subsidised share ranges from 33% (Household EE), to 50% (industrial EE), to 80% for nature based solutions. The total leverage ratio varies over time as technology costs change and the size of the energy gap changes, both especially affecting the volume of investments required in renewables (wind, solar, etc).

Economic output, gross value added (GVA) and employment

While no bespoke economic modelling was undertaken to develop the estimates used here, with the use of commonly-accepted multipliers and established ratios of spending to output it was possible to estimate GVA and employment impacts in this study. The ratios that are used include not only the direct impacts, but also the indirect impacts in the supply chain and the induced impacts from the changes in income and other effects caused by the RECCS direct and indirect impacts.

The results of the comparison between RECCS and the base case are presented below in Table 6-4. The results show that in each of the selected years RECCS significantly outperforms the base case in terms of economic and employment impact. This outperformance is driven by the higher spending (investments) that are made under RECCS compared to the base case. In terms of economic output RECCS is estimated to outperform the base case by around EUR 15.8 billion in 2030, with this also translating into EUR 12.1 billion additional GVA and potentially more than 232 000 additional jobs across the whole economy. As noted above, as investments increase so do the economic and employment impacts of RECCS compared to the base case.

Amongst the measures driving the largest impact are residential energy efficiency measures, which due to their relatively low subsidy share draws in significant additional investment from others (especially households themselves). Additionally, nature protection measures provide a significant impact, particularly to employment, not only direct jobs in the one-off works and ongoing management of protected and restored habitats, but also the indirect jobs such as those from nature tourism and supply of maintenance equipment, and then the induced jobs this brings in sectors such as hospitality and retail. It should be noted that the additional investments in the RECCS case would come with an opportunity cost (i.e. impact of alternative uses of the investment capital drawn in by RECCS), this is not calculated.

Table 6-4 Comparison of economic and employment impact of base case and RECCS for selected years, for economic output, GVA and employment values are totals of direct, indirect and induced impacts

Indicator	Unit	Base case	RECCS	Difference	Wind	Solar	Other RES	Grid	Residential EE	Industrial heat pumps	Green hydrogen	NbS: Forests	Nbs: Inland wetlands (peatland)	Nbs: Coastal wetlands (salt marsh)
2030														
Annual investment	[M EUR]	7 835	17 501	9 666	3 739	3 453	511	887	4 949	707	707	2 091	375	83
Economic output	[M EUR]	13 799	29 648	15 850	6 263	6 043	868	1 463	8 512	1 112	1 031	3 608	609	141
Gross Value Added	[M EUR]	11 995	24 121	12 126	5 010	5 438	608	1 097	6 469	807	649	3 337	579	127
Employment	[FTE]	176 435	408 640	232 205	80 944	91 546	6 945	11 191	109 970	12 115	7 947	73 503	11 696	2 782
2040														
Annual investment	[M EUR]	7 835	50 065	42 229	9 156	7 949	1 379	1 931	16 306	1 398	3 261	7 144	1 264	276
Economic output	[M EUR]	13 799	84 627	70 829	15 337	13 911	2 345	3 186	28 047	2 198	4 758	12 323	2 053	470
Gross Value Added	[M EUR]	11 995	68 497	56 502	12 269	12 520	1 641	2 389	21 316	1 596	2 993	11 399	1 951	423
Employment	[FTE]	176 435	1 174 880	998 445	198 227	210 755	18 756	24 370	362 365	23 952	36 662	251 087	39 427	9 277
2050														
Annual investment	[M EUR]	7 835	77 509	69 674	12 779	10 225	2 146	3 004	27 149	2 327	5 430	11 905	2 086	460
Economic output	[M EUR]	13 799	130 886	117 087	21 405	17 894	3 647	4 956	46 696	3 659	7 922	20 536	3 390	781
Gross Value Added	[M EUR]	11 995	105 547	93 552	17 124	16 104	2 553	3 717	35 489	2 658	4 983	18 996	3 220	703
Employment	[FTE]	176 435	1 818 006	1 641 571	276 658	271 092	29 179	37 913	603 317	39 879	61 040	418 417	65 079	15 431

Source: Own calculations

Note: Multipliers were used for these calculations based on Supply, Use and Input-Output tables[195], with individual measures matched to composite multipliers from the most relevant economic sectors for each measure. Type II multipliers were used so that direct, indirect and induced effects are included. The results have been compared against sector published actual data on output and employment, and the employment multipliers in reports from the IEA and other organisations. This comparison demonstrated consistency of the results with the actual observed economic output and employment ratios. For example in the wind energy sector, Wind Europe estimates that for each GW of wind installed around EUR 2.2 billion (onshore) and EUR 2.5 billion (offshore) GDP, both direct and indirect, is created. Applying these ratios to the planned capacities to be installed in RECCS in 2030, i.e. 1.2 GW (onshore) / 0.9 GW (offshore), results in an estimate of EUR 4.9 billion, which is consistent with the our calculated 2030 GVA figures for wind of EUR 5.0 billion.

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[195] The 2020 tables were used from here: https://www.gov.scot/publications/about-supply-use-input-output-tables/pages/user-guide-multipliers/#:~:text=The%20GVA%20multiplier%20is%20expressed,the%20economy%20as%20a%20whole.

Other economic impacts

The RECCS also has other broader economic impacts and these can also bring important benefits.

The impact on **energy prices and costs** is important for industry competitiveness (see below) and household energy costs. Whilst it is not possible to fully model anticipated energy prices per scenario a comparison of average levelized costs of energy provides a strong indicator of the underlying energy costs that will drive prices. In the base case scenario the electricity provided by biomass and BECCS is very expensive relative to other technologies, with a (electricity generation) weighted average of 137 EUR/MWh in 2025, increasing, due to the high cost of BECCS to 167 EUR/MWh by 2050[196]. In contrast, the same amount of power in the RECCS scenario has a weighted average levelized cost of 73 EUR/MWh in 2025, and this declines to 40 EUR/MWh by 2050. This shows that the RECCS scenario provides power at almost a quarter of the levelized cost of the base case. In terms of costs savings this already totals almost EUR 6.1 billion per year in 2025 and this increases to more than EUR 40 billion by 2050. **This demonstrates the key message that the RECCS alternatives are much cheaper than biomass and BECCS and can save the energy system and consumer hundreds of billions of euros over the coming decades.** This can be an important contributor to lower energy prices, which can also have social benefits in reducing **energy poverty**.

In terms of **innovation** the support provided to renewable energy and industrial efficiency measures could have a particularly beneficial impact on innovation. For the renewable energy technologies the innovation learning curves for wind and solar PV have shown remarkable cost reductions in the last decade. These cost reductions are expected to continue through to 2030 and likely beyond, due to innovations in size (especially for offshore wind), efficiency (especially for solar PV) and production processes. By funding significant capacity additions of both technologies, and storage, RECCS will indirectly play a part in growth and innovation in both these sectors. A broader technological approach could also be considered under RECCS, where supporting innovation for technologies with a longer term potential might be of interest. Small modular nuclear development, fusion energy development, marine energy or deep geothermal technology are amongst the most promising high potential but not yet commercial low carbon energy technologies. Perhaps the largest innovation impact may be driven by the allocation of funds to invest in energy network and storage technologies, which could indirectly impact innovation in battery and other power storage and management technologies.

The largest innovation impact with economic benefits is likely to be found in the adoption of industrial emissions reduction measures. The funding of investments in industrial heat pumps and green hydrogen address technologies which are at the start of being adopted by industry and where there remains significant innovation potential. This is particularly the case for heat pumps and green hydrogen, the former where efficiency gains and higher temperature applications can be explored, the latter where there is significant potential, and need, for reducing the costs of electrolysers (particularly stacks). RECCS funds significant investment in both of these technologies and at a scale which will be quite impactful in these sectors, driving innovation, competitiveness and decarbonisation.

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[196] The average levelized cost of electricity (LCOE) is calculated for the total of primary solid biomass, BECCS and the equivalent replacement volume of RES in the RECCS case. It does not represent an overall system LCOE (the affected generation represents around 5% of the estimated 2050 total demand). The current LCOE estimates are presented in chapter 3, and those for wind and solar are linearly reduced to 2050 based on IEA energy modelling assumptions. LCOE for hydro is left unchanged, whilst the LCOE for biomass and BECCS are reduced by 12% and 9% by 2050.

Competitiveness impacts for Europe can be driven in a few ways, including: directly, i.e. how do the measures affect the costs and revenues of the directly affected organisations; indirectly, i.e through how the RECCS affects overall costs and prices of energy and materials; and also through balance-of-trade effects. In the energy generation sector the direct impact of RECCS will be to support wind, solar PV, solar thermal (CSP) and other RES, these industries will grow. In the wind sector, the large EU wind manufacturing industry will be a major beneficiary from the additional investments spurred by RECCS. For solar PV the main manufacturing occurs in east Asia (especially China), with potentially increasing EU imports. However, as panel and equipment prices decrease an increasing share of the investment is spent locally on the balance of plant and installation costs, which will benefit the EU solar installer industry. In the RECCS scenario the direct import costs for biomass will also be significantly reduced, as highlighted in section 2.1.4, this could save up to EUR 350 million per year (and more in future due to planned biomass increases). Indirectly, the key impact of RECCS will be felt through changes in energy prices, which, as shown in section 3.2.1 and earlier in this section, the levelized cost of energy from biomass, and especially BECCS, is much higher than for the renewable energy alternatives. Compared to the base case the RECCS scenario will lead to lower power prices as higher shares of lower cost renewables are integrated. Lower power prices have significant economic and competitiveness benefits across the whole economy.

In the industrial sector, the competitiveness impacts are more complex to estimate, the key factor in this is the relative cost of production of European industry compared to non-European industry. Reduced power prices will be a useful benefit for European industry, particularly for sectors with high electricity consumption, e.g. Aluminium manufacturing, but more importantly, the focus of the industrial measures is on decarbonisation and therefore the price of emissions is crucial. Within the EU every tCO_2 avoided, will avoid industry incurring costs from the EU Emissions Trading System (ETS). ETS costs have averaged EUR 60-100/ tCO_2 in the last years, but can be expected to increase in the long term as the ETS emissions cap tightens. Subsidising measures to reduce emissions will have a double benefit for European industry, not only reducing emissions, but reducing costs of the transition, which can also benefit competitiveness.

Security of supply impact could be significant, in the base case domestic sources of forest biomass would be unable to satisfy the projected increase in demand, at least not without significant deforestation, therefore significant increases in imports of forest biomass would be required. This would increase energy dependency in Europe, contrary to existing trends where increased use of renewable energy and electrification is reducing energy dependence. RECCS, by focusing on further domestic renewables production and energy efficiency technologies, would provide a much stronger benefit to European energy independence and security of supply than a forest biomass strategy driven primarily by imported forest biomass.

Distributional impacts are important as there can be winners and losers from the different scenarios. Most obviously the RECCS strategy intends to reduce the use of solid forest biomass for energy and this can have an effect on the sectors and regions in the EU and elsewhere that are most active in the supply chain for the production of forest biomass for energy. However, at the same time the alternative support from RECCS will drive higher overall economic growth, as demonstrated in the previous sub-section. A first point to note is that the forestry sector represents only a very small share of the European economy, contributing around 0.2% of gross value added in 2020, only in a handful of countries (Finland, Estonia and Latvia) is the share higher, e.g. 1-2%. Similarly for employment, it represents only 0.3% of the European total, with the highest numbers employed in Poland (58.9k), Romania (50.2k), Germany (41.9k), Italy (38.6k), and Sweden (35.2k).

It is also the case that reducing the use of forest biomass for energy may free up some sustainable biomass production for alternative more sustainable uses, such as construction, mitigating any actual economic losses to the sector. For the regions and communities most affected by any eventual reduction in the forest biomass energy sector, the alternatives funded by RECCS offer a number of opportunities for employment and economic activity. Especially the nature-based solution measures which focus on conservation, protection, restoration and management of forests and other habitats offer a direct alternative in many regions that can be affected. For example protection and restoration work can help to build up local tourist industry supporting a broader range of businesses and activities in the affected regions. Exploring payment for ecosystem services finance options (see chapter 7) could also help to maintain incomes to land and/or forest owners in the areas. A further aspect of the RECCS could be to tie the funding/incentives provided to compensate regions that can be negatively affected, i.e. by encouraging new renewable energy infrastructure or green manufacturing facilities to locate in these regions.

Finally, there would be assorted other potential economic benefits, for example likely fiscal implications of the RECCS, particularly that the higher employment and improved economic performance would also drive higher tax receipts than in the base case. This could be used to fund compensatory measures to address the distributional impacts mentioned above, and/or to further deepen and expand the RECCS programme. Additionally, protecting and restoring various ecosystems would boost climate resilience and reduce the impacts and damages from extreme events, saving on insurance, repair and recovery costs.

Environmental and social impacts

GHG emissions are not the only serious environmental impact of the use of forest biomass for energy, the environment is also heavily affected at source i.e. biodiversity loss from logging of forests; and also during combustion where other emissions pollute the air.

Air pollution and the resulting human (and natural habitat) health impacts is an important area in which the RECCS can deliver significant benefits compared to the base case. The link between air pollution and human health has been heavily researched in the last decades, with a clear causal link shown between air pollution and human health impacts. Within Europe it is estimated that air pollution from all sources causes around 325 000 premature deaths each year, the largest share of these from chronic exposure to particulate matter[197]. Forest biomass use for energy can have particularly significant particulate (and other) emissions, stemming from both the fuel processing (wood pellet manufacturing) stage and especially when the forest biomass is burnt for electricity production[198] as it combusts less 'cleanly' than other fuels such as natural gas[199]. We believe the numbers associated with RECCS would be even better if health impacts were considered from avoided burning of biomass; a

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[197] EEA, 2023, 'Harm to human health from air pollution in Europe: burden of disease 2023

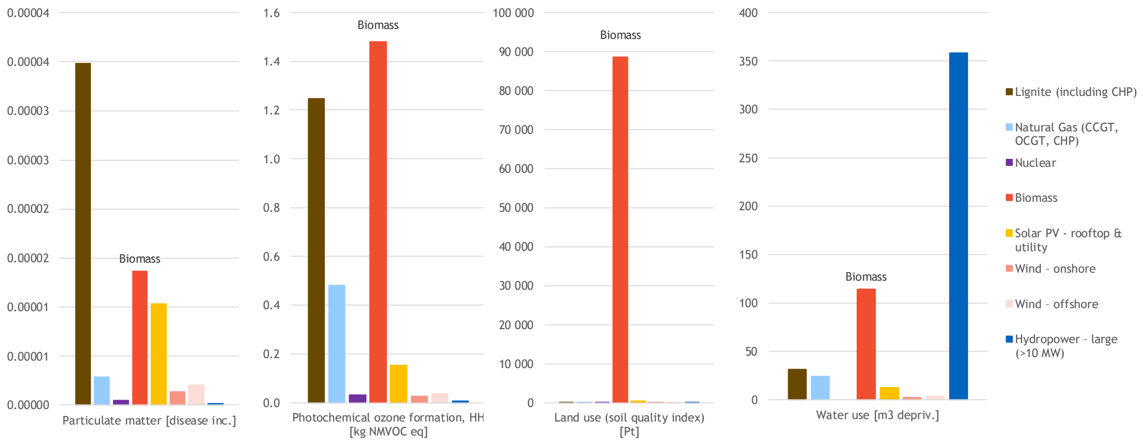
[198] Noting that the energy supply sector as a whole is a relatively minor contributor to total particulate emissions, e.g. less than 7% of the total PM2.5 emissions in 2021.

[199] In Spain, a separate study has shown how increases in Ozone causing emissions from the energy sector is being driven almost entirely by planned increases in power generation from biomass. See Oliveira, M. Guevara, O. Jorba, X. Querol, C. Pérez García-Pando, A new NMVOC speciated inventory for a reactivity-based approach to support ozone control strategies in Spain, Science of The Total Environment, Volume 867, 2023, available at: https://www.sciencedirect.com/science/article/pii/S0048969723000645

quantitative analysis of those impacts, however, is beyond the scope of this study. Nevertheless, in the next paragraph we provide some analysis comparing some of the key environmental impacts of electricity from biomass and other power technologies.

Life cycle analysis of energy technologies has shown clearly that biomass is one of the most polluting and resource consuming energy technologies. A comparison of key environmental impacts is shown in Figure 6-11 below, and this highlights that in every case electricity from biomass is ranked either 1st or 2nd for negative environmental impacts in these categories. For particulate matter impacts[200] it is ranked 2nd, behind only lignite. The other technologies have much lower particulate matter impacts, with the exception of solar which has particulate emissions associated with panel manufacture in China. For photochemical ozone formation biomass has the highest impact, higher than both lignite and natural gas, with forest biomass containing more volatile organics than other fuels and lower efficiency of combustion leading to higher emissions[201]. As can be expected the land use impact of biomass dwarves other energy technologies due to the large forest area required, whilst for water use the management of forest areas also requires significant water use, placing the impact of forest biomass 2nd behind hydropower for this impact. Results for human toxicity can also be produced and show similar results, with power from forest biomass showing the worst impacts of the compared power technologies, however, the methodology and results for human toxicity are less reliable than for the other impact categories and therefore are not presented here.

Figure 6-11 Life cycle impact comparison of electricity generation technologies for six environmental indicators, units in category names, impact per MWh electricity generation



Source: Own work based upon Trinomics and VITO (2020) for European Commission DG ENER; External costs: Energy costs, taxes and the impact of government interventions on investments : final report.

The contribution of the energy supply (power and heat) sector to total air pollution in Europe has declined significantly over the last two decades, and for the major pollutants the sector contributes only a relatively minor share (i.e. less than 15% of the total, with the exception of Sulphur Dioxide where the share is around 40%, mostly from coal). Therefore whilst the benefits to air pollution from

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[200] The figures refer to impacts as the life cycle analysis already applies methodologies to convert the emission into the most relevant impact, for the case of particulate matter this is disease incidence, particularly respiratory and cardiovascular disease. Further information on the method can be found in the source study from 2020, see endnote to the figure.

[201] Oliveira, M. Guevara, O. Jorba, X. Querol, C. Pérez García-Pando, A new NMVOC speciated inventory for a reactivity-based approach to support ozone control strategies in Spain, Science of The Total Environment, Volume 867, 2023

the RECCS will be real and welcome, as the alternatives each have lower impacts than electricity from biomass, they are unlikely to be hugely significant. However, the RECCS not only affects the power sector, but also addresses the residential and industrial sectors through the measures on residential energy efficiency and industry decarbonisation. The residential sector can be particularly relevant as domestic biomass stoves and boilers have become one of the most important contributors to increased air pollution in some localities. Increasing building energy efficiency and switching to heat pumps under this measure can both contribute to improved air quality. Similarly the replacement of gas, coal or biomass in industry with industrial heat pumps can also contribute reduced air pollution impacts.

Biodiversity benefits from RECCS can be achieved especially through the protection and restoration of natural habitats through the nature-based solution measures described in chapter 4. In particular the land area that could be protected under RECCS is potentially huge based on the cost and subsidy assumptions set out earlier. We estimate that the EUR 2 001 million subsidy could be used to protect or restore almost 4.5 million hectares of land in 2025, and the volume of land would grow over time as more land is protected or restored. The scale of financing available through RECCS means that by 2030 around 9 million ha could be treated. By 2050 this could grow to more than 53 million ha, or around 12.5% of the EU land area, and larger shares of the specific ecosystem types being treated. This may not be entirely realistic as costs could increase over time, and suitable sites may not be available and alternatives explored, however it is indicative of the large conservation potential of the size of funding that could be provided by RECCS.

Skills impacts can be a notable benefit of implementing the RECCS, as the RECCS would not only have a positive impact on total employment as shown in previous sections but it would also change the types of jobs in which people work and the skills that are required. In the current supply chain for forest biomass for energy the employment tends to be skilled manual work, e.g. in forest planting, maintenance and harvesting; the transport and processing of fuel; and then the operation of the bioenergy facilities. These jobs are physically demanding and may not be well paid. The employment in RECCS in alternative industries also includes a range of manual skilled roles, e.g. for home energy efficiency installers, construction workers, solar PV installers, but also includes the need for a wider range of skilled technical and engineering jobs in the power sector and industry. These are higher skilled and typically better paid.

Cost of living impacts are also of interest. As shown in the economic impact section the cost of energy from the replacement renewable energy technologies is far lower in the RECCS than in the base case, where both bioenergy and BECCS are notably expensive and would only increase overall system costs. These lower costs, whilst only affecting part of the electricity generation, could still help to reduce total costs and provide savings to households. Perhaps the most impactful part of the RECCS is the range of measures for deep renovation of households, with deep renovation not only shown to have important energy and cost saving benefits for households but also great quality of life benefits. Targeting some or all of the deep renovation measures towards low-income households would increase the benefits for cost-of-living and **reduce energy poverty**.

6.6 Summary comparison

The following table (6-5) compares the RECCS strategy against the base case of continuing to invest in high cost, high emission industrial scale use of forest biomass for energy and BECCS. This aims to clearly and concisely summarise the findings from the earlier chapters and to show that the proposed RECCS can generate exactly the same volume of electricity as the base case using exactly the same volume of subsidies but by using these subsidies differently also provide significant energy savings, cheaper energy, higher investments and economic output, more jobs, improved health, cleaner air, lower pollution, better environmental impacts and lower greenhouse gas emissions. Indeed, after discarding the false assumption of carbon neutrality of biomass use for energy, the emissions savings from the RECCS are highly significant and can provide the equivalent of 27% of the emissions reductions required to hit net-zero by 2050. The other differences are also sizable and demonstrate the positive economic, social and environmental impact of pursuing RECCS.

Table 6-5 Summary comparison of the Base case and RECCS approaches

Indicator	Base case		RECCS	
Description	Continued use and subsidisation of high emission industrial-scale power and heat from forest biomass, plus subsidisation of high cost BECCS technology.		Switch from industrial-scale forest biomass use to subsidies equivalent volume of alternative renewables, complemented through use of remaining subsidies to fund energy efficiency measures for households, industrial efficiency and decarbonisation measures plus investments in nature-based solutions for carbon absorbent ecosystems.	
	2030	2050	2030	2050
Energy system impacts				
Electricity generated by biomass or by alternative renewable energy sources [TWh]	**Electricity:** **107 TWh Total** 107 TWh Biomass	**Electricity:** **321 TWh Total** 170 TWh Biomass 151 TWh BECCS	**Electricity:** **107 TWh Total** 21 TWh Biomass 46 TWh Wind energy 29 TWh Solar PV 6 TWh Solar CSP 5 TWh Other RES	**Electricity:** **321 TWh Total** 21 TWh Biomass 0 TWh BECCS 163 TWh Wind energy 101 TWh Solar PV 21 TWh Solar CSP 15 TWh Other RES
Energy saved [TWh]	**Heat:** 2 141 TWh total **0 TWh saving**	**Heat:** 1 664 TWh total **0 TWh saving**	**Heat:** 2 129 TWh total **12 TWh saving**	**Heat:** 1 508 TWh total **156 TWh saving**
Cost of energy [EUR/MWh]	134	167	67	40
Economic impacts				
Total Investments [EUR bn]	21.0	177.7	101.5	1 160.9
Economic output [EUR bn]	13.8	13.8	29.6	130.9
GVA impact [EUR bn]	12.0	12.0	24.1	105.5
Employment impact [‘000 jobs]	176.4	176.4	408.6	1 818.0
Impact on competitiveness and innovation	0	-- Negative due to high cost of BECCS	+	+++ Drives innovation in renewables, industrial decarbonisation and efficiency. Lowers energy prices.
Distributional impact	0	0	-/+ Important for RECCS alternative measures to target regions adversely	-/+ Important for RECCS alternative measures to target regions adversely

			impacted by cuts to biomass. RECCS can provide benefits to energy poverty, reducing inequality.	impacted by cuts to biomass. RECCS can provide benefits to energy poverty, reducing inequality.
Social impacts				
Skills impacts	0	0	+	+
Health impact	- Air pollution causes negative health effects	-- Increased air pollution with expansion of biomass and BECCS leads to increased negative health impacts	+ Reduced air pollution brings health benefits. Better housing improves health outcomes.	++ Significant reductions in air pollution compared to base case, reduces negative health impacts. Better housing improves health outcomes.
Environmental impacts				
GHG emissions impact [MtCO$_2$e]	0 savings +31 MtCO$_2$/pa emissions from new biomass (compared to 2020)	0 savings +112 MtCO$_2$/pa from new biomass +76 MtCO$_2$/pa from BECCS	**Total: 177 MtCO$_2$/pa savings** 105 MtCO$_2$/pa alternative renewable power 2 MtCO$_2$/pa residential energy efficiency 28 MtCO$_2$/pa industrial efficiency 42 MtCO$_2$/pa from nature based solutions	**Total: 870 MtCO$_2$/pa savings** 259 MtCO$_2$/pa alternative renewable power 31 MtCO$_2$/pa residential energy efficiency 349 MtCO$_2$/pa industrial efficiency 232 MtCO$_2$/pa from nature based solutions
Marginal abatement cost [EUR RECCS subsidy/tCO$_2$e]	N/A		36.8	
Environmental impact (air, land, water, resources)	- Increasing particular matter pollution, land and water use	-- Increasing particular matter pollution, land and water use	+ Lower air pollution, land and water use compared to base case	++ Lower air pollution, land and water use compared to base case
Biodiversity impact	- Lost forest habitats with attendant dis-benefits - species depletion, sedimentation, flooding, loss of amenity/tourism benefits etc	-- Lost forest habitats with attendant dis-benefits - species depletion, sedimentation, flooding, loss of amenity/tourism benefits etc	+ Reduced destruction of forests. Protection and restoration of ecosystems through NbS conservation measures. **Total 9 million ha protected or restored**	++ Reduced destruction of forests. Protection and restoration of ecosystems through NbS conservation measures. **Total 53 million ha protected or restored**

6.7 Important considerations

The analysis up to this point has built a compelling case for why continued subsidies for industrial scale use of forest biomass for energy are counterproductive and damaging for the climate and will only become more so in future. It has also shown that removing and redirecting these subsidies to other activities could address the energy needs at much lower cost and allow for a range of other measures to be implemented which would bring further benefits. It is the clear conclusion of this work that further subsidy of forest biomass for energy, and particularly of BECCS, would be expensive and result in far worse outcomes for the energy system, climate, economy, society and environment than the Renewable Energy and Climate Change Strategy measures we have proposed.

Redirecting subsidies to the RECCS measures of alternative renewables (solar, wind, batteries), energy efficiency (deep renovation of households, industrial heat pumps, green hydrogen) and nature based solutions (Protection and restoration of carbon absorbent ecosystem) and away from forest biomass and BECCS should therefore be prioritised. We note that there are a number of practical considerations to take into account when making such changes, and that implementation of a RECCS could not happen overnight, some important considerations include:

- **Potential investment opportunities are much higher in the RECCS case:** compared to the base case, much more additional capital needs to be invested. This is part of how the RECCS case generates much greater economic impact than the base case. One challenge for the RECCS is from where the additional capital for these investments will come. The following chapter (Chapter 7) maps the variety of public and private finance options, from which we are confident that the subsidies proposed in the RECCS are set at a level sufficient to attract the required matching capital (public and private) to fund the investments.
- **Balance of measures within the RECCS:** the balance of subsidies across the measures is somewhat arbitrary, and could be adjusted in the actual implementation in a RECCS. However the assessment provides an insight into the impacts of the individual measures and comparing these side-by-side on marginal abatement cost and other impacts shows that each has value and addresses a particular target group. Adjusting the balance between the measures would still result in a large positive impact compared to the base case. This is important to address cases where measures could 'max-out' their potential, e.g. after 20 years of subsidisation there may be little additional potential for industrial heat pumps, or similarly for protection of particular habitats.
- **Review and adjustment of RECCS in future:** the further into the future we go the harder it is to predict the emergence of new and useful technologies that would also warrant funding under RECCS. Breakthroughs in geothermal energy, industrial processes, material efficiency/circular economy, fusion energy, or a variety of other technologies could make these attractive investments for clean energy, emissions reduction or energy savings in future. A RECCS should provide long-term certainty for those receiving subsidies, i.e. no retroactive changes, but it should also review its approach, technology focus and strategy on a regular basis, e.g. every five years, to ensure that new innovations can also become targets for funding. This can be the most effective and efficient way to deliver the desired energy, emissions, economic, social and environmental outcomes.
- **A RECCS helps to avoid risks in future biomass sourcing:** the future European biomass use relies heavily on forest biomass which is subject to a number of important risks. It also relies on unproven and risky assumptions on the use of lignocellulosic biomass. Reliance on such technologies carries high risks of high costs and/or that in the case that it does not perform as planned that more solid forest biomass is used to fill the gap, with consequent pressure on EU forests and/or imports from forests elsewhere, increasing energy dependence and reducing energy security.
- **Policy should address other bottlenecks that could slow the adoption of RECCS:** the proposed RECCS measures could face challenges to scale up to the desired levels, particularly for renewables there are supply chain, skills and capacity (e.g. trained heat pump engineers), planning, network capacity and other barriers that can slow down investments. Policymakers should support a RECCS with reforms and support to alleviate these barriers and speed the adoption of the measures. One important aspect for forests will be to ensure state forest agencies are positively engaged in supporting the delivery of RECCS measures in forests.

- **Subsidies should be targeted to address the financial needs of enterprises and should be supported by other policies:** the level of subsidies proposed for renewable energy and industry is consistent with observed successful policy measures currently used. Specifically for industry these address the cost of the initial investment which has an important influence on final investment decisions by private enterprise. Contact with industry stakeholders signalled support for the overall goals of RECCS but also a need for support to ensure it is commercially attractive for them to invest in decarbonisation. The subsidies are set at a level to ensure this is the case. Further policy support, to provide business investment advice, industrial process advice, and/or regulating to incentivise decarbonisation would further boost the case for enterprises to invest.
- **Policy should avoid biomass emissions leakage:** it would be foolish to eliminate subsidies to biomass in Europe only then to see the European biomass industry continue to cut forests to export to non-European countries where the net-zero emissions fallacy of biomass remains. Policy should also be joined up and adjust accordingly to avoid this. Adjustments to tax and/or tariff policy, or regulations, can help to ensure that it is not economically rational to export forest biomass for industrial scale energy use.
- **Energy system impacts are considered:** compared to wind and solar, biomass offers higher availability and dispatchability. Rapid advances in battery and storage technologies are quickly reducing the cost and complexity of managing the intermittency of renewable energy such as solar PV and wind, so this become less and less a problem each year. The RECCS recognises the challenge and takes advantage of this by reserving part of the subsidy total to strengthen grid infrastructure and to invest in storage, enabling these alternatives to fulfil the same or similar function as biomass in the energy system.
- **Compensation of those negatively affected:** the proposed changes may result in economic and job losses for affected companies and communities. Whilst part of the losses would be of companies outside the EU pursuing destructive practices, part of the losses will be felt by EU communities which rely on forests economically. Part of these losses will be addressed by the forest biomass being used for more sustainable purposes, e.g. construction or furniture; but not all losses are likely to be addressed in this way. Targeting RECCS measures to encourage their locating in the most affected communities will be important to securing support, this could be foreseen in the RECCS subsidising protection and restoration of forest areas and this leading to increased potential for tourism or payments for ecosystem services.
- **RECCS can provide significant savings to consumers:** by investing in efficiency and cheaper energy sources the RECCS will reduce the total subsidies to the energy system, reducing the cost to consumers bills. This will avoid tens of billions of euros of additional costs to consumers to subsidise unproven BECCS technologies which have higher emissions than renewables.
- **RECCS lessons are broader than the EU:** whilst data quality wasn't sufficient to provide detailed modelling for other European countries in this RECCS report the key messages and lessons are believed to apply in much the same way to other European countries. For the UK, Norway, countries in the Balkans, Belarus, Russia, Ukraine, Switzerland, there may be variations in the specific RES technologies that are most relevant, measures and costs for household energy efficiency and ecosystem types, but the overall lessons will apply in the same way. In each of these countries burning biomass for power will be a major source of GHG emissions and often subsidised. Removing subsidies allows for the same energy goals to be achieved at lower cost, with actual emissions reductions and the potential for a range of energy, economic, social and environmental benefits. Not only in Europe, these lessons could

also apply similarly in North America, East Asia and around the world, wherever biomass for electricity is subsidised a form of RECCS would be likely to deliver much better outcomes for the energy system, emissions, economy, society and the environment.

7 Existing and additional sources of funding for RECCS objectives and synergies with existing and potential policy goals

Key points

- **RECCS can attract significant private investment into emissions reduction, energy savings and nature protection.** The RECCS generates significant annual investments starting at around EUR 20 billion per year in 2025, the subsidies reallocated from forest bioenergy under the RECCS already provide around half of these costs on average. The remainder will be leveraged from private investment, attracted by the reallocated RECCS subsidies.
- **Significant public funding is available at EU level in the 2021-2027 timeframe.** Instruments such as the European Regional Development Fund, Recovery and Resilience Fund offer the largest potential. Additionally, Coherence Funds, the Just Transition Fund, Innovation Fund, Horizon Europe and LIFE+ all offer potential co-funding opportunities for the RECCS measures. The latter are particularly relevant for industrial green hydrogen and nature-based solutions.
- **Private finance is also crucial, particularly for renewable energy alternatives.** The redirection of subsidies from biomass should help to attract private finance to take investment decisions for other renewables, including some finance redirected from forest biomass.
- **Innovative private finance instruments will become increasingly important, especially for nature-based solutions.** Although still often at the development stage and still providing a small proportion of overall funding, instruments such as carbon and biodiversity credits and offsets and the payment for ecosystem services (PES) agenda generally offer a growing route to attract private finance to fund RECCS related projects.

Introduction

In previous chapters, we have provided an indication of available resources from subsidy reallocation as well as an analysis of alternatives to industrial-scale use of forest biomass for energy. To complement this work, in this section we identify and analyse further funding sources and/or instruments that are most suitable to be catalysed by, complement and/or potentially leverage further finance to support RECCS implementation. In doing so, this can provide guidance to policymakers and project developers on how the renewable energy, energy efficiency and nature-based solutions measures identified in earlier chapters and prioritised in the RECCS set out in chapter 6 can be fully funded and potentially further expanded.

One important note on funding sources is that the type of support proposed varies per element of RECCS. For the renewable energy measures to fill the energy gap (see chapter 3) the RECCS proposes subsidy support to the electricity they generate. Regardless of whether the governments paid directly or this was paid by end users in their energy bills the subsidy would effectively be publicly funded (or mandated). However, the proposed supporting investments in energy storage and networks, would be a grant or other subsidised finance to support the initial investment. This is also the case for the energy efficiency measures (in buildings and industry - see chapter 5) and nature-based solutions measures (see chapter 4), where the redirected subsidies are proposed to be used to part-finance the initial investment cost, attracting other finance for the total funding.

In chapter 6 we make assumptions for each type of measure on the share of funding to be provided from the RECCS through the subsidy redistribution and the remainder which is required to come from other sources. For energy efficiency measures, there is sometimes an economic case for a measure, therefore the RECCS funding could expect to be matched by private investment (from residents or businesses). However, this is not possible, for example, in some cases where the efficiency measure would cost more than the individual household or business are willing or able to finance themselves. In these instances, further public or private funding is needed to fill the gap.

For nature based solutions, it is often more difficult to prove a positive financial case for investment, as the benefits are often not yet monetised, and/or can accrue to a broad group of stakeholders or society as a whole, rather than the investor or project developer[202]. However, a range of instruments (e.g. payments for ecosystem services, biodiversity or carbon credits) have been developed to help monetise positive environmental impacts, with a small but rapidly growing market emerging as methodologies, indicators and monitoring all improve. For nature based solutions, finding matching public funding sources remains particularly important in many cases, but these more innovative sources are becoming increasingly relevant, also for RECCS implementation.

7.1 Public funding sources for RECCS

EU funding schemes can serve as a crucial source of finance for the RECCS alternatives to forest bioenergy. Among the available sources of EU public funding are the following[203]:

Cohesion Policy and European Structural Investment Funds (ESIF)

Cohesion Policy and **European Structural Investment Funds (ESIF)** include instruments such as the **JTF, CF and ERDF:**

- **Just Transition Fund (JTF):** it supports the territories most affected by the transition towards climate neutrality, particularly regions dependent on solid fossil fuels and on carbon-intensive industries to cushion the socio-economic impacts of their transformation. While the implementation of the Just Transition Plans in member states is still at early stages, investment in activities including clean energy and energy efficiency is among activities supported by the fund[204]. One issue to be noted is that the JTF in some cases is funding activities that may expand industrial scale use of forest biomass[205], this makes JTF an especially important target for potential co-funding to steer funding towards alternative RECCS projects.
- **Cohesion Fund (CF):** the Cohesion Fund supports a set of 15 Member States - Bulgaria, Croatia, Cyprus, Czechia, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia and Slovenia. The objective of the fund is to reduce the economic and social gap between and within those countries. Its funding is allocated under the Greener Europe and Connected Europe policy objectives to projects falling under EU environmental priorities and to trans-European transport networks. According to EC, 37% of the overall

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[202] EIB & EC, 2023

[203] Data collected is for the EU financial period 2021-2017 and has been retrieved from the Open Data Portal on European Structural Investment Funds: https://cohesiondata.ec.europa.eu/funds/erdf/21-27 .

[204] https://ec.europa.eu/regional_policy/funding/just-transition-fund/just-transition-platform/opportunities_en#inline-nav-2

[205] https://ec.europa.eu/enrd/sites/default/files/enrd_publications/publi-enrd-rr-28-2019-en.pdf

financial allocation, i.e. around EUR 18 billion, of the Cohesion Fund for 2021-2027 are expected to contribute to climate objectives[206].

- **European Regional Development Fund (ERDF):** The ERDF is one of the main cohesion policy instruments of the EU (more than EUR 300 billion available between 2021-2027) and provides funding for investments towards jobs and growth goals, with a strong focus on the policy objectives "Smarter Europe" and "Greener Europe", indicating respectively the policy areas broadly defined around environmental sustainability objectives.

In Table 7-1 we provide an overview of how the current funding allocation of these programmes overlaps with the RECCS measures identified in chapters 3-5 and which are prioritised in the RECCS in chapter 6. In doing so we highlight the scale of public funding that could be matched to the RECCS to support its implementation.

The table is based on funding allocations, as data on actual disbursement and use of the funds is not available. In reality part of the allocated funding will already be awarded or spent, which does provide a limitation to how much could be used to support the RECCS measures – however, it remains the case that a share of these funds has yet to be awarded. This therefore provides an opportunity for implementation of a RECCS to make use of these funds. Overall, we see that the largest potential matching funding source by far is the ERDF, with over EUR 38 billion in available investment matching to the categories of measures of RECCS, whereas the Cohesion Funds (CF) (EUR 4.2 billion) and the Just Transition Fund (JTF) (EUR 2.9 billion) have less funding.

Table 7-1 Allocations of ESIF funds matched to identified measures of RECCS, 2021-2027, M EUR

Category of spending	Just Transition Fund (millon EUR)	Cohesion Fund (million EUR)	ERDF (million EUR)	Total	Aligns with	Total
Renewable energy - wind	111	0	456	***567***	Filling the energy gap - Chp 3 measures	**13 483**
Renewable energy - solar	816	129	3 517	***4 461***		
Renewable energy - other (eg marine, geothermal, hydro)	296	132	3 283	***3 712***		
Smart energy systems and related storage	411	103	4 229	***4 743***		
Nature protection and restoration	155	891	5 080	***6 126***	Nature-based Solutions - Chp4 measures	**7 588**
Other relevant nature expenditure (natural heritage, ecotourism, emissions reductions, rehabilitation industrial sites)	98	48	1 316	***1 462***		
Energy efficiency in industry and business (inc. material efficiency)	437	72	3 843	***4 352***	Industrial energy efficiency - Chp 5	**4 352**
Energy efficiency in housing and public buildings (inc. district heating)	392	2 799	14 928	***18 119***	Energy efficiency measures in buildings - Chp 5	**19 704**
High efficiency co-generation district heating and cooling	208	13	1 364	***1 585***		
Total	**2 925**	**4 187**	**38 016**	***45 128***		**45 128**

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[206] https://ec.europa.eu/regional_policy/funding/cohesion-fund_en

Category of spending	Just Transition Fund (millon EUR)	Cohesion Fund (million EUR)	ERDF (million EUR)	Total	Aligns with	Total
Percentage share of fund’s total budget	**9%**	**8%**	**12%**			

For the **renewable energy measures of the RECCS more than EUR 13.4 billion is available in the 2021-2027 period.** ERDF is by far the biggest source for renewable energy, with the JTF relevant to a lesser extent, and the CF much less. As can be seen, funding available for wind energy is quite low, and therefore greater prioritisation of other funding sources will be needed to support investments in this category. However, for solar the JTF and ERDF can be targeted as potential co-funding sources. For other renewables (solar CSP, geothermal, etc) and energy systems and storage investments there are significant amounts of co-funding potentially available, especially via the ERDF. To give just one example, renewable energy projects under the ERDF include a programme implemented in Slovakia[207] supporting the installation of small renewable energy equipment that caters for the energy consumption of the building. The programme ran from 2014 to 2020 and totalled EUR 45 million, of which the ERDF co-financed 80%.

For the **nature based solutions measures of the RECCS** which prioritise the protection and restoration of carbon absorbent ecosystems almost EUR 7.6 billion is available in the 2021-2027 period. ERDF is by far the biggest source of funding, additionally almost EUR 1 billion could be available via the CF, although much less is available via the JTF. The funding is especially focused on nature protection and restoration which aligns closely with the types of measures the RECCS intends to support. The ERDF and Cohesion Fund in particular could be targeted as potential co-funding sources for these measures. As an example from the previous multiannual financial framework of the type of projects supported, funds from the ERDF were directed at “Climate Protection and Biodiversity of Diepholzer Moorniederung”[208], in the region of Hanover, Germany. The programme, running from 2016 to 2021 and totaling EUR 1.85 million, aimed at reducing greenhouse gases in bogs, restoration of natural function as a carbon sink, including monitoring activities.

For the **energy efficiency measures of the RECCS** almost EUR 24.1 billion is available in the 2021-2027 period, split between funding for industry (EUR 4.4 billion) and funding for efficiency measures in buildings (EUR 19.7 billion). For buildings efficiency the categories that are supported are split out a bit further in the source data and show within the totals a significant allocation is made to deep renovation of residential and public buildings, i.e. within ERDF these account for more than EUR 11.5 billion of the total. This aligns very closely with the proposed RECCS measures and makes the ERDF (and Cohesion Fund) especially important potential sources of co-funding for RECCS implementation – and as can be seen from the following example, high-levels of co-funding (up to 85%) are possible. A project advancing energy efficiency ran from 2016 until 2021 in Riga, Latvia[209]. The project supported the implementation of energy efficiency improvement measures in apartments and covered a number of activities including free consultations and grants for up to 50 % of the eligible costs of implementation of energy efficiency improvement measures. The programmes total budget exceeded EUR 176 million, of which the ERDF co-financed 85%.

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[207] https://kohesio.ec.europa.eu/en/projects/Q3107934
[208] https://kohesio.ec.europa.eu/en/projects/Q3307689
[209] https://kohesio.ec.europa.eu/en/projects/Q3056918

Recovery and Resilience Fund

The **Recovery and Resilience Facility (RRF)**, is the key instrument at the heart of Next Generation EU[210] and is a performance-based temporary recovery instrument designed to mitigate the economic and social impacts of COVID-19. The EC raises funds by borrowing on the capital markets (issuing bonds on behalf of the EU). These are then available to the Member States, to implement ambitious reforms and investments that contribute to a set of objectives related to the green and digital transition. Its aim is also to make EU economies and societies more sustainable, resilient and better prepared for the challenges and opportunities of green and digital transitions. This makes the RRF another important potential co-funding source, with up to EUR 723 billion available in loans and grants, and of which 37% must be allocated to green measures. The RRF is divided into **six policy pillars**, of which "Green Policy" is the most relevant one for potential support of RECCS measures. Around EUR 250 billion is allocated to this green policy pillar, and within this, most relevant to the RECCS measures:

- **Energy efficiency is allocated EUR 72.5 billion** (29%), this encompasses various measures and reforms addressing building renovations across all sectors (private and public, and residential and commercial buildings). The key reforms involve streamlining or enhancing the regulatory framework (with a focus on the discontinuation of outdated heating systems and encouraging their substitution with renewable energy sources or district heating solutions), developing long-term renovation strategies, establishing single-point service centres, and enhancing the training and retraining of workers.
- **Renewable energy and networks is allocated EUR 35.3 billion** (14%), distributed across 61 different initiatives, including the development of offshore or onshore wind energy projects (along with associated infrastructure like energy islands), the installation of solar PV, renewable energy for industry and other innovations in renewable energy integration into buildings and production processes.[211]
- **Protection and restoration of biodiversity and ecosystems is allocated EUR 7.5 billion** (3%), Creating protected areas, green and blue infrastructure, restoring ecosystems, rewilding and facilitating nature-based solutions to climate change.[212]

The volume of funding here is significant, and this could potentially be a major co-funding sources for RECCS measures. The types of projects supported are consistent with the measures proposed in the RECCS. Of the total funding made available under the RRF, to date approximately EUR 176.3 billion has been disbursed, around 24% of the total EUR 723 billion foreseen by the RFF Regulation[213]. Of this, as of Dec 2023, EUR 21 billion has been disbursed under the green policy pillar, representing about 8% of the EUR 250 billion allocated to this pillar, which covers the funding relevant for RECCS identified above - energy efficiency, renewable energy and nature protection. The funding allocation of the RRF is performance-based, meaning that funds are disbursed based on the achievement of targets and milestones set in accord between the EC and Member State recipients. This process involves iterations in an approval procedure by the EC, therefore requiring engagement with Member States. In particular,

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[210] The EU Recovery Fund developed in support of Member States to address the economic and social recovery following the COVID-19 pandemic. It was adopted in December 2020 and is effective between 2021 and 2026 in line with the 2021-2027 MFF.

[211] https://ec.europa.eu/economy_finance/recovery-and-resilience-scoreboard/assets/thematic_analysis/1_Clean.pdf

[212] https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en#:~:text=The%20EU's%20biodiversity%20strategy%20for,contains%20specific%20actions%20and%20commitments.

[213] Regulation (EU) 2021/241 of the European Parliament and of the Council of 12 February 2021 establishing the Recovery and Resilience Facility

Member States have time until the end of 2026 to provide their reform plan and to receive funding. There is potentially still time for RECCS measures to be included in such plans and receive co-funding under the RRF.

Other EU public funding sources

Other EU programmes of interest include: the **LIFE/LIFE+ programme** which has EUR 5.4 billion funding between 2021-2027 to fund primarily nature, biodiversity and climate activities and for which there are dedicated provisions to fund nature based solutions; the **Horizon Europe** research and innovation programme with a budget of EUR 95.5 billion and which includes missions which address innovations relevant for all types of measures under RECCS; the **Innovation Fund** (EUR 40 billion) which uses revenues from the EU Emissions Trading Scheme to fund innovations in industrial decarbonisation measures, including those proposed in the RECCS; there are numerous other potential EU funding sources, including via the **European Investment Bank (EIB), and also national, regional and local** sources. These could each be interesting funding sources in the earliest years of a RECCS when there may still be a need to demonstrate the upscaling and adoption on innovative measures, e.g. CCS and Green Hydrogen, both of which would be leading candidates for co-funding.

Summary

The previous sub-sections set out the main EU funding instruments and show the clear alignment of the three RECCS streams (RES, Energy Efficiency, nature-based solutions) with different streams of the funding instruments. This highlights clear opportunities for match funding to be found from these instruments to help finance RECCS. Specific matches to the objectives of the funding can be identified, for example the RRF prioritises economic recovery and the green and digital transition, whilst it covers all three RECCS streams the largest funding is available for energy efficiency, so the RECCS funding of residential deep renovation to improve energy efficiency has a strong match. The economic evidence presented in section 6.5 can help to strengthen the case for RECCS funding. Similar opportunities and matches are available for all funding instruments.

7.2 Private sector funding sources for RECCS

Investors perspective

Private capital offers a potential funding source that could be many times greater than public funding. For private investors their perspective on biomass and RECCS should take into account various considerations, including:

- **Energy from forest biomass is amongst the least cost-effective forms of energy production**, and has limited potential for further improvements in efficiency or productivity. Therefore, in the majority of cases it is dependent on subsidy for survival. This is already a risky general proposition, i.e. the business case is not self-standing.
- **The rationale for energy from forest biomass is based on flawed carbon accounting assumptions**, and as scientific evidence mounts on this, the case to continue subsidising forest bioenergy becomes weaker and weaker. This is known also by investors, for example two large bioenergy corporations (Drax and Albioma) were expelled from the Dow S&P Clean Energy Index in New York for this reason in 2021[214], and have not been reinstated since. This

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[214] https://www.spglobal.com/marketintelligence/en/news-insights/blog/sp-global-sustainable1-compass-series-approaching-the-climate-risk-horizon

highlights the risks to continued financial support, without which energy from forest biomass is not viable.

- **There is also reputational risk in investment in energy from forest biomass**, with concerns about false accounting of sustainability certifications, opposition to forest destruction and biodiversity loss, and related health and environmental damage issues. The first point recently illustrated by the largest user of forest biomass for energy in Europe, Drax Power, being fined GBP 25 million by regulators due to poor data control and reporting of its forest biomass supply. The risk increases as feedstock sources from tropical forests e.g. in Indonesia, start to become more common.
- **Security of feedstock supply is not guaranteed,** with biomass often sourced from forests in the United States and Canada, where the recent bankruptcy of Enviva, the worlds largest wood pellet supplier, highlights the potential risks to supply chains from long distances and volatile prices.
- **Alternative uses of capital, namely in all three streams of the RECCS agenda, perform much better on all of these criteria**. The investments are very often and increasingly profitable on their own, with RECCS (and similar) subsidies reducing investment risk by providing guarantees against market instability. Investments in RES and Energy Efficiency all address technologies where there is continued innovation, driving productivity and efficiency gains, and cost reductions. The measures all deliver genuine emissions reductions, and also largely avoid controversies of the types faced by destroying forests, indeed as shown in chapter 6 they deliver a range of positive economic, social and environmental impacts that bolster the case for investment, for example RECCS is estimated to boost annual GVA by EUR 24 billion per year compared to the base case, a significant improvement in economic outcomes.

To conclude this enterprise-focused approach to capital usage that is likely to gain momentum, compounded by shortages of capital from a slow post-Covid economic recovery and growing demand for funds from the Ukraine and other emergent needs. The diversion of finance that would have been attracted by subsidies to invest in forest bioenergy is the most rational, lower risk-high return approach for investors. The availability of the reallocated subsidies, together with a sounder overall investment proposition, would act as a convincing catalyst for such funding. This is especially relevant for portfolios seeking proportionate allocation of funding to clean energy or climate related investments, where investment returns are not wholly dependent on official subsidy, and actually addresses rather than worsens climate change.

Private finance sources

There are a variety of potential new private funding sources that can also be attracted to implementing RECCS, including:

- Debt or equity finance: standard investment sources
- Market-based instrument finance: either voluntary or mandatory markets for credits or payments for ecosystem services
- Philanthropy finance: which can provide grants or other finance to RECCS projects.

If the business case exists for a measure then a combination of these sources will be likely to finance it. Alternatively there may simply be a regulatory requirement, e.g. buildings energy efficiency requirements, or industrial emissions restrictions, that obliges individuals, companies or public authorities to take action. This is not the case for nature based solutions in RECCS, although some instruments (credits, offsets, payments for ecosystem services generally) do seek to provide funding.

Subsidies can be used to improve the business case for these measures, where public funding can be used to reduce the risks attached to financing a project. In this way the subsidies redirected by RECCS can be used to leverage in significant private finance. The following sub-sections address specific instrument types which could be used.

Green financial products

Various financial instruments and services can be employed to raise capital for projects or companies that generate both financial returns and positive biodiversity outcomes. Examples include green bonds, green loans, and sustainability-linked loans, which offer environmentally friendly alternatives to traditional lending methods. Equity investments are also utilized to allocate capital in a way that yields financial profits as well as benefits for biodiversity. The market for green financial products is experiencing rapid growth, with a wide range of innovative ideas being tested and a substantial influx of capital into the market. The diversity of green financial products makes these versatile instruments able to finance and act on all objectives pursued by the RECCS.

Green bonds are debt instruments issued by public or private entities to raise capital in domestic and international markets. As an illustration, the **Agence France Trésor** (AFT) manages the French state's finances, including the issuance and repayment of French sovereign debt. AFT issued the first French sovereign green bond in 2017, backed by the French state, with subsequent issuances increasing the total amount raised to €25.3 billion as of April 2020. The proceeds from these bonds have financed eligible expenditures in the French state budget, focusing on climate mitigation, climate adaptation, biodiversity, and pollution reduction across various sectors. The financing can be further complemented though green bond proceeds, a potential area of financing from the private sector, where these can be aligned with climate and energy policy objectives and finance specific measures. The nature based solution measures of the RECCS should prioritise seeking co-funding from these sources.

Payments for ecosystem services

Ecosystem services encompass the benefits humans receive from ecosystems, whether they are tangible goods and services such as clean water and flood protection, or intangible values like aesthetically pleasant scenery and spiritual experience, all of which may hold both monetary and non-monetary value. By implementing structured schemes like Payments for Ecosystem Services (PES), incentives can be provided to protect or expand these services for the collective benefit. These voluntary exchanges necessitate three essential components: (1) a clearly defined ecosystem service, ideally quantifiable or tangible, which can be evaluated against efforts to enhance or preserve its provision; (2) a buyer or user of the service; and, (3) a provider or seller of the service.

PES schemes are inherently context-specific, tailored to the unique characteristics of each locality since ecosystem services vary greatly based on environmental conditions. Consequently, these schemes manifest in diverse forms, although the following elements constitute the most common conditions for their effectiveness:

- **Property/use rights**: Insufficiently defined or inadequately enforced property or use rights can diminish the incentive for users or buyers of ecosystem services to engage in PES schemes due to uncertainty about implementation;

- **Transaction costs**: The costs associated with designing and implementing PES schemes can be significant and may require subsidies from public entities;
- **Precise quantification**: Robust biophysical assessments are necessary to determine the price associated with an ecosystem service, which may exclude many services from consideration for PES schemes due to a lack of data or monitoring protocols.

Overall, public funding must sufficiently address the transaction costs and also incentivise land owners to participate in PES schemes. Incentives need to be at a level that provides sufficient compensation compared to alternative approaches to the land / service in question. The nature of RECCS, through its measures on nature based solutions for ecosystem protection and restoration, and its scale, i.e. treating millions of hectares, provides for a huge and unique opportunity for PES instruments. With very large sums of public funding becoming available through RECCS private investors can be attracted to PES-type approaches for nature based solutions in carbon absorbent ecosystems. In implementing RECCS it would be smart for the nature-based solutions measures to welcome the use of PES and set up schemes in a way that ecosystem services credits can be monetised to attract matching investment. PES schemes have been trialled and applied already, one example can be found in Portugal where the government, through its Environmental Fund, has funded a PES project in the Tagus International Natural Park to support re-naturalisation of forest areas, manage water streams and address other environmental objectives across an area of more than 26 000 hectares[215].

Philanthropy finance

Philanthropic foundations are independent legal entities set up for charitable or public benefit purposes, and funded by private actors (individuals, families, corporations, etc.). Foundations are increasingly driven by environmental and sustainability motives, potentially becoming relevant actors in driving change towards these objectives. We provide here a synthesis of available information on foundations' spending into biodiversity and nature conservancy, of potential direct and indirect relevance for objectives of RECCS.

The most comprehensive overview of biodiversity-related financing by philanthropic foundations in Europe are published either biennially or triennially by the European Foundation Centre (EFC). Three reports include financial data within the period 2014-2020: volume 3 (on year 2014),[216] volume 4 (on year 2016),[217] and volume 5 (on year 2018),[218]. The total number of reporting foundations has increased, from 75 in Volume III to 127 in Volume V.

The EFC reports split foundations' spending into themes, two of which are at least to some extent relevant for RECCS objectives:

- Biodiversity and species preservation, which covers work that protects particular species. This includes support for botanic gardens and arboretums, academic research on botany and zoology, and the protection of (endangered) species and their habitat.

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[215] https://environment.ec.europa.eu/document/download/7339baef-56af-4b32-a083-540b1a989902_en?filename=Payments%20for%20ecosystem%20services.pdf

[216] EFC (2016) Environmental funding by European foundations volume 3: https://efc.issuelab.org/resources/25711/25711.pdf

[217] EFC (2018) environmental funding by European foundations volume 4: https://www.efc.be/uploads/2019/03/Environmental-Funding-by-European-Foundations-Volume-4.pdf

[218] EFC (2021) environmental funding by European foundations volume 5: https://www.efc.be/uploads/2021/04/Environmental-Funding-by-European-Foundations-vol.5.pdf

Terrestrial ecosystems & land use, which includes support for land purchases and stewardship, national or regional parks, landscape restoration and landscape scale conservation efforts, tree planting, forestry, and work directed to stopping de-forestation and the impacts of mining.

The findings and figures provided by the EFC are gathered in the table below for the two categories of spending.

Table 7-2 Biodiversity-relevant funding allocated by foundations to recipients in Europe, in million EUR.

Theme	2015	2016	2017	2018	2019	2020
Biodiversity & species	*59.5*	43.5	*48.1*	52.6	*52.6*	*52.6*
Terrestrial ecosystems	*17.0*	10.1	*13.0*	15.9	*15.9*	*15.9*
TOTAL	***76.5***	**53.6**	***61.1***	**68.5**	***68.5***	***68.5***

Financing coming from philanthropy activities can potentially contribute to all objectives pursued by the RECCS. Nonetheless, as most of environment and sustainability related funding is directed at biodiversity and nature objectives, it is likely that philanthropy finance will be mostly directed at the enhancement of carbon-absorbent ecosystems. Based on the estimations of EFC, approximately EUR 68 million each year are invested in the protection of biodiversity, which are in principle aligned with the aims of the RECCS.

Biodiversity and carbon credits and offsets

A **biodiversity credit** is an economic instrument in the voluntary market used to finance activities that produce net positive biodiversity gains through the creation and sale of biodiversity units governed by a set of measurable metrics[219]. Different credits involve different metrics according to their creating organisation. Their composition and pricing must be transparent, and they can be used alongside carbon credits[220]. A biodiversity credit is not generally related to specific ecological damage, although critics are concerned there may be little difference in practice between this and a biodiversity offset.

Biodiversity offsets often in a regulatory context are actions taken to **compensate for the negative impacts** of development on wildlife, habitats, and ecological values by restoring, enhancing, and protecting equivalent resources elsewhere. They are an integral part of environmental policies and standards implemented by governments, financial institutions, and corporations. The purpose of offsets is to ensure that, overall, nature is conserved or restored, although there is often criticism that 'compensated' biodiversity does not actually match what was destroyed. They are particularly relevant in development projects in sectors like energy, mining, infrastructure, and commercial agriculture, where the costs of biodiversity impacts are often externalized to nature and society.

Carbon offsets with credits have a longer history and have been more commonly implemented and sold than biodiversity. The market for these voluntary carbon offsets is currently unstable and there has been significant negative media coverage of these schemes in the last years. Negative coverage has focused on fraud, double counting, lack of additionality, questions over the permanence of emissions savings, leakage and inflated baselines.

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[219] https://www.weforum.org/stories/2022/12/biodiversity-credits-nature-cop15/

[220] https://news.mongabay.com/2022/12/emmanuel-macrons-biodiversity-credits-what-are-we-talking-about/

Nevertheless a multi-billion (estimated around $2 billion) annual global market for voluntary carbon offsets does exist, to meet the demand from private firms and individuals, who are willing to pay sometimes significant amounts (per tCO_2e) for robust, real offsets. The nature based solutions approaches in RECCS can aim for this market segment with protection and reforestation projects amongst the project types that can deliver such robust real carbon benefits. However, strong guidance and oversight would be needed to avoid the issues highlighted in the negative coverage of these schemes. RECCS finance for projects that generate offsets can help unlock private investments in the RECCS measures. Working with offset aggregators could help to pool the required levels of private finance in an efficient way. Wherever possible, carbon credits & offsetting should be combined with progressive reductions in the relevant funder’s emissions (carbon insetting).

The objective of biodiversity offset programs is to achieve a net gain or, at the very least, no net loss of biodiversity by effectively addressing the biodiversity losses caused by development projects. The Paulson Institute[221] provides a set of estimates for different countries on their biodiversity offset expenditures.

7.3 Combining instruments to fund RECCS

As shown in chapter 6 implementing RECCS presents a significant opportunity for investors. The re-directed subsidies from RECCS can provide a significant incentive~~s~~ in the form of subsidies that guarantee revenues, or by part-financing these investments. There is also a strong case for providing the additional public and private financing needed through instruments discussed in the previous sections. There are two important factors in bringing these different sources together to fund RECCS:

Public funding to leverage private capital - public financial instruments that aim to mobilise private capital can include affordable loans or partial funding for eligible investment projects. These instruments target both industry and also private citizens. To estimate expected leveraging of private capital, governments anticipate multiplier effects specific to a sector or an investment. The multiplier effect can vary greatly across countries and sectors. A precise estimate of public finance leverage is difficult to attain, but a recent study published by the European Commission DG ENER[222] focusing on the impact of the RRF on energy sector projects has shown that a multiplier effect of around 3 or 4 can be expected from the RRF investments. In other words, public investment in energy projects under the RRF are expected to mobilise for every euro of the initial public investment 3 to 4 euros from private capital. The assessment of these effects is based on estimates of the member states interviewed as a part of the DG ENER study, providing the following examples:

- Bulgaria expects multiplier effects of three times for one of its energy-related funds under the Economic Transformation Programme
- Romanian Portfolio guarantee for climate action is four times the initial amount.
- Greek Loan Facility specified that RRF loans will be leveraged with third-party financing at a minimum level of 50%, including own equity and loans by commercial banks.
- France estimated that its Recovery Participatory Loans could mobilise up to EUR 20 billion of additional funding, making its expected multiplier effect of the initial RRF funding of EUR 250 million rather ambitious.

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[221] https://www.paulsoninstitute.org/wp-content/uploads/2020/10/FINANCING-NATURE_Full-Report_Final-with-endorsements_101420.pdf

[222] https://op.europa.eu/en/publication-detail/-/publication/740f657f-9e33-11ed-b508-01aa75ed71a1/language-en

These multiplier effects provide an important insight into the type of private capital mobilisation that could be expected from the reallocation of subsidies towards RECCS objectives.

Re-directing private investment away from forest biomass - attracting private investors currently investing in industrial scale use of forest biomass for energy would be a win-win for the RECCS. A significant volume of capital would be available from this source. By our estimate, in the base business-as-usual case, approximately EUR 21 billion would be invested in energy from forest biomass in the period 2025-2030, with this investment planned to significantly increase to almost EUR 8 billion per year if the planned investments in expensive BECCS take off in the 2030s. On one hand this will be difficult as investors are often specialised in particular industries or have other interests that make investment in biomass for energy attractive. However, on the other hand, the removal of subsidies would be expected to already have a very important impact on the business case for biomass for energy, making it less economic and competitive with other energy sources, deterring further investment. The redirection of subsidies to other renewable energy sources could tempt investors to invest in these projects instead, and this can be an attractive option for those looking to invest in low carbon technologies. Increased awareness of the emissions fallacy of biomass for energy, including for BECCS, is also important for redirecting investment to the measures outlined in the RECCS.

Bringing the sources together

The following table 7-3 matches the available funding to the main categories of measures to be supported by RECCS for the first three years of a RECCS implementation beginning in 2025. This identifies the multiple potential public and private funding sources in each case, with an overall summary of how measures of this type could attract matching finance. Recommendations on the basis of this table and the rest of the chapter are made in the following section.

Table 7-3 Summary of RECCS investment needs (based on modelling of RECCS support and matching investment requirements) and potential funding sources 2025-2027

Category of spending	Investment required 2025-2027 [M EUR]	Subsidised by RECCS [M EUR]	Possible Public funding [M EUR]	Sources	Possible private funding Sources	Overall assessment
Renewable energy - wind	11 217	0	Up to 567 million, (i.e. less than 10%) plus national & loans	*JTF, ERDF, EIB, national*	Banks, project developers, energy utilities	Low availability of public finance. Significant need for private finance to match RECCS contributions. Excellent business case with subsidies should attract investors.
Renewable energy - solar	10 359	0	Up to 4 461 m (i.e. >50% of total)	*JTF, ERDF, CF, EIB, national*	Banks, project developers, energy utilities, households	Good availability of public finance and likely availability of private finance to match RECCS contributions. Excellent business case standalone.
Renewable energy - other (marine, geothermal, hydro)	1 532	0	Up to 3 712 m (i.e. ~90%)	*JTF, ERDF, CF, EIB, national*	Banks, project developers, energy utilities,	Strong availability of public finance and likely availability of private finance to match RECCS contributions
Smart energy systems and related storage	N/A	2 409	Up to 4 461 m (i.e. >100%)	*JTF, ERDF, CF, EIB, national*	Banks, energy utilities	Strong availability of public finance and likely availability of private finance to match RECCS contributions
Nature protection and restoration	6 078	7 570	Up to 7 558 m (i.e. >100% of total)	*ERDF, CF, national, RRF, LIFE*	Philanthropy, Credits, Offsets	Strong availability of public finance, and growing sources of public finance to match RECCS contributions. Should be more

Category of spending	Investment required 2025-2027 [M EUR]	Subsidised by RECCS [M EUR]	Possible Public funding [M EUR]	Sources	Possible private funding Sources	Overall assessment
					markets, PES, Firms	than sufficient to achieve 0.25 leverage.
Energy efficiency in industry and business (industrial heat pumps)	1 865	932	Up to 4 532 m (i.e. >100%)	*JTF, ERDF, CF, EIB, national*	Firms, banks	RECCS needs to leverage x1 the subsidised amount. Business case for heat pumps is strong, firms may invest. Significant public finance is available.
Energy efficiency in industry and business (Green hydrogen)	1 865	932		*JTF, ERDF, CF, EIB, national, Innovation Fund*	Firms, banks	RECCS needs to leverage x1 the subsidised amount. Innovative firms may invest themselves. Significant public finance is available, especially Innovation Fund can be an opportunity.
Energy efficiency in housing and public buildings (inc. district heating)	13 054	4 351	Up to 18 119 m (i.e. >100%)	*JTF, ERDF, CF, EIB, national*	Households, banks	RECCS needs to leverage x2 subsidised amount. Large public funds available. Households have been shown to provide matching investments.
Total	**45 969**	**16 195**				

Source: Own calculations

Summary recommendations for financing RECCS

As shown in chapter 6 RECCS presents a significant opportunity for investors, attracting annual investments of EUR 16.4 billion in 2025, increasing over time to EUR 17.5 billion by 2030 and EUR 78.3 billion by 2050. The RECCS strategy provides support to attract and incentivise investors, for example for renewables it provides a subsidy to the electricity generated, providing revenue guarantees to reduce risk and assure returns. For the other measures RECCS provides part of the initial capital investment again making the investment attractive to match funding from other public or private investors. Based on the analysis in the report, we make the following recommendations for financing RECCS implementation:

For **renewable energy** potentially up to EUR 13.5 billion or more is available from public finance, mostly from the ERDF and the JTF. This compares to an estimated annual investment in these measures in the RECCS of around EUR 7.6 billion in 2025, primarily targeting solar and wind energy technologies. In addition, RECCS reserves EUR 750 million for supporting grid strengthening and storage measures to complement the RES alternatives. As shown in Table 7-3, estimated public funding available to support grid and storage measures was found to be approximately EUR 4.5 billion. This means that the priorities of the RECCS are perfectly within the funding scope for public sources. However, the volume of public finance is insufficient to fund the necessary investments, and therefore private capital will also be needed. The subsidy incentives proposed under the RECCS are intended to result in an attractive business case for investors and this, potentially matched with some of the available public funding, should be sufficient to bring forward the required investments. This is how existing subsidy schemes successfully work. Private or public-private instruments such as green bonds (as described above) could also deliver significant investment in renewable energy.

For **energy efficiency** the total for **industrial efficiency measures** of potentially up to EUR 4.5 billion from public funding streams, which compares to an estimated annual investment in these measures in the RECCS of around EUR 1.2 billion in 2025. The public funding comes mostly from the ERDF and JTF and includes industrial heat pumps, CCS and green hydrogen within the scope of what could be funded. The total potential investment for **efficiency measures in buildings** potentially up to EUR 18.1 billion or more compares to an estimated investment in these measures in the RECCS of around EUR 4.3 billion annually in 2025. This highlights that there is significant potential co-funding available from public sources. Deep renovation and industrial heat pump measures typically have short payback periods and high cost effectiveness, therefore these measures should be able to attract sufficient private investment. In addition it is expected that the firms benefitting from such measures would also be required to provide matching funding themselves, this is normal practice as part of firms investment cycles and also for firms to access public money. However, up to now there has been little independent private finance for green hydrogen, and most projects have waited for public funding to complement or lead private funding. Funds like the Innovation Fund can complement opportunities also available in JTF and ERDF, and would help to unlock private finance. Existing analysis has shown that public funding can leverage up to 3-4 EUR of private investment per public EUR invested, such a ratio would easily provide sufficient investment funds for the RECCS.

For residential energy efficiency measures it is normal that the households provide the 2/3 of the finance for the **deep renovation** measures themselves, as they are the main beneficiary and typically wider-ranging household renovations also take place at the same time. If necessary significant public funds are also available to support with further matching funds.

For **nature based solutions** potentially up to **EUR 7.6 billion** or more is available in total from public sources between 2021-2027, with a large majority of the funds targeting nature protection and restoration measures. This compares to an estimated investment in these measures in the RECCS of around EUR 2.6 billion annually in 2025 in carbon-absorbent ecosystems. As RECCS seeks to subsidise 80% of the investment cost the required matching contribution is much less. There are significant public funds available, totalling almost 100% of the total investment requirement, therefore there should be sufficient opportunity, particularly through the ERDF and RRF, to find matching funding for the planned measures.

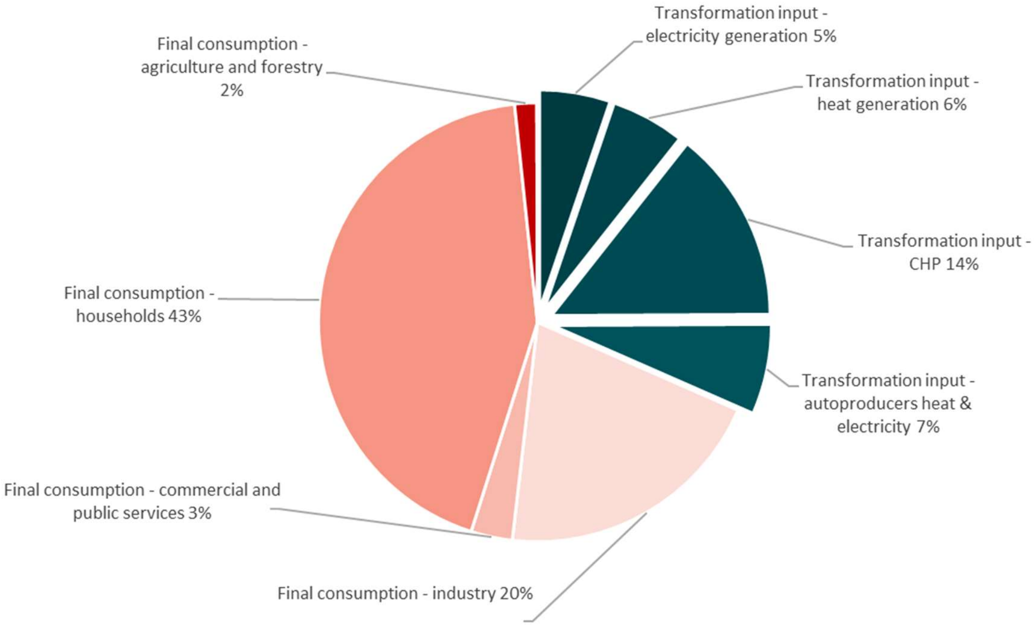
Private sources could also complement the RECCS finance with emerging but rapidly growing funds from instruments for payment for ecosystem services, green bonds and carbon/biodiversity crediting which are offering ways to attract private investors and complement the RECCS and other finance sources. Furthermore, philanthropic foundations could also provide a small-medium source of complementary finance from organisations focused on nature and biodiversity conservation and protection.

Annex A – Detailed breakdown of biomass use for energy

Overview of current use

In the EU27, in 2021, total energy supply of forest biofuels (PSB)[223] amounted to 1 211 TWh (see Figure 0-1). Of these, 32% went as transformation input for energy use, i.e. to electricity or heat production plants; and 68% was available for final consumption, i.e. for combustion on-site, such as in residential furnaces or boilers, or to supply industrial processes. Of PSB used as transformation input for heat and electricity generation, 17% (6% of total energy supply) went to the production of heat only, 5% to the production of electricity only and 45% (14% of total energy supply) to the production of heat and electricity together (CHP plants). A further 18% (7% of total energy supply) was produced and used by industry on-site (auto-producers). Of the PSB that went to final consumption, 63% went directly to households (43% of total energy supply) and 30% went to industry (20% of total energy supply). The scope of this work is focused on commercial scale biomass use, therefore all transformation input segments are relevant, plus also the final consumption segment for industry, commercial and public services, and agriculture and forestry – in total, and before further filters are applied, 57% of the total is relevant for the analysis in this report.

Figure 0-1 Primary solid biofuel use[224], share of use



Looking at the energy flows (see Figure 0-2), these patterns are clearer, this shows how around 30% of the primary solid biomass use in the EU (384 161 GWh of 1 160 327 GWh total) flows into electricity and heat production. Whilst the remainder (891 857 GWh) flows towards final consumption. This final consumption is split across the sectors as highlighted in the previous figure, with the largest shares going to residential heating and industrial heat.

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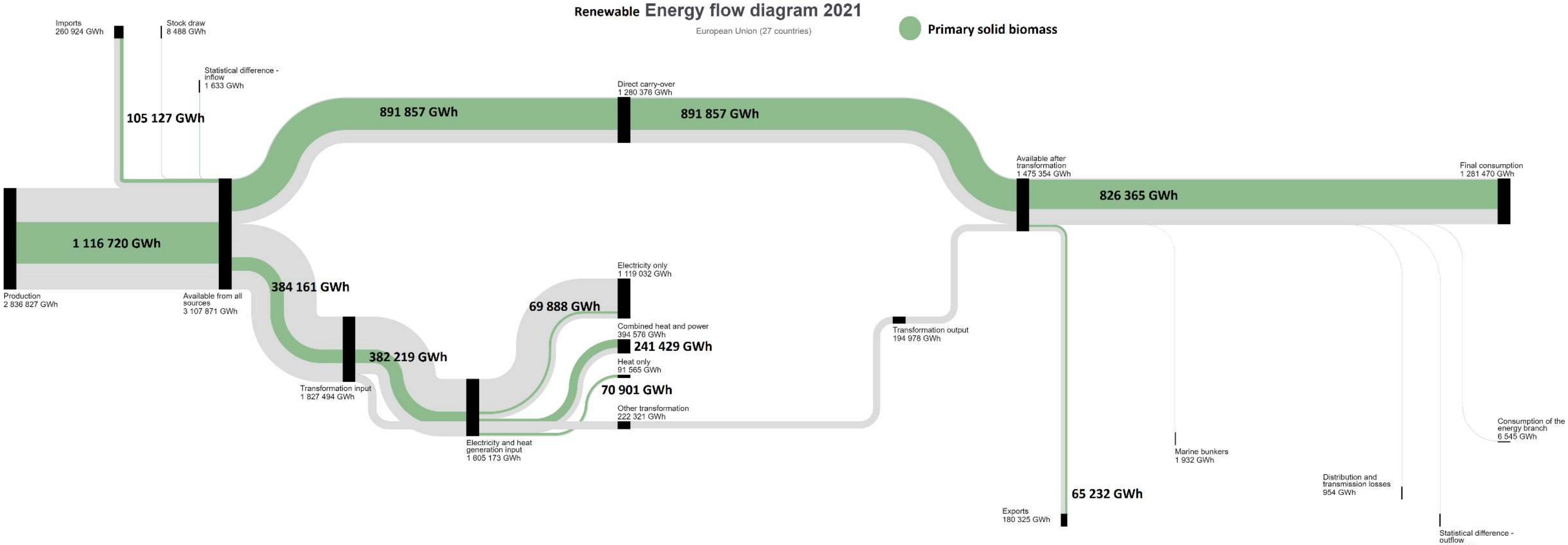
[223] Definition from Eurostat: Primary solid biofuels is a product aggregate equal to the sum of fuelwood, wood residues and by-products, black liquor, bagasse, animal waste, other vegetal materials and residuals and renewable fraction of industrial waste.

[224] Source: Eurostat, energy balances 2021

Figure 0-2 Sankey diagram of renewable energy flows – highlighting role of primary solid biomass, for the European Union in 2021, GWh



Source: Eurostat

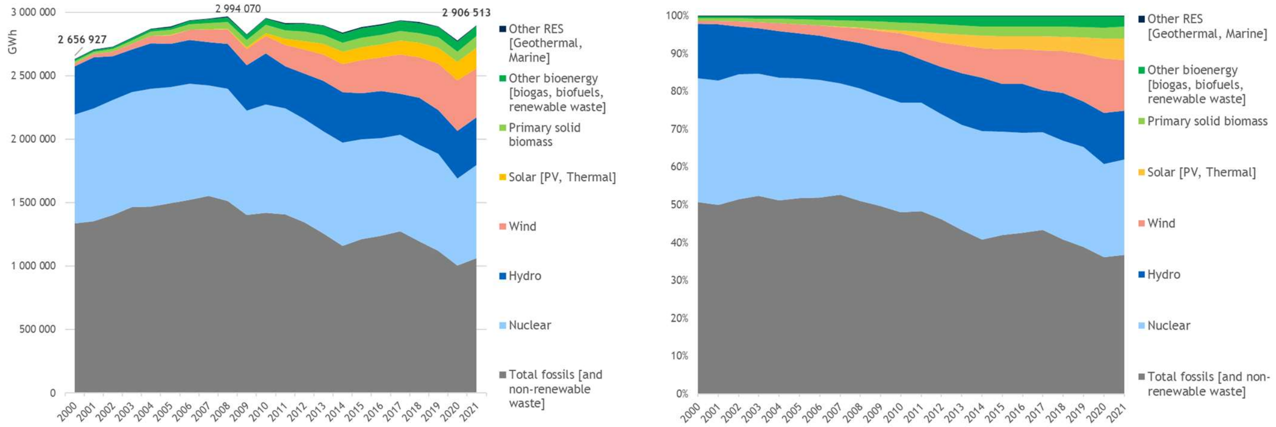
The figure also highlights the role of forest biomass within the renewable energy supply of the EU, accounting for 1 116 720 of 2 835 827 GWh of renewable energy production in the EU, or around 39% of the total renewable energy production. For electricity and heat production (transformation inputs) the share of the total is lower, accounting for around 24% of inputs (382 219 of 1 605 173 GWh), and after accounting for the thermal losses in production the share is lower again. Thermal losses in production in a typical dedicated biomass power plant result in an efficiency of around 30%, i.e. of the total transformation input (forest biomass fuel), around 30% is turned into electricity, if forest biomass with 100 GWh energy content is burnt then only 30 GWh of electricity is produced. Efficiency ratings are higher for Combined Heat and Power plants as the heat that is otherwise wasted is also captured and used. Figure 2-4 where the share of bioenergy in electricity production is around 15%, and specifically primary solid biomass is 8.4%. However, for final consumption (particularly for residential and industrial heating) biomass accounts for around 64% of total renewables, highlighting the important role it plays in renewable heating – although as noted previously the largest part of this is small-scale residential use, beyond the scope of this work.

Recent trends in use of biomass for electricity

The following, Figure 0-3, provides an overview of the developments in the EU electricity generation mix since 2000. These show a few interesting trends, amongst these:

- EU electricity generation peaked in 2008 at just under 3 000 TWh and since then has seen two dips, first during the financial crisis 2009-2010 and then during the COVID19 pandemic in 2020.
- The main story within the mix is the growth of renewables with wind and solar power especially leading the growth, pushing the share of fossil electricity down from 50% in 2000 to 37% in 2021, and the share of renewables increasing from 16% to 38% over the same period

Figure 0-3 Electricity generation in the EU27, split by fuel, 2000-2021, by GWh (left) and share of total (right)



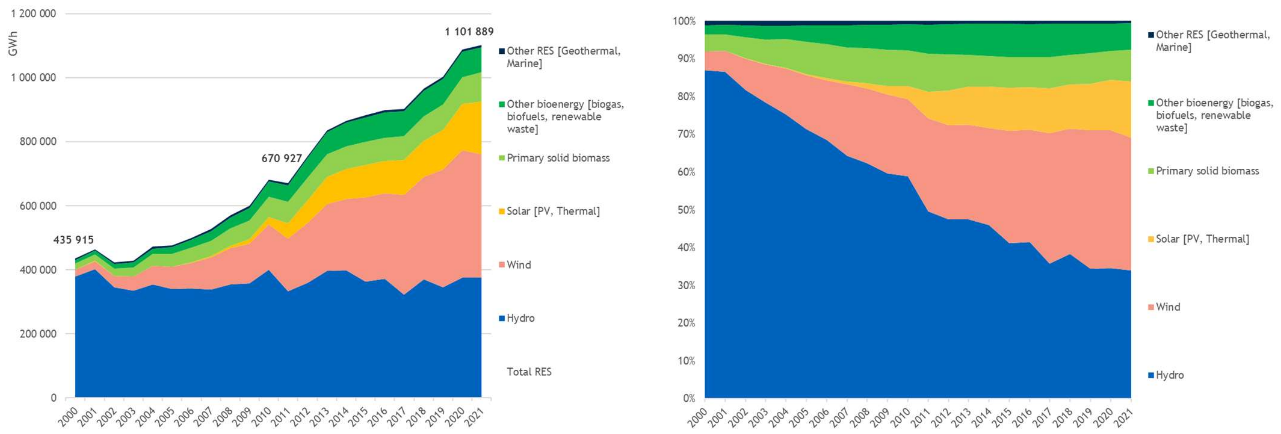
Source: Trinomics based on Eurostat

Zooming in on electricity from renewable energy the role of forest biomass becomes clearer, see Figure 0-4, we see:

- **Electricity from renewable energy has increased by 151% since 2000,** reaching more than 1 100 TWh by 2021. It has increased by 25% between 2015 and 2021.
- Wind energy has seen by far the largest growth, overtaking hydropower in 2020 to become the largest single renewable energy source. Since 2010 solar power has also shown significant growth.

- **Since 2000 electricity from forest biomass has increased from less than 20 000 GWh, to more than 90 000 GWh in 2021, a 370% increase.** It has also increased 29% between 2015 and 2021, faster than the overall growth rate for renewable electricity over this period. This contrasts with electricity from other forms of bioenergy which did not grow in the same period.
- Therefore, whilst wind and solar power are the dominant growth stories in renewable electricity, it should not be forgotten that **electricity from primary solid biomass is also growing rapidly.**

Figure 0-4 Electricity generation from renewable energy sources in the EU27, split by type, 2000-2021, by GWh (left) and share of total (right)



Source: Trinomics based on Eurostat

Recent trends in use of forest? biomass for heat

The following, Figure 0-5, provides an overview of the developments in the EU heat generation mix[225] since 2000. These show a few interesting trends, amongst these:

- EU heat generation peaked in 2010 at around 720 TWh and has largely stabilised since then.
- **In contrast to electricity, where low carbon sources are in the majority, fossil fuels remain by far the dominant source of heat,** this highlights this part of the decarbonisation challenge.
- **Similar to electricity, the main story within the mix is the growth of renewables, but with solid biomass leading the growth over this period**, pushing the share of fossil electricity down from 90% in 2000 to 70% in 2021, and the share of renewables increasing from 10% to 30% over the same period.

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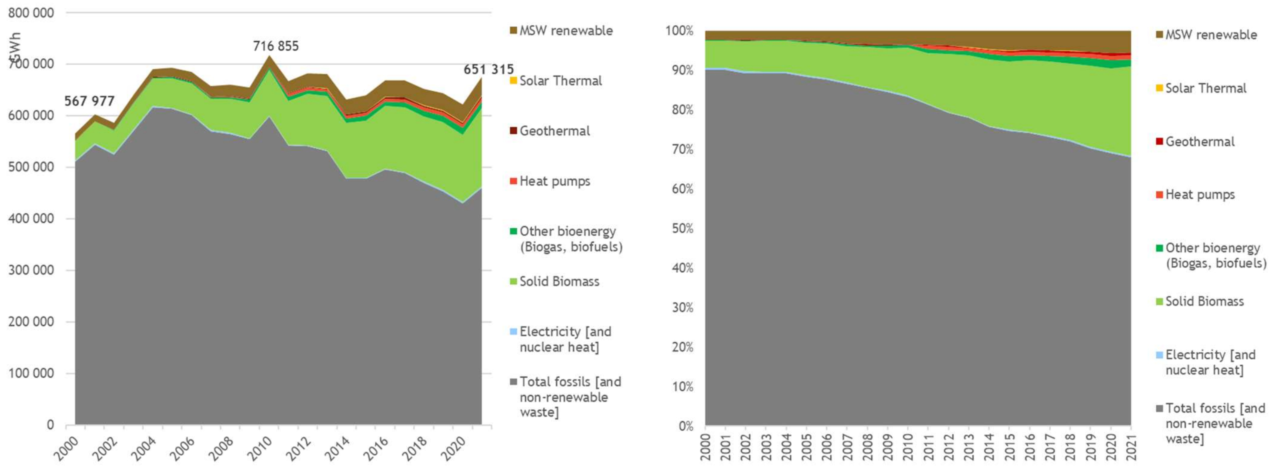
[225] These data focus on inputs to heat plants, either dedicated or CHP. They do not include final consumption by households, industry or end-users.

Figure 0-5 Heat generation in the EU27, split by fuel, 2000-2021, by GWh (left) and share of total (right)



Source: Trinomics based on Eurostat

Zooming in on heat from renewable energy the role of forest biomass becomes clearer, see Figure 0-6, we see:

- **Heat from renewable energy has increased by 310% since 2000, more than quadrupling** in this period to reach more than 210 TWh by 2021. It has increased by 34% between 2015 and 2021.
- **Solid biomass has seen by far the largest growth in absolute terms, increasing from 38 TWh to 152 TWh between 2000 and 2021**, in line with the overall growth of renewable heat.
- There has also been growth in heat from municipal solid waste which remains the second largest heat source, although this has not grown as quickly as forest biomass.
- Heat pumps have also emerged as a small but growing contributor since 2011, although this remains a significantly smaller heat source in the statistics. As the selected statistics focus on large generation units these do not fully account for the role of heat pumps – but highlight a growing role for industrial scale heat pumps (see also chapter 5). Taking a broader view would show that in reality heat pumps provide a significant and rapidly growing share of heat in the EU. For example around 20 million EU households (about 10% of total) are now estimated to have heat pumps.[226]

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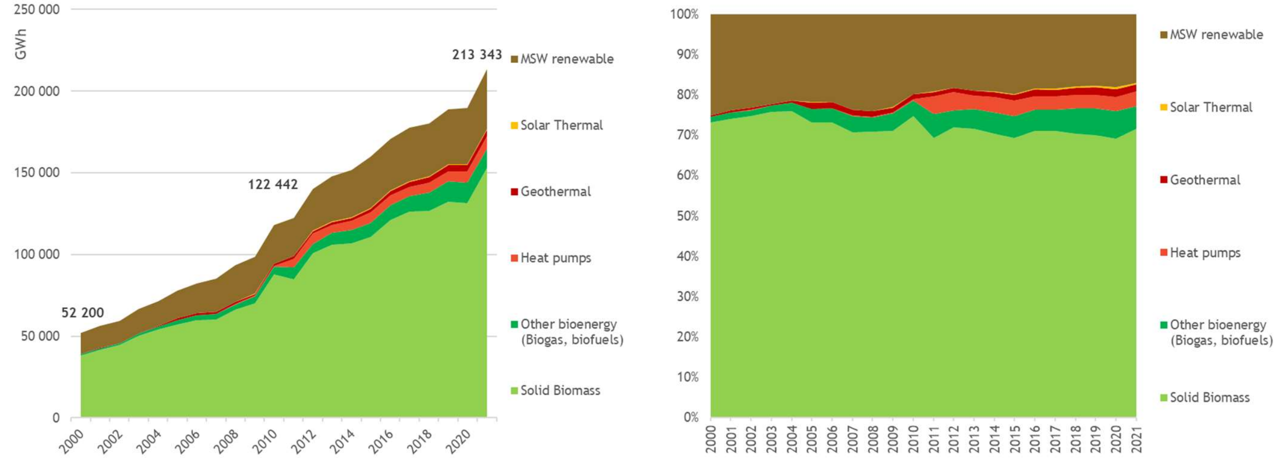
[226] Source: https://www.ehpa.org/market-data/ and from total of around 198 million EU households

Figure 0-6 Heat generation from renewable energy sources in the EU27, split by type, 2000-2021, by GWh (left) and share of total (right)



Source: Trinomics based on Eurostat

Recent trends in use of biomass for energy in industry

The industry sector accounts for about a quarter of the EU's final energy consumption, with 2 796 TWh consumed in 2021.[227] During the last decade (2012-2021), the total amount of final energy consumption remained relatively constant. Fossil fuels and non-renewable waste contribute around 51% of this total, a share which has basically remained unchanged over the last decade, with small declines in coal and oil use compensated by increased natural gas and non-renewable waste use.

Forest biomass contributes around 9% of the total, providing 245 000 GWh per year, therefore a significant amount compared to biomass use for electricity and heat as outlined in the previous sections. Forest biomass consumption by industry has increased by 15% over this period, a slow but steady growth trend. Primary biomass use is concentrated in a handful of industrial sectors, with it contributing more than 10% of the energy use within only two sectors the Wood and Wood products sector (57% of total) and the paper, pulp and printing sector (38%)[228]. Together these account for more than 83% of the primary solid biomass use for energy by industry. These sectors use wood waste and byproducts of their production process to power their own plants, usually CHP, and are therefore relatively efficient and circular in their usage. This is distinct from larger commercial power and heat plants (addressed in the previous sub-section), which have often to resort to roundwood to satisfy their input quantities.[229] Besides their direct use of solid byproducts, the pulp and paper industries are expanding into the production of biofuel and biogases, also from production residues.[230] In part these are also used for self-consumption, but in some cases are sold to other users.

However, precise data on the use of biomass for energy in these sectors is scarce and there is some evidence that industry is also exploiting subsidies well beyond their original aim, for example in Portugal, "*Less than half of the woody biomass burned by the sector comes from bark and other*

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[227] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_industry_-_detailed_statistics#Energy_products_used_in_the_industry_sector

[228] Based on analysis of Eurostat EU27 energy balances.

[229] https://policy.friendsoftheearth.uk/insight/future-drax-old-inefficient-damaging-and-expensive#:~:text=Drax%20burns%20a%20lot%20of,could%20do%20to%20its%20furnaces.

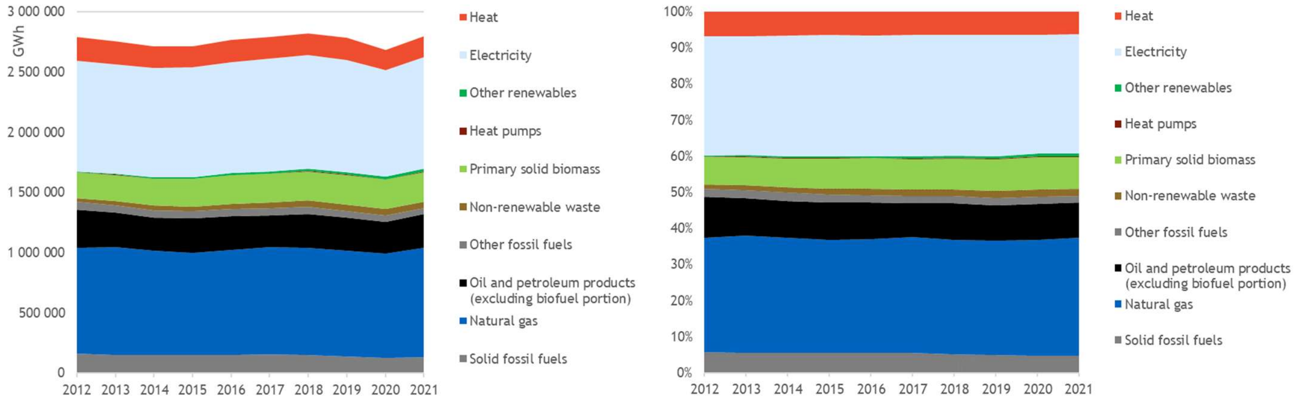
[230] https://www.fisheri.com/blog/could-the-pulp-and-paper-industry-play-a-role-in-producing-bio-products

industrial by-products"[231]. A survey of the Finnish sawmill industry[232] showed that all factories surveyed were producing bioenergy, with 61 also selling either electricity or heat to external users. Among the key factors in driving bioenergy use, respondents indicated government subsidies, suggesting that the case for bioenergy without these will be limited, including in industries where residues are immediately available. Removing subsidies for bioenergy would therefore also be likely to directly affect those industries that are the main generators and users of bioenergy, and where the biomass that is burned is often a byproduct of their production process, resulting in 'stranded assets'. Alternatives and efficiency measures in industry can therefore have a significant positive impact on biomass use.

Other renewables and heat pumps play a tiny role in industrial final consumption, together contributing only 1% of the total. However, both are rapidly growing their contributions (+175% / +664% respectively between 2012-2021) and particularly industrial heat pumps offer an important option to decarbonise industrial energy use (see also chapter 5).

The other major options to decarbonise industrial energy use include electrification (combined with a low carbon electricity supply), application of carbon capture and usage/storage (CCUS) technologies or the use of hydrogen / synthetic fuels.

Figure 0-7 EU's final energy consumption by industry per energy product (2012-2021), absolute GWh (left), share of total as % (right)



Source: Eurostat (NRG_BAL_S)

MS summary of PSB in electricity and heat

The following table summarises the role of PSB in electricity and heat at MS level.

Table 0-1 Primary Solid biofuels use in 2021 – Electricity and Heat[233]

Country	Electricity			Heat		
	Forest biomass [GWh]	As % of Renewable Energy Sources (RES)	As % of Total Electricity	Primary solid biomass [GWh]	As % of RES	As % of Total Heat

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[231] https://www.biofuelwatch.org.uk/2023/portugal-pulp-mills-and-biomass/
[232] https://www.tandfonline.com/doi/pdf/10.1080/14942119.2012.10739965?needAccess=true&role=button
[233] Data from Eurostat, UK from DUKES

EU27	92 753	8.4%	3.2%	152 813	71.6%	23.5%
Belgium	2 763	11.7%	2.8%	246	24.7%	4.3%
Bulgaria	2 373	22.5%	5.0%	2 307	98.1%	21.5%
Czechia	2 665	22.4%	3.1%	2 914	80.5%	8.8%
Denmark	7 133	27.3%	21.6%	19 964	75.4%	52.7%
Germany	10 909	4.6%	1.9%	7 699	35.3%	6.0%
Estonia	1 694	58.8%	23.5%	3 901	95.5%	61.8%
Ireland	471	4.0%	1.5%	0	N/A	N/A
Greece	42	0.2%	0.1%	0	N/A	0.0%
Spain	5 095	4.0%	1.9%	0	N/A	N/A
France	4 314	3.4%	0.8%	15 057	65.1%	29.2%
Croatia	660	6.2%	4.3%	1 116	85.0%	25.8%
Italy	4 529	3.8%	1.6%	4 472	44.5%	7.2%
Cyprus	0	0.0%	0.0%	0	0.0%	0.0%
Latvia	570	15.3%	9.7%	4 673	95.2%	53.9%
Lithuania	387	11.6%	7.9%	6 532	93.8%	65.5%
Luxembourg	285	14.5%	12.9%	1 205	96.5%	70.3%
Hungary	1 775	25.7%	4.9%	1 095	50.6%	8.0%
Malta	0	0.0%	0.0%	0	N/A	N/A
Netherlands	7 860	19.4%	6.5%	4 492	64.0%	16.4%
Austria	3 523	6.2%	5.0%	11 963	89.3%	46.8%
Poland	6 398	20.4%	3.6%	5 817	89.1%	6.8%
Portugal	3 392	10.2%	6.7%	0	N/A	0.0%
Romania	580	2.2%	1.0%	987	88.7%	5.8%
Slovenia	169	3.0%	1.1%	509	90.3%	18.2%
Slovakia	1 325	18.7%	4.4%	1 773	86.8%	19.7%
Finland	12 668	33.2%	17.6%	24 192	85.6%	50.0%
Sweden	11 174	9.7%	6.5%	31 898	70.5%	56.9%
Iceland	0	0.0%	0.0%	0	0.0%	0.0%
Norway	29	0.0%	0.0%	1 919	42.7%	26.8%
United Kingdom	27 703	22.3%	9.0%	975	100.0%	5.3%
Bosnia and Herzegovina	36	0.5%	0.2%	338	100.0%	20.3%
Montenegro	0	0.0%	0.0%	0	N/A	N/A
Georgia	0	0.0%	0.0%			

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