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By 2050 the Mitigation Effects of EU Forests Could Nearly Double through Climate Smart Forestry

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Abstract: In July 2016, the European Commission (EC) published a legislative proposal for incorporating greenhouse gas emissions and removals due to Land Use, Land Use Change and Forestry (LULUCF) into its 2030 Climate and Energy Framework. The Climate and Energy Framework aims at a total emission reduction of 40% by 2030 for all sectors together as part of the Paris Agreement. The LULUCF proposal regulates a "no debit" target for LULUCF (Forests and Agricultural soils), and regulates the accounting of any additional mitigation potential that might be expected of it. We find that the forest share of the LULUCF sector can achieve much more than what is in the regulation now. We elaborate a strategy for unlocking European Union (EU) forests and forest sector potential based on the concept of "climate smart forestry" (CSF). We find that to-date, European policy has not firmly integrated forest potential into the EU climate policy framework. Nor have climate objectives been firmly integrated into those of the forest and forest sector at either the EU or national level. Yet a wide range of measures can be applied to provide positive incentives for more firmly integrating these climate objectives into the forest and forest sector framework. With the right set of incentives in place at EU and Member States levels, we find the current literature supports the view that the EU has the potential to achieve an additional combined mitigation impact through CSF of 441 Mt CO_2/year by 2050. In addition, CSF, through reducing and/or removing greenhouse gas emissions, adapting and building forest resilience, and sustainably increasing forest productivity and incomes, tackles multiple policy goals.

Keywords: European forests; carbon sequestration; harvested wood products; bio-energy; climate smart forestry

1. Introduction and Aim

In July 2016, the European Commission (EC) published a legislative proposal for incorporating greenhouse gas emissions and removals due to Land Use, Land Use Change and Forestry (LULUCF proposal) into its 2030 Climate and Energy Framework. The Climate and Energy Framework aims at a total emission reduction of 40% by 2030 for all sectors together as part of the Paris Agreement [1,2]. The LULUCF proposal regulates a "no debit" target for LULUCF (Forests and Agricultural soils) and an accounting framework to handle any additional mitigation potential. European Union Member

States have negotiated with the European Commission over the respective approach by which forests will contribute to their overall goals. This has led to the incorporation of compensation mechanisms in case a debit would arise and complicates the regulation further in many country specific clauses [3].

Already in the negotiations leading up to the Kyoto Protocol in 1997, concerns about the consequences of incorporating the existing forest sink into the climate targets had the policy outcome of imposing significant limits on the forest climate change mitigation role [4]. In particular, requirements related to "caps", and "forest (management) reference levels" (FMRL now called FRL) were introduced over time in the UNFCCC framework, and this set of rules has now evolved further within the new EU-level LULUCF proposal [3]. We argue that the current LULUCF proposal limits the role of forests and the forest sector in climate policy and find that this role could be much greater than what was assessed in the initial Impact assessment report [5]. This is further substantiated in the Policy section below.

Against this backdrop, the aim of this paper is to elaborate a strategy for unlocking European Union (EU) forests and forest sector potential based on the concept of "Climate Smart Forestry" (CSF) which we see as a more specific (climate-oriented) form of the Sustainable Forest Management paradigm. The idea behind CSF is that it considers the whole value chain from forest to wood products and energy, and illustrates that a wide range of measures can be applied to provide positive incentives for more firmly integrating climate objectives into the forest and forest sector framework [6,7]. CSF is more than just storing carbon in forest ecosystems; it builds upon three main objectives; (i) reducing and/or removing greenhouse gas emissions; (ii) adapting and building forest resilience to climate change; and (iii) sustainably increasing forest productivity and incomes. These three CSF objectives can be achieved by tailoring policy measures and actions to regional circumstances in Member States forest sectors. The aim here is to quantify a realistic potential mitigation role of EU forests and the forest sector, and to devise a novel policy regime that tries to incentivize action according to the three main CSF objectives. Below we first quantify the mitigation role of EU forests and the forest sector towards 2050 taking into account its full impact along the forest ecosystem-wood products-energy value chain. We then devise an alternative policy regime, and last, we identify actions and actors, taking into account the high degree of variation across regional circumstances in the EU Member States.

2. Methods

For the quantitative part of this analysis, we conducted a literature search and review, searching in Google Scholar and online journal outlets. Search keywords were "Forest CO_2 sequestration/sink, EU LULUCF strategy, Member States national LULUCF/forestry strategies, forest measures for mitigation, LULUCF, forest and wood products value chain, forest value chain, carbon balance, cascade, and material and energy substitution". We selected articles that focused on the climate change mitigation potentials. We then quantified the full CO_2 impact of the forest and forest sector, although we are aware that in current accounting of the impacts of bioenergy, for example, the latter impacts are accounted in the energy sector. Thus, we regard the full impact along the forest ecosystem-wood products-energy value chain, using Intergovernmental Panel on Climate Change (IPCC) methods and conversion factors [8]. For the policy part of the study, we used existing public documents on LULUCF regulation, impact assessments [5], as well as EU workgroup meeting minutes together with scientific literature on the topic.

3. Results: The Mitigation Role of EU Forests and the Forest Sector through CSF

Based on our synthesis of the literature, we developed the CSF concept. It is derived from a more holistic and effective approach than one based solely on the goals of storing carbon in forest ecosystems. The core of CSF is that it considers the whole forest and wood product chain, including material and energy substitution and foremost takes regional circumstances into account. Furthermore, CSF not only aims at climate change mitigation, but tries to achieve synergies with other forest functions, such as adaptation to climate change, biodiversity conservation, ecosystem services and the bio-economy.

CSF through (1) reducing and/or removing greenhouse gas emissions; (2) adapting and building forest resilience; and (3) sustainably increasing forest productivity and incomes, tackles multiple policy goals. The greater the synergies and the fewer the trade-offs between climate policy and other societal, forest-related goals, the more likely climate objectives will be effectively implemented in practice.

Given that the EU aims at an ambitious 80% emission reduction by 2050, it will be essential to involve all the sectors and thus to include EU forests and the forest sector in order to achieve this aim (Figure 1). Although EU forests cover 40% of the land, the scientific literature has occasionally pointed to a limited, but additional mitigation role for EU forests on the order of 90–180 Mt CO_2/year by 2040 [6]. We find, however, that with adjustments to the LULUCF policy framework, and with CSF implementation, EU forests and the forest sector can play a much larger role than previously thought.

The current annual mitigation effect of EU forests via contributions to the forest sink, material substitution and energy substitution is estimated at 569 Mt CO_2/year, or 13% of total current EU emissions [4,9–14]. With the right set of incentives in place at EU and Member States levels, we find, based on a literature review (and accounting for regional circumstances (Table 1), that the EU has the potential to achieve an additional combined mitigation impact through the implementation of CSF goals, of 441 Mt CO_2/year by 2050 (see Appendix Tables A1 and A2). In this estimate, we simply consider the total impact of forests and the forest sector on the atmosphere from a climate perspective. We arrive at this number based on the four following measures (see also Table 1).

Table 1. Summation of the Climate Smart Forestry mitigation effect. All numbers are approximations.

Main Category of Forest Management Measure	Sub Measure	Mitigation Effect (Mt CO_2 a^{-1})
1. Improved forest management		172
	1a. fullgrown coppice	56
	1b. enhanced productivity & improved management	38
	1c. reduced disturbances, deforestation, drainage	35
	1d. material substitution wood products	43
2. Forest area expansion		64
3. Energy substitution		141
4. Establish forest reserves		64
Total		441

3.1. Improved Forest Management in Existing Forests and Wood Chains

Projections of forest resources under alternative management and policy assumptions indicate that carbon storage in existing EU forests could continue to increase, providing additional sequestration benefits of approximately up to 172 Mt CO_2/year by 2050 [15–20] (see Table A2 for calculations). Measures could include enhanced thinning of stands leading to additional growth and higher quality raw material, regrowth with new species, planting of more site-adapted species, and regeneration using faster growing species. For example, large areas of low productivity hardwoods previously only used for firewood production (some 350,000 km^2 of old coppice forests), could be regenerated and replaced by more productive mixed deciduous and coniferous forests, generating an additional sink of ~56 Mt CO_2/year [21]. This can be done by using new provenances better adapted to future climates, without the need for exotic species. Furthermore, we recommend this measure only be carried out on sites with lower biodiversity values. Some coppice sites are highly valuable for nature conservation strategies arising out of centuries old cultural historical management [22].

An increase in the productivity of forests through the above measures is feasible on ~700,000 km^2 of forest land, yielding increased stemwood growth of ~1 m^3/ha/year [16,23]. Converting this area into carbon measurements using IPCC standards (Table A1), the additional growth could potentially yield an addition to the forest sink of ~38 Mt CO_2/year (see country examples in [18,19,24,25]). Moreover, serving as a support for the EU Bioeconomy strategy, this measure would add ~35 million m^3 of future harvest potential (see Appendix Table A1 factor "harvest rate of additional wood growth") to the EU's

current fellings of 522 million m^3 [26], although possible trade offs with other services should always be kept in mind [27].

Harvested wood products: Not only the carbon in forest ecosystems plays a role in climate change mitigation. The long-term use of harvested wood products (HWP) can also contribute to mitigation. Using wood resources in this way can substitute for the use of fossil fuels—in particular for CO_2—and energy-intensive materials like steel and concrete in the construction sector. According to meta-analysis estimates, for example, each additional ton of wood products substituted for ordinary Portland cement, helps to avoid an average of 2 tons of CO_2 emissions [21]. Favoring wood-use in the construction sector (when carried out in synergy with the above-mentioned production increase) could therefore potentially help avoid future emissions on the order of ~43 Mt CO_2/year [11,28]. With the additional implementation of cascaded use for quality wood products, only post-consumer wood products would be used for energy production; this strategy would provide additional substitution impacts [18]. Currently, however, 25% of all EU harvested wood is used directly in non-commercial low efficiency household fire places [29]. We acknowledge that there is still much new research needed to improve the substitution multipliers, so that we will be able to provide more accurate estimates of the potential mitigation impacts.

Combining adaptation with reduced emissions: Emissions occur in European forests as well. Annual deforestation, as exemplified by land use conversions to infrastructure of close to 1000 km^2/year, causes emissions of ~15 Mt CO_2/year [12].

Further, natural disturbances such as wind storms and forest fires [30–32], on average, cause emissions of ~18 Mt CO_2/year. Draining of peat soils under forests emits ~20 Mt CO_2/year [10]. Forest management and the improved protection of forest areas in Europe can aim to reduce all of these emissions. In Spanish forests, for example, a more active management regime that also aims at introducing more adapted species could significantly reduce fire risk and thus land-use change. If we conservatively assume that 2/3 of the above emissions can be avoided, this would reduce emissions by a further ~35 Mt CO_2/year.

3.2. Forest Area Expansion

Some 150,000 km^2 of farmland are projected to be abandoned in the EU by 2030 [33]. These lands are in remote locations, currently with low biodiversity value, on land that is unprofitable for agriculture and where labor is not easily available. In such areas, forestry represents a good option without leakage of agriculture to developing countries. Using new tree species that easily achieve stem wood growth of ~8 m^3/ha/year, and using IPCC conversion factors, the expansion of forests onto this area could provide an additional sink of ~64 Mt CO_2/year and could further provide the additional spinoff benefit of an additional harvesting potential of ~60 million m^3 with spinoffs to the HWP pool etc.

3.3. Producing Biomass for Bioenergy

Currently, woody biomass already provides 7% of total EU energy needs [17,34]. Because of this bioenergy contribution, fossil fuel emissions have currently been reduced by 190 Mt CO_2/year. The potential, however, is larger. Based on EU domestic woody biomass availability, secondary residues and low-quality thinning wood, estimates suggest that a sustainable additional 200 million tons of woody biomass can be produced. This represents an additional 5% of total EU energy needs and potential avoided emissions of ~141 Mt CO_2/year [35–38]. Projects like Biomassfutures and Biomasspolicies [36,37] have paid a lot of attention to the sustainable management of the forest resources preserving soil quality and nutrient levels, thus arriving at the carefully assessed estimates provided above.

3.4. Forest Reserves

Setting up strict forest reserves—which currently cover 2% of European forests [26] will strengthen short term CO_2 sequestration. NGOs have continuously asked for an overall goal of 10% of EU forests to be set aside as strict reserves. If we assume that 2/3 of this goal (a 7% share of EU forests for set-aside forests) can be achieved by 2050, an additional CO_2 sequestration of ~64 Mt CO_2/year could be achieved on ~120,000 km^2 (Tables A1 and A2). This would benefit the EU Biodiversity Strategy and the EC Natura2000 network of protected areas.

4. The EU LULUCF Proposal and How to Approach Reform

The LULUCF proposal [1] places forestry together with agricultural land-CO_2 into one compartmentalized sectoral package (the LULUCF "Pillar"), with very limited flexibility and potential for exchange with other sectors. A no-debit rule applies for the combined LULUCF forestry and agricultural land-CO_2, meaning that these quantities together should not result in net emissions (i.e., create more emissions), and should ideally contribute to a continuously increasing sink. Emissions from agricultural land may be compensated by change in the forest sink, but only above a forest (management) reference level (a baseline sink, FMRL, FRL), and only up to a maximum 3.5% of a country's total, economy-wide, base year emissions, in sum 160 Mt CO_2/year for the EU as a whole. However, due to high reference levels and/or small caps in individual Member States, many of them will be inadequately encouraged to achieve this potential [4]. The proposal further allows for a small exchange with the Effort Sharing Decision (ESD) sectors, which sets reduction targets for the transport and housing sectors, and non-CO_2 emissions from agriculture. The exchange, however, is capped at 280 Mt CO_2/10 years and can only be achieved through specific activities such as afforestation and cropland management—the forest management activity has been excluded from this quantity, for now, although it is under discussion. Because of the limited set of allowable measures, this maximum is not likely to be achieved either. Thus, we find, based on the quantitative estimates provided above, that the EU climate policy framework should ideally provide improved incentives that strengthen the forest and forest sector likelihood of contributing to climate change mitigation. Furthermore, the overall strategy should be greatly simplified in order to avoid unnecessary technical complications and costs. The current web of caps, reference levels, targets and pillars have the effect of marginalizing incentives for forests, wood products and energy-related mitigation efforts.

The range of earlier concerns toward including LULUCF in the climate targets was primarily related to uncertainty in reporting on the forest sink, opposition to using the forest sector as a tool for "offsetting" industry-level emission reduction commitments, a strong interest in preserving "environmental integrity", and questions regarding the relative permanence of forest-based carbon sequestration. Many or most of these (earlier) concerns hampered innovation in the LULUCF policy framework. However, many of these concerns have been sidelined by important changes since the early 1990s. Continuous increased growth in European forests over the last several decades [39], as well as continuous improvement in forest inventory reporting practices since the initial UNFCCC reporting requirements were agreed, have helped to reduce concerns related to uncertainty and permanence.

To deal with the concerns regarding environmental integrity, the 2011 Durban inclusion of forests in the UNFCCC effectively turned a baseline sink into a forest sector commitment that has been added on top of the regular commitment framework. This baseline sink is now called the Forest Management Reference Level (FMRL) and must be achieved before any additional forest sector achievements can be counted. The structure of these rules essentially enforces the additive role of the forest contribution. Despite this raised ambition (existing commitment + the FMRL commitment) and the presence of additional emission reduction pathways, forests continue to play a marginal role in the climate policy framework.

As soon as Member States fail to achieve this baseline (the FMRL), they are debited for the shortfall. For many Member States, this may represent a significant obstacle to their mitigation goals, in particular the increasing use of bioenergy. Though countries are likely permitted additional harvesting in their

FMRL (management intensity) projections, this placement of constraints on how additional annual growth in European forests can be used may have unintended consequences. First, forest owners invest resources in productive forests. Perceived limits on the use of these productive resources (through the implementation of reference levels) may well create disincentives for future forest investments. Second, additional forest and forest resource use (rising harvesting levels as in the bio-economy case of Finland and Sweden) may in the short-term lead to a reduced sink. Even though these countries will likely continue to have a net sink, they will be debited for any shortfall. Finally, the difficulty in projecting future demand for bioenergy resources over longer periods of time is only likely to exacerbate these tensions.

We thus find there is every reason to propose better ways to encourage future forest investments and promote climate-friendly uses and the ecosystem services of forests and forest-based resources. Imposing limits on the potential use of forest resources—in particular, where these can negatively impact cost-efficient climate change mitigation strategies—does not represent a wise use of existing resources.

Therefore, we propose the following four policy revisions:

A. Eliminating caps and the current reference levels.

Our alternative policy approach is based on incentivizing ambition, in particular through elimination of the limits on access to carbon credits. Removing limits, in particular, on the cap, can provide an immediate financial incentive framework as well as the appropriate resources for stimulating additional forest-related CSF efforts. This can provide opportunities for Member States to develop strategies that build upon other efforts e.g., the EU's Biodiversity Strategy [40], and provide the potential availability of additional resources for the Bio-economy Strategy [41]. In contrast to the Impact Assessment (IA) of the LULUCF regulation [5] carried out by the Commission, we especially look for alternative policy incentives outside the current scope of the regulation. The IA only looked for small alternatives within the scope of the Regulation.

A core of our approach is to set higher ambitions for the LULUCF sector: Member State forest and forest resource-based climate mitigation targets can be determined through a joint effort by the European Commission and the Member States, based on principles of fairness, the state and size of forest resources, current forest sinks, Gross Domestic Product, as well as cost-efficiency. Moreover, these targets can and should be set to further raise ambition and strengthen CO_2 mitigation. However, the placement of these targets in the forestry sector through the creation of a forest "Pillar" immediately gives rise to concerns about the future use of the forest resource and encourages lobbying focused around the setting of the FMRL. If these targets are instead added on top of the economy-wide emission reduction commitment and the FMRL is removed, these targets will no longer directly impinge upon actions within the forest sector. Doing this would thereby facilitate the decoupling of forest emission reduction targets from future potential forest resource uses (e.g., wood raw material flows), the confounding of which has been a cause for great concern.

Removing the FMRL would thus make it possible to eliminate the cap and thereby free up the right to claim carbon credits for additional carbon sequestration in standing forests. With this achieved, Member States would then be able to more freely incentivize climate-friendly forest actions. When forest sector targets are set together with this type of enabling framework for promoting investments in forest management, this will make it possible to further incentivize forest growth. The long-standing debate over "whether to store more carbon, or use the forests", misdirects attention away from the real challenge, which is how to stimulate additional forest growth, such that it becomes possible to both maintain and increase harvest, while at the same time maintaining the sink. Such an approach is entirely in line with the IPCC 4AR (2007) which concluded "In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit".

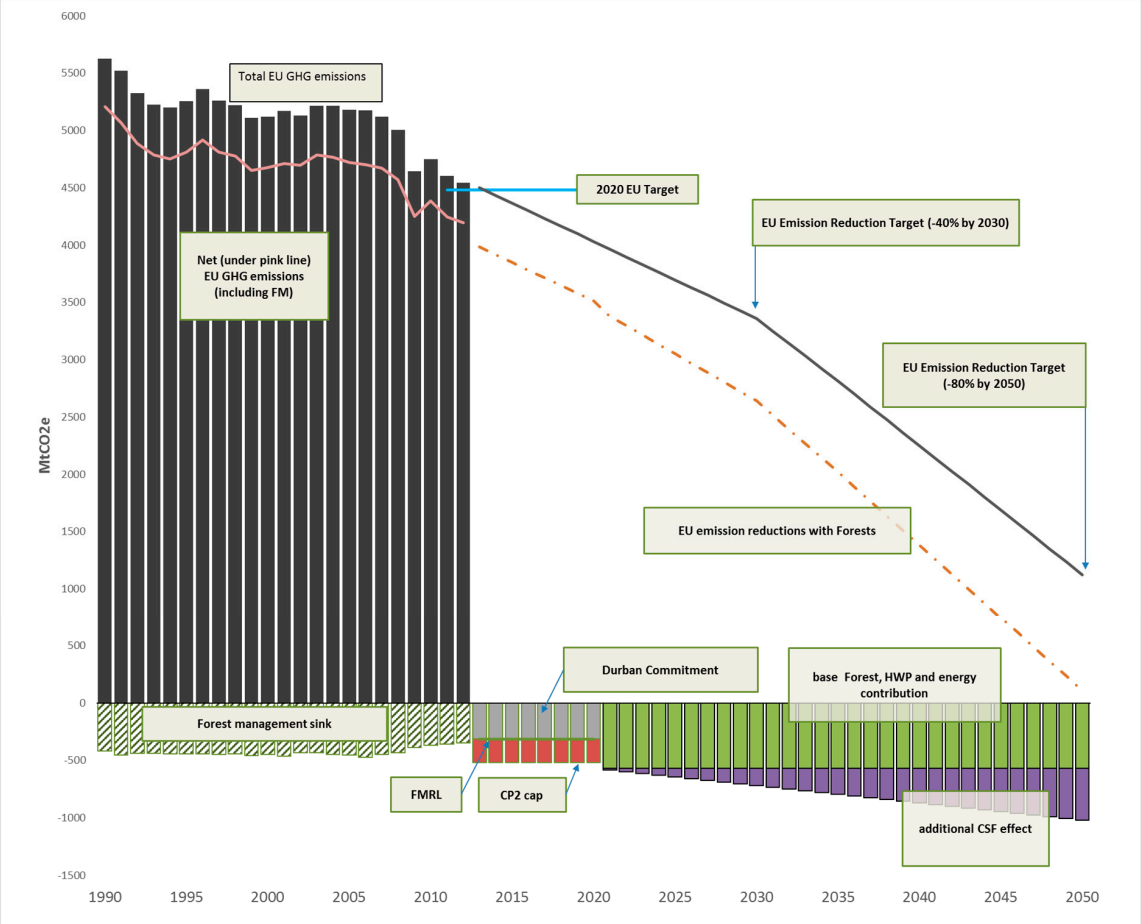

Figure 1. Total Projected European Union (EU) Emission Reductions by 2050, with and without climate Smart Forestry. Reported data were used through to 2012 (emissions of all sectors positive and sinks negative). The expected impact of both the Durban commitment created by the introduction of the Forest Management Reference Level (FMRL), and the cap for the second Commitment Period (CP2 cap), through 2020 is projected by the red and grey bars. Further, we project the potential forest contribution from climate smart forestry from 2020 to 2050 through bright green and purple bars. These consist of forest (net removals), harvested wood products and bio-energy. The green bars provide the projected base forest contribution from 2020 to 2050. The purple bars are the additional Climate Smart Forestry (CSF) effect based on the potential introduction of additional incentives as described in this article. These total potential contributions from CSF forestry on net EU emissions (displayed as negative bars) is then copied by the brown and purple line and suggests a significant impact compared to the EU's current 80% emission reduction target by 2050. GHG: Greenhouse gases; FM: Forest management

The potential climate-friendly use of forest resources would thus be unrestricted (Member States could thus choose more effectively between the most appropriate climate-friendly actions, as well as being free to fulfill their emission reduction commitments by other means). Motivated either by the ability to claim credits or receive additional financing, forest owners would be more strongly encouraged to pursue additional climate-friendly forest management efforts. This in turn would create powerful motivation for providing additional forest growth without necessarily impinging upon the potential use of the existing forest resources.

B. Investments, economic incentives, and carbon price.

Member States currently dedicate very few resources to forestry. On average, they spend some 26€ per ha per year [26], mostly on State Forest Services and for supporting private owners with

management plans and tree regeneration. However, the EU currently has a number of programs that could potentially provide additional financial resources for EU forests and the forestry sector. These include: the Emissions Trading Scheme (ETS), the Rural Development Program (RDP), the Common Agricultural Policy (CAP), and for knowledge generation the Framework Program for Research and Innovation (Horizon 2020). Further, Member States (e.g., Austria, France, Finland, Germany, Italy, Netherlands, Spain and Sweden) also have national programs for their forests that can provide additional support.

Under the current trend of reducing state budgets, Member States may find it difficult to financially support additional forest measures. The above-mentioned programs suggest, however, that funds are available at the EU level. EU funding strategies and mechanisms have previously and primarily been directed at renewable energy strategies and the development of new renewable technologies. Thus, funding for climate-friendly, forest resource-based activities has been far more limited. With relatively modest changes to existing EU programs, however, it is possible to introduce a CSF-based strategy to provide support to Member States and/or forest owners, and to encourage additional forest-based carbon sequestration efforts. Because a CSF strategy will mobilize both Member States and forest owners, it may prove more effective at promoting flexibility, resilience and additional forest revenues than the current European Forest Strategy proposed by the Commission. This would require, however, the Commission and the Member States to undertake efforts to weave forests and forest-based CSF measures more firmly into the current mitigation (and adaptation) framework, which is possible under the current Article 10 of Decision no 529/2013. Under Article 10, Member States must submit information on their most relevant current and future LULUCF actions in land use activities such as afforestation, forest management, cropland and grassland management, and wetlands management. CSF can be an overarching measure reported under Article 10.

Additional revenues for motivating forest mitigation efforts and providing an improved support framework for private sector investment could also be funded through the EU emissions trading system (ETS). In its updated EU ETS Directive, the European Commission is proposing to increase revenues for climate mitigation for the next ETS commitment period (2021–2030). Growing numbers of countries are implementing carbon taxes (e.g., Denmark, Finland, France, Great Britain, Ireland, Netherlands, Portugal and Sweden), and the revenues from these taxes could also be partly redirected to climate-friendly, CSF-based forest sector investments. The new activities funded by this would also help generate more public revenue and could help encourage urgently needed joint ventures between Member States and bottom-up private interests in undertaking additional mitigation efforts [42]. Income thus generated—if spent on forest climate measures—would represent an important motivation for the 16 million private forest owners, industry, and public forest owners in the EU to implement CSF.

C. Flexibility.

As the EU regionally encompasses a large variety of forest types and forest-sector characteristics, a forest related target should allow adequate flexibility across the full range of mitigation options. Member States are capable of deciding how best to meet their national and LULUCF sector targets, and establishing best strategies and measures for meeting these overall commitments—in conjunction with forest and forest sector bio-economy and biodiversity goals.

The EU and the Member States can set a facilitating framework by providing the appropriate setting for encouraging additional forest growth through EU Bioeconomy, Biodiversity and CSF goals. Removing limits on the right to claim carbon credits could likewise further provide the impetus Member States need to provide latitude for promoting national level incentive strategies. Flexibility can be further increased by raising the degree of fungible exchange across climate change mitigation sectors in the EU climate policy framework (in particular across LULUCF, the Effort Sharing Regulation and possibly also the EU ETS), thereby enhancing mitigation in activities where the marginal costs of mitigation are lowest. Flexibility should not compromise the transparency and effectiveness of climate policy. However, neither should we forego the opportunity for a more rapid, efficient and

cost-effective mitigation strategy, especially when it can help raise ambition and ease progress toward the climate goal.

D. Actors and synergies.

Forest policy is drawn-up and implemented at the Member States level and ideally builds an effective link between national level goals and the interests of actors at other levels. This is the level that can best take account of local circumstances. Forest owners, the forest industry and NGOs are the actors that can implement actions to achieve productive and resilient forest ecosystems and fulfill biodiversity objectives (see Table 2). They must also achieve an economically viable forest value chain that provides forest products, income, energy and jobs. The regularly managed forests and forest sectors in Europe provide a good basis for achieving these goals. If the major regional actors do not support the policy, it will bear the burden of not succeeding in practice.

Table 2. Examples of measures for implementing Climate Smart Forestry and their local synergies.

Forest Management Measure	Regional Specific Climate Smart Forestry Incentive (+Actor (in Bold))	Synergies Achieved
Regenerate full grown coppice forest areas with more productive and climate adapted species	Create tax incentives for regeneration with improved provenances. **National and regional governments, industry**.	Synergy with climate change adaptation can be achieved. It will also enhance woody biomass flow for the Bio-economy and the Renewable Energy Directive. Resilient forests will also function in synergy with biodiversity goals
Stimulate ecosystem service promotion and preservation	Encourage explicit attention to the benefits of harmonizing carbon, water, soil and forest interactions. Award CO_2 credits and other payments for ecosystem services. **Private sector with interest in e.g., recreation, pollination or water and soil protection.**	A resilient forest ecosystem will hold a sustainable carbon balance and will protect the water and soil resources underneath, which will optimize forest-based mitigation and adaptation efforts.
Enhance regeneration in older declining (drought susceptible Norway spruce (*Picea abies* L. H. Karst.) forest and stimulate establishment of climate adapted species	Award CO_2 credits for creating a more productive, resilient mixed forest ecosystem. Paid from CO_2 taxes. **Member States with private sector and large forest owners.**	The regenerated and mixed forest can be managed in synergy with climate change adaptation and will enhance woody biomass flow for the Renewable Energy Directive. Also, regenerated resilient forests will function in synergy with biodiversity goals.
Merge or stimulate cooperation between fragmented forest owners that are now avoiding investment nor mobilise wood	Create tax exemptions when an adjacent property is bought. The budget can be derived from CO_2 taxes and rural development programmes. **EU + national governments, forest owner associations, certifiers.**	This is in synergy with wood mobilization strategies for an enhanced bio-economy and with rural development strategies. Furthermore, larger owners and cooperatives have more opportunities to invest in regeneration and thus in climate-adapted forest estates.
Reduce drainage of low productive drained peatlands	Reduce drainage of formerly drained peatland and award CO_2 credits. **Forest owner associations, NGOs.**	In synergy with biodiversity objectives and an increase in CO_2 sink.
Reduce disturbance risks in storm or fire prone forest areas and regenerate with drought resistant species	Reduce growing stock through harvest and regeneration or through thinning, producing wood for bioenergy. Funding derived from rural development budgets. **EU & Member States, State forest services, large forest owners, industry.**	This reduces the chance of CO_2 emissions, reduces forest owner vulnerability to climate events and stimulates adaptation to climate change through regeneration with new species. This measure is also in synergy with an increased wood flow for the bio-economy, creating jobs in synergy with rural development and the Renewable Energy Directive.
Improve transparency of the regional wood raw material market, aiming at improved cascading	Better insight and open access to data on wood resources and qualities leading to most optimal uses of wood. R&D budget. **Research creating improved databases, education, outreach organisations.**	This measure leads to more optimal uses of woody raw material, avoiding carbon debts and aiming at higher value chains. It can be achieved in synergy with jobs and rural development.
Promote wood use in building sector	Stimulate wood use through tax exemptions when using wood, or CO_2 taxing when using steel or aluminum etc. **National governments, Public procurement to favor wood in construction, education of builders and architects.**	In synergy with greenhouse gas emission substitution, environment-friendly buildings, improved city environment.

Table 2. *Cont.*

Forest Management Measure	Regional Specific Climate Smart Forestry Incentive (+Actor (in Bold))	Synergies Achieved
Afforest abandoned farmland	Improved mapping and land use databases in combination with afforestation schemes. Designate budget in Common Agricultural Policy and derive funds from CO_2 credits and CO_2 taxes. **EU & Member States, industry, investors.**	An increased CO_2 sink can be achieved in synergy with the production of additional woody raw material from new forest areas, and will create new bio-economy opportunities. Will help climate change adaptation through e.g., forest corridors. Jobs will be created by interactions between rural development and Natura 2000.
Establish large strict forest reserves in remote areas and/or low-productivity areas	Award CO_2 credits for introducing large connected reserves in existing forests paid from CO_2 taxes. **Forest owner associations, EU + Member States, State Forest Service, NGOs.**	In synergy with Natura 2000 and Biodiversity strategy and in line with increase CO_2 sink in the forest ecosystem.

5. How to Implement CSF

Too little work has been done on connecting the forest policy framework at the EU level with national level strategies directed at land and forest owners. We highlight synergies that can potentially provide leverage between these levels and the private sector in Table 2. Forestry has always been characterized by a long-term planning horizon. Given these long-cycle patterns of forest management and in order to give actors time to respond, the LULUCF timetable should extend beyond 2030. A forest-related strategy should aim, for e.g., at 2050, with an initial learning and implementation phase taken up in the five year cycles of the Indicative Nationally Determined Commitments (INDC)

Politically realistic climate-friendly forest and forest sector policy strategies that are taken up in practice by forest sector actors require an implementation strategy that adequately links the interests of these forest sector actors with the over-arching Member States and EU level policy framework. To-date, such linkage is either partially or entirely missing [43]. Moreover, while both national and EU level strategies envision important emission reductions by the year 2030 and 2050, the failure to provide appropriate strategies for motivating forest owners essentially means they may be more likely to respond to other kinds of incentives (e.g., economic concerns), irrespective of their climate impact.

Finding synergies between a forest climate target and other forest related concerns like biodiversity loss, forest fire, loss of peat carbon, forest health problems under climate change, fragmented ownership, low demand for wood raw material, etc., will help provide the levers to make things happen (Table 2). As suggested in Table 2, this requires balancing climate change mitigation measures with goods and services provision; biodiversity, water services, forest resilience, surface cooling, adaptation, and the bio-economy. Likewise, different regional options and strengths are needed to achieve mitigation in the forest sector and forests. For example, in drought and fire prone regions, CSF is geared to creating a fire-resistant landscape. Or in industrial forestry countries, CSF measures are more geared toward the bio-economy and new biomaterials. Table 2 provides examples of a potentially much more extensive list of measures adapted to regional circumstances.

6. Discussion

How certain are the above quantifications and suggested impacts of policy change? Of course these do contain uncertainty. Projecting the large (diverse) European forest resources, its management and wood demand in the future is uncertain [44] and thus we are not certain even how the baseline sink may develop. Further, our method was a literature review building on quite a wide range of other applied methods or modelling studies. Naturally those studies portray a range of possibilities and a range of quantified mitigation potential. Still, many studies point in the same direction of a significant additional potential.

Further, how the suggested policy changes will be elaborated and implemented and what the impacts will be, is also uncertain. However, such uncertainties also surround the other sectors and are no reason to do nothing. The climate change problem is grave enough to make any effort in a sector

worthwhile. To avoid disappointments, we highlight synergies with other targets, such as biodiversity, a resilient ecosystem and a productive forest sector.

It is increasingly being acknowledged that reaching the Paris Agreement climate targets will require fundamental changes in economies and societies, and therefore climate policy should be planned in connection with this systemic change [45]; this also applies to land use and forestry. Can CSF really work and have the additional 441 Mt CO_2 mitigation impact as outlined in this article? Yes, we think it can, but it will require effort (like in any other sector) and it will only work when climate policy builds upon interconnections with other societal policy goals and minimizes trade-offs. Without achieving this, there is a danger that climate policy targets will not be politically possible to implement.

7. Conclusions

In conclusion, Figure 1 provides a graphical representation of the potential mitigation impact that both the revisions suggested in this article and the introduction of CSF measures could potentially have on the EU's Climate and Energy Policy Framework. The graph shows that towards 2050 the total mitigation impact of the forest and forest sector reaches close to 20% of total EU emissions in the base year. A very significant impact with many synergies can be achieved, provided the effort is made.

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Appendix A

Table A1. Annex.

Conversion Factors	Value	Unit	Reference
Convert from stemwood volume to dry matter	0.45	tonne dry matter/m^3 stemwood	[19]
Convert from dry matter to carbon	0.5	unitless	[19]
Convert from stem carbon to whole tree carbon	1.3	unitless	[19]
Convert from carbon to CO_2	3.67	unitless	[19]
Harvest rate of additional wood growth	0.5	fraction	Assumed based on current harvest rate in Europe of 70% [26]
Carbon (C) stock in deforested forest average for EU	40 [1]	ton C/ha	[26]
Material substitution factor for wood use instead of steel, aluminium etc.	0.28	ton C/m^3 wood product	[21]
Wood going into structural use every year	169	Mm^3/y	[29]
Additional woody biomass potential from primary, secondary and tertiary residues	88	Million tonnes oil eq.	[36]

[1] Average carbon stock in the whole EU forest is 61 ton C/ha. We assume that the deforested forest (i.e., land use change) are not the best sites. E.g., shrub-like, half-open forest in the Mediterranean. Therefore 40 ton C assumed/ha.

Table A2. Calculations Table, with Explanations in Footnote References.

		Area (ha)	Additional Stemwood Volume Growth (m^3/ha year)	Additional Sink/Substitution (Mt CO_2/year)
1a	Full grown coppice	35,000,000 [1]	1.5	56 [9]
1b	Enhanced productivity	70,000,000 [2]	1 [6]	38
1c	reduced natural disturbance (fire/wind)			12 [10]
	reduced deforestation	100,000 [3]		10 [11]
	reduced drainage of peat soils			13 [12]
1d	Material substitution wood products			43 [13]
2	Forest area expansion	15,000,000 [4]	8 [7]	64
3	Energy substitution			141 [14]
4	Establish forest reserves	12,000,000 [5]	5 [8]	64 [15]

[1] McGrath et al 2015 [46]. [2] Eggers et al [16] apply measures on 95 Mha. We assume measures are only feasible on 3/4 of this based on share of EU forests in the hands of larger forest owners, e.g., 40% of EU forests are in the hands of state owners. Then another 30–35% is in the hands of large industry or large private owners. These respond, respectively, to regulations and price incentives. [3] Current deforestation in EU forests (i.e., land use change) is 100,000 ha per year. [12] [4] Keenleyside & Tucker 2010 [33]. [5] Although the aims of NGOs differ quite a lot, an often voiced aim is to set aside 10% of European forests as strict reserves. [47]. 18% of Europe's land is now under Natura 2000 [48]. However, the Natura2000 designation is not a strict protection. Less than 2% of current forests are now in "strict reserves" (IUCN class 1.1) [26]. We have assumed that in the studied time frame, an additional 6–7% of forest land under strict reserves can be achieved. This equals 12 Mha's. [6] Eggers et al 2008 [16] find a 20% increase in increment when management is improved. 20% of the current EU average of 5 m^3/ha year is 1 m^3/ha year. [7] Average increment of plantations is assumed 60% higher than average increment of total existing forests in EU, which is now 5 m^3/ha year [26]. [8] Average increment of total existing forests in EU is now 5 m^3/ha year [26]. [9] Assumed that additional growth is harvested at a rate of 50% during the studied time frame. So factor "harvest rate of additional wood growth" also applied. [30,32]. [10] Emissions from disturbances are ~5 Mton C/year = 5 × 3.66 = 18 Mt CO_2/ year [30]. Assumed effective on 2/3rds of forests. [11] Assumed deforestation can be brought back with 2/3. [12] EU CRF submission to UNFCCC: emissions from peat soils under forests are 20 Mt CO_2/year. Assumed effective on 2/3 of land. [13] Assume one quarter of sawnwood ends up in structural longer term use, displacing steel, aluminium, etc. [14] Elbersen gives 88 million tonnes oil equivalents as realistic additional potential. This is 5.23% of total energy use in EU (1683 Million tonnes oil equivalents). Because of the large mix of energy use, we assume that this will lead to a reduction of total emissions of the same amount; 5.23%. Thus 5.23% of emissions from 4500 Mt CO_2 = 235 Mt CO_2. The EU requires a 60% saving of emissions when applying renewables. We assume the same 60% efficiency. 0.6 × 235 = 141. [15] Additional growth is not harvested in this time frame.

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