Forest biomass for energy in the EU: current trends, carbon balance and sustainable potential

for BirdLife Europe, EEB, and Transport & Environment

- FINAL REPORT -

prepared by

IINAS - International Institute for Sustainability Analysis and Strategy

EFI - European Forest Institute, and

JR - Joanneum Research

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Content

List of Figures

List of Tables

Acronyms

AEBIOM	European Biomass Association
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (German Federal Ministry for Environment, Nature Protection and Nuclear Safety)
EC	European Commission
EEA	European Environment Agency
EFI	European Forest Institute
ETS	EU Emissions Trading System
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
IC	Imperial College
IINAS	International Institute for Sustainability Analysis and Strategy
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
M	Million
MS	Member States
MtOE	million tons of oil equivalent
RED	Renewable Energy Directive (EU 28/2009)
t	ton
tOE	tons of oil equivalent
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
WWF	World-Wide Fund for Nature

Executive Summary

This study aims to clarify possibilities and implications of woody bioenergy supply for the natural environment and climate for the EU by 2020 and 2030.

For this, the amount of forest-derived and woody biomass is estimated that could be sustainably supplied for energy uses without compromising material uses of wood. Particular attention is given to biodiversity and GHG emissions implications of woody bioenergy supply.

The role of sustainable woody bioenergy in the future EU energy system was then analyzed for electricity, heat and transport fuels, taking into account the potentials for energy efficiency, and non-bioenergy renewables.

Three scenarios were modeled to evaluate how sustainable woody bioenergy could be used by 2020 and 2030:

- The reference scenario (REF) is based on the EC 2013 PRIMES reference. Overall demand for material uses of wood will increase, and co-firing of imported pellets becomes relevant. In REF, bioenergy from EU forest will provide about 1700 PJ by 2030, and woody residues and SRC will contribute with 1300 PJ while about 750 PJ of wood pellets would be imported to the EU. Non-woody bioenergy would contribute about 600 PJ.
- Two contrasting scenarios - one for greenhouse-gas emission reduction (GHG), and one for ambitious sustainability (SUS) assume **more stringent energy efficiency and higher renewable energy targets**.
- The reduced GHG emissions scenario (GHG) considers C stock changes for forest bioenergy, and implements cascading use of woody material. With that, the use of EU forest products is reduced to 1100 PJ by 2030, and imports can be reduced by 80 %. Domestic woody bioenergy from residues, wastes and SRC would supply 3100 PJ by 2030, a doubling compared to the REF scenario. Non-woody bioenergy use would also increase to 1200 PJ, mainly from straw, and manure.
- The sustainable bioenergy scenario (SUS) assumes same demand as in the other scenarios but reduces forest bioenergy use to avoid associated risks, especially from imports. As in the GHG scenario, cascading use of woody material is massively increased. The use of EU forest bioenergy will be only about 350 PJ by 2030, and **no woody bioenergy would be imported**. The use

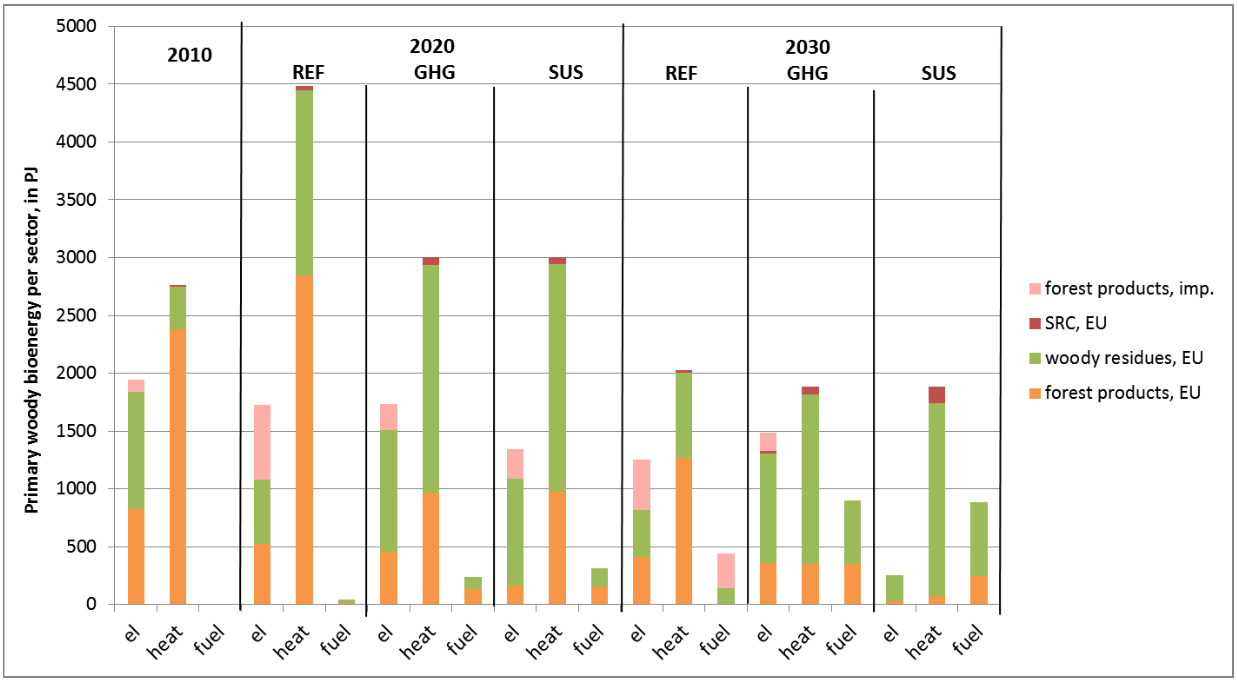
of woody residues, wastes and SRC would increase to 2700 PJ, and non-woody bioenergy would contribute about 3100 PJ.

The implementation of stringent energy efficiency measures in all scenarios would significantly reduce the final energy demands for heat and transport while electricity demand could remain almost constant.

For electricity generation, the share of woody bioenergy will remain at 5% in the REF and GHG scenarios, while in the SUS scenario it will be less than 1 % by 2030. The amount of woody bioenergy used for heat would be about 8% (REF) and 9% (GHG+SUS) by 2030, but the source of the wood is very different in the scenarios.

For transport, the contribution of woody bioenergy in the REF scenario would reach 2% by 2030, while in the GHG and SUS scenarios it will be 6% - 7%, respectively. The GHG scenario would further reduce feedstocks imports by 60% compared to the REF scenario by 2030, while the SUS scenario would phase-out imports completely. Both the GHG and SUS scenarios would instead use woody residues and straw for 2nd generation biofuels.

The different role of woody bioenergy in the scenarios is depicted in the following figure for the respective EU energy demand sectors.



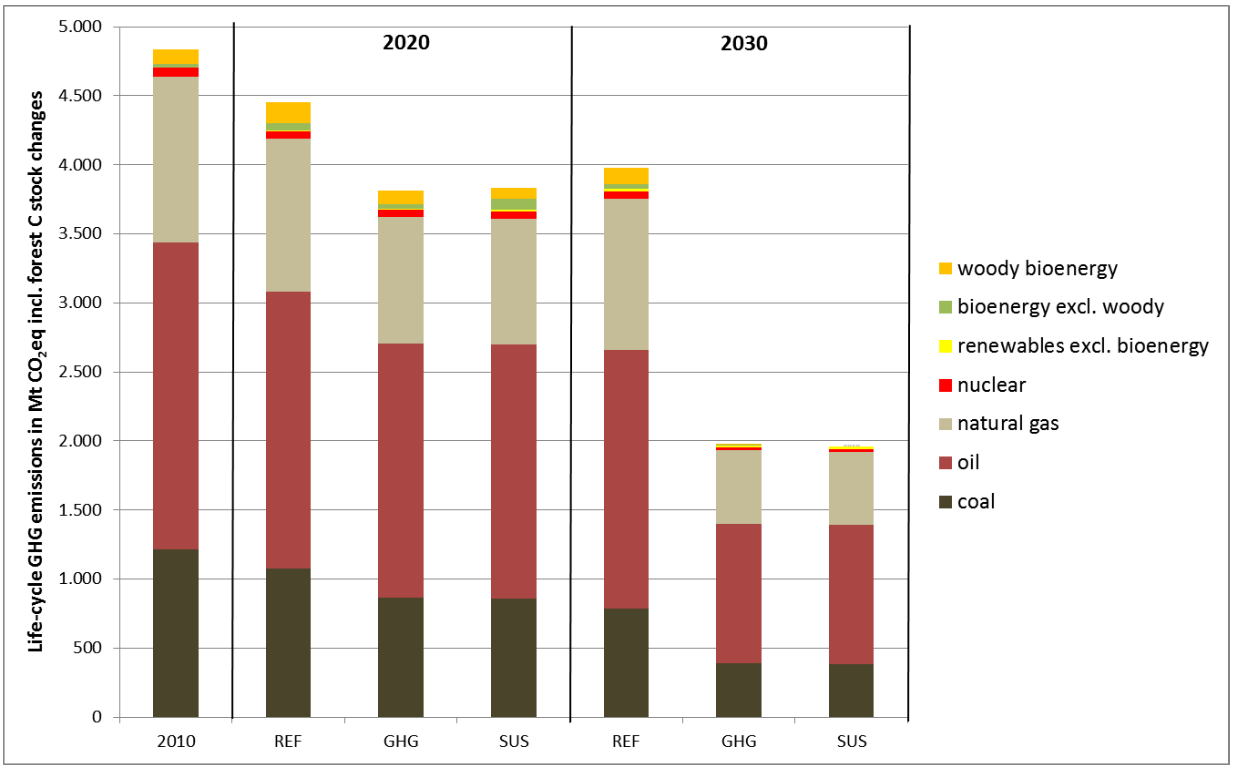
Source: IINAS calculations

The **GHG emissions from bioenergy** in the REF scenario would reach 59 to 116 Mt CO_2eq by 2030, depending on the time horizon of the forest C balance, and the forest reference case assumed.

In contrast, bioenergy GHG emissions by 2030 would be -40 to 8 Mt CO_2eq in the GHG scenario and -45 to -33 Mt CO_2eq in the SUS scenario, respectively.

This includes a reduction of GHG emissions from displaced electricity and construction materials due to cogeneration and cascading use of woody biomass in new buildings in the EU.

The **overall GHG balance** must include emissions from fossil, nuclear and non-bioenergy renewables and was calculated using life-cycle data which also factor in fossil fuel imports accordingly, as shown in the following figure.



Source: *IINAS calculations; GHG emissions from woody bioenergy are shown for the 20 year time horizon and the pessimistic forest reference case (i.e. the worst-case)*

This clearly indicates that biogenic GHG emissions from **woody bioenergy are rather small**, compared to the emissions from the remaining fossil fuels.

The differences between the results for the 20-year time horizon and the ones for the 100 year time horizon are also quite small, showing that the discussion of the "carbon debt" associated with forest bioenergy becomes **insignificant if sustainable and low-C options for forest bioenergy are used**, and the total energy system is considered.

The scenario results also show that with **regard to policy**,

- sustainable forest biomass potentials in the EU will be reduced by up to 30 % by 2030 if stringent sustainability requirements are considered;
- sustainable forest biomass potentials still suffice to meet woody material demands if **resource-efficient cascades** are implemented, more paper recycled and post-consumer wood be re-used;
- reducing energy demand by implementing stringent energy efficiency targets is key;
- a sustainable scenario **without** bioenergy imports and using only about 25% of the EU forest bioenergy consumed in 2010 is possible as long as woody and agricultural residues are mobilized;
- cascading biomass use for energy, improving biogenic waste collection and recycling allow for significant net GHG reductions;
- if sustainable and low-C options for forest bioenergy are used, the "carbon debt" discussion is not relevant.

Current EU and Member State energy and climate policies **do not stimulate** these developments, though:

- Bioenergy, forest, and waste policies are fragmented and unaligned, and incentive schemes mainly address bioenergy **without** considering the full GHG emissions from bioenergy use.
- Bioenergy supply - especially from forests and for electricity/heat - is not subject to any coherent sustainability regulation. Only few Member States have started to develop respective policies, which might lead to **imbalances within** the EU if no framework regulation is implemented.
- Imports of woody bioenergy is - with very few exceptions - **unregulated** as well, but growing relevance of pellets for bioelectricity (co-firing) imply a respective need for EU-level action to avoid internal market distortions.

Last but not least, sustainable woody bioenergy supply also requires regulating biodiversity impacts for forests in a legally binding manner for both the EU, and imports from abroad.

1 Introduction and Overview

1.1 Scope and Overview

The Brussels-based NGOs Birdlife Europe, European Environment Bureau and Transport & Environment commissioned the International Institute for Sustainability Analysis and Strategy (IINAS) in cooperation with the European Forest Institute (EFI) and Joanneum Research (JR) to carry out a **brief study on sustainable woody bioenergy in the EU-27**.

The study aims to clarify implications of increasing forest bioenergy supply for the natural environment and climate until 2020, and to estimate the amount of forest-derived and woody biomass that could be sustainably supplied for energy uses within the EU to 2030 (quantitatively) and 2050 (qualitatively). Given this background the study:

- classified woody biomass resources (Section 2.1)
- identified woody bioenergy potentials in the EU which pose low biodiversity risks (Section 3)
- determined the greenhouse-gas emission balances of woody bioenergy for several time horizons and reference assumptions (Section 4)
- developed three scenarios for future woody bioenergy use in the EU for 2020 and 2030 (Section 5), and
- determined the GHG balances of these scenarios (Section 6) as well as
- implications for policy (Section 7).

Due to limitations in scope and available budgets, the study had to **simplify the modelling** of the EU energy system:

- Issues of renewable fluctuating power (e.g. storage, transmission, and system effects) for electricity were **not** explicitly considered
- No changes in the **mix** of non-bioenergy renewables (only minor adjustments of total supply) and in the fossil fuel **mix** (e.g. to reduce GHG emissions) were made.
- No changes in the demand for food/feed and respective ex- and imports were considered, thus **excluding** possible changes in available land resources.

Cost changes and implied economic effects were also outside of the scope of the analysis, although some respective data is available upon request.

1.2 Introduction

Woody and especially forest biomass has a relevant role to play within the Renewable Energy Directive (RED) 2020 target of a 20 % renewable energy share, as well in the ongoing discussions about a 2030 energy and climate strategy, and the longer-term 2050 perspective of a resource-efficient and sustainable European energy system.

From 1990-2010, total solid bioenergy production has more than doubled (Eurobserver 2012). In 2010, the EU used about 113 million tons of oil equivalent (MtOE) of primary biomass of which 9.5 MtOE were imported and 4.2 MtOE were exported (AEBIOM 2012).

In 2010, about half of all woody biomass was used for energy purposes (AEBIOM 2012). 50% of total woody bioenergy is used in the residential sector and 25% each by the wood industry, and powerplants (UNECE-FAO 2012).

According to the National Renewable Energy Action Plans (NREAPs), domestic supply of wood directly from forestry is expected to account for approx. 32 % of the total heat and power generated with biomass by 2020 (IC et al. 2012).

Results of the EU Biomass Futures project show that projected EU woody demands are considerably lower than sustainable EU bioenergy potentials for 2020 and 2030 (IC et al. 2012). Still, mobilization of wood will not depend just on availability but on prices, and resource efficiency as well as possible biodiversity, climate and social impacts. Trade-offs between these factors need to be assessed.

On the other hand, at present, there are various European policies under revision that will have significant effect on medium-term biomass mobilization such as the EU RED "iLUC" revision[1], the sustainability criteria for solid and gaseous biomass[2] and the future of the EU Emission Trading System (ETS).

In 2010, the total area of forest in the EU27 area was over 157 million hectares (Mha) or almost 38% of land area (Forest Europe et al. 2011).

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[1] The EC proposal to revise the RED (EC 2012a), limiting the share of first generation biofuels from edible feedstocks in the transport sector to 5% and promoting advanced biofuels, and later proposals from the European Parliament and the Council found - as of late December 2013 - no majority.

[2] The EC is working on the extension of binding sustainability criteria to solid and gaseous biomass, applying the same approach as for biofuels and bioliquids under the EU RED but considering, to some extent, sustainable management of procurement areas (Volpi 2012). A respective report is expected in 2014.

Of this, 133 Mha was estimated to be available for wood supply. The following table describes the key facts of the European forests.

Table 1 Key Facts on European Forests

	Unit	North	Central-West	Central-East	South-West	South-East	EU27
Forest area	Mha	69.3	36.9	22.5	30.8	29.9	157.2
Forest as % of total land	%	52.1	26.4	30.0	34.8	23.1	37.6
Forest per capita	ha	2.16	0.14	0.26	0.26	0.25	0.32
Forest area available for wood supply	Mha	54.5	34.4	19.6	24.8	21.9	133.3
Growing stock per ha	m^3/ha	117	227	237	81	140	154
Net annual increment per ha[#]	m^3/ha	4.7	7.8	8.0	3.9	5.9	5.8
Fellings	Mm^3	180.5	172.4	93.2	29.3	16.9	469.3
Fellings as % of increment	%	71.1	65.0	66.1	37.4	46.9	64.9
Roundwood removals from forest	Mm^3	152.7	150.5	80.7	33.0	36.1	412.8
Forest undisturbed by man	%	5.8	0.3	1.7	0.4	5.5	3.1
Semi-natural forest	%	92.3	85.8	90.9	86.0	77.2	88.6
Plantations	%	1.9	13.8	7.4	13.6	17.3	8.2
Share of forest dominated by introduced tree species	%	1.6	10.7	3.7	7.3	1.4	5.2
Share of forest area protected for biodiversity	%	6.6	10.4	3.5	23.3	5.5	10.6
Share of forest area protected for landscape	%	2.3	26.2	12.3	6.0	0.8	10.1
Share of forest area designated for the protection of soil, water and other ecosystem services	%	11.9	17.6	25.0	41.6	9.8	19.8
Share of forests in private ownership*	%	70.7	62.3	26.9	72.5	16.6*	59.6
Forest sector work force	1000 FTE	346	923	658	582	405	2560

Source: Forest Europe et al. (2011); FTE = full time equivalent employes

2 Sources and Potential of Woody Biomass

This study distinguishes between primary and secondary sources, as follows:

- Primary biomass sources
  - Woody biomass from forests (residues, thinnings, stemwood)
  - Woody biomass from landscape care, urban park management, gardening
  - Short-rotation coppice on agricultural land
- Secondary biomass sources
  - Solid forest and wood industry by-products (sawmill residues, bark, wood industry wastes)
  - Liquid forest industry by-products (black liquor)

A description of these categories is given in Annex 1.

2.1 Woody Biomass Potentials with low Biodiversity Risks

Bioenergy policies which result in high levels of mobilization may have adverse effects on biodiversity (e.g. Verkerk et al. 2011a). The loss and degradation of the forest types that are naturally most diverse as well as the low levels of decaying wood in managed forests are the most relevant threats to forest biodiversity (Hanski, Walsh 2004).

37 Mha of the European forest area is protected for conservation purposes by the Natura 2000 network (EC, 2009; Forest Europe, 2011). The legal constraints on forest management range from a total ban on management to no limitations for sustainable management.

Protected areas play a critical role in conservation of biodiversity, maintaining genetic resources, protecting important ecosystem functions and helping to protect many fragile human communities and cultural landscapes (Dudley, Phillips 2006).

Protected Areas of various levels cover about 11% of forest area in the EU27. According to Forest Europe (2011), protected forests are classified in

(i) non active intervention (1%),
(ii) minimum intervention (3%) and
(iii) conservation through active management (7%).

In Northern Europe and in some Eastern European countries, restrictive protection with no or minimal intervention dominates, whereas in Central and

Southern European countries, active management in protected areas is emphasized (Forest Europe 2011).

The uniform forest structure associated with commercial forest management is a cause for concern when considering sustainability. The retention of some trees beyond the normal harvest cycle has been used as an approach to counteract this. It involves leaving some live and dead trees and small areas of intact forest in situ at the time of harvest (Gustafsson et al. 2012). Deadwood in the form of both standing dead trees and down wood and debris, is an essential structural component for biodiversity in forest systems (Janowiak, Webster 2010) and it has been acknowledged as a measure of habitat quality (EEA 2011).

Due to shorter cycles, deadwood volumes can range from 2 m^3/ha to 10 m^3/ha in managed forests while in natural forest the amount of deadwood may reach more than 200 m^3/ha (EEA 2011). Forest Europe (2011) reported average volumes of deadwood, both standing and lying, in European Forests from approx. 8 m^3/ha in Northern Europe to 15 m^3/ha in South-East Europe.

Although retention levels can range more than forty fold, a minimum amount of 5-10 % in terms of the area or wood volume retained has been suggested (Gustafsson et al. 2012).

Stricter environmental criteria

If more strict environmental criteria are applied, we can also evaluate how this might impact on forest biomass potentials. Lower mobilisation rates in comparison with the reference potential were examined which applied a stricter set of environmental constraints (see Annex Report). Some significant differences between these and the reference mobilisation included stricter constraints on residue and stump removal from unproductive poor soils, slopes, shallow soils and peatlands.

For the low mobilisation, application of fertilizer to limit detrimental effects of removing logging residue on the soil was not permitted. Stump extraction was also not permitted.

The main differences between the mobilisations include:

- soil productivity was not considered a constraining factor for crown biomass removal after early thinning in the high mobilisation as it was assumed that fertiliser could be applied to replace lost nutrients
- soil productivity was not considered a constraining factor for residue removal after final felling in the high and medium mobilisations as it was assumed that fertiliser could be applied to replace lost nutrients

- a maximum of 67% of residue removal from thinning was allowed on poor soils for the high mobilisation potential, but residue extraction from theses soils was not allowed for the medium and low mobilization potentials.
- 67% of stumps after final fellings were extracted on poor soils for high mobilization, 33% for medium and 0% for low.
- the high mobilization potential allowed stump extraction from peatland areas, however, in practice this only occurs in Fennoscandia (frozen soils in winter), as constraints on soil bearing capacity prevented extraction elsewhere.
- 67% of logging residues from thinnings could be extracted from slopes up to 35% for the high mobilization, 33% for medium, 0% for low.
- 67% of stumps from final felling could be extracted on slopes up to 35% for high mobilization, 33% for medium, 0 for low.
- stumps from thinnings are not extracted in the medium or low mobilization potentials.
- stump extraction is not allowed at all in the low mobilization potential.

Hanski, Walsh (2004) concluded that neither the current level of deadwood nor the protected areas were enough to avoid adverse effects on biodiversity (extinction debt[3]) in Northern and Central Europe forests.

In order to reverse that situation, the amount of decaying wood at stand level should be 50 m^3/ha (or 20-30 m^3/ha if this average is met in wider areas). However, since this threshold is not achievable in managed forests they have proposed increasing the network of protected areas of various forest types to at least 10 percent of total forest area.

2.2 Methodology

For this study, we build on recent forest biomass resource assessments done for the EUwood and EFSOS II studies (Mantau et al. 2010; UN-ECE/FAO 2011) which used the large-scale European Forest Information SCENario model (EFISCEN) (Sallnäs 1990; Schelhaas et al. 2007).

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[3] Extinction debt refers to the numbers of species that will disappear sooner or later under the current environmental conditions

These studies examined biomass resource potentials for o 2020 and 2030 under various assumptions. This study evaluates the biomass potentials in line with sustainability criteria and focuses in particular on quantifying biomass potentials which still leave room for more ambitious protection of biodiversity.

The sustainable potential for forest biomass supply was estimated for the period 2010 to 2030 in three steps:

First, the maximum theoretical availability of forest biomass in Europe was estimated using EFISCEN (see box). These projections were based on recent, detailed National Forest Inventory (NFI) data on species and forest structure and provided the theoretical biomass potentials from broadleaved and coniferous tree species separately in the following assortment categories: stemwood; logging residues (i.e. stem tops, branches and needles); stumps; early thinnings (thinning in very young stands; also referred to as pre-commercial thinnings).

Second, multiple environmental and technical, constraints were defined that reduced the amount of biomass that can be extracted from forests.

Third, the theoretical potential according to EFISCEN was combined with the constraints to assess the realisable biomass potential from European forests (Verkerk et al. 2011a).

EFISCEN is a large-scale forest scenario model that assesses the availability of wood, and projects forest resource development on regional to European scale (Nabuurs et al., 2007; Eggers et al., 2008). A detailed model description is given by Schelhaas et al. (2007). In EFISCEN, the state of the forest is described as an area distribution over age- and volume-classes in matrices, based on forest inventory data on the forest area available for wood supply. Transitions of area between matrix cells during simulation represent different natural processes and are influenced by management regimes and changes in forest area. Growth dynamics are simulated by shifting area proportions between matrix cells. In each 5-year time step, the area in each matrix cell moves up one age-class to simulate ageing. Part of the area of a cell also moves to a higher volume-class, thereby simulating volume increment. Growth dynamics are estimated by the model's growth functions whose coefficients are based on inventory data or yield tables.

To assess biomass in branches, coarse roots, fine roots and foliage, stemwood volumes were converted to stem biomass by using basic wood density (dry weight per green volume) and to whole-tree biomass using age- and species specific biomass allocation functions. During thinning and final felling logging residues are formed. These residues consist of stemwood harvest losses (e.g. stem tops), as well as branches and foliage that are separated from the harvested trees. In addition to these logging residues, stumps and coarse roots are formed. In EFISCEN, it is possible to define which share of the residues and stumps/coarse roots are removed from the forest during thinning and final felling. Residues and stumps/roots that are left in the forest will decay eventually. During harvest operations more stemwood is felled than is removed from the forest. The proportion of volume from thinning or final felling being removed from the forest was calculated at country level, distinguishing between coniferous and broadleaved species (UNECE/FAO, 2000). The proportion that is not removed as logs represents stemwood harvest losses and could be extracted as part of the logging residues.

2.3 Forest Biomass Mobilization Potentials

In this study, we examine biomass potential in the context of EU 2020 policy objectives. The reference potential we employ is the maximum *realizable* potential under B2 emissions[4].

This realizable potential is obtained by applying various environmental and technical constraints to a theoretical potential which is based on the average volume of wood which could be harvested taking into account annual growth increment, age structure, stocking level and harvest losses (Mantau et al. 2010). It is assumed that if EU renewable energy objectives are to be achieved that this maximum potential will need to be mobilised. It assumes a strong focus on the use of wood for producing energy for the years we examine and that policy recommendations have been successfully translated into measures that lead to an increased mobilisation of wood, including the formation of more forest owner associations and cooperatives which develop improved access of wood to the markets. It is also assumed that increased mechanisation is being adopted across Europe with existing technologies being shared between countries with improved information exchange. To exploit this potential, biomass harvesting guidelines would not be restrictive.

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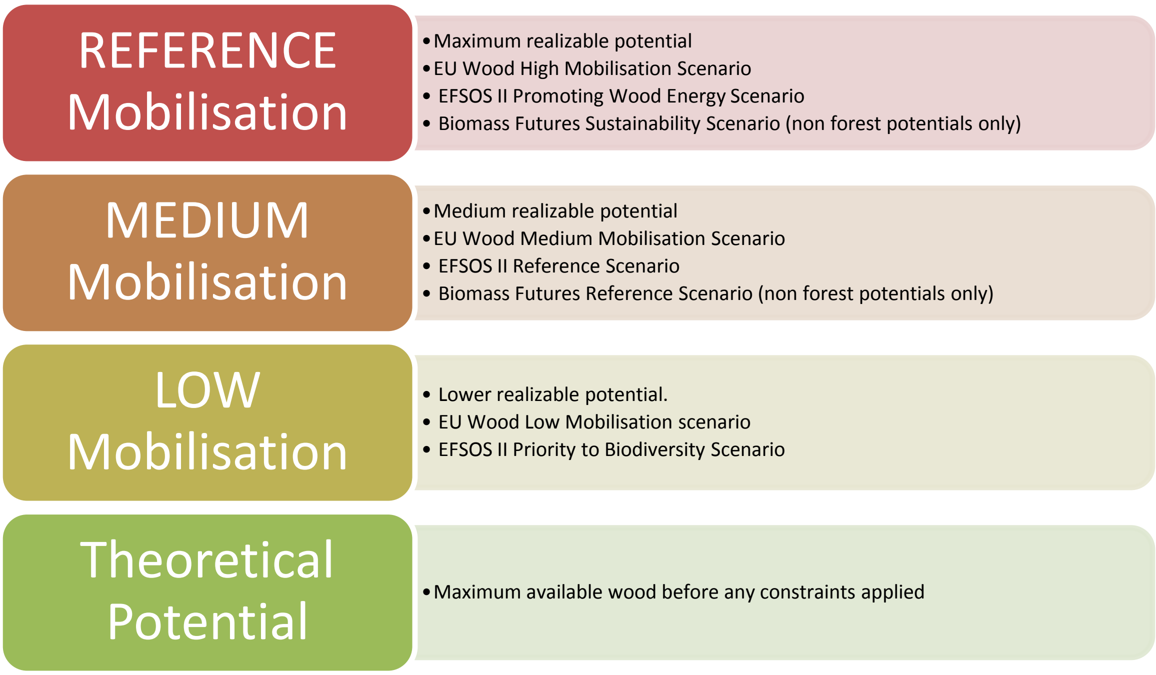
[4] The mobilisation potentials for 2020 and 2030 utilized the B2 socioeconomic IPCC scenario (Nakicenovic et al. 2000). The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. In the B2 reference future, production and consumption growth rates slow down over the outlook period, with the exception of sawn-wood consumption. This slowing down of consumption growth is most pronounced for paper products and wood pulp. This is consistent with a future world characterised by heightened environmental concern, where, e.g., a higher demand for bioenergy drives up the prices of inputs for the wood-based panels and pulp & paper industry, while at the same time the sawn-wood industry will mainly benefit from this development through a growing demand for energy efficient and renewable construction.

The negative environmental effects of intensified use of forest resources would be weighed against and considered less important than the negative effects of continued reliance on fossil fuels. Fertiliser application is allowed to compensate for the loss of nutrients through forest residue extraction. In this study we evaluate the effect of applying various additional sustainability constraints to the reference forest biomass potential.

Figure 1 How each forest wood mobilization potential in this study (left column) is comparable with scenarios from previous studies (right column).



REFERENCE Mobilisation	• Maximum realizable potential • EU Wood High Mobilisation Scenario • EFSOS II Promoting Wood Energy Scenario • Biomass Futures Sustainability Scenario (non forest potentials only)
MEDIUM Mobilisation	• Medium realizable potential • EU Wood Medium Mobilisation Scenario • EFSOS II Reference Scenario • Biomass Futures Reference Scenario (non forest potentials only)
LOW Mobilisation	• Lower realizable potential. • EU Wood Low Mobilisation scenario • EFSOS II Priority to Biodiversity Scenario
Theoretical Potential	• Maximum available wood before any constraints applied

Source: EFI compilation

2.3.1 Constraints to forest biomass potential

The theoretical forest biomass potentials estimated by EFISCEN are higher than what can realistically be supplied from the forest due to various environmental, social, technical, and economic constraints. The EU Wood study identified quantifiable constraints and applied them to the theoretical potential (see appendix). The constraints considered in this study include site productivity, slope, soil surface texture, depth, compaction risk, bearing capacity, retained trees and protected forest. The constraints applied are described in further detail in the appendix.

For each constraint, a raster layer was created in ArcMap, with a resolution of 1 km. Extraction rates were assigned to the constraints according to the tables above. On a cell-by-cell basis, all relevant layers were combined and the minimum extraction rate was defined for each cell. This was done separately for thinning residues, final felling residues and stumps. The resulting raster layers were then combined with a forest map, also on a 1 km resolution. Using zonal statistics with EU28 country layers and the EFISCEN region layer as zones, the weighted average per zone was calculated.

2.3.2 Assessment of biodiversity risks

To examine the effect of increasing the area of protected forest on biomass potentials we used the previous resource assessments of EUwood and EFSOS-II and carried out a more detailed examination and quantification of biodiversity impacts. The sustainability constraints that were used to calculate the forest biomass potentials with EFISCEN were adjusted in order to examine their effect. This provides more information on how increasing the area of protected forests impacts on the biomass potentials from European forests.

Protected areas:

Where management in protected areas is allowed under conservation designations, it is implemented as 'close-to-nature' or similar low-impact management (EEA 2007), with no or very limited residue or stump extraction. However, in fire prone areas, leaving residues in the forest could increase the forest fire risk.

This study assumed that residues could only be harvested in protected areas that have a high or very high fire risk.

Retained trees: An increase of 5 % in retained trees was evaluated.

Stricter environmental criteria:

If more strict environmental criteria are applied, one can also evaluate how this might impact on forest biomass potentials. Lower mobilisation rates (medium, low) which applied a stricter set of environmental constraints (see Annex) in comparison with the reference potential were examined.

2.4 Results

2.4.1 The potential of European forests for wood supply in 2020 and 2030.

Biomass potentials from forests were calculated for EU28 countries for 2010, 2020 and 2030 (see Table 2 - Table 4). It should be noted that this includes woody potentials both for industrial use as well as bioenergy. The largest contributor to available volumes is stemwood from thinnings and final harvest. The pre-commercial thinning using the EUwood/EFSOS II assumptions were proportionally very low.

Table 2 The reference potential (RP) for biomass from EU28 forests in 2010, 2020 and 2030

	2010	**2020**	**2030**
Austria	35.93	43.01	41.90
Belgium	5.22	5.97	5.80
Bulgaria	8.13	9.87	9.91
Croatia	7.21	8.34	8.16
Cyprus	0.04	0.04	0.04
Czech Republic	25.11	29.96	27.66
Denmark	3.97	4.59	4.87
Estonia	13.12	14.57	13.88
Finland	85.51	111.89	111.60
France	88.11	101.69	108.02
Germany	103.25	128.26	124.15
Greece	4.45	5.41	4.97
Hungary	10.81	12.90	12.64
Ireland	3.12	4.42	5.16
Italy	26.74	29.19	28.07
Latvia	18.39	20.23	24.65
Lithuania	10.54	12.26	13.40
Luxembourg	0.98	1.10	1.04
Malta	0.00	0.00	0.00
Netherlands	1.48	1.74	1.90
Poland	58.41	68.94	67.32
Portugal	10.80	12.36	13.78
Romania	32.54	36.73	36.13
Slovakia	11.38	12.52	12.93
Slovenia	8.43	9.41	9.10
Spain	24.79	30.52	29.80
Sweden	111.92	142.98	154.09
UK	15.45	17.28	17.60
Grand Total	**725.86**	**876.20**	**888.57**

Source: *EFISCEN calculations; data is given in Mm^3 overbark; note that no data was available for Malta. The Croatian figures were derived from EU average values, the Cyprus figures were derived from average Greek values*

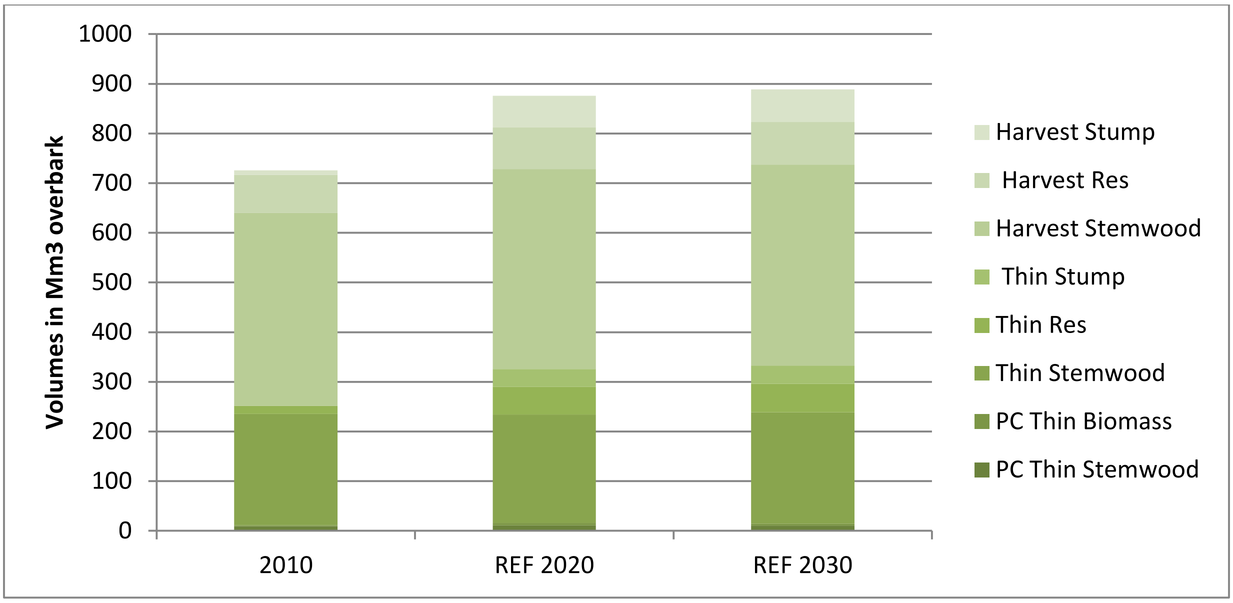
Table 3 Potential biomass available from broadleaf forests in European countries (no data for Cyprus and Malta)

	Ref			Ref w/o constraints on stump and residue removal in protected areas		Ref with additional 5% strict forest protection		Ref with additional 5% strict forest protection and retention trees		Medium		Low	
	2010	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**
Austria	4546	6099	6802	6372	7111	5816	6485	5533	6168	4882	5463	4214	4725
Belgium	1902	1653	1528	1746	1611	1574	1455	1494	1381	1421	1318	1253	1160
Bulgaria	4831	5299	5282	6326	6305	5040	5024	4781	4766	4668	4647	4135	4111
Croatia	7026	8070	7888	8328	8140	7680	7507	7289	7126	7099	6939	6477	6331
Czech Rep.	5070	6242	5944	6667	6350	5948	5662	5654	5381	5308	5069	4764	4565
Denmark	1235	1047	1367	1082	1413	998	1303	950	1239	811	1068	704	928
Estonia	7037	7405	6850	7587	7019	7038	6510	6671	6170	6666	6160	5969	5515
Finland	12700	23111	28525	23598	29090	22058	27187	21006	25848	16088	20432	13887	17425
France	44738	51626	52463	53789	54724	49133	49943	46641	47423	43401	43898	37787	38157
Germany	34630	40251	40067	42227	42060	38317	38140	36384	36212	33785	33594	29890	29738
Greece	2142	2553	2347	2586	2377	2428	2231	2303	2116	2273	2089	1964	1805
Hungary	9237	10771	10307	11825	11306	10248	9808	9726	9310	9211	8808	8161	7783
Ireland	802	460	538	475	555	437	511	414	485	419	491	381	448
Italy	20108	22043	21128	22942	21998	20949	20079	19855	19030	19473	18689	16768	16100
Latvia	7761	10771	13578	11160	14075	10242	12909	9712	12241	8969	11273	7659	9620
Lithuania	3570	4220	5194	4457	5487	4016	4940	3811	4685	3478	4317	3089	3821
Luxembourg	722	657	467	695	495	624	444	592	421	582	412	514	363
Netherlands	619	700	797	774	880	666	759	633	720	579	658	516	586
Poland	13132	14011	14318	15194	15526	13331	13620	12650	12923	12195	12499	11113	11392
Portugal	8484	9373	10551	9566	10768	8906	10024	8438	9497	7893	8897	6950	7839
Romania	19195	19962	19221	21085	20301	18986	18283	18010	17345	18025	17337	16137	15490
Slovakia	4994	5792	5985	6608	6834	5511	5696	5231	5406	5033	5205	4486	4651
Slovenia	3070	3351	3262	3476	3385	3186	3101	3020	2941	3055	2964	2729	2645
Spain	6415	6536	5895	6835	6165	6218	5608	5900	5321	5461	4922	4662	4198
Sweden	12066	18091	21475	18420	21862	17252	20467	16413	19459	13278	15863	11585	13811
UK	4423	4444	4315	4548	4415	4227	4104	4010	3893	3793	3683	3285	3186
Grand Total	**240453**	**284537**	**296094**	**298369**	**310250**	**270829**	**281801**	**257122**	**267509**	**237847**	**246696**	**209077**	**216393**

Table 4 Potential biomass available from conifer forests in European countries (no data for Cyprus and Malta)

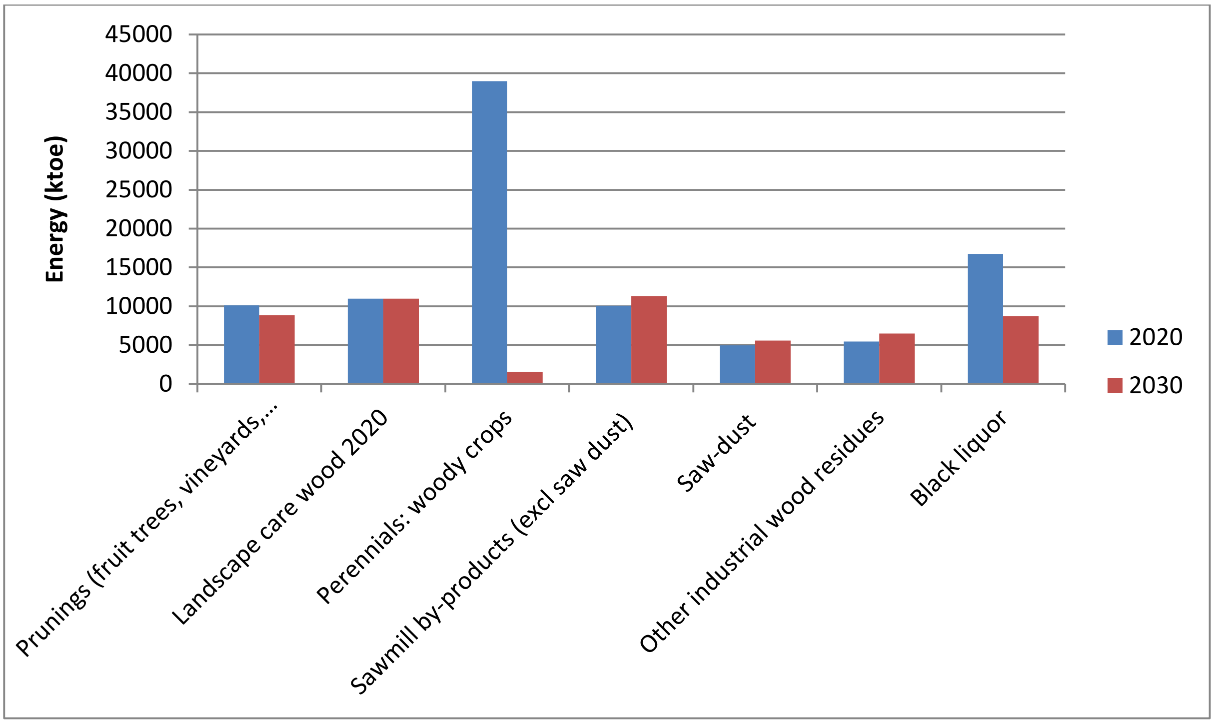
	Ref			Ref w/o dedicated constraints on stump and residue removal in protected areas		Ref with additional 5% strict forest protection		Ref with additional 5% strict forest protection and retention trees		Medium		Low	
	2010	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
Austria	31363,88	36909,83	35100,61	38066,55	36239,36	35106,16	33388,61	33302,49	31676,62	30598,87	29046,29	26715,82	25366,55
Belgium	3322,211	4321,445	4271,887	4616,151	4576,442	4109,122	4061,543	3896,798	3851,199	3698,756	3640,86	3248,361	3161,846
Bulgaria	3296,809	4574,348	4630,044	5684,139	5692,352	4361,439	4413,793	4148,529	4197,543	3605,033	3728,898	2909,798	3087,711
Croatia	184,5114	271,0937	270,8712	285,0532	284,267	258,3902	258,0603	245,6867	245,2494	210,4872	214,5557	184,8147	189,4787
Cyprus	36,90136	43,14219	43,14219	43,91926	43,91926	41,03715	41,03715	38,93211	38,93211	36,90136	36,90136	30,88029	30,88029
Czech Rep.	20040,59	23723	21717,16	25888,06	23677,04	22582,63	20668,1	21442,25	19619,03	19832,14	18203,1	17448,65	16060,04
Denmark	2736,417	3548,33	3501,753	3694,831	3640,853	3376,661	3332,626	3204,991	3163,498	2750,265	2747,715	2321,034	2333,902
Estonia	6084,514	7166,714	7032,162	7408,788	7269,833	6816,003	6687,709	6465,293	6343,256	6228,507	6114,658	5491,324	5389,925
Finland	72807,3	88783,56	83074,17	90473,42	84663,37	84550,71	79124,94	80317,85	75175,7	70513,65	65588,47	57532,37	53536,27
France	43367,61	50067,89	55552,33	52033,34	57730,92	47693,11	52931,42	45318,34	50310,51	39834,61	43933,69	33994,17	37337,9
Germany	68620,17	88005,47	84082,26	93480,1	89390,09	83786,16	80054,32	79566,85	76026,38	71254,16	67637,82	61595,28	58162,05
Greece	2308,991	2854,505	2623,415	2905,011	2669,832	2715,184	2495,373	2575,864	2367,332	2450,208	2251,848	2057,592	1891,017
Hungary	1576,776	2133,849	2331,174	2390,759	2587,912	2031,934	2217,49	1930,018	2103,806	1712,765	1932,145	1460,114	1685,382
Ireland	2321,456	3961,215	4621,403	4158,833	4844,391	3766,887	4394,183	3572,558	4166,964	3365,057	3956,879	3035,995	3572,97
Italy	6624,611	7144,267	6940,944	7468,455	7254,708	6798,243	6603,998	6452,218	6267,052	6068,193	5917,712	5095,939	4980,381
Latvia	10629,45	9454,563	11073,66	9810,499	11484,72	8998,848	10534,46	8543,132	9995,257	7626,26	9037,256	6541,222	7750,71
Lithuania	6973,575	8042,668	8206,086	8664,719	8848,286	7658,094	7813,178	7273,52	7420,27	6265,306	6392,196	5378,102	5474,116
Luxembourg	261,0982	441,0062	573,3893	471,4317	612,4241	419,6751	545,4227	398,3439	517,456	372,5197	490,08	319,909	423,0485
Netherlands	863,4556	1038,203	1102,233	1181,497	1246,581	988,6672	1049,381	939,1315	996,5296	821,5287	881,3688	727,382	777,0237
Poland	45281,82	54927,66	53005,87	60954,72	58938,5	52297,06	50460,15	49666,47	47914,43	44251,7	42641,54	39252,49	37768,49
Portugal	2317,635	2982,329	3224,934	3042,794	3291,027	2838,62	3069,445	2694,911	2913,956	2369,301	2563,868	1940,725	2105,808
Romania	13341,46	16769,81	16912,85	18014,84	18079,57	15946,79	16082,25	15123,76	15251,64	14710,8	15016,2	12741,31	13166,5
Slovakia	6389,955	6724,706	6942,366	7744,326	8115,002	6395,76	6604,699	6066,813	6267,032	5847,214	5884,603	5202,634	5091,991
Slovenia	5362,867	6062,668	5840,092	6381,291	6159,722	5763,369	5551,792	5464,07	5263,492	5424,105	5209,755	4800,11	4595,292
Spain	18375,99	23978,94	23904,47	24907,09	24832,04	22815,28	22740,63	21651,61	21576,78	20021,96	20070,06	16809,18	16904,15
Sweden	99849,82	124888,6	132617,6	127489,9	135268,7	118998,8	126409,8	113108,9	120202	99099,15	103877,6	79373,24	83602,12
UK	11032,15	12839,85	13282,14	13093,48	13541,06	12205,51	12623,32	11571,18	11964,5	11654,74	12118,51	10017,97	10363,48
Total	485372	591659,7	592479,1	620354	620982,9	563320,1	564157,8	534980,6	535836,4	480624,2	479134,6	406226,4	404809

Figure 2 Potentials of forest biomass in 2010, 2020 and 2030 from final harvest, thinning and pre-commercial (PC) thinnings



Source: EFISCEN calculations – EFI compilation; REF = reference potential; Res = residues; PC = pre-commercial

Figure 3 Energy potentials from in 2020 and 2030 from other biomass sources



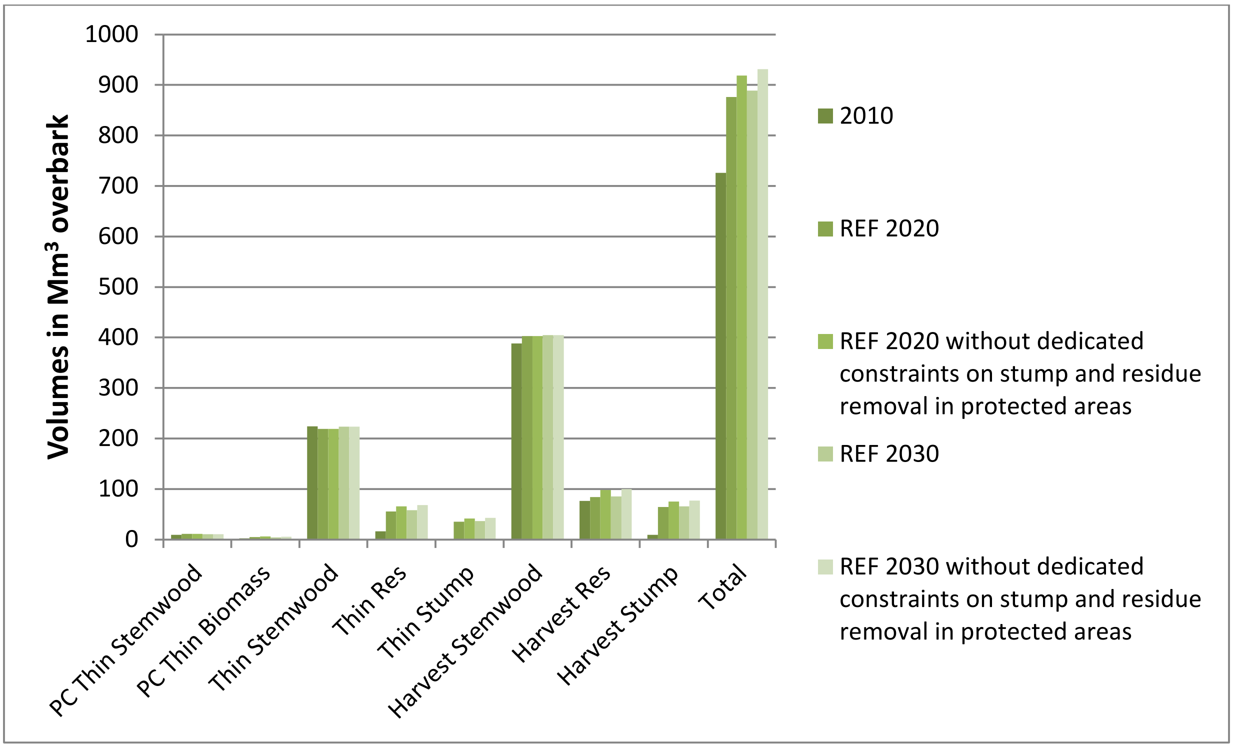
Source: Sustainability Scenario of the Biomass Futures project (IC et al. 2012)

Energy potentials from other biomass (see Annex for definitions) were also derived from data gathered in the Biomass Futures project. Due to the variation in physical properties between these biomass sources, the figures are presented in kilotons of oil equivalent (ktOE). The drop in potential for some biomass types in 2030 was due to carbon mitigation requirements becoming stricter for sustainability reasons (Elbersen et al. 2012).

2.4.2 Effects of more protected forest areas

In this study we removed the constraint on residue extraction from protected forest area to evaluate the effect of this constraint: in this case, the total volume available increased from 876 Mm^3 to 918 Mm^3 – an increase of 42.5 Mm^3 in 2020 (Figure 4). The volume available increased from 888 to 931 Mm^3 in 2030 which was an increase of 43 Mm^3.

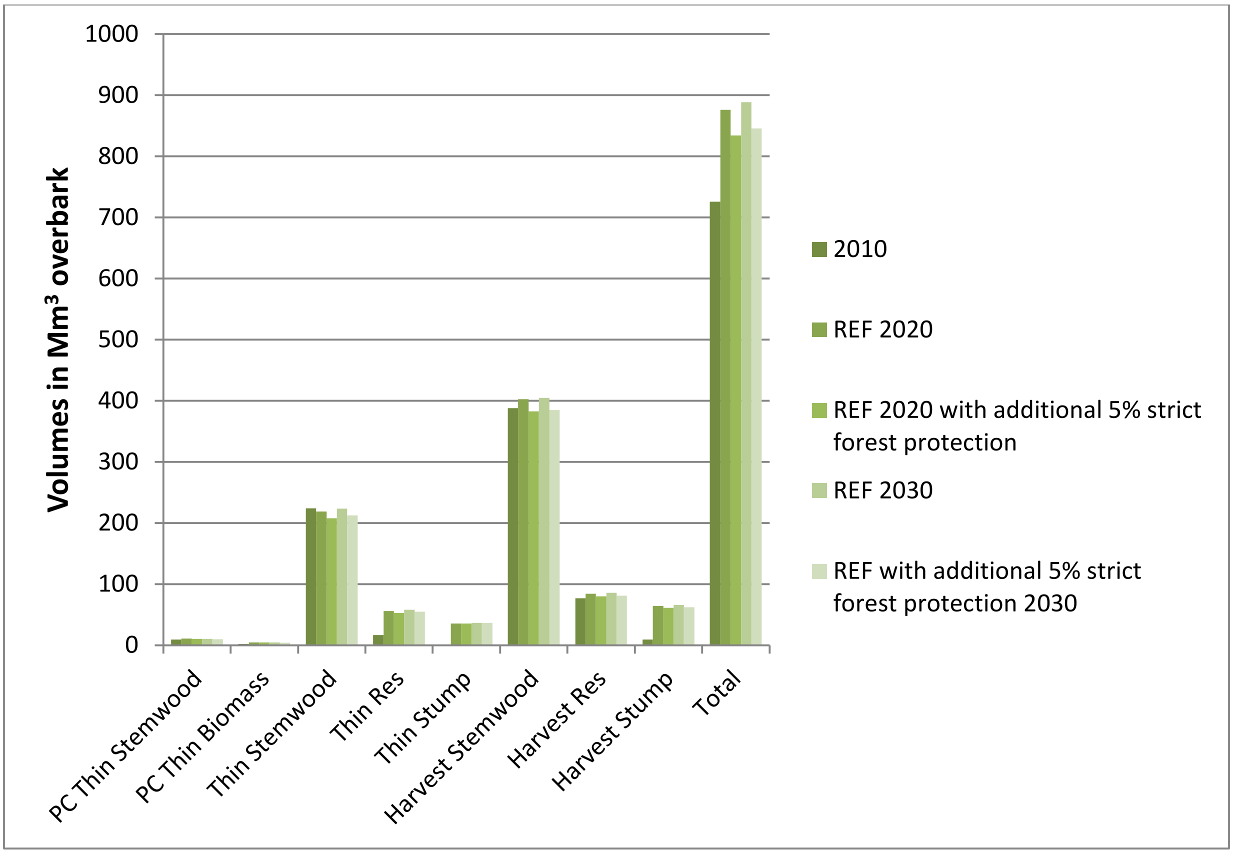
Figure 4 Effect of removing constraints on residue extraction from protected forests on forest biomass potentials



Source: EFISCEN calculations – EFI compilation; REF = reference potential; PC = pre-commercial

The effect of an increase of 5% in strictly protected forests was also quantified (Figure 5). This resulted in a decrease of 42 Mm^3 in available volume (from 876 to 834 Mm^3) in 2020 and 43 Mm^3 (from 888 to 845 Mm^3) in 2030.

Figure 5 Effect of increasing the area of strictly protected forest by 5% in 2020 on forest biomass potentials



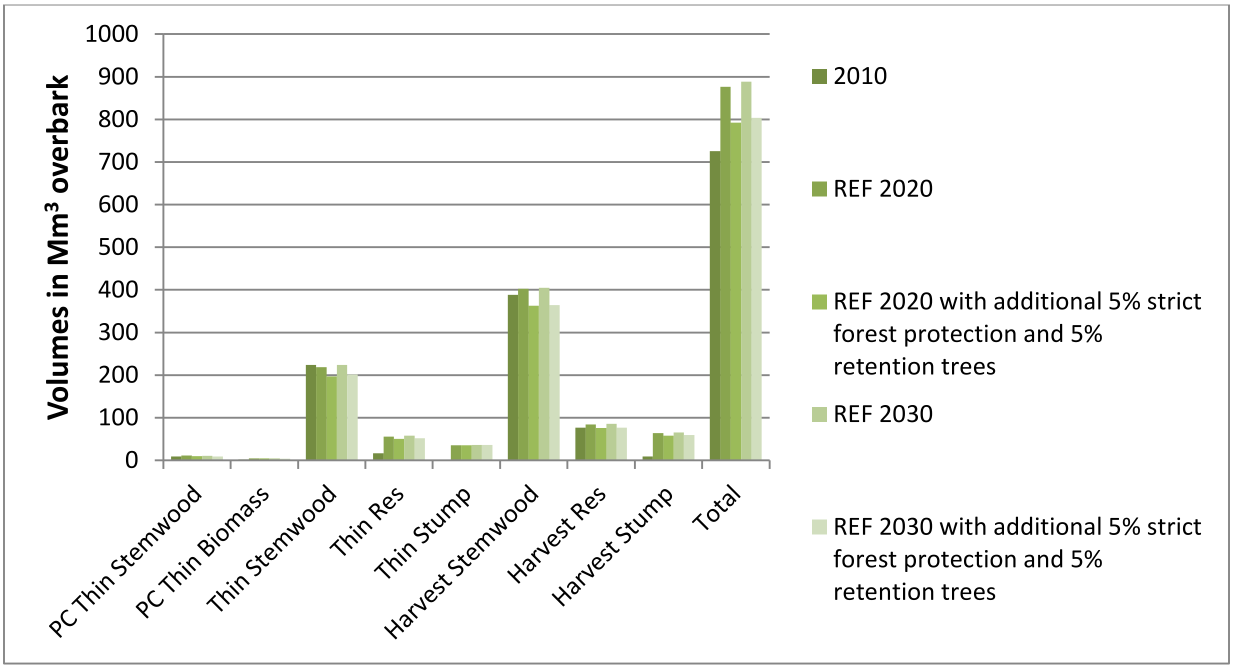
Source: EFISCEN calculations – EFI compilation; REF = reference potential; PC = pre-commercial

2.4.3 Effects of more tree retention

It is difficult to evaluate the effect of forest biomass mobilization on standing deadwood over the short time frame of this study as any policy objectives would take much longer than twenty years to make an impact. However it was possible to evaluate how an increase in retained trees would impact on the forest biomass potentials.

Figure 6 shows that a 5% increase in retained trees in combination with a 5% increase in strictly protected forest applied to the reference potential would result in a 9.5% decrease from 876 Mm^3 to 792 Mm^3 in available forest biomass by 2020 and from 888 Mm^3 to 803 Mm^3 in 2030.

Figure 6 Effect of additional 5% strict forest protection plus 5% retained trees on forest biomass potentials



Source: EFISCEN calculations - EFI compilation; REF = reference potential; PC = pre-commercial

2.4.4 Effect of stricter environmental criteria

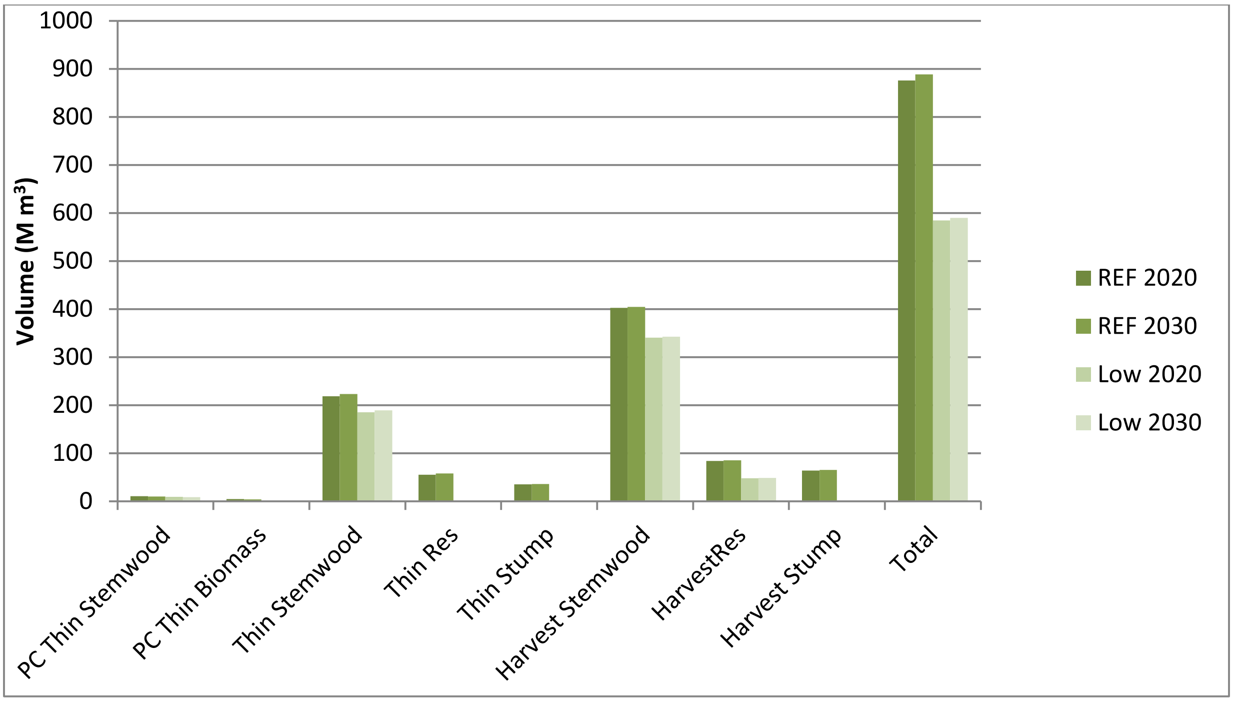
The stricter set of environmental constraints – compared to the reference mobilization potential – concern no residue removal from unproductive poor soils and a maximum of 70% residue removal on other soils.

For the low mobilization potential, application of fertilizer to limit detrimental effects of removing logging residue on the soil and stump extraction were not permitted.

These stricter environmental constraints had a significant effect on biomass availability (Figure 7).

The low mobilisation would give potential volumes of 583 Mm^3 or 33% less available biomass compared to the reference mobilization potential.

Figure 7 The effect of stricter environmental criteria on the availability on EU28 forest biomass by 2020 and 2030



Source: EFISCEN calculations – EFI compilation; REF = reference potential; PC = pre-commercial

The reference mobilization allowed limited residue extraction from forests located on peatland (see Annex Report Section 1), and set a 33% maximum extraction rate of stumps and residues for thinning and final felling. Stump and residue extraction was not permitted from peatland forests for the medium and low mobilization potentials. In the EUwood Methods report (Mantau et al. 2010), a sensitivity analysis was carried out which evaluated the effect of increased removal of residues and stumps from forests on peatlands (from 0%-33%). If the restrictions on residue extraction on peatlands were reduced for environmental reasons (i.e. allow more extraction of residues), it was found in many countries to be technically still difficult to extract biomass from these areas due to the low soil bearing capacity.

Finland and Sweden were an exception to this, as harvesting on frozen soil is possible in these countries. This means that other constraints are often the main limiting factor and do not allow much more residues or stumps to be extracted.

Table 5 Potential availability of forest biomass (in volume) in 2010 and for 2020 and 2030 from final harvest, thinnings and pre-commercial (PC) thinning for reference mobilization, additional constraints, and low mobilization potential

volumes (Mm³ overbark)	**PC Thin stemwood**	**PC Thin residues**	**Thin stemwood**	**Thin residues**	**Thin stumps**	**Harvest stemwood**	**Harvest residues**	**Harvest stumps**	**Total**
REF 2010	9.4	2.1	223.8	16.5	0.0	388.1	76.5	9.4	**726**
REF 2020	11.0	4.7	218.7	55.7	35.3	402.7	84.0	64.1	**876**
REF 2020 without dedicated constraints on stump and residue removal in protected areas	11.0	5.7	218.7	65.7	41.5	402.7	98.1	75.2	**919**
REF 2020 + additional 5% strict forest protection	10.4	4.5	207.8	52.9	35.3	382.6	79.8	60.9	**834**
REF 2020 + add. 5% strict forest protection and 5% retention trees	9.9	4.2	196.9	50.1	35.3	362.4	75.6	57.7	**792**
REF 2030	10.4	4.4	223.6	57.9	36.3	404.9	85.4	65.6	**889**
REF 2030 without dedicated constraints on stump and residue removal in protected areas	10.4	5.3	223.6	68.2	42.5	404.9	99.5	76.8	**931**
REF 2030 + additional 5% strict forest protection	9.9	4.1	212.5	55.1	36.3	384.6	81.2	62.4	**846**
REF 2030 + add. 5% strict forest protection + 5% retention trees	9.4	3.9	201.3	52.2	36.3	364.4	76.9	59.1	**803**
LOW 2020	9.4	0.6	185.3	0.0	0.0	340.9	48.4	0.0	**585**
LOW 2030	8.9	0.5	189.2	0.0	0.0	342.7	48.8	0.0	**590**

Source: EFISCEN calculations – EFI compilation

Table 6 Potential availability of forest biomass (in energy) in 2010 and for 2020 and 2030 from final harvest, thinnings and pre-commercial (PC) thinning for reference mobilization, additional constraints, and low mobilization potential

Energy (PJ)	**PC Thin stemwood**	**PC Thin residues**	**Thin stemwood**	**Thin residues**	**Thin stumps**	**Harvest stemwood**	**Harvest residues**	**Harvest stumps**	**Total**
REF 2010	81.8	18.3	1947.1	143.6	0.0	3376.5	665.6	81.8	**6314**
REF 2020	95.7	40.9	1902.7	484.6	307.1	3503.5	730.8	557.7	**7623**
REF 2020 without dedicated constraints on stump and residue removal in protected areas	95.7	49.6	1902.7	571.6	361.1	3503.5	853.5	654.2	**7992**
REF 2020 + additional 5% strict forest protection	90.5	39.2	1807.9	460.2	307.1	3328.6	694.3	529.8	**7258**
REF 2020 + add. 5% strict forest protection and 5% retention trees	86.1	36.5	1713.0	435.9	307.1	3152.9	657.7	502.0	**6891**
REF 2030	90.5	38.3	1945.3	503.7	315.8	3522.6	743.0	570.7	**7730**
REF 2030 without dedicated constraints on stump and residue removal in protected areas	90.5	46.1	1945.3	593.3	369.8	3522.6	865.7	668.2	**8101**
REF 2030 + additional 5% strict forest protection	86.1	35.7	1848.8	479.4	315.8	3346.0	706.4	542.9	**7361**
REF 2030 + add. 5% strict forest protection + 5% retention trees	81.8	33.9	1751.3	454.1	315.8	3170.3	669.0	514.2	**6990**
LOW 2020	82	5	1612	0	0	2966	421	0	**5086**
LOW 2030	77	4	1646	0	0	2981	425	0	**5134**

Source: EFISCEN calculations; and conversion into energy by IINAS; energy content expressed as lower heating value of air-dry wood

Table 7 Potential availability of forest biomass from 2010 - 2030 by country

Volume (1000 m^3 overbark)		**REF**		**REF without constraints on stump/residue removal in prot. areas**		**REF + add. 5% strict forest protection**		**REF + add. 5% strict forest prot. + 5% retention trees**		**Low mobilization - strict site constraints**	
	2010	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**
Austria	35909	43009	41903	44439	43350	40922	39874	38835	37844	29302	28508
Belgium	5224	5975	5800	6362	6188	5683	5516	5391	5233	4265	4095
Bulgaria	8128	9874	9912	12010	11997	9402	9438	8930	8963	6674	6820
Croatia	7210	8341	8159	8613	8424	7938	7765	7535	7372	6311	6177
Czech Rep.	25111	29965	27661	32555	30027	28530	26330	27096	25000	21043	19539
Denmark	3971	4595	4869	4777	5054	4375	4635	4155	4402	2866	3090
Estonia	13122	14572	13882	14996	14288	13854	13198	13136	12513	10857	10331
Finland	85508	111894	111599	114072	113753	106609	106312	101324	101024	67660	67226
France	88106	101694	108015	105822	112454	96826	102875	91959	97734	68003	71522
Germany	103251	128256	124150	135707	131450	122104	118194	115951	112239	86670	83273
Greece	4451	5408	4970	5491	5047	5143	4727	4878	4484	3810	3502
Hungary	10814	12904	12638	14215	13894	12280	12026	11656	11413	9115	8970
Ireland	3123	4421	5160	4633	5399	4204	4906	3987	4652	3238	3809
Italy	26732	29187	28069	30411	29253	27747	26683	26308	25298	20713	19970
Latvia	18390	20225	24652	20970	25560	19240	23444	18256	22236	13453	16457
Lithuania	10543	12263	13401	13122	14335	11674	12753	11085	12106	8021	8806
Luxembourg	983	1098	1041	1166	1107	1044	990	990	939	790	744
Netherlands	1482	1738	1899	1955	2126	1655	1808	1572	1717	1178	1291
Poland	58414	68939	67323	76148	74464	65628	64081	62317	60838	47715	46574
Portugal	10802	12356	13776	12609	14059	11744	13093	11133	12411	8423	9422
Romania	32536	36731	36134	39100	38381	34933	34365	33134	32596	27358	27148
Slovakia	11384	12516	12928	14352	14949	11907	12300	11298	11673	9179	9231
Slovenia	8433	9414	9102	9857	9545	8949	8653	8485	8204	7133	6859
Spain	24791	30515	29799	31743	30997	29033	28349	27551	26898	20341	19992
Sweden	111915	142979	154092	145910	157130	136250	146877	129521	139661	86171	92286
UK	15455	17284	17597	17641	17956	16432	16728	15581	15858	12603	12836
Grand Total	725825	876196	888573	918723	931233	834149	845959	792102	803345	582919	588507

3 GHG Balances of Woody Bioenergy

In addition to the biodiversity risks, the direct and total greenhouse-gas (GHG) emissions from bioenergy were analyzed. The emissions from bioenergy systems can be separated into two components:

a) **Life-cycle emissions:** These are the emissions occurring due to biomass combustion and upstream processes (e.g. fossil fuel for harvesting, transport, processing) - see Section 3.1.1.

b) **C stock change emissions:** These are CO_2 emissions from changes in the forest carbon stock, e.g. extraction of forest thinnings for bioenergy, and C absorption as the forest regrows. In the case of forest residues, a time series of emissions occurs if the residues were left to decay.

To calculate the C-stock change emissions it is necessary to define a **bioenergy system** (what happens to the carbon stocks when biomass for energy is extracted) and a **reference system** (what happens to the carbon stocks when biomass is **not** used for energy). It is important to realise that the reference system and its associated reference emission series is **counterfactual**. It should represent the most likely situation **in absence** of the bioenergy system. The selection of reference system effects the net emissions and energy dramatically.

Table 6 list the assumed reference uses of biomass in the analysis. In some cases where the choice of reference system is not clear, it is advisable to produce two net emission and energy series which represent the systems that produce the lowest and highest net emissions and energy. For example, for the analysis of pre-commercial thinning an optimistic and pessimistic model were created.

The C stock change emissions were calculated for 20 and 100 year time horizons[5] to show the sensitivity of the results. Furthermore, optimistic and pessimistic forest reference cases were used in the calculation for the same reason.

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[5] The time-horizon indicator is the sum of emissions over the specified number of years due to of an action today. By using the time varying nature of the changes in carbon stocks is captured. However, the time-horizon is an indicator of emissions and not the actual emissions in a given year from an action sometime previously.

Table 8 Summary of reference systems for various biomass types

Biomass Source	**Reference System**
Forest residues	Residues remain in the forest and decay naturally without catastrophic disturbance
Stumps	Stumps remain in the forest and decay naturally without catastrophic disturbance
Pre-commercial thinning	Optimistic option: Thinnings remain in the forest and decay naturally without catastrophic disturbance. The forest grows in a similar manner with and without biomass use for energy. Pessimistic option: Pre-commercial thinning does not occur. The unthinned forest has consistently more biomass than does the thinned forest (i.e. parallel growth curves)
Commercial Thinning	Thinning occurs in the same manner as in the bioenergy system, but the biomass from thinning is used for a mixture of purposes: % Sawnwood 0% % Panels 25% % Paper 22% % Energy 53%
Advanced Harvests	The forest is harvested, but later than the “optimal” time. In the bioenergy systems, the forest is harvested at the “optimal time”. The delay, as compared to the bioenergy system, allows for an increase in forest biomass, and biomass at final harvest. The same proportion extracted biomass is used directly for sawnwood, panels, paper and energy in both the bioenergy and reference systems

Source: Consortium assumptions

3.1 Methodology for the GHG Emission Calculation

3.1.1 Life-Cycle GHG Emissions

The life-cycle emissions were calculated with GEMIS[6], assuming that these are constant for all regions of Europe, but different over time (2020, 2030)[7].

The fossil-fuel emissions (from coal, oil, natural gas)[8] and life-cycle GHG emissions from nuclear and non-biomass renewables are also calculated with GEMIS for 2020 and 2030 as EU averages.

3.1.2 Emissions from C stock changes in Forests

The time-varying GHG emissions from C stock changes in forests were modeled to reflect the growth rate of forests, decay rates of residues depend on forest type, climate (temperature and precipitation) and residue quality, and the time horizon (20 vs. 100 years) as well as the forest reference case (counterfactual situation without bioenergy extraction). A more detailed description of the modelling assumptions and data background is given in the separate Annex Report.

3.2 Emission factors

There are two types of emission factors to consider; the emission factor from the consumption of an amount of biomass in a single year, and the effective emission factor of the continuous consumption of biomass. The latter is calculated by summing the emissions from a specific year to the year of interest and dividing it by the total biomass consumed over the same period, hence it is the time average emission factor.

Figure 8a shows the emission factors excluding supply-chain emissions of the presented models for Austrian forests and conditions. For example, the emission factor for the use of residues decreases quickly with time. The effective emission factor, however, is dependent on the amount of biomass consumed in specific year.

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[6] GEMIS (Global Emissions Model for integrated Systems) is a public-domain (i.e. freely available) life-cycle model and database maintained by IINAS (see www.gemis.de).

[7] This simplification is needed to reduce the data requirements. From earlier projects, bioenergy life-cycle data for most EU Member States is available, but shows comparatively minor differences.

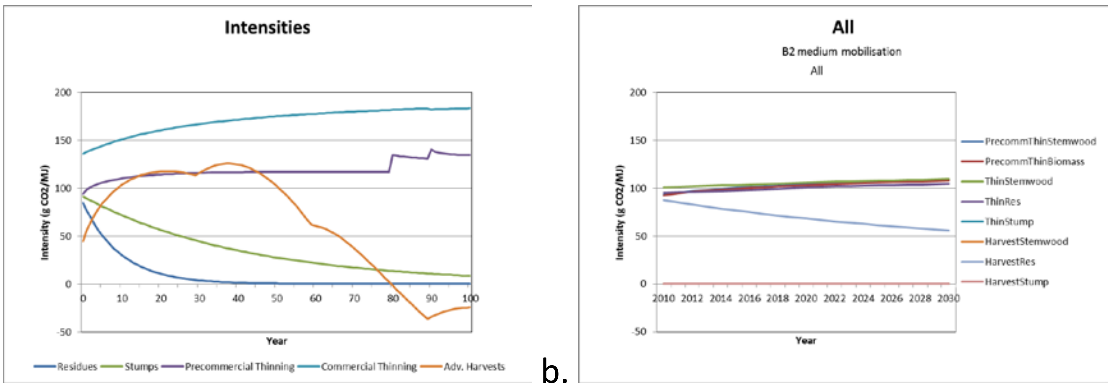
[8] The oil and gas comparators for 2030 can be varied also to reflect synthetic crude oil ("Tar Sands") and shale gas ("fracking"). In the results presented here, the average oil and gas emissions were used.

For example, if the amount of bioenergy from residues is increasing the effective emission factor will decrease less quickly than for the case of consumption in a single year. This occurs because the effective emission factor includes both biomass extracted for many years and extracted recently. Since more biomass is extracted recently, it has a greater impact on the effective emission factor. Figure 8b shows the effective emission factors of the various biomass sources for a specified biomass scenario.

Of the five models, only biomass from the two residues the advanced harvest biomass have intensities that over time are below the intensities of fossil fuels (coal = 88 g CO_2/MJ, oil = 73 g CO_2/MJ, and natural gas = 51 g CO_2/MJ).

Typically the intensity should start somewhere near that of wood without regrowth (94 g CO_2/MJ). The advanced harvest model starts with a lower intensity because there are wood products created. The commercial thinning model starts with a higher intensity because material products are forsaken to create energy. The amounts above and below the typical value are approximately the same.

Figure 8 (a) Greenhouse gas emission factors excluding supply chain emissions of the presented biomass models for the one-time biomass use for Austrian forest conditions and (b) the effective greenhouse gas emission factors for a specific supply scenario (B2 Medium) for all Europe.

a.  b.

Note: Joanneum (2014) own elaboration. Stumps and stemwood are purposely not considered in the B2 medium mobilisation scenario. Their effective emission factors are not shown.

When the models are applied to a biomass supply scenario (Figure 8b), the emission factors are different than for the individual models because intensity of the scenario is calculated as the sum of emissions to a specific year divided by the sum of energy to the same year.

Table 9 The effective greenhouse gas emission factors for a specific supply scenario (B2 Medium) by country

Country	PrecommThin Stemwood	PrecommThin Biomass	Thin Stemwood	Thin Res	Thin Stump	Harvest Stemwood	Harvest Res	Harvest Stump
AT	109	109	149	150	0	89	65	0
BE	111	111	152	153	0	109	55	0
HR	108	108	149	150	0	101	36	0
CY	0	0	151	152	0	102	47	0
CR	109	109	149	150	0	90	61	0
DK	110	110	150	152	0	100	60	0
ES	108	108	149	150	0	90	50	0
FI	111	111	150	151	0	99	68	0
FR	109	110	150	151	0	101	46	0
DE	109	110	149	150	0	95	55	0
GR	0	0	151	152	0	104	43	0
HU	109	109	150	151	0	105	39	0
IE	115	115	154	156	0	108	61	0
IT	108	108	150	151	0	108	36	0
LV	139	139	158	160	0	49	53	0
LT	110	110	150	151	0	105	60	0
LU	115	115	157	158	0	59	42	0
MA	0	0	0	0	0	0	0	0
NL	109	108	150	151	0	100	51	0
PO	110	110	150	151	0	98	60	0
PT	110	110	152	153	0	103	38	0
RO	109	109	150	151	0	108	47	0
SK	110	111	151	151	0	105	53	0
SI	109	109	150	151	0	105	54	0
ES	108	108	149	150	0	90	50	0
SW	110	110	149	150	0	89	70	0
UK	110	111	151	151	0	102	55	0

Table 9 shows the effective emission factors by country for the different types of biomass. The general trend is that warmer countries have faster decay rates and hence lower emission factors from the use of residues. This was also suggested by Repo et al. (2011).

There are slight variations in the effective emission factors of other biomass sources too. For example, countries with longer rotation lengths have a lower emission factors from the use of harvest stemwood than do countries with shorter rotation period. This is because the typical current harvest delay is assumed to be 1/3 of the rotation period.

3.3 GHG Emission Factors for Using Forest Bioenergy

Based on the model calculations, the emission factors for woody bioenergy were determined for two key assumptions of the reference forest system for pre-commercial thinnings and residues from commercial thinnings:

- In the **optimistic forest reference case** it is assumed that this biomass would remain in the forest and decay, i.e. release CO_2 over time.
- In the **pessimistic forest reference case** it is assumed that this biomass would be taken out of the forest but used as feedstock for pulp & paper, and other low-quality wood use, i.e. without immediate CO_2 release.

Both cases were calculated for the 20 and 100 year time horizons. The respective emission factors are given in the following table.

Table 10 Forest Bioenergy GHG Emission Factors for C Stock Changes

Emission factor in g CO_2/MJ for	**Pre-comm. thinning stemwood**	**Pre-comm. thinning residues**	**Thinning stemwood**	**Thinning residues**	**Harvest residues**
20 a optimistic	3.6	3.6	116.0	3.0	3.0
20 a pessimistic	118.0	118.0	118.0	3.0	3.0
100 a (both cases)	0.2	0	0.1	0	0

Source: Joanneum Research calculation; note that emissions do not include supply chains or the emissions saved from the displaced fossil energy

4 Scenarios for Woody Bioenergy in the EU

In order to estimate the future use of sustainable bioenergy in Europe, three scenarios were modelled to determine how much bioenergy would be needed by 2020 and 2030[9] for the different end-uses (i.e. electricity, heat, and transport) as well as the respective primary energy use, and GHG emissions.

The scenarios consist of the **reference** (REF), a "**reduced GHG emissions**" (GHG) and a "**sustainable bioenergy**" (SUS) case.

The REF scenario is based on the most recent EC reference scenario (EC 2013), while for the other two scenarios, the EUwood study (Mantau et al. 2010; Verkerk et al. 2011b), results of the Biomass Futures project (IC et al. 2012), EFSOS II (UNECE, FAO 2011) as well as Teske et al. (2012) and GP, EREC, GWEC (2012) were considered (see details in Section 5 of the Annex report).

In the GHG and SUS scenarios, additional **cascading use of wood** was applied as a simplified strategy[10] to increase sustainable wood use in buildings. The respective additional **sawmill** residues as well as improved recycling of woody material were considered accordingly.

4.1 The Reference (REF) Scenario

The REF scenario was built using the 2013 PRIMES reference scenario (EC 2013) for electricity and transport fuel demand and supply as well as end-energy and primary energy supply mix. Due to a lack of access to the PRIMES data for heat, the respective demand and supply were modeled using data from the reference case of the EC 2050 roadmap (EC 2011).

The assumed contributions of **non-biomass** renewables to the final energy demand is shown in the following figures.

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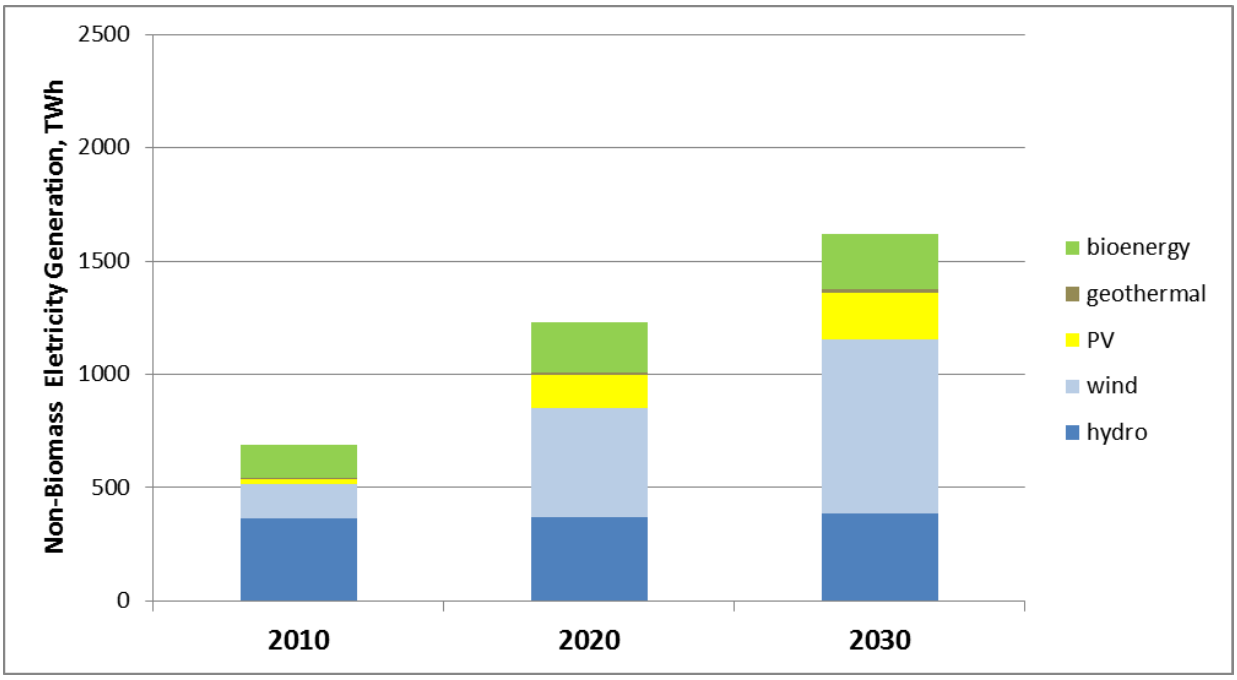
[9] Due to the lack of consistent projections for both the energy and agriculture/forest sector for 2050, only qualitative perspectives could be derived for this timeframe.

[10] See e.g. Keegan et al. (2013); Sikkema et al. (2013).

Figure 9 Renewable Electricity Generation in the EC REF scenario for the EU27 from 2010-2030

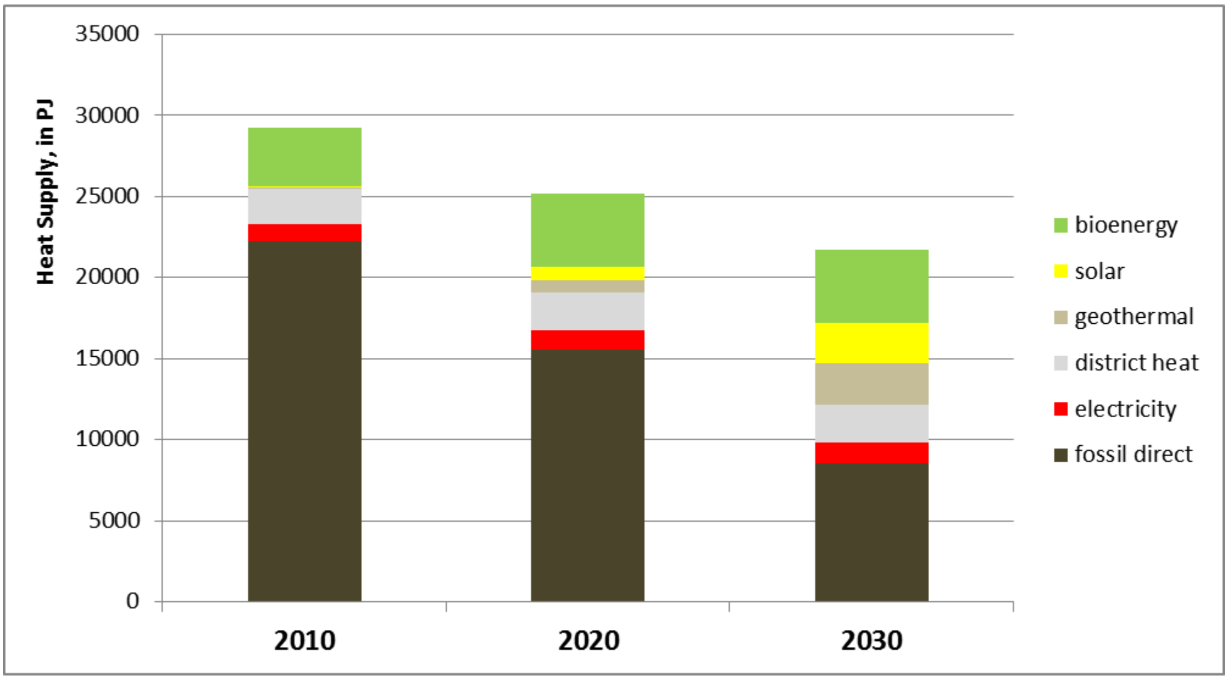


Source: IINAS calculation based on EC (2013)

REF assumes that electricity from non-biogenic renewables increases from 2010 to 2030 by a **factor of 2.3** while electricity from bioenergy increases by a factor of 1.7, with a rising share from woody bioenergy (see Section 5.1).

In the REF **heat** sector, geothermal and solar energy will gain significant shares until 2030, while biomass will increase only marginally (see Section 5.2). The non-bioenergy heat supply in REF is shown in the following figure.

Figure 10 Heat Supply in the EC REF Scenario for the EU27 from 2010-2030



Source: IINAS calculation based on EC (2013). Note that electricity and district heat also come partially from renewables.

In the transport sector, the EC 2013 REF scenario assumes that the RED target of 10% renewable transport fuels by 2020 is met (with double-counting), and that the renewable transport share is increased slightly to 11% by 2030 (excluding multipliers), but only with a slight increase of biofuels share, as the (renewable) electricity share in transport increases far more.

The overall demand for biofuels in the REF scenario is assumed to nearly double by 2020 (compared to 2010), while remaining on this level by 2030.

As regards **wood resources**, the REF scenario by 2030 requires approx. 3700 PJ of woody bioenergy, mainly for electricity and heat (less than 10% for biofuels).

Of that, about 2400 PJ come from forests (30% of that from imports), and about 1300 PJ from woody residues, and SRC.

In addition, the domestic **non-energy** use of woody materials will be approx. 5100 PJ by 2030 (energy equivalent, see Section 5.2 in the Annex Report).

Thus, the **total woody biomass resource demand** in the REF scenario by 2030 – expressed in energy terms[11] - will be approx. 8800 PJ.

The high mobilization potential of EU woody biomass from forests - **without** any sustainability constraints - is about 7700 PJ (see Table 5b) plus approx. 2500 EJ of woody residues and SRC, i.e. a **total** of about 10000 PJ of woody biomass in the EU by 2030 (excluding post-consumer wood).

The EU domestic wood potential **alone** could theoretically supply the total EC REF demand for woody products by 2030 - but this would be significantly more costly than imported wood. Therefore, the REF scenario assumed that about 750 PJ of wood will be imported by 2030 which represents a **drastic increase** compared 2010 when woody bioenergy imports were in the order of 110 PJ.

4.2 The GHG Reduction (GHG) Scenario

In the GHG scenario, significantly improved energy efficiency measures were assumed based on recent studies[12] to achieve a 30% reduction of final energy demand by 2030 compared to the REF scenario, and a 22% reduction compared to 2010. This leads to **significantly reduced demands** for electricity, heat and transport fuels in all sectors.

These **very ambitious** targets to reduce final energy demand in all sectors are achievable, as they are based on detailed potential studies on the EU level[13].

Next, the amount of renewables was increased using the mix given in the EC reference case, and taking into account the non-biomass renewable supply data given in Teske et al. (2012) to achieve renewable shares in final energy demand (including renewable electricity and district heat) of 25% by 2020, and of 45% by 2030, respectively.

Next, the use of woody bioenergy was changed, reflecting the aim to reduce the CO_2 emissions associated with forest C stock changes (see Section 3).

For this, the use of forest products for bioenergy from EU forests was reduced by 25% compared to the REF scenario by 2030, and the use of imported forest products was reduced by nearly 80%. To balance this, the use of woody residues (mainly from sawmills) and from SRC was increased drastically, as these feedstocks have lower CO_2 emissions.

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[11] Note that the non-energy wood demand expressed as an energy equivalent is based on the lower heating value of the wood, even if the wood is not used for energy.

[12] See ISI (2012a+b); OEKO (2011); Teske et al. (2012); GP, EREC, GWEC (2012)

[13] See studies given in footnote 12.

In the **electricity** sector, the woody bioenergy contribution by 2030 is reduced by 12% compared to the REF scenario, and woody bioenergy from EU forests and imports are decreased by about 14% and 62%, respectively.

In **heat** supply in 2030, EU forest products are reduced by 57% compared to REF, and imported woody biomass is completely phased-out. In parallel, use of EU woody residues and SRC increased accordingly.

In the **transport** sector, 1G biofuels - both domestic and imported - were nearly replaced by 2030 through 2G biofuel from domestic lignocellulose (mainly straw and black liquor) and all woody product imports are phased-out.

A key additional assumption of the GHG scenario is to mobilize **sustainable stemwood** from EU forests for increased **cascading use.** For this, additional wood use in 2.5% of new residential buildings in the EU by 2020 (increasing to 5% by 2030) was assumed which leads to a substitution of concrete and steel as construction materials, and also increases the amount of sawmill residues.

The additional stemwood demand from this increase in material use of wood represents 17 Mt of roundwood (about 34 Mm^3) by 2020 which would increase to 67 Mt (about 134 Mm^3) by 2030, and would displace some 8 Mt of concrete and 3 Mt of steel by 2020, and some 33 Mt of concrete and 13 Mt of steel by 2030, respectively.

The additional roundwood demand represents an energy equivalent of approx. 310 PJ by 2020, and 1250 PJ by 2030, respectively.

The **sustainable low-mobilization** potential for stemwood from thinnings and final harvest represents approx. 4500 PJ (see Table 5b). The wood demand for **material use** represents about 5000 PJ (see Section 5.2 in the Annex Report), of which about 1000 PJ are used for pulp & paper production, i.e. approx. 20% of industrial wood use. It is assumed that **increased cascading use** of wood for paper and packaging could achieve a 50% reduction of fresh fiber needs by 2030 and 20% of low-quality material wood use (for short-live building materials, and furniture) could be re-used so that an equivalent of 500 PJ of woody material previously used for fiber and some 500 PJ of low-quality wood uses can be mobilized by 2030 with cascading technologies in the European wood-using industries. Thus, a potential sustainable supply of 5500 PJ of domestic EU wood products would be able to meet the (reduced) material demand of 4000 PJ, leaving approx. **1500 PJ for bioenergy use**. Furthermore, the additional wood for building materials will provide some 100 PJ (by 2020) and 380 PJ (by 2030) of sawmill residues which can be used for bioenergy.

Finally, post-consumer wood is assumed to be increasingly recycled for energy which would provide some 1200 PJ by 2030.

The available domestic woody bioenergy potential in the GHG scenario is thus about 1500 PJ from EU forests (approx. 170 Mm^3), and about 3800 PJ from residues, wastes and SRC, i.e. a total of 5300 PJ.

The woody bioenergy demand in the GHG scenario would reach about the same level (5300 PJ by 2030) and would be supplied by the domestic potentials plus a minor amount of imported wood pellets (around 160 PJ), i.e. the import demand for woody bioenergy could be reduced by nearly 80% compared to REF.

In parallel, use of EU **non-woody bioenergy** would increase: about 630 PJ of straw for biogas and biofuels and 550 PJ of manure for biogas would be mobilized by 2030, a nearly 3-fold increase compared to the REF scenario.

4.3 The Sustainability (SUS) Scenario

In the SUS scenario, the same demand levels for electricity, heat and transport fuels as in the GHG scenario are assumed, but the use of woody bioenergy is changed not only to reduce the CO_2 emissions associated with forest C stock changes (see Section 3), but also to **reduce biodiversity risks associated with EU bioenergy and respected imports** - both for wood and (biofuel) crops.

For this, the use of forest products for bioenergy from EU forests was reduced by 74% compared to the REF scenario by 2030, and **no imported** forest products are used. To balance this, the use of woody residues (mainly from sawmills) and from SRC was increased to about the same level as in the GHG scenario, and **additional EU non-woody** bioenergy from agricultural residues and wastes was assumed to be mobilized more than in the GHG scenario.

In the **electricity** sector, forest bioenergy by 2030 is nearly phased out (94% reduction vs. REF) and use of woody residues and wastes more than halved. To compensate for this reduction, **non-woody bioenergy** use increases about 3.6-fold compared to REF.

In **heat** supply in 2030, EU forest products are again nearly phased out. In parallel, use of EU woody residues and SRC increases accordingly.

In the **transport** sector, 1G biofuels - both domestic and imported - are fully phased-out by 2030 through 2G biofuel from domestic lignocellulose (mainly straw and black liquor) and **no biofuel imports** are assumed.

As in the GHG scenario, **sustainable stemwood** from EU forests is increased through **cascading use.** For this, additional wood use in 2.5% of new residential buildings in the EU by 2020 (increasing to 5% by 2030) was assumed which leads to a substitution of concrete and steel as construction materials, and also increases sawmill residues (same assumptions as in the GHG scenario).

The SUS scenario also shifts post-consumer organic wastes: incineration is phased out, and biowastes used more efficiently in decentral cogeneration plants[14].

In summary, SUS reduces demand for EU forest products to 400 PJ (below 50 Mm^3) which is 76% less than in REF, and uses about 3900 PJ of domestic woody residues and wastes plus a small amount (140 PJ) of SRC. In parallel, some 1500 PJ of domestic straw plus 1550 PJ of manure are used for bioenergy.

4.4 Summary of the Scenarios

The qualitative description of the scenarios is given in the following table.

Table 11 Scenario Description

	Reference Scenario (REF)	**Climate Scenario (GHG)**	**Sustainability Scenario (SUS)**
Storyline	"Unrestricted" woody bioenergy use	Reduce GHG emissions, including those from bioenergy	Reduce GHG emissions, avoid biodiversity risks from imports and in domestic forests
Wood material demand	+ 4 % in 2020; + 10% in 2030	same as REF, but includes more EU construction wood (5% of new buildings by 2020 and 10% by 2030 use wood)	same as GHG, plus intensified cascading of woody materials for energy; wood bioenergy demand reduced by **more non-woody** bioenergy use
Technologies	Co-firing of imported pellets, and 1st G biofuels (also imports)	Co-firing of (imported) pellets, no 1st G biofuels by 2030	No co-firing by 2030, no 1st G biofuels by 2030, more decentral bioenergy use
Imports	market driven (increase)	Low biofuel imports, reduces wood imports by 50% by 2030	No imports of wood and biofuels by 2030

Source: IINAS compilation

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[14] This requires a better "back end", i.e. improved selective collection of biomass wastes: the solid bio-waste components are to be collected separately and chipped, while the organic (green) components are also collected separately and used for biogas, and the digestate is then composted.

5 Scenario Results

The results of the scenario calculations are summarized in the following figures. The respective tables are included in Section 5 of the Annex Report.

The summary begins with the sectoral end-use demands for electricity (Section 5.1), heat (Section 5.2) and transport fuels (Section 5.3), and the respective supply from bioenergy, other renewables, and non-renewable energy carriers.

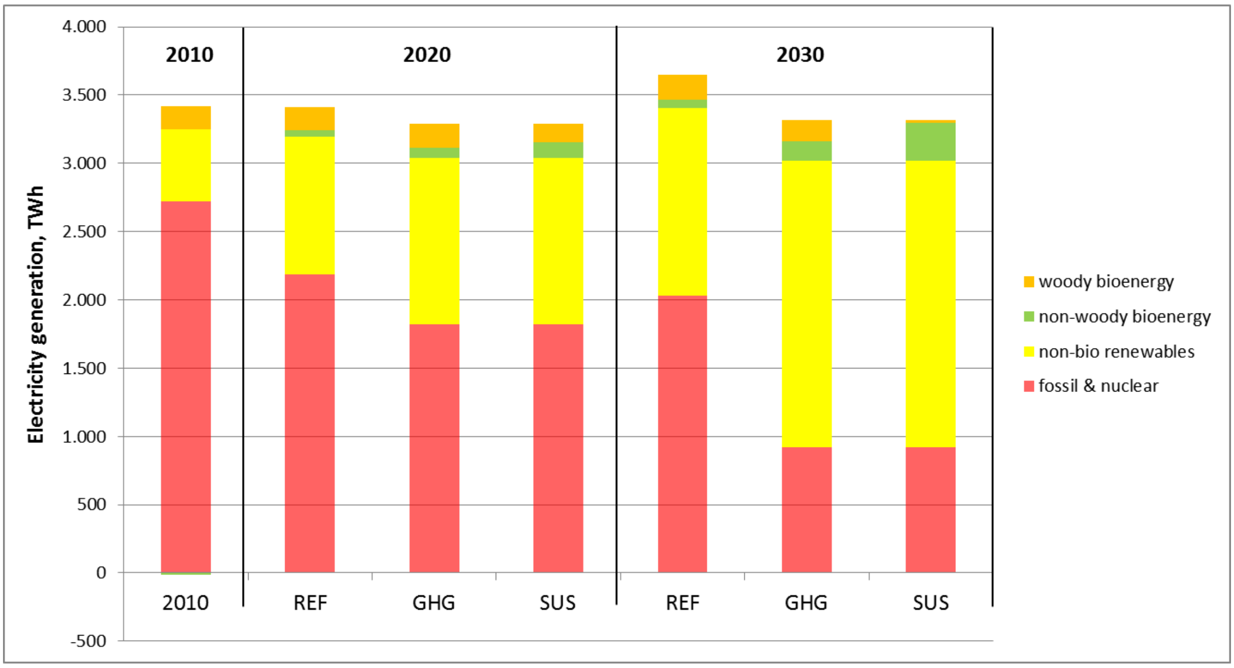
From the total final energy demand and supply (Section 5.4), the primary energy demand is calculated (Section 5.5), as well as the respective GHG emissions from bioenergy (Section 5.6) and those from overall primary energy (Section 5.7).

5.1 Electricity Generation

Total electricity generation in 2010 was 3410 TWh, and would remain stable by 2020 and increase to 2650 TWh by 2030 in the REF scenario. In the GHG and SUS scenarios it could be reduced by efficiency measures to 3290 TWh by 2020 and to 3320 TWh by 2030, respectively, as illustrated in Figure 11.

In 2020, the share of woody bioenergy will remain at 5 % in the REF and GHG scenarios, while in SUS it will be 4 %. By 2030, the woody bioenergy share in REF remains at 5% while in the GHG scenario it is reduced to 4.9% and in the SUS scenario, only 0.8% of the electricity would come from woody bioenergy, but with a growing contribution of non-woody bioenergy.

Figure 11 Electricity Generation in the EU27 from 2010-2030



Source: IINAS calculations

The most relevant difference between the REF, GHG and SUS scenarios is the origin of woody bioenergy used for electricity:

In the REF scenario, imported woody bioenergy is increasingly used for electricity generation, rising from about 100 PJ to 650 PJ in 2020, and is then reduced to 430 PJ in 2030. In the GHG scenario, imported wood pellets increase to only 230 PJ by 2020, and then are reduced to some 160 PJ in 2030.

In the SUS scenario, non-woody (domestic) bioenergy replaces a high share of the imported wood pellets, and woody bioenergy mainly is sourced from EU wood residues and wastes, not from forests. Also, SRC contribute to replacing pellet imports, but on a rather low level (approx. 140 PJ). By 2030, woody bioenergy imports are **completely phased-out**.

5.2 Heat Production

The first difference between the REF and the GHG/SUS scenarios for heat are the demand level: while in REF heat demand in 2020 increases by more than 10% compared to 2010, and remains higher than in 2010 even in 2030 (9%), the GHG and SUS scenarios assume far stricter demand-side efficiency measures which lead, compared to 2010, to a very light increase of demand in 2020 (<1%) and a net reduction of 9% by 2030, respectively.

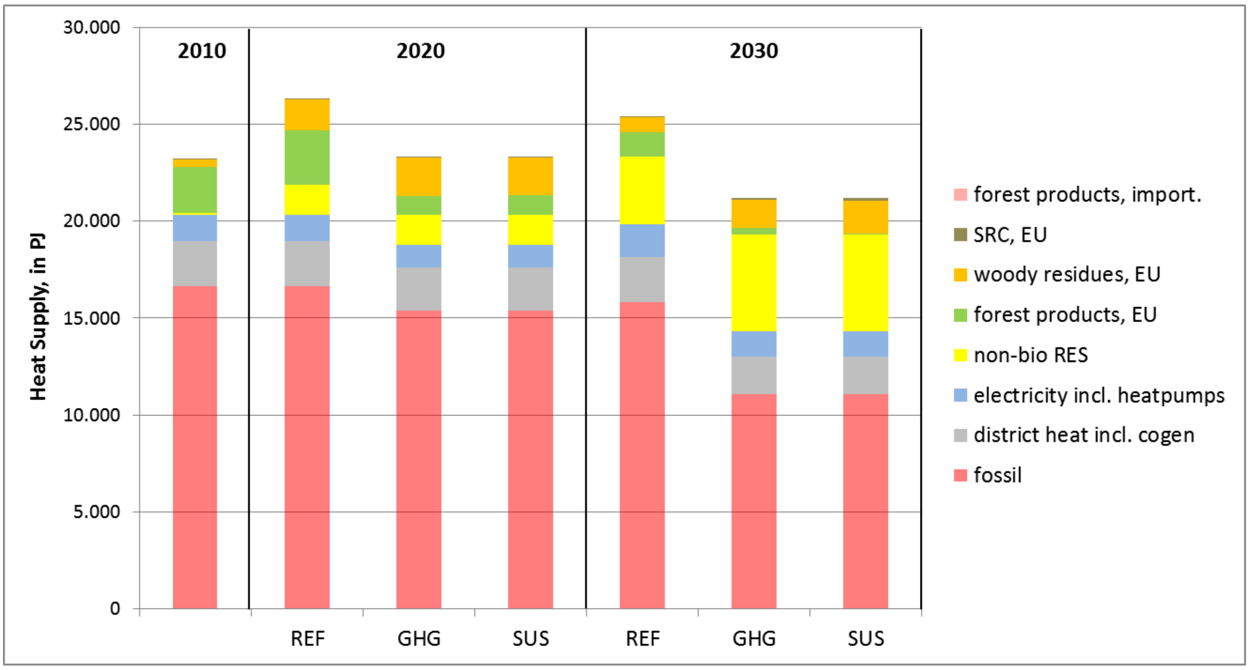
The second difference is the more prominent use of non-bioenergy renewables for heat in the GHG and SUS scenarios: solar and geothermal heat increase from less than 150 PJ in 2010 to 1550 PJ by 2020 and 5000 PJ by 2030. The REF scenario assumes 3500 PJ by 2030.

The other difference is again the source of wood for bioenergy: in the REF scenario, EU forest products supply the major share, while residues and wastes are about only 1/3 of total woody bioenergy. In the GHG and SUS scenarios, forest products are reduced through increased sourcing of residues and wastes (see Figure 12).

In the SUS scenario, EU forest product use is reduced by 94% compared to 2010 and replaced by domestic woody pellets from residues, wastes and SRC.

In all scenarios, direct wood heating relies on domestic sources, i.e. no imported pellets are used.

Figure 12 Final Energy Supply for Heat in the EU27 from 2010-2030



Source: IINAS calculations

It should be noted that there is also "indirect" bioenergy included in the electricity and cogenerated heat segments of the final heating supply (for detailed data see Annex Report).

5.3 Transport Fuels

In transport, the final energy demand in the REF scenario will decrease from about 16 EJ in 2010 to 15 EJ by 2020 and remain there by 2030, as shown in Figure 13.

In the GHG and SUS scenarios, transport fuel demand can be reduced to 12 EJ by 2020 and 9 EJ by 2030, respectively. This is a consequence of the assumed massive increase in efficiency of road transport, and modal shifts, and not connected to biofuels.

In REF, the contribution of renewables (including electricity) will increase from 4.2 % in 2010 to 8.9 % by 2020 and 11% by 2030, not considering double-counting or multipliers for electricity.

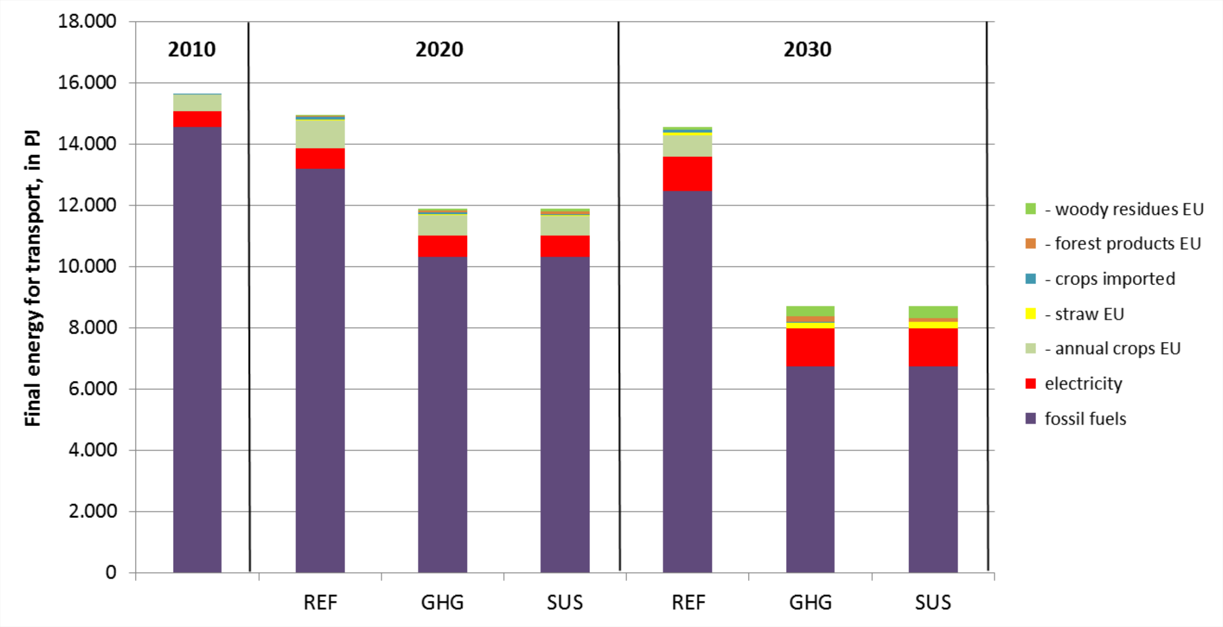
In REF, the contribution of biofuels and woody bioenergy in 2020 will reach 7.3% and 0.4%, respectively, and in 2030 the shares will be 7.7% and 2.1%, respectively.

In the GHG and SUS scenarios, biofuels and woody bioenergy will contribute in 2020 with 7.5% and 1.4% - 1.7%, respectively, and in 2030 with 8.4% and 6.7% - 6.1%, respectively.

The bioethanol and biodiesel **shares** will be the same in all scenarios, but the role of advanced conversion and the origin of the feedstocks are different:

In the REF scenario, 1G biofuels will still dominate in 2030, and imports will contribute about 30% of total biofuels. In the GHG and SUS scenarios, all 1G biofuels are phased-out by 2030 with the exception of a small share of sugarcane EtOH from Brazil in the GHG scenario. For biodiesel, the key resources will be black liquor and woody residues, while for bioethanol, domestic straw will become the dominant source.

Figure 13 Final Energy Supply for Transport in the EU27 from 2010-2030



Source: IINAS calculations

5.4 Final Energy Demand

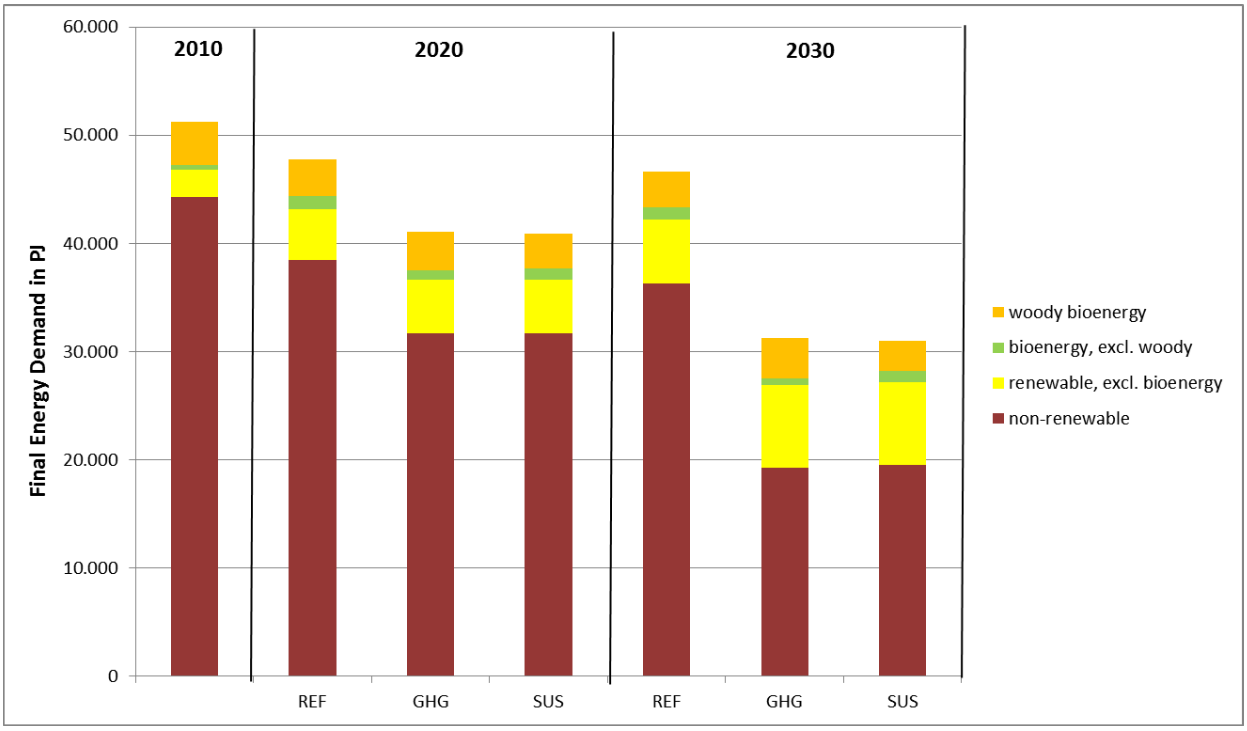
In the REF scenario, the final energy demand will decrease from about 51 EJ in 2010 to 48 EJ by 2020 and will reach 50 EJ again by 2030, with shares of all renewables (including electricity and cogenerated heat from renewables) increasing from 13% in 2010 to 20% by 2020 and 27% by 2030, respectively.

In the GHG and SUS scenarios, final energy demand will be reduced due to the assumed massive investments in energy efficiency to 42.5 EJ in 2020 and 37 EJ in 2030 (see Figure 14). The total renewable share will increase to 25% by 2020, and to 48% by 2030, respectively.

The woody bioenergy shares in the REF scenario will decrease slightly from 8% in 2010 to 7% by 2020, and will remain there by 2030.

In the GHG and SUS scenarios, the shares will remain at the 2010 level (except in GHG scenario in 2030 where it reaches 10%).

Figure 14 Final Energy Demand in the EU27 from 2010 to 2030



Source: IINAS calculations; shores from electricity and cogenerated heat are included in the categories

5.5 Primary Energy Supply

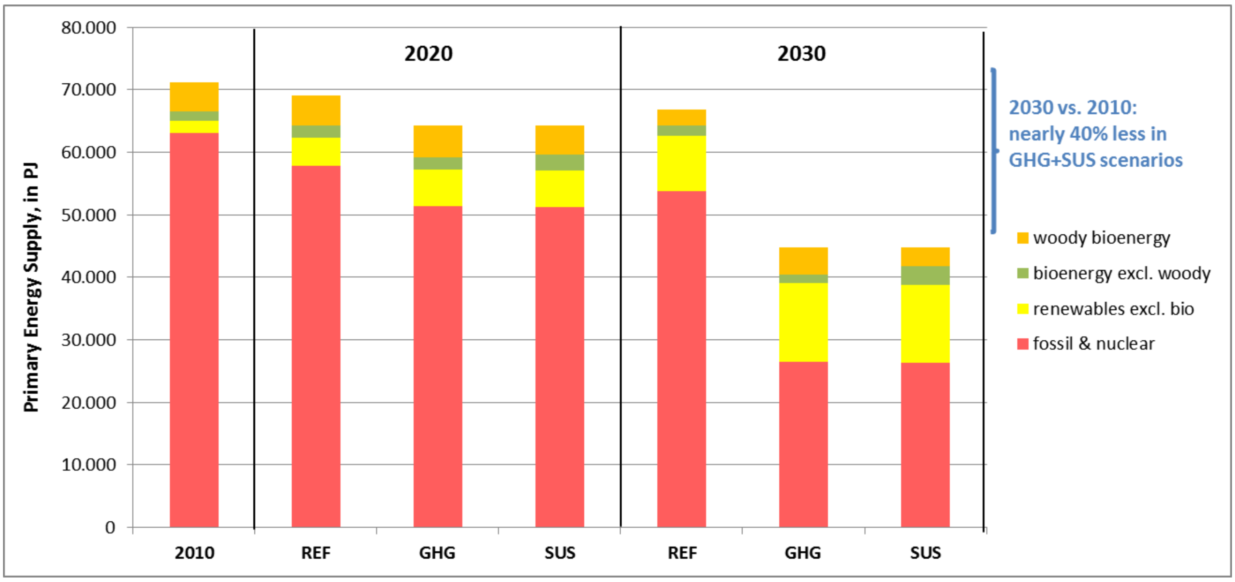
Primary energy supply in the EU27 in 2010 was about 71 EJ, and will be reduced in the REF scenario to about 69 EJ by 2020 and 67 EJ by 2030, respectively.

In the GHG and SUS scenarios, the primary energy supply will be reduced to 64 EJ by 2020 and 45 EJ by 2030, respectively.

As depicted in Figure 15, primary energy supply in the GHG and SUS scenarios will be reduced by nearly 40 % by 2030, compared to 2010, while the REF scenario achieves only a 6% reduction.

Woody bioenergy contributed 7% in 2010, and could reach 7% (REF + SUS) to 8% (GHG) by 2020 and 4% (REF), 10% (GHG) and 7% (SUS) by 2030.

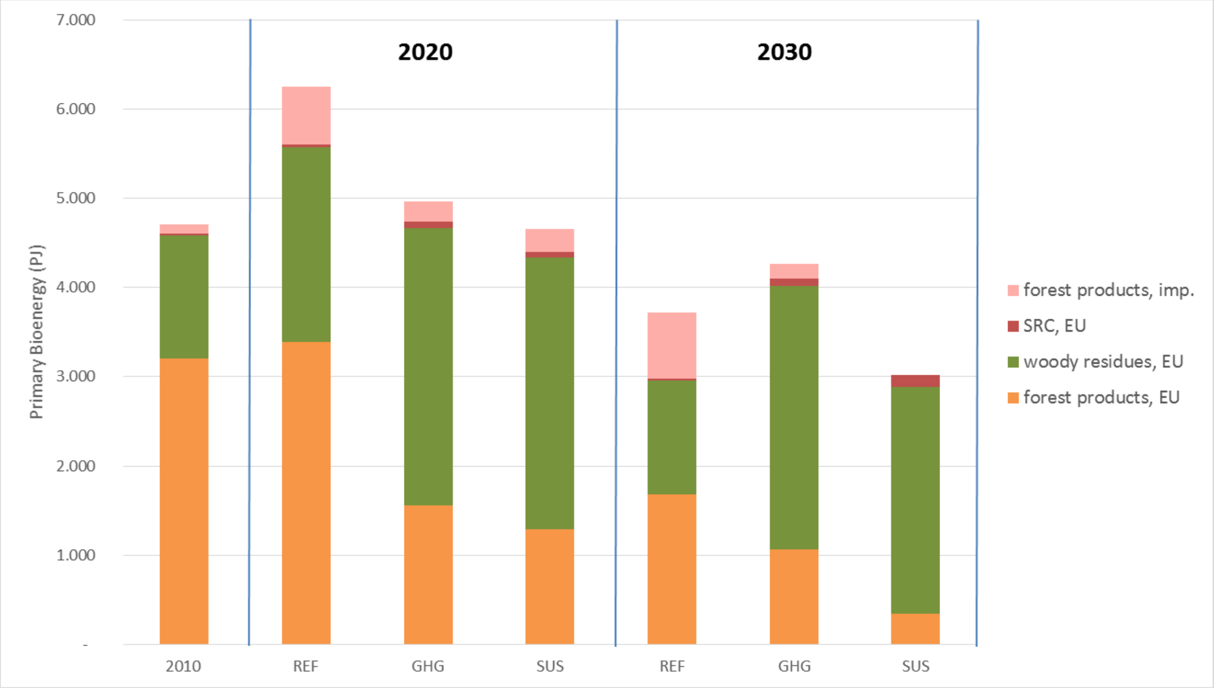
Figure 15 Primary Energy Supply in the EU27 from 2010-2030



Source: IINAS calculations

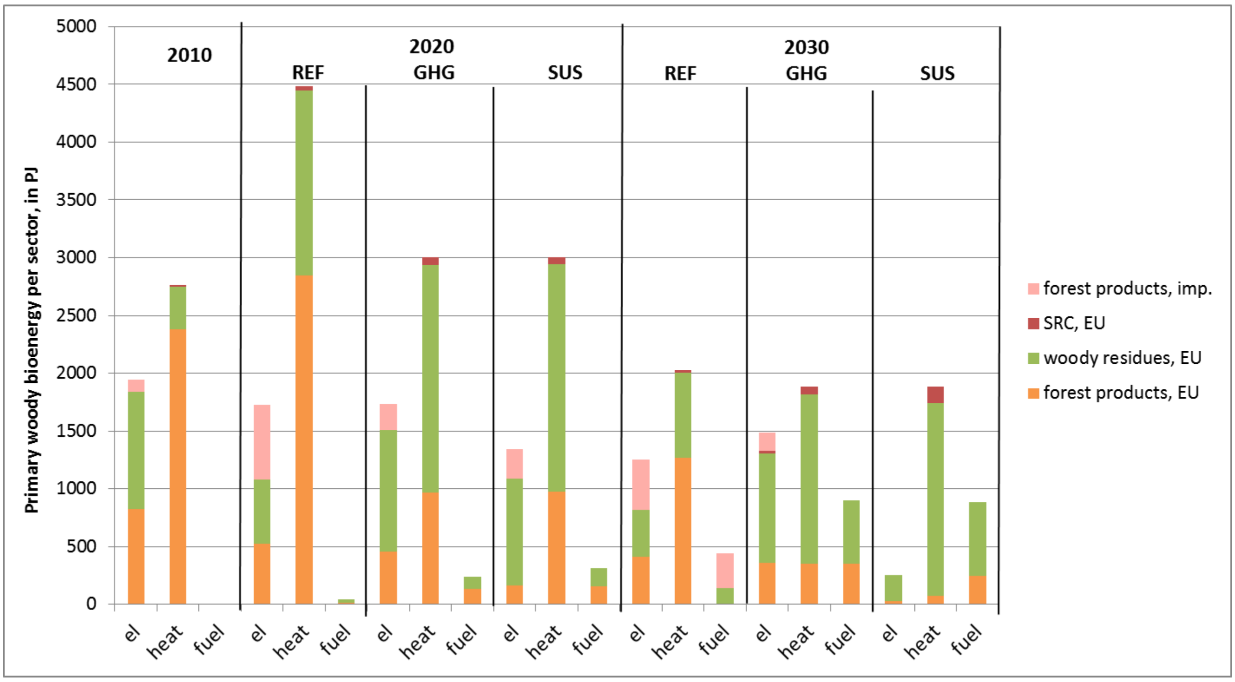
The total amount of primary woody bioenergy varies between the scenarios, as reflected in Figure 16 and 17, but contributions of the various bioenergy sources, and their use for electricity, heat and transport fuels shows even more significant differences between the scenarios.

Figure 16 Primary Woody Bioenergy in the EU27 from 2010-2030 by source



Source: IINAS calculations

Figure 17 Primary Woody Bioenergy in the EU27 from 2010-2030 per Sector



Source: IINAS calculations

The use of woody biomass – including non-energy uses – and the respective potentials are shown in the following figure.

Table 12 Bioenergy Demand and Potentials in the EU27 from 2010-2030

		2020			2030		
Biomass, energy equiv. [PJ]	**2010**	**REF**	**GHG**	**SUS**	**REF**	**GHG**	**SUS**
forest products, EU for non-energy	4000	4200	3750	3500	5100	4000	4000
forest products, EU for bioenergy	3204	3387	1554	1291	1682	1058	345
total forest products, EU	**7204**	**7587**	**5304**	**4791**	**6782**	**5058**	**4345**
share of potential (excl. imports)	91%	95%	97%	94%	89%	82%	71%
woody residues/wastes EU, for energy	1384	2185	3119	3049	1276	2960	2539
share of potential	45%	78%	70%	68%	64%	82%	70%
SRC in EU, for bioenergy	14	34	68	60	25	87	141
share of potential	3%	4%	4%	4%	10%	44%	72%
straw to biogas + biofuels	8	57	93	421	217	633	1553
used share of straw potential	0%	3%	4%	20%	11%	32%	76%
manure to biogas, for bioenergy	108	216	260	450	373	546	1567
used share of manure potential	6%	11%	13%	23%	19%	26%	75%

Source: IINAS calculations

This table clearly illustrates that the GHG and SUS scenarios can reduce both the demand on EU forest products, and for imports. In parallel, the use of agricultural residues and wastes will increase significantly above the REF levels.

5.6 GHG Emissions from Bioenergy

The GHG emissions from all bioenergy systems were calculated using GEMIS life-cycle emission factors, as given in the Annex Report (Table 17 in Section 4.5).

For bioenergy systems using forest biomass, also the CO_2 emissions from forest C stock changes were included which depend on time horizon (20 or 100 years), and optimistic or pessimistic forest reference case (see Table 3 in Section 3.3).

The overall balance further takes into account GHG emission savings from substituting construction materials with wood (see Table 20 in Section 4.6 of the Annex report) which is part of the GHG and SUS scenarios.

Note that these balances do not take into account the GHG emissions of fossil energy systems - this will be considered in the next section.

The GHG and SUS scenarios do reduce the biogenic emissions compared to those of the REF scenario, both for 2020 and 2030.

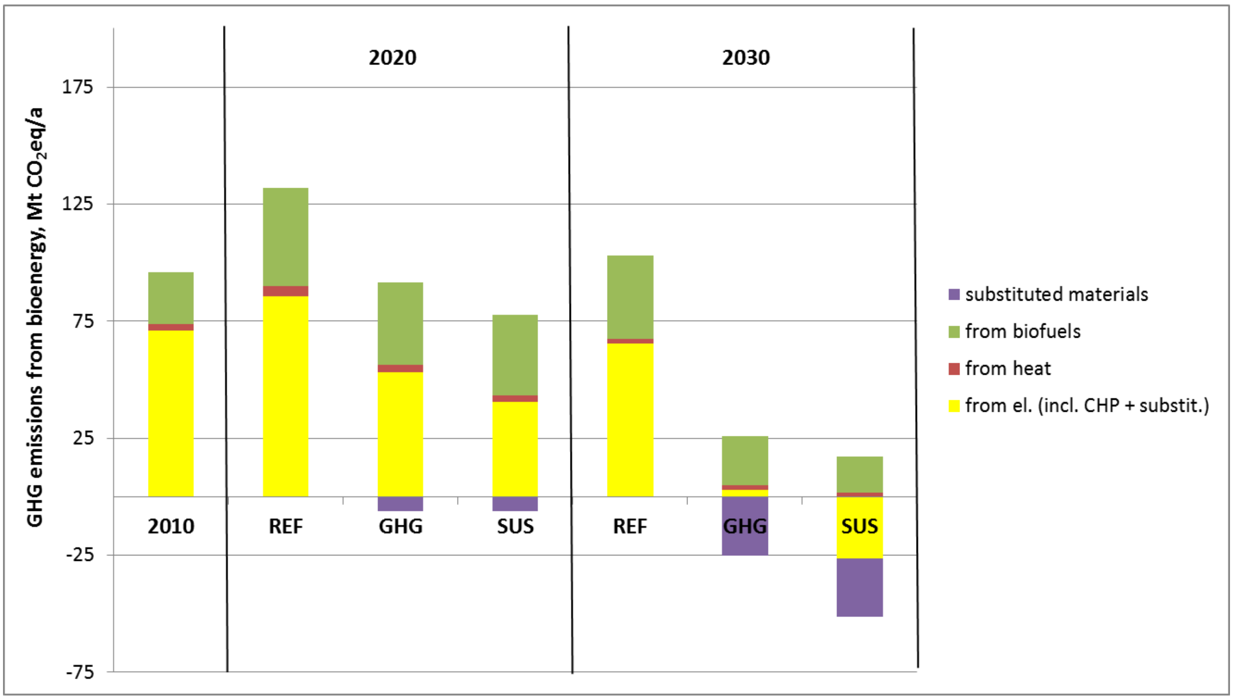
The most relevant reductions are for bio-electricity, and through the substitution of non-renewable construction materials with wood.

In the SUS scenario, the substitution effect from woody construction materials **alone** is nearly as large as the total biogenic GHG emissions so that this scenario can nearly achieve full carbon neutrality, i.e. nearly **zero net GHG emissions** by 2030.

Figure 18 GHG Emissions from Woody Bioenergy 2010 - 2030 (20 year time horizon)

a) pessimistic forest reference case

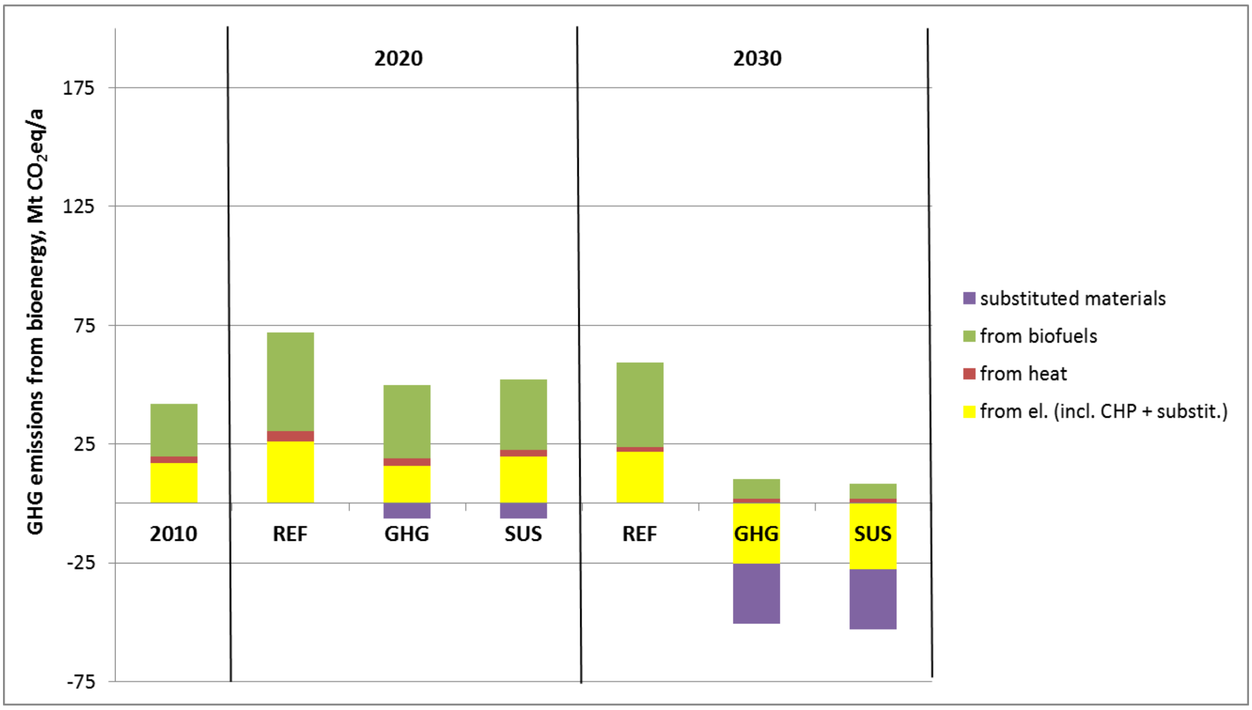
b) optimistic forest reference case



Source: IINAS calculations using GEMIS life-cycle emissions and forest C stock change emission factors from Joanneum Research

The same pattern can be observed for the GHG emissions using a 100-year time horizon (see Figure 19).

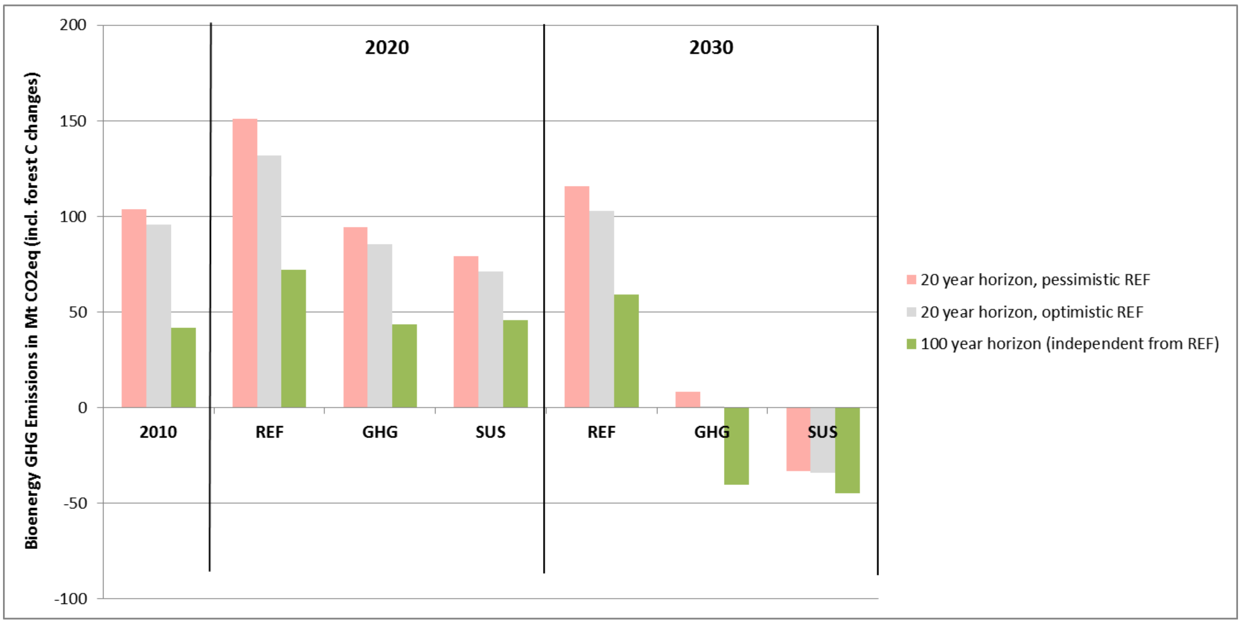
Figure 19 GHG Emissions from Woody Bioenergy 2010 - 2030 (100 year time horizon)



Source: IINAS calculations using GEMIS life-cycle emissions and forest C stock change emission factors from Joanneum Research; for the 100 year time horizon, the results are independent from the pessimistic or optimistic reference scenario

In Figure 20, the GHG emissions from bioenergy are again shown for the totals and the assumed time horizon and forest references cases.

Figure 20 GHG Emissions from Woody Bioenergy 2010 - 2030 depending on the Time Horizon and Forest Reference Cases



Source: IINAS calculations using GEMIS life-cycle emissions and forest C stock change emission factors from Joanneum Research; for the 100 year time horizon, the results are independent from the pessimistic or optimistic reference scenario

This clearly shows that the **GHG and SUS scenarios do reduce the overall GHG emissions from bioenergy** compared to the REF scenario, whatever the time horizon of the GHG accounting, and disregarding which forest reference case is chosen.

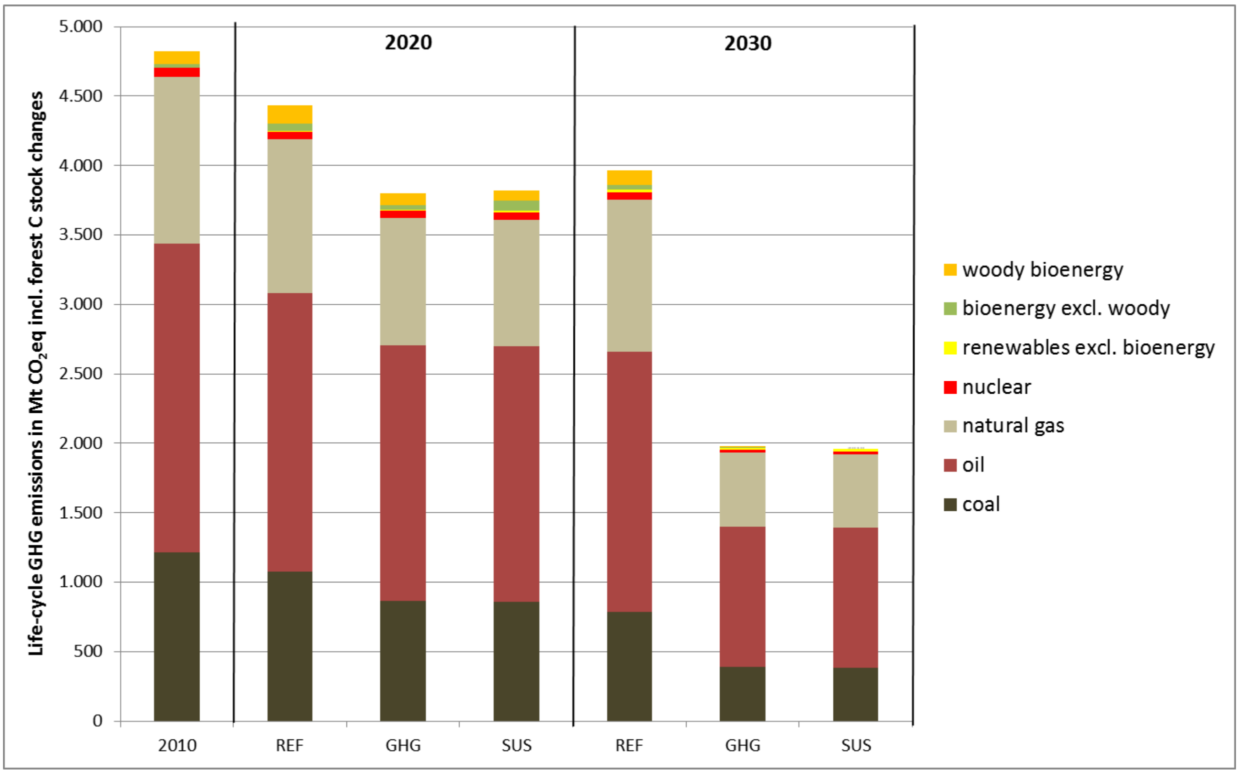
For the optimistic forest reference and 20 year and 100 year time horizons, the GHG and SUS scenarios achieve **more** than full carbon neutrality, i.e. **net GHG emission reductions** by 2030.

5.7 Overall GHG Emissions from Energy Supply and Use

To complete the GHG emission balance, the emissions from the non-biogenic energy systems must be factored in. For this, the life-cycle GHG emissions for all other energy systems were also taken from the GEMIS model: the fossil and nuclear systems (see Annex Report Table 18 in Section 4.6) and the non-bio-renewable electricity systems (Annex Report Table 19 in Section 4.6) also contribute to the overall GHG emissions of the EU energy system.

The overall GHG emission balance of the total EU energy system is shown in the following figures, again differentiating between the 20 and 100 year time horizons for the forest bioenergy systems, and the optimistic and pessimistic forest reference case.

Figure 21 Life-Cycle GHG Emissions from Energy Supply and Use in the EU27 from 2010-2030 with GHG Emissions from Forest Bioenergy for 20 Year Time Horizon and Optimistic Forest Reference Case

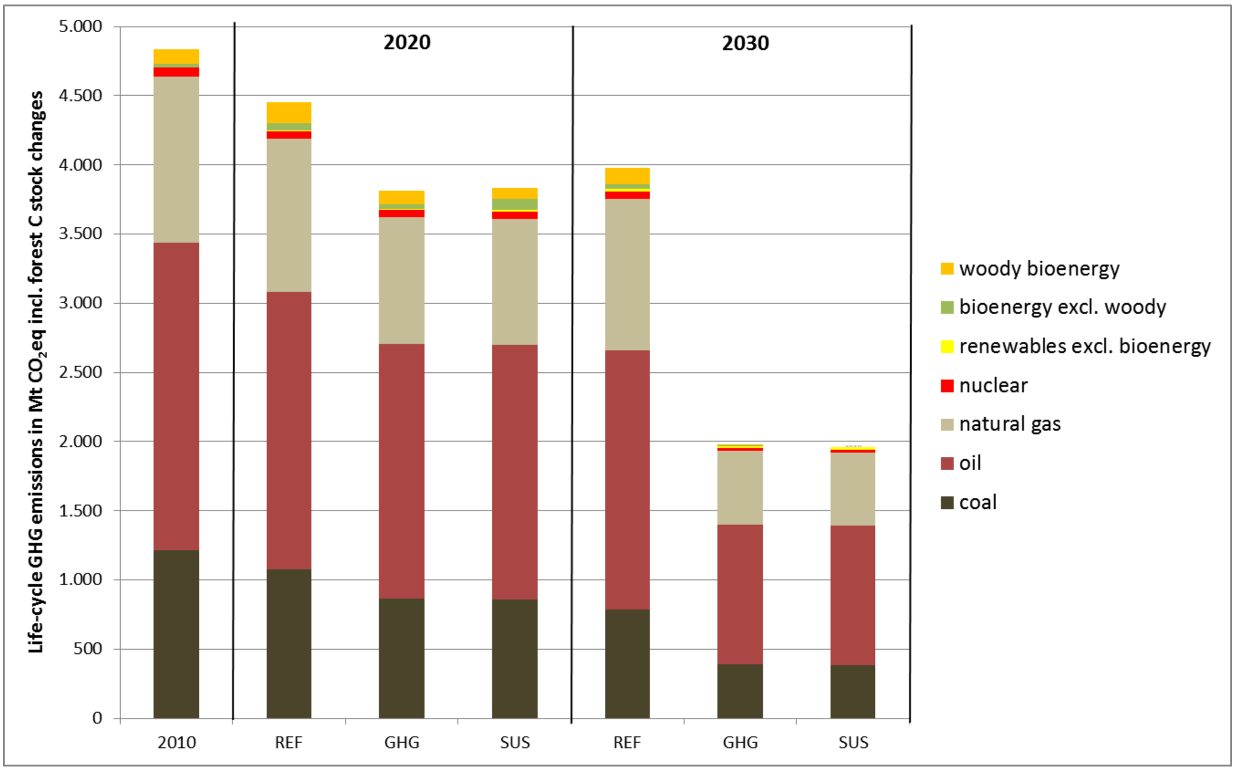


Source: IINAS calculations; data include upstream life-cycle GHG emissions for all energy, and GHG emissions from forest bioenergy using a 20 year time horizon and optimistic forest reference case

The overall GHG emission balance clearly indicates that the biogenic GHG emissions are rather small, compared to the emissions from the remaining fossil fuels. Also the GHG emissions from non-bio-renewables are very small.

These results do not change if a pessimistic forest reference case is assumed for the forest bioenergy, as shown in the following figure.

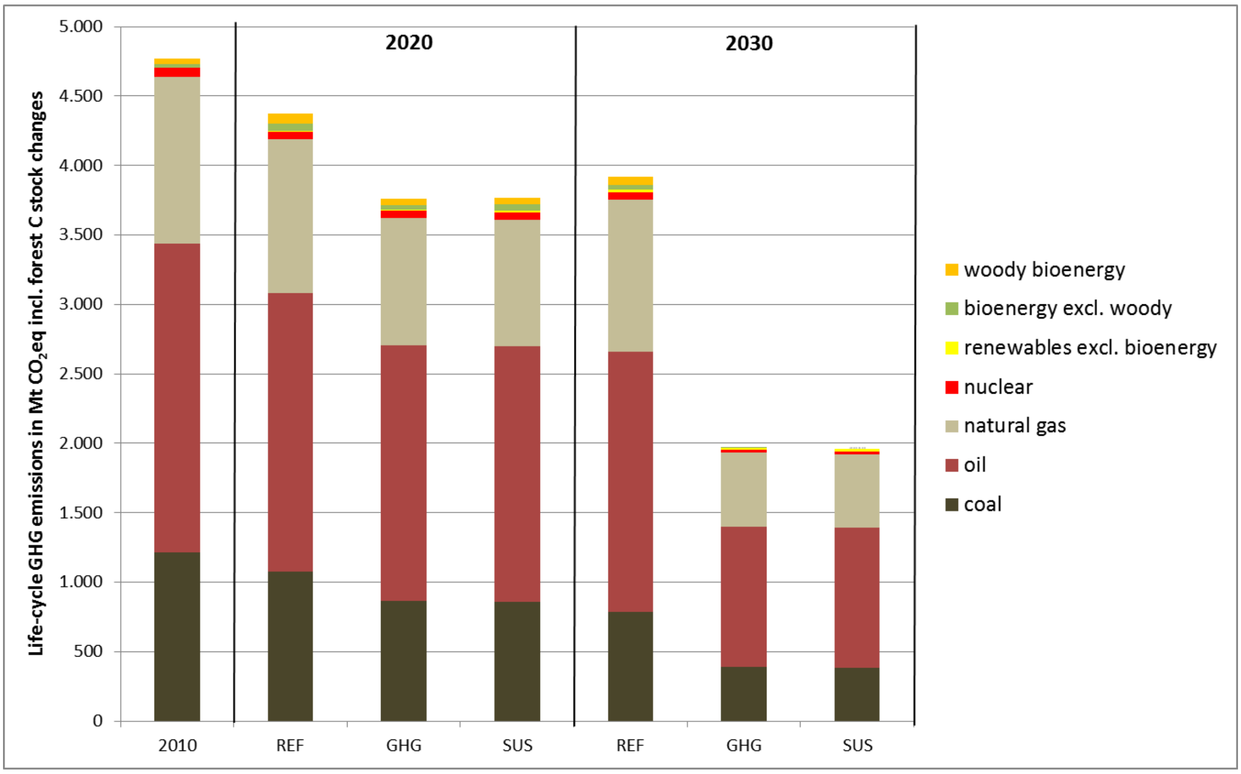
Figure 22 Life-Cycle GHG Emissions from Energy Supply and Use in the EU27 from 2010-2030 with GHG Emissions from Forest Bioenergy for 20 Year Time Horizon and Pessimistic Forest Reference Case



Source: IINAS calculations; data include upstream life-cycle GHG emissions for all energy, and GHG emissions from forest bioenergy using a 20 year time horizon and pessimistic forest reference case

The differences between the results for the 20-year time horizon and the ones for the 100 year time horizon (see following figure) are also quite small - this shows that the discussion of the “carbon debt” associated with forest bioenergy becomes **insignificant if sustainable and low-C options** for forest bioenergy are used.

Figure 23 Life-Cycle GHG Emissions from Energy Supply and Use in the EU27 from 2010-2030 with GHG Emissions from Forest Bioenergy for 100 Year Time Horizon



Source: IINAS calculations; data include upstream life-cycle GHG emissions for all energy, and GHG emissions from forest bioenergy using a 100 year time horizon (results are independent from forest reference case)

For the 100 year time horizon, the net GHG emissions from woody bioenergy in the GHG and SUS scenarios are **less than zero** due to the substitution effect from cogeneration and use of woody construction material.

The remaining fossil fuels dominate the GHG emission balance, with still high contributions from oil, while emissions from coal are reduced significantly, and natural gas is in between.

It should be noted that for oil and gas, the GHG emission factors used here do not reflect potential future contributions from “unconventional” sources such as tar sands, or shale gas **which have higher GHG emissions**.

Furthermore, the GHG balances include emissions from outside of the EU (“upstream” parts of imported energy life-cycles) so that the results cannot be compared directly to the EU GHG emission reporting which is based on a territorial concept.

6 Conclusions and Policy Implications

The EU target of supplying 20% of its energy from renewable sources by 2020 implies to increase the domestic use of renewables significantly, and discussions on the role of renewables for 2030 and beyond are taking place (EC 2014).

- Currently, woody biomass from forests and residues is the largest source of renewables in Europe, and is expected to be used **even more** by 2020.
- For 2030, the role of woody biomass - and bioenergy in general - was analysed with a special focus on potential environmental consequences. Evaluating respective constraints such as biodiversity and GHG emissions showed that these would impact on EU forest biomass potentials.
- Extending protected forests area in the EU and restricting biomass extraction from existing forests would reduce forest potentials by 5% for 2020 and 2030. Applying strict environmental criteria will reduce biomass potential by 30 % compared to the reference potential.
- Considering time-dependent carbon balances of forest bioenergy leads to excluding high-quality roundwood from energy options to reduce GHG emissions in the timeframe of this study.
- On the other hand, the EU potentials for secondary and tertiary wood residues and wastes are high and could be mobilized through **cascading use** policies without negative impacts on biodiversity, and with high net GHG emissions reductions[15].
- Bioenergy is currently also imported to the EU, and imports are expected to increase due to rising demand and cost advantages in the REF scenario. The GHG scenario could reduce imports by 50%, while the SUS scenario would allow to **phase-out imports** not only of woody bioenergy but also of biofuels and their feedstocks.

Fundamental to sustainable bioenergy use is to **reduce demand** by implementing **stringent energy efficiency targets** by 2020 and 2030, respectively. Furthermore, more environmentally-compatible non-biomass renewables such as geothermal, solar and wind should be considered, as these options have high domestic potentials and comparatively low overall cost.

Under these assumptions, the SUS scenario by 2030 uses only **about 25%** of the forest bioenergy consumed in 2010, **completely avoids imports** of woody

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[15] This study also analyzed non-woody bioenergy residues and waste options such as straw and manure. For the straw potentials, soil and carbon conservation was assumed as well based on IC et al. (2012).

bioenergy and biofuels, and shifts towards **domestic bioenergy residues** and wastes, mainly from wood industries and post-consumer wood, and agricultural residues (straw, manure).

In parallel, a **60% net GHG emission reduction** from the energy system (including those from C stock changes in forests) could be achieved in the SUS scenario by 2030, compared to 2010, while the REF scenario would achieve only close to 20% reduction, respectively.

A prerequisite for the GHG and SUS scenarios is to successfully introduce cascading biomass use for energy, improving biogenic waste collection and recycling, and to establish **binding sustainability requirements** for woody and gaseous bioenergy, in parallel to tightening the existing requirements for biofuels.

The sustainable forest biomass potential will suffice to meet woody material demands if **resource-efficient cascades** are implemented, more paper recycled and post-consumer wood be re-used. Additional stemwood for construction material for 5% of new residential buildings in the EU by 2030 would then be available and would lead to significant GHG emission savings from substituting conventional building materials.

Current EU and Member State energy and climate policies **do not stimulate** these developments, though:

Bioenergy, forest, and waste policies are fragmented and unaligned, and incentive schemes mainly address bioenergy **without** considering the full GHG emissions from bioenergy use.

Bioenergy supply - especially from forests and for electricity/heat - is not subject to any coherent sustainability regulation. Only a few Member States such as Denmark, the Netherlands and the UK have started to develop respective policies, which might lead to imbalances within the EU if no framework regulation is implemented.

Imports of woody bioenergy is - with very few exceptions - unregulated as well, but growing relevance of pellets for bioelectricity (co-firing) imply a respective need for EU-level action to avoid internal market distortions.

Last but not least, sustainable woody bioenergy supply also requires regulating biodiversity impacts for forests in a legally binding manner for both the EU, and imports from abroad.

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