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How can solid biomass contribute to the EU's renewable energy targets in 2020, 2030 and what are the GHG drivers and safeguards in energy- and forestry sectors?

Richard Sikkema [a], Svetlana Proskurina [b, **], Manjola Banja [c], Esa Vakkilainen [b, *]

[a] Wageningen University & Research (WUR), Environmental Sciences Group, Droevendaalsesteeg 3a, 6708, PB, Wageningen, the Netherlands
[b] LUT University, Yliopistonkatu 34, 53850, Lappeenranta, Finland
[c] Expert, Air and Climate Unit, Directorate for Energy, Transport and Climate, Joint Research Centre, European Commission, Via Enrico Fermi, 2749, I – 21027, Ispra, Italy

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ABSTRACT

European Union set an ambitious 20% target of its energy consumption from renewable resources 20% by 2020. The aim of this paper is to assess the contribution of solid biomass to renewables use in the EU. During 2010–2018 the share of solid biomass increased from 6.1% to 8.0% of total GFEC, an increase of almost 300 PJ. The paper identifies leading and lagging countries in biomass development by focusing on their current solid biomass share in GFEC. The study shows that leading countries have reached or are close to reach their target, while lagging countries are far from their targets. ETS and non-ETS targets play both a role in the growing use of solid biomass. Despite some challenges, the forest biomass sector allows the sustainable increase of bioenergy in the EU, when the harvest level remains below 90% of net annual increment (except for natural disasters) and there is a stable division between fuelwood and harvested wood for solid products. Forests available for wood supply (FAWS) should be treated differently from non-FAWS areas (protected forests, biodiversity areas), because of different carbon dynamics. The EU Member States may wish to introduce a fixed ratio between FAWS and non FAWS areas, in order to optimally meet the corresponding wishes in EU's forest and biodiversity strategies.

1. Introduction

Deployment of renewable energy sources (RES) for energy purposes has become increasingly significant in the European energy markets. The EU agreed upon a 20% RES target for 2020 (based on Gross Energy Final Consumption or GFEC), which was allocated over individual EU Member State shares under the requirements of the Renewable Energy Directive (RED I) [1]. The revised Renewable Energy Directive (RED II) [2] establishes a binding EU level target of at least 32% for 2030 with a review for increasing this figure in 2023. The role of bioenergy is important for achieving renewable energy (RE) targets. According to the complementing Efficiency Directive [3], biomass fuels should be combusted for electricity and heat in an efficient way. This allows maximising energy security and greenhouse gas (GHG) emissions savings, as well as limit emissions of air pollutants and minimise the pressure on limited biomass resources (RED II) [2]. Finally, there is need for greater synergies between the circular economy and various biomass uses, particularly given the fact that wood can be used for a range of products with higher added value than just energy [4].

The use of RE in the EU has grown from 13.2% in 2010 to 18.0% in 2018. Solid biomass shows one of the largest growths by almost 300 PJ in 2010–2018 [5]. Woody biomass, especially wood pellets, is increasingly used for heating and power production, supported by national support schemes [6,7] and in light of relatively low external costs to reduce GHG emissions [8,9]. Meeting the future RES targets in 2020 (20% via NREAP's) and 2030 (32% via NCEP's) requires a further increase of RE or reducing final energy demand, or both. Next to additional solid biomass that the EU has to source by 2020, it is also relevant to study the impact of policies to reduce GHG's [10]. In RED-I [1], the EU agreed upon 20% GHG emission reduction in 2020, further allocated over the EU Member States (MS) via individual targets. The EU plans to reduce GHG emission in

* Corresponding author.
** Corresponding author.
E-mail addresses: svetlana.proskurina@lut.fi (S. Proskurina), Esa.Vakkilainen@lut.fi (E. Vakkilainen).

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List of abbreviations and definitions

CHP	Cogeneration or combined heat and power
CP	Commitment period (CP1: 2008–2012; CP2: 2013–2020; CP3 2021–2030
CO_2	Carbon dioxide
EROI	Energy Return on Investment Coefficient
EU	European Union
FAWS	Forest available for wood supply
GFEC	Gross Energy Final Consumption
GHG	Greenhouse gas
HWP	Harvested Wood Product
IEA	International Energy Agency
ILUC	Indirect Land Use Change
IR	Industrial Roundwood
IRENA	International Renewable Energy Agency
LCA	Life-cycle Assessment
LULUCF	Land Use, Land Use Change and Forestry
MS	Member States
NECP's	National Energy and Climate Plans (2021–2030)
NREAP's	National Renewable Energy Action Plans (2020 targets)
RE	Renewable Energy
RED	Renewable Energy Directive
RES	Renewable Energy Sources
UK	United Kingdom
WEM	projections "with existing measures"
2009/28/EC	Directive of the European Parliament and of the Council of April 23, 2009 on the promotion of the use of energy from renewable sources (RED-I)
2018/410/EC	Directive to enhance cost-effective emission reductions and low-carbon investments (ETS directive)
2018/841/EC	Regulation of the European Parliament and of the Council lays down accounting rules on greenhouse gas emissions and removals relating to land use, land-use change and forestry ('LULUCF Regulation')
2018/842/EC	Regulation on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement (Effort sharing regulation)
2018/2001/EC	Directive (EU) 2018/2001 of the European Parliament and of the Council of December 11, 2018 on the promotion of the use of energy from renewable sources (RED-II)
2018/2002/EC	Directive (EU) 2018/2002 of December 11, 2018 amending Directive 2012/27/EU on energy efficiency

2030 by at least 40% from 1990 levels [4,11,12]. The effort sharing decision (ESD) [13] is one of the pillars of the EU's 2030 climate and energy framework. Together with the recently revised Emission Trading Scheme (ETS) [14] and the new regulation [15] on land use, land use change and forestry (LULUCF regulation), it creates the binding legal framework for the EU to reduce overall GHG emissions [16]. The Kyoto Protocol did not include agriculture and forests for compliance with GHG emission reduction targets. Since the Paris Climate Agreement [17], forests are officially recognised as a contributor to GHG targets beyond 2020 (i.e. CP3 from 2021 to 2030).

Some studies found a strong correlation between the use of renewable energy sources and GHG emissions. York and McGree [18] conclude that typically nations with more electricity from renewable sources have lower CO_2 emissions per capita, controlling for other factors, than nations with less renewable energy production. Apergis and Payne [19] have similar results: an increase in CO_2 emissions increases renewable energy consumption, while an increase in renewable energy consumption reduces CO_2 emissions in the short run. The European Energy Agency [20,21] showed that the additional consumption of RES allowed the EU to cut its demand for fossil fuels and their associated GHG emissions by about 11% in 2018, compared with a situation in which renewables would have remained at 2005 levels. The avoided gross GHG emissions, due to the approximated estimated increase of RE consumption were divided over 420 million tonnes CO_2eq (77%) by ETS and about 125 million tonnes CO_2eq (23%) by non ETS sector in 2018. The estimated contribution of solid biomass in those sectors is 115 million tonnes of CO_2eq emission reduction.

Our study tries to clarify the role of the set EU RE target in 2020 for achieving lower CO_2 emissions and focuses on the solid biomass usage. One of the drivers of bioenergy development is climate change mitigation and the interest to decrease emissions. In addition, the main research question considered is; did the EU Member States keep their promises to reach RE targets in 2020? Two additional research questions are: ii) to what extent are the GHG emission saving goals in the energy sector an extra driver for using solid biomass? iii) what could be limiting, environmental factors to provide more wood from forests within the EU beyond 2020? The paper is structured in the following manner: section 2 describes the methodology used to facilitate the research topics. Section 3 reviews the progress of solid biomass in each MS, based on the target achievements in NREAP's 2020 (research question 1) and continues with wood pellets as the most dynamic developed solid biofuel in Europe. Section 4.1 reviews the goals and gaps of the energy sector (research question 2) and in section 4.2 he sink changes from forests and harvested wood products (HWP) are regarded. Section 5 is the Discussion part, in which the limitations and safeguards (research question 3) for increasing solid biomass for EU's goals in the NCEP's 2021–2030 are considered. Section 6 ends up with conclusions & policy recommendations.

2. Methodology and basic data assumption

The paper shows the achievements of EU MS in bioenergy shares during 2010–2018. In order to evaluate the best ways, how to reach 2020 and 2030 renewable energy and bioenergy targets, it has a special focus on the sourcing from European forests. To address the research questions in this study, it was decided to divide the EU member countries into three groups. The division and ranking is based on the difference of the share of solid biomass in GFEC. The progress of the development RE also depends on the development of other RE sources such as wind and solar. However, our study focuses on the role of solid biomass as main RE in the EU [91]. This methodology is adopted from Proskurina et al. [22] with leading, intermediate and lagging countries. In Table 1, mostly all data was taken from Eurostat [5].

The EU member states with a share of solid biomass used for electricity and heat production over 12% in 2018 GFEC were ranked as Group 1 (Leading countries). Countries whose solid biomass share in GFEC was from 12% to 6% were ranked as Group 2 (Intermediate countries) and countries whose solid biomass share is less

Table 1
EU countries divided into groups for this study - The gross final energy consumption and the use of solid biomass (including solid bio-waste) for electricity production, and heating & cooling [5,23].

Share of solid biomass in GFEC		Total GFEC (PJ)		Share of energy from renewable sources in GFEC (%)			Gap to 2020 targets (pp)	NREAPs plan solid biomass (PJ)	Solid biomass-el (incl.solid biowaste) (PJ)		solid biomass-th (incl. solid biowaste) (PJ)	
2018		2018	changes from 2010	2010	2018	target 2020	2018	2020	2018	changes from 2010	2018	changes from 2010
over 12%	Leading countries (Group 1)											
31.9	Latvia	183	1	30.4	40.3	40	-0.3	59	2	2	56	14
31.1	Finland	1,131	-15	32.4	41.2	38	-3.2	193	45	6	307	44
26.3	Sweden	1,457	-72	47.0	54.6	49	-5.6	454	43	0	341	-7
26.2	Estonia	138	5	24.6	30.0	25	-5.0	27	4	2	32	3
22.1	Denmark	672	-30	21.9	36.1	30	-6.1	126	19	4	129	31
20.6	Lithuania	242	30	19.6	24.4	23	-1.4	44	1	1	48	12
16.4	Croatia	299	-15	25.1	28.0	20	-8.0	18	1	1	48	-4
15.0	Austria	1,209	11	31.2	33.4	34	0.6	167	15	2	166	-2
13.9	Romania	1,045	38	22.8	23.9	24	0.1	168	1	1	143	-22
6-12%	Intermediate group (Group 2)											
11.9	Bulgaria	455	40	13.9	20.5	16	-4.5	46	5	5	50	12
11.7	Portugal	740	-38	24.2	30.3	34.5	4.2	110	10	1	76	-14
10.3	Slovenia	217	-3	20.4	21.1	25	3.9	22	1	0	22	-3
10.2	Czech R.	1,128	-3	10.5	15.1	13	-2.1	97	8	2	107	21
9.8	Hungary	800	41	12.7	12.5	13	0.5	61	7	-1	71	-3
7.6	Poland	3,140	245	9.3	11.3	15	3.7	231	20	-2	219	28
6.7	France	6,468	-252	12.7	16.6	23	6.4	714	21	9	410	3
6.5	Italy	5,089	-493	13.0	17.8	17	-0.8	248	24	8	309	-9
6.0	Slovakia	475	-21	9.1	11.9	14	2.1	29	4	2	25	2
below 6%	Lagging countries (Group 3)											
5.6	Germany	9,349	-270	11.7	16.5	18	1.5	463	61	7	460	-47
5.3	Greece	698	-128	10.1	18.0	18	0.0	52	0	0	37	1
5.1	Spain	3,733	-140	13.8	17.4	20	2.6	225	18	7	171	17
4.6	Belgium	1,542	-64	5.6	9.4	13	3.6	116	16	3	56	8
4.1	UK	5,599	-427	3.8	11.0	15	4.0	225	98	75	134	69
3.5	Cyprus	70	-3	6.2	13.9	13	-0.9	1		0	2	2
2.7	Netherlands	2,114	-245	3.9	7.4	14	6.6	70	13	-8	43	11
2.2	Luxembourg	170	-7	2.9	9.1	11	1.9	4	1	0	3	1
2.1	Ireland	510	-1	5.7	11.1	16	4.9	21	1	0	10	2
0.2	Malta	23	5	1.0	8.0	10	2.0	0		0	0	0
8.0	EU	48,699	-1,810	13.2	17.98	20	2.0	3,992	439	127	3,476	172

than 6% as Group 3 (Lagging countries). Table 1 shows these three groups. The European solid biomass demand is expected to reach around 4000 PJ in 2020 in the NREAP's (Table 1).

This study is a continuation of previous study by Proskurina et al. [22] in which the group division of EU countries was based on the difference of the share of biomass in 2013 according to Renewable Energy Progress [24] and the achievement of bioenergy targets in 2020 according to National Renewable Energy Action Plans (NREAPs) [23]. Our update focuses on regrouped leading, intermediate and lagging countries, based on their solid biomass development the period 2010–2018. This three part division (leading, intermediate and lagging) is also used in the overviews in sections 4.1 (GHG emissions energy sector) and 4.2 (GHG sinks in forest sector).

3. Results renewable energy targets

This section identifies the main progressive countries in solid biomass development in each studied group of the EU countries. Solid biomass consists of woody biomass, agricultural biomass and renewable waste fractions.

3.1. Biomass progress leading countries (Group 1)

In the Leading countries (Group 1), almost all have exceeded their 2020 plans on solid biomass use for electricity and heating/cooling purposes, except Austria and Romania (see Table 1 where countries are ranked according to their 2018 solid biomass share in the GFEC). Latvia, Denmark, Finland, Lithuania, and Estonia have increased the most their solid biomass share in GFEC. Sweden showed little progress in the share of solid biomass in GFEC, i.e. smaller than 1% points (pp). In other Group 1 countries; Croatia, Austria, and Romania the change followed a negative pace (Fig. 1).

In Baltic countries (Estonia, Latvia, Lithuania), the local biomass use in district heating has increased in the last 5–10 years [25]. Natural gas use has become less popular due to high prices and the policy to reduce import dependency. In 2018, around 50% of the heating demand is served by biomass, mainly from forest chips (slash), locally produced wood chips and wood waste, in the Baltic countries. It is expected that biomass usage continues to increase up to 2030 with additional developments of municipal solid waste and electric heat pumps. In electricity generation, biomass is also used to replace fossil fuels. There is strong competition for biomass resources both domestically and as an export product, but the EU-LULUCF and RE directives [2,3,15] may change the classification of sustainable biomass and alter the available amounts and prices [26]. Moreover, Baltic countries have made much progress in the wood pellets production and its export [6] and this trend is continuing (see section 3.4).

Estonia is active in biomass development. Bioenergy accounts about 95% from the total RE share. Solid biofuels have the largest share in bioenergy in the country. In 2015, the Auvere power plant was launched in Narva by Eesti Energia. The plant uses oil shale as its main fuel, and up to 50% of it can be replaced with biomass [27]. Estonia has launched a bioenergy research project. Its objective is to identify options for Estonia's bioeconomy and potential development of its main value chains as well as exploitation of bioresources to increase competitiveness of Estonia's bioeconomy [28,29]. In 2017, the government of Estonia informed about participation in the IEA Bioenergy Technology Collaboration Programme [29].

Sweden, Finland followed by Denmark are very developed bioenergy users and they will continue to use high share of it.

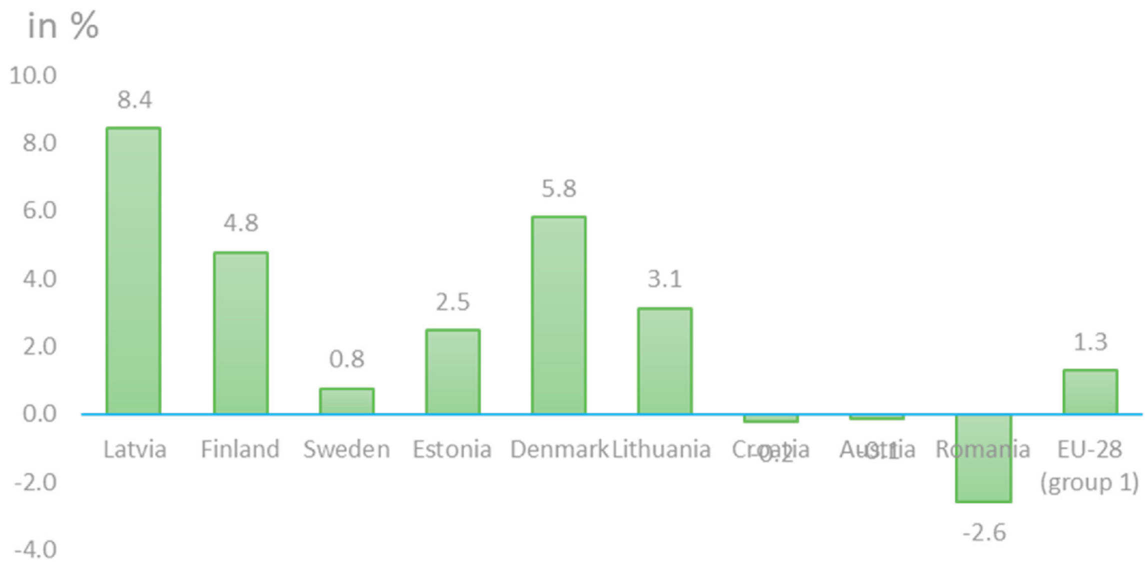

Fig. 1. Changes of solid biomass share in GFEC during 2010–2018, in Group 1, in percentage points [5].

Denmark has committed to phasing out coal by 2020. That means that additional facilities will likely be converted to wood chips or other forms of lower value waste. Alternatively, wood pellet can be used. There is no fuel switch between wood pellets and chips, once the plant is constructed and started up. The majority of future wood pellets growth in Denmark will come from small-scale district heating and continued growth in the residential sector [30]. In Finland, the use of fossil fuel for energy production has decreased every year. In 2018, the use of renewable biomass for district heating and industrial heat continued to grow and was more than 50% of the total energy use [31]. In Sweden, in 2016 in northern Stockholm, the latest of Sweden's biomass-fuelled combined heat and power plants, Värtaverket plant, was commissioned with an installed capacity of 280 MW heat and 130 MW electricity. This is the biggest facility of its kind in Sweden and one of the largest in the EU. The annual output capacity from the facility is rated at 750 GW h electricity and 1700 GW h heat [32].

3.2. Biomass progress in intermediate countries (Group 2)

In the Intermediate countries (Group 2) most of the countries; Italy, Hungary, Poland, Bulgaria and Slovenia have already exceeded their 2020 plans on solid biomass. In this group the share of solid biomass in GFEC over period 2010–2018 increased the most in Bulgaria and Czech Republic. A slight increase took place in Slovakia, Italy, France and Poland (Fig. 2). The increase of solid biomass share in GFEC in Slovakia is explained by the fact that biomass has become popular thanks to replacement of old technology by modern biomass-incinerating equipment in local heating plans. Currently biomass generates almost 5% of the total energy consumed in Slovakia, but there is potential for development. Biomass is one of the basic priorities of the Energy Policy of Slovakia to increase RE share in the country [33].

In Italy, the increase in the share of solid biomass in the GFEC is higher than in France only because Italy has decreased its GFEC by about 5%, Italy also uses additional wood in its heating/cooling sector. Italy is one the largest players on the European wood pellet for residential heating ('bagged pellets') with of 2.6 million tons in 2018 [34], i.e. the consumption has doubled in comparison with 2010. Remarkable: the production declined by 20% in 2010–2018, whereas the import increased by 175%. Next to the import from other EU countries, Italy sources a considerable volume from the US [7,34–36]. France increased slightly the use of solid biomass in its energy sector. However, the country has the largest gap to its 2020 plan among the countries in Group 2. In France, despite of increase of biomass in GFEC, a large difference between current biomass use and targets by NREAP is apparent for both electricity and heat sectors [5,23]. Most likely, switching political priority to other renewables like wind energy and solar energy which increased relatively more than solid biomass, affected the solid biomass share in GFEC in France and Italy [37]. In Portugal, Slovenia, and Hungary the share of solid biomass in GFEC has decreased over this period.

3.3. Biomass progress in lagging countries (Group 3)

Only Cyprus and Greece of the countries in Group 3 have reached or exceeded their 2020 plans on solid biomass. All countries, except for Germany, showed positive development of the solid biomass share in their GFEC, over period 2010–2018 (Fig. 3). The UK had the largest increase, partially explained by the significant decrease of its total GFEC consumption (Table 1). The other reason is that the UK present the largest absolute progresses in solid biomass development. In the UK, overall renewable energy capacity increased with 43.2 GW (GW) in July–September 2018. That is up to 10% higher compared to the same period of the previous year. Generation from bioenergy, including co-firing is the highest among all renewable technologies with 9 TW h. That is more than 15% compared to the July–September 2017 with bioenergy capacity increasing by 10% [38]. Significant progress has been seen in Cyprus mainly related with the very low level of solid biomass in 2010. In other countries the increase of the solid biomass share in GFEC has been found at or below 1 pp. In Greece, the deployment of solid biomass for electricity has remained almost unchanged over this period, and the use of solid biomass for heating/cooling has decreased after 2012. In Netherlands, the use of solid biomass in electricity sector has decreased since 2012 being 38% below that level in 2018. The main progress of solid biomass in Ireland is in the electricity sector [5].

In Germany, renewables addition is related to the rapid deployment of other renewables than solid biomass, especially wind and solar photovoltaics in electricity sector and due to the considerable decrease of GFEC. Germany has had strong bioenergy

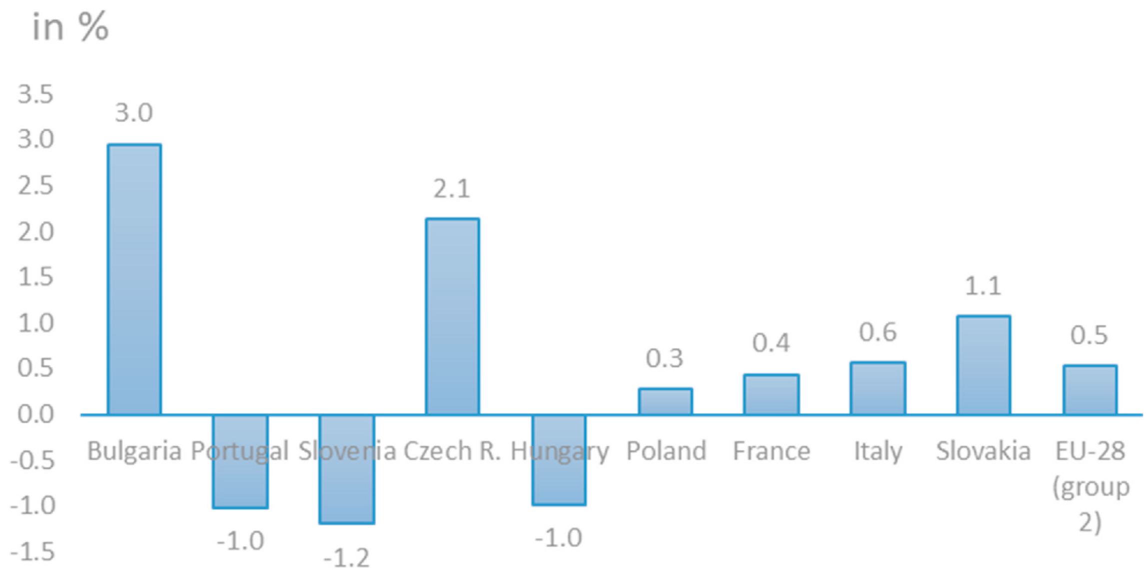

Fig. 2. Changes of solid biomass share in GFEC during 2010–2018, in Group 2, in percentage points, [5].

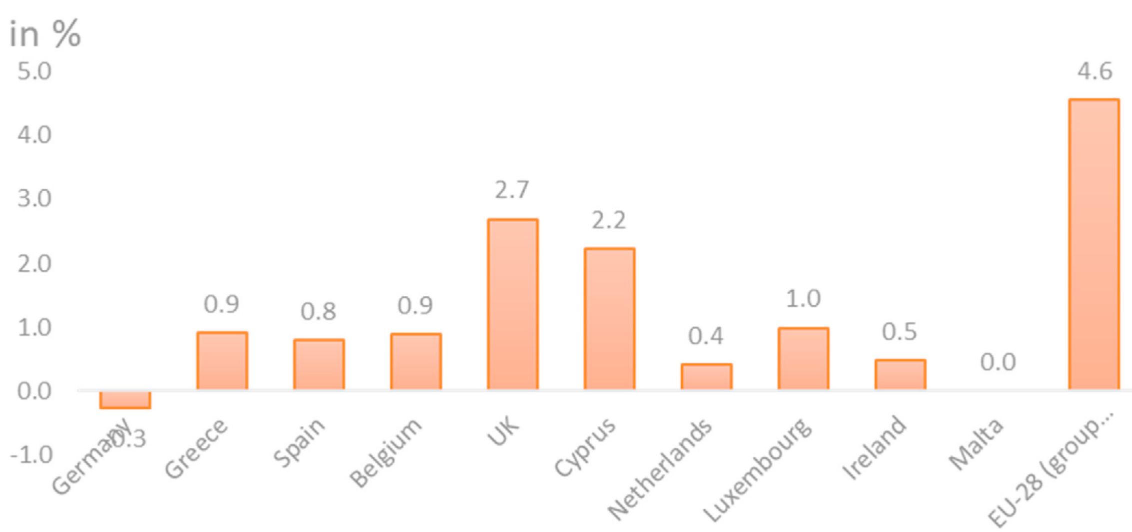

Fig. 3. Changes of solid biomass share in GFEC during 2010–2018, in Group 3, in percentage points [5].

policy support. In 2014, the number of power plants (more than 550), that use solid biomass, increased from the previous years [39]. After wind, biomass is the most important RE source for German electricity production. Electricity generation from biomass and bio-waste waste increased from 32.6 TW h (2010) to 51 TW h (2018). However, the use of solid biomass for heating has decreased since 2015 [5].

3.4. Progress in solid biomass: wood pellets as a key commodity

The EU pellet production has grown by about 80% in the period 2010–2018 [34–36], i.e. by about 7.5 million tonnes. This growth needed a woody feedstock of about 15 million m^3 of woody feedstock, either from industrial residues (sawdust, shavings, particles) or from the forest (low quality roundwood). Those feedstock needs are excluding the use of so called 'hogfuel' (bark and other low quality wood residues) for drying any wet feedstock at the pellet production facilities. Woody fuel is a GHG savings alternative to natural gas drying [2]: it is estimated that up to 24% of carbon neutral "hogfuel" is additionally needed for the pellet production process [40]. Further, relative few post-consumer waste wood is used as feedstock in the pellet production process. This is remarkable, as cascading of such waste wood with energy use at the end is promoted [41]; thus waste fibers for pellet production should be preferred over the use of fresh fibres. One of the large bottlenecks for using post-consumer waste fibers is the administrative barrier: i.e. the EU Waste Framework that is applicable for the transport of waste wood pellets from one country to another [42]. During 2010–2018, new wood pellet production plants have opened and, or the utilization rate of pellet production capacity has increased in the EU Member States. The highest absolute growth in pellet production was recorded throughout all groups: France (+985 Ktonne; 212% increase), Latvia (+962 Ktonne; 156%), Estonia (+867 Ktonne; 205%); Poland (+690 Ktonne; 135%), Germany (+668 Ktonne; 38%), Austria (+495 Ktonne; 58%), Romania (+425 Ktonne; 243%) and Spain (+409 Ktonne; 222%).

Fig. 4 shows the total demand (consumption and export) and supply (production and import) for some key pellet markets, with a supply or demand exceeding 0.35 million tonnes. The pellet markets can be further divided into industrial pellet markets for large scale electricity and combined heat & power production and non-industrial pellets for medium scale district heating and small scale residential heating [7,40]. Three large producers of industrial wood pellet production are from the first studied group: i.e. Estonia, Latvia and Portugal. They export most of the pellets to other EU Member as energy feedstock for large scale power production [34,43]. The largest non-industrial pellet producers are Sweden, Austria (group 1), France, Poland (group 2) and Germany (group 3). Most of their production remains within the country for medium scale district heating or small scale residential heating. In case of Sweden and Poland, also large volumes of industrial pellet qualities are produced for domestic use [43].

UK, and Belgium, the largest consumers of industrial wood pellets are from the third studied group, while Denmark and Sweden are belonging to Group 1 of leading countries (Fig. 4). The total demand for wood pellets in the EU has increased from 10.9 million tonnes in 2010 to 25.7 million tonnes in 2018. The 2010–2018 increase is just more than 50% covered by EU supplies and less than 50% is sourced from outside the EU (USA, Canada and Russia) [34,44].

In 2018, in UK, wood pellet consumption has been increased thanks to the commission of EPH's 396 MW Lynemouth Power Station conversion and the conversion of a 4th unit at the Drax Power Station. The UK pellet consumption is by far the largest in Europe with almost 10.5 million tonnes. Further increase will occur with a ramp up to full operation at Lynemouth and increased availability at the Drax power station in 2019 [43]. The UKdemand is expected to decrease after 2027, as current support for combustion of pellets and other solid biomass under the Renewables Obligation scheme, shall come to an end in 2027 [45]. In Belgium, over the last several years, industrial wood pellet demand has remained relatively stable thanks to mostly two power stations that use wood pellets, both operated by Engie Electrabel, the 80 MW Les Awirs and the 205 MW Max Green power station. Belgium increased wood pellet imports in 2018. This is likely reflective of a higher capacity factor at the biomass plants due to strong electricity markets, and improved conditions in the domestic heating market [30]. The Dutch Energy Agreement stipulates that SDE + subsidies will be used to promote a maximum of 25 PJ of renewable energy per year from co-gasification and co-firing of biomass in coal-fired power stations. Dutch subsidies were already awarded in 2016 for co-firing at four large scale power plants. However, the compliance process of biomass (mostly wood pellets) with the new sustainability requirements was not yet ready and caused some delay. It is expected that Dutch power plants soon increase their pellet volumes for cofiring on a larger scale. If so, then the Netherlands becomes a major player again on the industrial wood pellets market with an expected annual demand in between 2 and 3.4 million tonnes [30,43].

4. GHG sources and sinks in the EU

4.1. Emission reduction in the energy sector

EU has created European Trading Scheme (ETS) to steer large greenhouse gas emitters. By having a yearly diminishing cap of emissions and possibility to trade them enables greenhouse gas emission reductions in a cost-effective way. The rest of the GHG, mostly from small emitters are lumped under the Effort Sharing Decision (ESD), indicated in our study as non-ETS, which is steered by national legislations.

The GHG drivers for increasing the solid biomass use are assumed to be twofold, either to close the gap in the ETS sector, in which the large power production companies have their stake or the gap in the non ETS sector, in which the heating and cooling sector is one of the key players. Whereas the power sector has increased the use of industrial pellets as main feedstock, the heating & cooling sector is making use of more diverse feedstock: from non-industrial pellets and wood chips, to agricultural residues and bio-waste.

4.1.1. ETS sector target gaps

Globally, the use of forest and other solid biomass for electricity production is steadily increasing [51].The biggest percentage increases in EU were in Poland and the UK from the Groups 2 and 3 respectively (Table 2). This shows that increasing biomass use for electricity significantly is possible if a country is willing to do that. The main driver for such increase seems to be the nationally targeted decreases in GHG emissions. In many countries this means substituting wood for coal. An overview of capacities for all solid

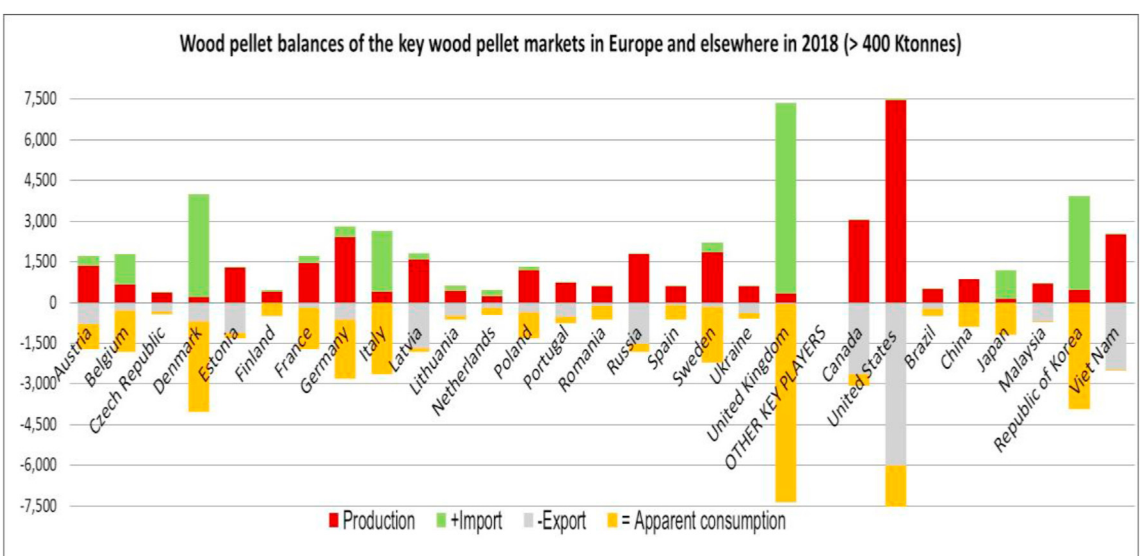

Fig. 4. Combined industrial and non-industrial wood pellets markets in the EU and outside the EU, the key players in 2018, in 1000 tonnes [34].

Table 2
The three groups for the purpose of this study, adopted from [46–50] - GHG emissions per EU Member State (excl. LULUCF), and expected gaps for ETS and non-ETS sectors to WEM in 2018.

Share of solid biomass in GFEC 2018		EU MS emission 2018 excl LULUCF [46] Mt CO2	Subdivision of annual emissions 2018: of which ETS * [47] in Mt CO2-eq	Subdivision of annual emissions 2018: o.w. non ETS (ESD emissions) [49, 50] Mt CO2-eq	Expected GAP 2020 ETS & non-ETS GAP MtCO2-eq	of which GAP ETS 2020 ** [48, 49, 50] Mt CO2-eq	of which GAP non ETS 2020 scenario 'existing ESD measures' [49, 50] Mt CO2-eq
over 12%	Leading countries (Group 1)						
31.9	Latvia	12	3	9	2	1	1
31.1	Finland	56	26	30	7	8	-0.5
26.3	Sweden	52	20	33	6	-1	7
26.2	Estonia	20	14	6	11	11	0.1
22.1	Denmark	48	12	32	5	5	0.2
20.6	Lithuania	20	6	14	3	1	1
16.4	Croatia	24	7	17	6	3	3
15.0	Austria	79	28	51	5	8	-3
13.9	Romania	117	40	74	36	23	13
6-12%	Intermediate group (Group 2)						
11.9	Bulgaria	58	31	27	39	38	1
11.7	Portugal	67	26	41	27	15	12
10.3	Slovenia	18	7	11	7	6	2
10.2	Czech R.	127	67	64	49	45	4
9.8	Hungary	63	22	43	21	11	10
7.6	Poland	413	200	218	149	150	0
6.7	France	452	98	343	42	45	-3
6.5	Italy	428	147	275	112	89	23
6.0	Slovakia	43	22	22	12	8	5
below 6%	Lagging countries (Group 3)						
5.6	Germany	858	422	441	230	255	-26
5.3	Greece	92	47	45	41	28	13
5.1	Spain	334	127	203	77	68	10
4.6	Belgium	118	44	71	7	10	-4
4.1	UK	466	129	329	117	73	45
3.5	Cyprus	9	5	4	3	3	0
2.7	Netherlands	188	87	102	47	33	13
2.2	Luxembourg	11	2	9	0	0.3	-0.5
2.1	Ireland	61	16	45	3	10	-7
0.2	Malta	2	1	2	1	1.0	-0.3
8.0	EU	4237	1655	2562	1064	945	118

* excluding aviation
** gap ETS = emissions 2020 (WEM scenario) - allowances installations & aircrafts

biomass is indicated in Fig. 5, with UK and Sweden as frontrunners.

Different solid biomass types can be used instead of coal, for example, torrefied biomass, which technical characteristics are close to coal [52] or industrial wood pellets. Closure of the least-efficient coal-fired power plants is very crucial in GHG emission reduction [53,54]. European wood-pellet-based power-plant generation capacity exceeded 6 GW in 2018 and is forecast to surpass 8 GW by 2020 [44].

It can be seen that the leading counties, i.e. countries significantly using solid biomass and other renewable energy sources, have much lower GAPs in the ETS sector than countries in the intermediate and lagging group. Some intermediate countries, and most of the lagging countries have large GAPs. It might be speculated that those latter countries have relative high needs for sourcing solid biomass for reaching their national goals in near future.

Most of the EU Member States have submitted their final NCEP's, except for Ireland. A prognosis for solid wood only cannot be made, as most of the 2030 expectations cover the full biomass segment, by including biogas and liquid transportation fuels. The inclusive 2030 prognosis results in a growth of biomass in leading countries (+8 PJ) and intermediate countries (54 PJ), but a decrease of 61 PJ in lagging countries in the period 2020–2030 [55]. The total biomass increase in groups 1 and 2 is thus counteracted by a decrease in group 3.The UK biomass demand is expected to decline after 2027, due to the end of the current subsidy support scheme [45].

4.1.2. Non ETS sector (ESD) target gaps

Measures addressing energy use for heating and cooling in the buildings sector helped deliver the largest contribution to overall reductions in Effort Sharing emissions between 2005 and 2018 (50%). Such measures were in particular improvements in energy efficiency and the switch to less carbon intensive fuels for heating and cooling, including renewable energy sources [56]. The use of solid biomass for district heating is one of those sources.

Even though the non ETS sector greenhouse gas emissions are a slightly larger than those of the ETS sector, the GAPs in the non ETS sector (under the WEM scenario) are considerably lower for the non ETS sector in 2018 (Table 2). Overall, the apparent ambition of non ETS (e.g. heating plants) to close the remaining gaps is lower than the one of ETS (power sector). So one should expect a relatively small growth of solid biomass use in heating plants until 2020.

Following the recent submission of final NCEP's [55], the heating and cooling sector is expecting an increase of respectively 75 PJ

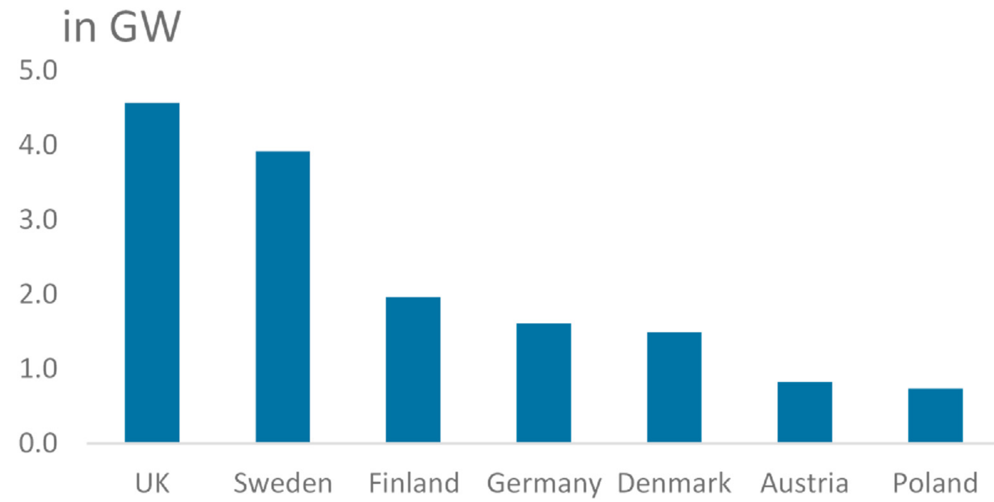

Fig. 5. The main EU countries in power production from burning solid biomass, in 2018, indicated in power production capacities GW [5].

(leading countries), nearly 300 PJ (intermediate countries) and 50 PJ (lagging countries), so an increase of around 425 PJ in between 2020 and 2030. Solid, gaseous and liquid biomass are included again as total biomass category in this data.

4.2. GHG sinks in the forest sector

To estimate whether additional future growth of solid biomass can comply with available feedstocks within the EU, the sink changes in the EU's forest sector are regarded. Any sink changes in forests of countries outside the EU are considered in the safeguard for sustainable sourcing (section 5.2). As wood is harvested on forests available for wood supply (FAWS; section 5.3), the sink changes in FAWS should be regarded. However, the current statistics show sinks in total forests, also including protected forests and nature reserves (bias). The Discussion section evaluates the possible additional harvests for energy and solid wood markets and the need for safeguards in sections 5.4 and 5.5.

In June 2018, the European Parliament and Council of the European Union adopted a legislative regulation for incorporating GHG emissions and removals from Land Use, Land Use Change and Forestry (EULULUCF) under its 2030 Climate and Energy Framework [15]. The LULUCF regulation aims to incentivise EU Member States to decrease GHG emissions and increase removals in the LULUCF sector.

In most EU countries the annual carbon sink in forests has decreased since 2010, except for Hungary, Poland, Germany, Cyprus and Luxemburg (Fig. 6; dark green bars). Nevertheless, all countries remain with a net GHG sink in the forests in 2018, except Denmark, Slovenia and Czech Republic [46]. Possible carbon uptake or release by forest soils is not included in these figures. The forest sink decrease can be two-fold, either the total forest is aging (less carbon is fixed by older, mature trees) and, or the harvest level has increased. More harvesting means more emissions on the one hand. The carbon from felled trees used for bioenergy, including woody feedstock for pellets, is reported as an immediate CO_2 emission. More harvesting can lead to renewed uptake of carbon in harvested wood products (HWP) on the other hand. There is a net carbon sink in HWP, when the buildup of carbon in the new products stock is larger than the decay of older existing stock of HWP. Countries with larger, increasing sinks in HWP are Finland, Romania and Spain (light green bars). Countries with decreasing HWP sinks (less fixation) are Sweden, France and Germany (orange bars). The role of Germany is an interesting example to highlight more in detail: the sink in the forest is increasing, while the one in HWP is decreasing. On the one hand, the production of fuelwood has decreased by about 5.4 million m^3 in the period 2010–2018 [34,57] The increasing forest sink is thus due to a decreasing fuelwood harvest (less immediate emissions), plus possible larger carbon uptake by relative young forests in 2018 in comparison with older forests in 2010. On the other hand, the production of industrial roundwood (for solid products) has increased by about 2.8 million m^3. The effect of additional inflow of new HWP in the HWP carbon stock is now more than counteracted by the outflow of older HWP (decay based on lifetimes of wood products).

Overall, leading and intermediate countries have relatively large decreasing forest sinks (red bars), also because they have relatively large forest areas (Fig. 6). When using more wood for bioenergy and saving GHG emissions in the energy sector, the GHG sink in the forests can change in an opposite direction in time. Actually, a possible sink decrease after harvesting wood for bioenergy (merely thinning of small trees) can be compensated in near future. This compensation is twofold: first, the regeneration of the harvested forest areas through natural seeding (or planted seedlings) shall lead to new carbon uptake. Second, the remaining larger trees (after thinning) may grow larger and thicker than in the former situation without thinning of trees.

5. Discussion

Environmental issues stimulate development of renewable energy in the EU countries including biomass development. For example, the substitution of coal by wood pellets for large-scale power production has fuelled solid biomass use. A serious drawback is whether fossil fuels are 100% substituted by biomass. York [58] claimed that the global increase of biomass is used to satisfy growing demands of electricity on top of current global needs. The policy challenge is to ensure that clean energy sources replace rather than add to carbon-based energy [4]. Another debate is the large import of wood pellets from one country to another. What happens with the carbon balance in the other forests, when using carbon neutral wood for substituting fossil fuels? For balancing of GHG emission reduction in the energy sector on the one hand, and maintaining or increasing carbon sinks in the forest sector on the other hand, five safeguards are important to keep track of.

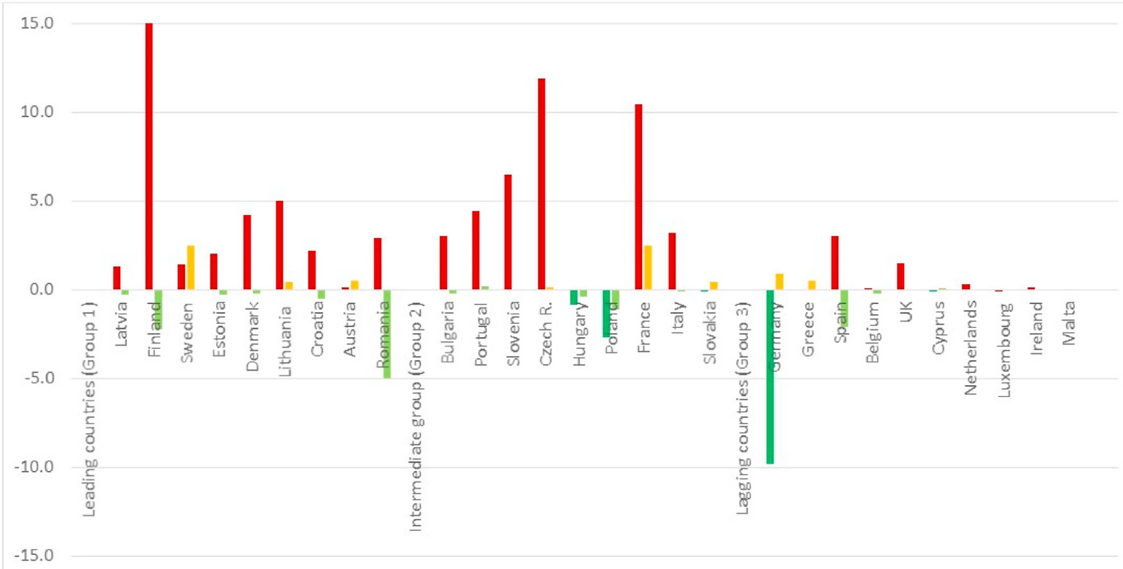

Fig. 6. GHG sink changes in forests and HWP in 2010–2018 in million tonnes of CO2-eq [46].

5.1. Energy efficiency (safeguard 1)

The RED II requires that at least 70% of the GHG emissions should be saved when switching from fossil fuel pathways to solid or gaseous biomass pathway after January 2021 and 80% after January 2026 [2]. Pellets would be more affected by fossil energy usage than wood chips, as more processing energy is needed for their production [59,60]. According to the accompanying Annex VI in the RED-II [2], pellet mills using a natural gas boiler to provide process heat to the pellet mills, have GHG emission savings generally less than 70%. When using a wood chips boiler, fed with pre-dried chips, the GHG savings threshold of 70% can be reached. The higher threshold of 80% can be reached when a CHP with pre-dried wood chips is used to provide electricity and process heat to the pellet mill [2].

To promote the synergies between circular bio-economy and various biomass uses (section 1) to the fullest, only efficient biomass to energy conversion should receive public support, except for security of power supply [4]. Financial support should focus on cost-effective methods for increasing energy efficiency, which would lead to a reduction in energy consumption [3]. Actually, we have different energy efficiency thresholds for biomass conversion at the end [2,61,62], ranging from relative low efficiencies (η) for small scale seasonal space heating using logs ($\eta = 30\%$) and large scale electricity production only (36%) to more efficient conversion pathways via seasonal space heating using pellets (65%), medium scale boilers (77%) and high efficient cogeneration (CHP). In a quick scan [63], the total solid biomass share by all EU households together was estimated at about 41% of total solid biomass consumption in the EU [24]. This residential use can be split into about 4% occurring via efficient pellet stoves and pellet boilers [64] and a remaining share of 37% via for other, non-pellet based appliances like less efficient fire places and log boilers (η 30% or lower). Further, the solid biomass share of relative low efficient cofiring of pellets in powerplants (η around 40%), was estimated in between 4% and 7% of total solid biomass use in 2017 [65].

5.2. Sustainable sourcing (safeguard 2)

The European Commission will also continue to support sustainable wood mobilisation through the EURural Development Policy. These levels of action are complementary in supporting sustainable forest management practices [4]. The four largest EU importers of solid biomass for energy (>1 million tonnes; mainly wood pellets) in 2018 were the UK, Denmark, Belgium and Italy. Those pellets were mainly sourced from North America, based on long term contracts. For the next decade, wood pellets shall be largely sourced from the United States [30,66]. The EU Member States have their regulatory requirements for trade and use of sustainable biomass. Those are based on the RED-II, plus some additional country specific requirements [66]. Following the original RED and RED-II [1,2], countries prescribe a threshold (electrical or thermal capacity) above which sustainability criteria should be applied. For example, the UKlegislation [67] requires operators of generating stations with a total installed capacity of at least 1 MW using solid biomass, to report against, and meet, the sustainability criteria to get support under the scheme. For generating stations with a declared net capacity in between 50 kW and 1 MW, operators must report against the sustainability criteria, but this does not link to support under the scheme. That means that small scale heating appliances, like residential pellet boilers and fireplaces, are not bound to those sustainability guidelines.

Generally, the EU power utilities and heating plants have to proof the sustainability concept, starting from the pellet production plant (domestic and abroad). As an example, the UK's timber procurement policies [67] accepts a risk based approach for pellet plants to document the sustainability of bioenergy feedstocks at a regional scale, or a more detailed approach with requirements at the level of a forest management unit (FMU). The second approach is combined with existing sustainable forest management (SFM) standards like Forest Stewardship Council (FSC) and Program for the Endorsment of Forest Certification (PEFC). For the first approach such a combination is possible, but then with the less demanding re-quirements from FSC Controlled Wood and PEFC Controlled Sour-ces. Also Denmark [68] and Belgium [69,70] have such solid biomass feedstock standards. The new Dutch framework [71] is the most stringent as it requires a FMU approach for pellet plants. Also there is a specific requirement to retain or increasing carbon stocks in the FMU in the medium or long term [66,72], next to the SFM certification at the FMU level. The forest carbon sink is also an item in the sustainable biomass partnership (SBP) of the EU's energy sector [73]. The SBP allows for a risk-based approach for the biomass sourcing, next to the option for certified FMU units. As such it fits almost seamlessly to the EU Member Sates' frameworks. Maintenance of carbon stocks is rather globally included as an element into SBP's risk-based approach. However, it is actually not applied when operators make use of FSC, PEFC or any other compatible SFM standards (SBP compliant feedstock).

Italy, the fourth largest EU importer of pellets, does not have specific sustainability requirements for energy feedstock. Earlier inventories [7,74,75] found that US pellet exports to Italy are mainly used for residential, domestic heating (put into small bags in the receiving harbor of Genoa), while the remaining part can be forwarded for heating or transshipped as industrial pellets to other EU Member States. Power plants now and then make use of this option, in time of shortage.

5.3. Forest available for wood supply (FAWS) and other forest areas (safeguard 3)

Since 2000, the EU forests available for wood supply are increasing by a little bit more than 1% [76]. The EU forest area available for wood supply has increased by about 95,000 ha per annum in the period 2010–2015 (Table 3). On average 84% of EU forest area is available for wood supply (FAWS) and 16% is not available for wood supply (non FAWS). The FAWS can be affected in different ways: i) an increase in total forest area (afforestation, reforestation) with part of the increase allocated for wood production; ii) a decline in total forest area (deforestation) or iii) changing forest functions of an existing area. With regards to the latter, when more forest area is protected for nature or other conservation purposes, the FAWS will decrease and this may result in aging forests (see section 4.2).

From 2000 to 2015, several countries in Group 1 (leading countries) dealt with decreasing areas available for wood supply; Finland, Sweden, Estonia and Romania. A shift towards more protected areas seems to have occurred, as the remaining forest area (non FAWS) has increased. On average, about 79% of group 1 forest area was available for wood supply and 21% of the total forest area was not available for wood supply in 2015.

In Group 2, Bulgaria, Slovenia, Czech Republic and Poland had also a shift from FAWS to non FAWS area, whereas France and Italy both had an increase in FAWS and non FAWS area. Portugal is an exception, with a decrease of both FAWS and non FAWS area. On average, about 86% of group 2 forest area is available for wood supply and 14% is not available for wood supply in 2015.

In Group 3, Greece, Spain and United Kingdom had an increasing FAWS and non FAWS area. Ireland had another trend with an increasing area of FAWS and a diminishing area of forests not available for wood supply. Overall, 87% of the forests in group 3 are available for wood supply. Although relatively more forests are available for wood supply in group 3, the absolute FAWS in group 3

Table 3
Forest available for wood supply in 1000 ha adopted from [76].

	Forest available for wood supply (FAWS) (1000 ha)				Other forests* (non FAWS) (1000 ha)				Share of non FAWS in total forest area (%)
	2000	2005	2010	2015	2000	2005	2010	2015	2015
Leading countries (Group 1)									
Latvia	3024	3088	3149	3151	217	209	205	205	6.1
Finland	20317	20051	19465	19465	2141	2111	2753	2753	12.4
Sweden	20771	20234	20033	19832	7392	7984	8040	8241	29.4
Estonia	2103	2074	2008	1994	140	178	226	238	10.7
Denmark	566	534	552	572	19	24	35	40	6.5
Lithuania	1756	1835	1852	1924	264	286	318	256	11.7
Croatia	1749	1745	1741	1740	136	158	179	182	9.5
Austria	3342	3343	3341	3339	496	508	519	530	13.7
Romania	5029	5049	5147	4627	1337	1342	1368	2234	32.6
Subtotal group 1	58657	57952	57288	56644	12143	12801	13643	14679	20.6
Intermediate countries (Group 2)									
Bulgaria	2258	2561	2387	2213	1117	1090	1350	1610	42.1
Portugal	2229	2206	2147	2088	1114	1090	1092	1094	34.4
Slovenia	1157	1166	1175	1139	76	77	72	109	8.7
Czechia	2561	2519	2310	2301	76	129	347	367	13.7
Hungary	1622	1684	1729	1779	285	299	317	290	14
Poland	8342	8417	8128	8234	717	783	1201	1201	12.7
France	14465	15195	15607	16018	824	666	817	971	5.7
Italy	7396	7741	7979	8216	973	1018	1049	1081	11.6
Slovakia	1767	1751	1779	1785	154	181	160	155	7.98
Subtotal group 2	41797	43239	43241	43773	5337	5333	6405	6877	13.6
Lagging countries (group 3)									
Germany	10833	10862	10886	10888	521	522	523	531	4.7
Greece	3317	3456	3595	3595	284	296	308	308	7.9
Spain	13942	13804	14575	14711	3035	3478	3672	3707	20.1
Belgium	663	665	668	670	4	9	13	13	1.9
United Kingdom	2954	3021	3059	3144	0	0	0	0	0
Cyprus	43	41	41	41	128	131	131	132	76.2
Netherlands	288	293	299	301	72	72	75	75	19.9
Luxembourg	87	86	86	86	0	1	1	1	0.7
Ireland	472	580	608	632	163	115	117	122	16.2
Malta	-	-	-	-	-	-	-	-	-
Subtotal group 3	32599	32808	33817	34068	4207	4624	4842	4888	12.5
EU	133054	134000	133172	134486	21686	22758	26064	26445	16.4

(34 million ha) is much lower than group 2 (44 million ha) and group 1 (56 million ha).

As an extra safeguard, both the FAWS and non FAWS (e.g. protected forests) have increased in 2000–2015. For comparison: a study by Song et al. [77] concluded that EU forest cover is growing, covering the period 1982–2016. Another study by Kauppi et al. [78] also concluded that the forest area expands in Europe. In the long-term perspective, more forest will be available in the EU with less losses of forest area.

5.4. Felling as a rate of net annual increment (safeguard 4)

On average, about 63% of the net annual forest growth in Europe is harvested, which means that the living biomass stock is growing (carbon sink). National forest authorities may allow for additional wood removals ("salvage logging") under extra ordinary circumstances (natural hazards like storms and insect attacks), to salvage timber and propagate risk control of insect outbreaks, fires, etc. Dead wood (mortality) is not considered within the net increment or felling figures, but generally included in gross increment. Deadwood remains in the forest for biodiversity purposes and is definitely not available as feedstock for solid wood products or bioenergy.

As an extra safeguard for the forest sector, we assumed a felling ceiling of 90% of the net annual increment [79]. Almost all EU Member States have a felling rate in between 60% and 90% (green bars in Fig. 7). Sweden and Austria have experienced unforeseen natural hazards in 2000–2009, consequent gradual salvage logging and reduction of the NAI according to the latest Forest Europe figures for 2010 [80]. At the end more than 90% of NAI was felled in 2010 (red bars). In case of Sweden, the large storm Gudrun (2005) lead to delayed removals of felled trees [81]. There is a slightly different compilation of merchantable tree volumes: the NAI is based on tree diameters (DBH) 10 cm and above, whereas the felling includes a small share of trees with a DBH smaller than 10 cm. In case of Austria, storm Kyrill (2007) and, to a lesser extent, bark beetles caused some delayed removal of trees from the forests [82]. The EU Member States with felling rates below 60% have the potential to increase their felling level (orange bars). Three of those countries are belonging to intermediate group 2 (Slovenia, Italy and France) and the remaining countries belong to lagging group 3. Theoretical simulations showed that under "continuation of forest management practices" the harvest (wood removals) in 26 EU countries (excluding Malta and Cyprus) increase from 430 million m^3 per year in 2000–2009 (base period) to 560 million m^3 per year in 2050 (+30%) mainly due to progressing age classes. When setting a felling maximum of 90% to the forest increment per EU Member State, the harvest could sustainably increase by 15%–493 million m^3 per year [34,83].

Moreover, bioenergy allows the utilization of low-quality wood, such as tops, branches, and early thinning, thanks to country specific incentives for sustainable forest management, like the support for early, non-commercial thinnings in Finland. The increment figures (Fig. 7) are usually based on the main stem of a tree (merchantable biomass), with tree sizes globally above 10 cm excluding branches, roots and foliage. The additional share of branches could range from 15% (old trees) to 40% (young trees) on top of the merchantable stem volumes.

5.5. Harvest ratio bioenergy and solid wood products (safeguard 5)

The average annual production of roundwood on the EU level in the period 2010–2018 increased by about 40 million m^3 to 470 million m^3 in comparison with the period 2000–2009 [34]. There was a growing use of fuelwood as feedstock for pellet production and other energy purposes, and a more or less stable use of industrial roundwood. The production of fuelwood increased by 30 million m^3 (+35%), while the industrial roundwood increased by 10 million m^3 (+3%). Industrial roundwood is processed for solid products, like sawnwood, wood based panels and paper products. Those solid products are indicated as harvested wood products (HWP). As a rule of thumb, the annual production of roundwood is about the same as fellings of trees, but minus 5%–10% of tops left behind in the forest after the harvest.

A new eminent sustainability aspect could be a kind of equilibrium between the harvest of wood for solid wood products on the one hand and for bioenergy on the other hand. In the LULUCF regulation [15], the European Commission stated that EU Member States MS) shall assume a constant ratio between solid and energy use of forest biomass, as documented in 2000–2009 (base period), for determining a forest reference level (FRL). Also the overarching national forestry accounting plans (NFAPs) shall contain information on how harvesting rates are expected to develop under different policy scenarios, with historical and future harvesting rates disaggregated between energy and non-energy uses [15]. The low-quality roundwood feedstock for pellet production belongs to the bioenergy category (fuelwood).

As a possible extra safeguard we assume that the 2000–2009

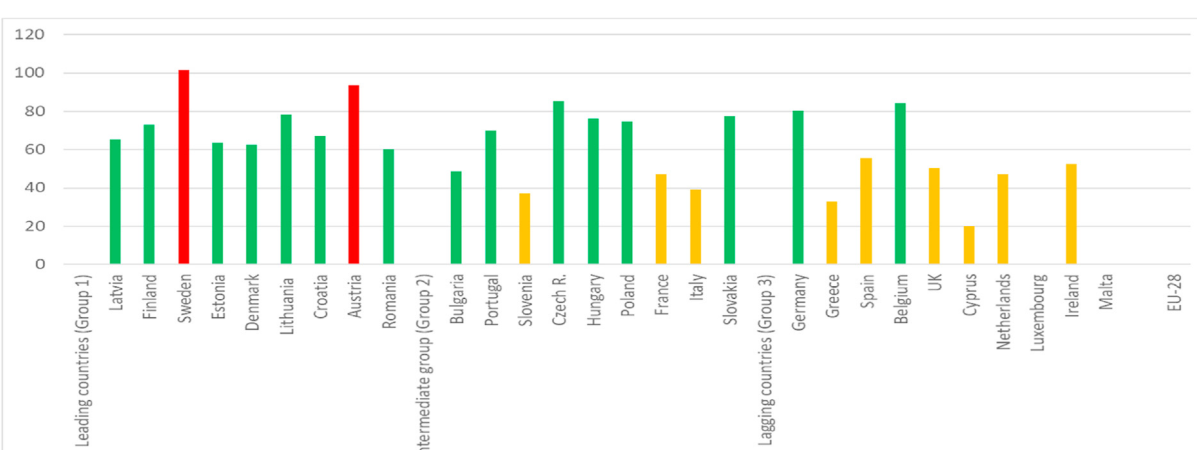

Fig. 7. Felling as percent of net annual increment in 2010 in FAWS [80,84]. Legend: Red bars >90% of NAI is harvested; green bars; up to 90% of NAI harvested, regarded as sustainable [83]; orange bars; underutilized harvest < 60%.

ratio could be maintained in the period beyond 2020, thus becoming applicable for a new commitment period (2021–2030) in the international climate framework [17]. What is the current development of the ratio solid wood and energy use over the period 2010–2018? For this purpose, we have analysed the bioenergy - solid wood ratio in the roundwood production of the fifteen largest pellet producing countries (Table 4). The ratio between bioenergy and solid use changed from 20/80 (base period) to 25/75 (latest period) on the EU level. In our assumptions, such a ratio change could hypothetically create 'fictive debits'.

While the consumption of non-industrial and industrial pellets is occurring across all EU countries, most of the supplies were provided by the leading countries, next to additional imports from North America and Russia (section 3.4). How has the harvest ratio in the EU countries developed? The leading countries show a fictive debit in the current period (2010–2018) except for Sweden with a negligible change of ratio (<1%). The other large pellet producing countries in group 2 and group 3 have a fictive debit on their GHG account, except for Portugal. To compensate for a hypothetical debit, energy wood mobilisation can be combined with an increase of industrial roundwood harvest for solid wood. The same safeguard should be valid for future mobilisation of wood beyond 2020: it is relevant to have a kind of stable equilibrium between the felling of industrial roundwood and of fuelwood.

6. Conclusions & recommendations

6.1. RES shares, GHG emissions energy sector and carbon sinks in forests (2020)

The role of solid biomass increased from 6.1% to 8.0% in gross final energy consumption in 2010–2018, divided over the use of power production (+127 PJ) and heating & cooling (+172 PJ). About 5–10 years ago, this seemed a very ambitious target [22], but with the latest data until 2018, it seems that the EU is going to reach its overall Renewable Energy targets. The leading countries from group 1, which have solid biomass share over 12% in the GFEC are in a good track to reach RE targets or have already reached it (Table 1). Nevertheless, some EU Member States from the Intermediate group (Portugal Slovenia, Poland and France) and the Lagging group (Belgium, UK, the Netherlands and Ireland) may have difficulties to reach their targets by 2020, as their RES gap is more than 3.5% of the RES target 2020.

The EU decreased its GHG emissions (excl. LUCF; excl. aviation) by 573 million tonnes CO_2 in 2010–2018, i.e. –12% [86]. In relative terms, the role of solid biomass for electricity and heating/cooling purposes was estimated at 21% of the overall GHG emission savings [20]. The ETS sector had in 2018 a gap of 945 million tonnes CO_2 to reach the NREAP 2020 targets and the non ETS sector a gap of 118 million tonnes CO_2. Power plants have a considerable share in ETS, whereas heating and cooling plants are mostly allocated to the non ETS sector.

Overall, the sink in the EU forests decreased by 15%, due to aging forests and to slightly increasing harvest levels in the period 2010–2018. The sink in the harvested wood products, after the harvest of industrial roundwood for solid products, increased by 12% in the same period. The overall EU forest sink in 2018 (uptake of carbon in living biomass; excluding carbon in soils) is about 365 million tonnes of CO_2, and the one in HWP about 45 million tonnes of CO_2eq.

6.2. Policy recommendations (2030)

The newly published NCEP's foresee a stabilisation of overall biomass use in the electricity sector and an increase of 425 PJ for heating and cooling in the period 2020–2030 [55]. Most of the current biomass use is sourced from solid biomass, next to gaseous biomass and liquid biomass. If we assume that 100% of future needs is solid woody biomass, then nearly 25 million tonnes of pellet equivalents is foreseen, with an equivalent woody feedstock of

Table 4
Changing shares of solid wood and bioenergy as represented by production of fuelwood and industrial roundwood (IR) in % of national harvests, for the fifteen largest pellet producers in the EU; adopted from [34,85].

	2000-2009		2010-2018		Hypothetical conclusion based on current period
	fuelwood	IR	fuelwood	IR	
Leading countries (Group 1)					
Latvia	9	91	12	88	Fictive debit
Finland	9	91	12	88	Fictive debit
Sweden	8	92	9	91	negligible
Estonia	20	80	30	70	Fictive debit
Lithuania	23	77	30	70	Fictive debit
Austria	23	77	28	72	Fictive debit
Romania	24	76	30	70	Fictive debit
Intermediate countries (Group 2)					
Portugal	6	94	6	94	negligible
Czechia	8	92	14	86	Fictive debit
Poland	11	89	13	87	Fictive debit
France	46	54	50	50	Fictive debit
Italy	65	35	82	18	Fictive debit
Lagging countries (Group 3)					
Germany	25	75	35	65	Fictive debit
Spain	13	87	23	77	Fictive debit
Belgium	13	87	17	83	Fictive debit

about 50 million m^3.

The European Commission has prescribed the key elements for the NCEP template [87], parallel with those for the NFAP's template (section 5.5). In an extra communication [88], the EC stated that the completeness of the NCEP information can still be improved. From an external perspective, the consistency of NCEP's with NFAP's and long term carbon effects (2050 horizon) can be further improved by prioritising some safeguards for using solid biomass for bioenergy.

6.2.1. Which key safeguards should be monitored and reported in the progress reports of the NCEP's 2030?

First, with regards to energy efficiency, the Member States may indicate in the NCEP's the rate of conversion efficiency (ETA) for each residential, industrial and other sectors. In addition they may wish to have a kind of step based approach to increase the efficiency in time, by switching to CHP's fuelled with solid biomass rather than large scale cofiring. Also, residential heating has a large share of biomass use, of which a large part is not highly efficiently converted to heat, due to inappropriate pre-treatment (relative wet feedstock) and outdated equipment (fireplaces).

Second, with regards to sustainable sourcing, the Member States may indicate which part of the consumption by large scale installations is sourced from fully certified sources (FMU level) and which part is based on risk-based assessments. Also here, the EU countries may wish to promote a stepwise increase of forest certification, with an extra safeguard for carbon stocks at the national level on top of it. In case of small FMU's, the option of group certification may be additionally supported in order to have more certified energy wood provided by small forest owners across Europe.

Third, with regards to the forest area, EU Member States may separately indicate forests available for wood supply (FAWS) and other forest areas (protected forests, designed biodiversity areas) in the NCEP's. Both areas have different carbon dynamics, while harvesting and regeneration of FAWS result in a fluctuating carbon reservoir in living biomass in the short term. In the long term both kind of forest areas must have a stable carbon reservoir. The EU Member States may also wish to strive for a stable or increasing total forest area, with about fixed ratio between FAWS and non FAWS. In this way they can meet the wishes for EU's Forest Strategy [89] on the one hand (productive forests), and EU's Biodiversity Strategy [90] on the other hand (biodiversity areas). In the end, it is recommended to have the existing sink reporting structure for total forest within the international framework of the UNFCCC [46] further split into a sink for FAWS and one for non-FAWS areas or a division into managed and non-managed forest areas [15]. This split up facilitates the option to zoom in on the long carbon dynamics of FAWS (or managed forest lands) after wood mobilisation.

Fourth, with regards to the sustainable fellings in FAWS (e.g. maximum 90% share of the NAI), there is an urgent need for more up to date figures. And those figures could be published in the NCEP's to indicate a country's harvest potential. So far, the latest figures published are related to 2010, and that makes future planning for wood mobilisation and sustainable felling somehow uncertain. It will not be that easy to have more up to date figures, as the submitted felling and NAI figures highly depend on the release of perennial national forest inventories (NFI's) in the Member States.

Fifth, with regards to wood mobilisation, the forest provides roundwood and forest harvesting residues (tops, branches, thin trees). With regards to roundwood, it is relevant to periodically monitor the ratios of fuelwood (bioenergy) on the one hand and industrial roundwood (solid products) on the other hand in the NFAP's [15]. Consequently, countries may wish to use to those (reference) ratios for estimating the fuelwood for bioenergy potential in the NCEP period 2021–2030. With regards to the forest harvesting residues, tailor made research should indicate the level of sustainable removal, based on nutrient balance, carbon sink changes, etc. The NCEP's reporting period (2021–2030) is of interest for EU's international commitments, i.e. the CP-3 in the Paris Agreement. For that reason, the EU Member States can evaluate the option of (fictive) carbon credits when the harvesting ratio is changing in favour of industrial roundwood and of (fictive) carbon debits when the EU Member States change the fellings in favour of relatively more fuelwood.

6.2.2. How can the key safeguards affect EU's future biomass needs in 2030?

In a recent study [83], the long term harvest potential (for 2050) was estimated at 63 million m^3 on top of current fellings, when harvesting not more than 90% of the increment. The harvest potential of 63 million m^3 could provide in 13–16 million m^3 of low quality fuelwood, when EU's fuelwood – industrial roundwood ratios of 2000–2009 (20/80) and 2010–2018 (25/75) are used as a reference. The remaining biomass needs (around 300 PJ) in the NCEP's 2030 [55] may be provided by biomass from the agricultural sector, bio-waste material - including post-consumer wood waste -, harvesting residues and any left-over wood processing residues from the forest sector. At the end, the EU can relieve biomass for energy markets, by switching biomass from low efficient to high efficient combustion processes. Public support could accelerate this switch and so promote the synergies of biomass with circular economy [4].

Declaration of competing interest

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