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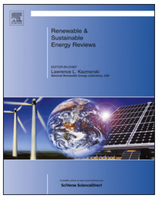

Renewable energy policy framework and bioenergy contribution in the European Union – An overview from National Renewable Energy Action Plans and Progress Reports

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ABSTRACT

The use of renewable energy is projected to increase substantially in the European Union to reach a share of 20% in final energy consumption and 10% renewable energy in transport by 2020. The renewable energy contribution is further expected to increase to 55%–75% of gross final energy consumption in 2050. According to the latest reports, the European Union has made significant progress since 2005 and is on track to reach its 2020 renewable energy targets. This paper provides a review of the policy framework for renewable energy in the European Union and an analysis of the progress made by the use of renewable energy as well as the expected developments until 2020 and beyond. It focusses on the contribution of bioenergy, the major source among renewables in the European Union. As biomass availability is a critical issue for the bioenergy production, this paper provides an analysis of the biomass demand for reaching the 2020 targets, in relation with the expected domestic supply and biomass potential.

Contents

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1. Introduction

Renewable energy provided about 19% of global final energy consumption in 2012. The contribution of modern renewable technologies accounts for 10%, while the traditional use of biomass is significant [1]. Renewables experienced an impressive development worldwide, with highest growth of solar photovoltaic (42% annual growth over the last decade) and wind (27% annual growth) [2]. The installed capacity of renewable energy reached 1440 GW in 2012 worldwide, of which 312 GW in the European Union (EU) [3]. In the heating and cooling sector, biomass, solar, and geothermal energies account for a rising share of final heat demand, amounting to 10% worldwide and even more than 15% in the European Union. The use of biofuels has increased continuously to reach about 106 billion litres worldwide in 2012, of which 82.6 billion litres of ethanol and 23.6 billion litres biodiesel. In the European Union, 3.7 billion litres of ethanol and 13.7 billion litres biodiesel were used in 2012, making the EU the highest biodiesel user [1,3].

The International Energy Agency estimated in the Energy Technology Perspectives 2012 that clean energy technologies offer the prospect of reaching the global goal of limiting the increase of the global mean temperature to 2 °C. Renewable energy technologies have made significant progress so far and have a large potential and could contribute to this goal, but still face technical and cost challenges [2]. In the European Union, the basis of a renewable energy at the European Union level was made in 1997 when the European Council and the European Parliament have adopted the "White Paper for a Community Strategy and Action Plan" and when the share of renewable energy was 6% of gross internal energy consumption [4]. Many steps forward have been made ever since and the European Council endorsed in 2007 a binding target of 20% share of renewable energies in the overall EU energy consumption by 2020 and a 10% binding minimum target to be achieved by all Member States for the share of biofuels in overall EU transport petrol and diesel consumption [5]. The use of renewable energy has increased significantly to 6.7 EJ in 2012 and a share of 14% in the gross final energy consumption in the EU. The use of renewable energy is expected to further increase to 10.3 EJ in 2020, to a share of 20% the share gross final energy consumption. The use of renewable energy in transport should also reach 10%, or about 1.5 EJ in 2020. On a longer term, the European Union has established the ambitious goal of building a competitive low carbon economy in 2050 and to reach 80%–95% GreenHouse Gas (GHG) emission reduction objective by 2050 [6]. The share of renewable energy could increase substantially in the European Union between 55% and 75% of gross final energy consumption in 2050 [7], with an intermediary milestone of 27% already set for 2030 [8].

The Member States (MS) had to prepare National Renewable Energy Action Plans (NREAPs) with detailed roadmaps and measures taken to reach the 2020 renewable energy targets and develop energy infrastructure [8]. Several reports have been published on the NREAPs [10,11], providing detailed information on the expected developments in the use of renewable energy in the EU. Several reports have been published on the progress registered on the renewable energy, including [12], providing a database with the data reported by MS for 2009 and 2011. Ecofys [13] has also provided more detailed information about the progress made during 2009–2011 by sector, renewable source and country, in comparison with the minimum trajectory provided along with the NREAPs. In addition, Ecofys also provided an outlook of the renewable energy deployment up to 2020 at the Member State level on the basis of a modelling exercise using the Green-X model and the data on the Renewable Energy Sources (RES) deployment until 2010, considering the current and planned policy initiatives. It concluded that the future progress in the short term (2012) and for 2020 would allow the MS to reach their 2020 targets. Some recent studies [14,15] and [16] also provided a detailed analysis on the progress registered in the 27 Member States of the European Union until 2010, as well as a detailed picture at MS level. EurObserv'ER collects data and provides annual reports on the state of the renewable energies in Europe, as well as on the prospects for future developments until 2020 [17,18]. AEBIOM also publishes annual statistical reports on the progress made by the bioenergy in the EU [19].

This paper provides a review of the policy framework for renewable energy and presents an analysis of the progress made in the field of renewable energy in the 28 Member States of the European Union (including Croatia, who joined the EU in 2013) until 2012. This study also discusses the expected developments until 2020 and beyond with a focus on the contribution of bioenergy, the major source among renewables in the European Union. Biomass availability is a critical issue for the bioenergy production. Competition between alternative use of biomass for food, feed, fibre and fuel is a major concern for bioenergy deployment, as well as the sustainability concerns related to the use of biofuels. This paper also made an analysis of the biomass demand for reaching the 2020 targets in relation with the expected domestic supply and biomass potential.

2. EU policy framework for renewable energy

2.1. Building a European energy policy

In 1997, the *White Paper for a Community Strategy and Action Plan Energy for the future: Renewable sources of energy* [4] set the basis for the European Union policy on renewable energy. This proposed doubling the share of renewable energy in the EU gross energy consumption from 6% to 12% by 2010. Several technology-specific targets were also set for 2010, namely 135 Mtoe of energy production for biomass; 40 GW installed capacity for wind energy; 3 GWp for photovoltaic energy; 5 GWth for geothermal heat; 1 GW for geothermal electricity and 105 GW for hydro. The reality has shown significant progress and the targets for 2010 have already been achieved or even exceeded by some renewable energies. The wind energy has reached an installed capacity of

80 GW at the end of 2010, ahead of the 40 GW target and the PV installed capacity was 29 GW, well above the 3 GW target. The Member States (MS) have made relevant progress towards achieving their national indicative targets, and the share of renewable energy in gross inland energy consumption has increased from 4.4% in 1990 to 9.8% in 2010 [20], then missing the indicative target of 12% renewable energy in gross energy consumption in 2010.

Renewable Electricity Directive 2001/77/EC set in 2001 a target of 21% of total electricity to be produced from renewable sources by 2010 [21]. In 1997, the share of renewable electricity in the EU was 12.9%. A national indicative target was defined for electricity generation from renewable sources. Following this Directive, the renewable electricity production has increased in the EU to 641 TWh in 2010, out of which 334 TW h hydro, 155 TW h wind, 123 TW h biomass, 23 TW h solar and 6 TW h geothermal. The share of green electricity has grown continuously, reaching 13.6% in 2005 and 19.5% in 2010 [20]. Thus, in spite of a very important growth, the EU did not reach its 2010 target of 21%. In 2010, hydropower contributed the largest share with 10.1%, followed by wind with 4.5%, biomass with 3.7%, and solar power with 0.7% of the green electricity production. The biggest increase between 2000 and 2010 in electricity production took place in wind (127 TW h increase) followed by biomass (89 TW h), solar (23 TW h), hydro (14 TW h). However, in relative terms, solar electricity production has expanded by far most rapidly, followed by wind power.

In 2003, the *Biofuels Directive* 2003/30/EC set a target for 2010 for the biofuels and other renewable fuels replacing petrol and diesel of 5.75% of all petrol and diesel used in transport [22], again in the form of indicative targets. The data showed that the 2010 target set was not met, despite certain progress [23]. The biofuel consumption in transport has increased from 125 PJ in 2005, (1.0% biofuels) to 556 PJ biofuels in 2010 (4.4% biofuels), below the target of 5.75% [17,20].

In 2007, the European Commission proposed an integrated *Energy and Climate Change* package on the EU's commitment to change (*Energy policy for Europe* (COM(2007) 1 final) [24] and *Limiting Global Climate Change to* 2 °C–*The way ahead for* 2020 *and beyond* (COM (2007) 2 final) [25]. This included an EU commitment to achieve at least a 20% reduction of GHG emissions by 2020 compared to 1990 levels and a mandatory EU target of 20% renewable energy, including a 10% target for renewable energy for 2020.

The *Renewable Energy Directive* (RED) 2009/28/EC on the promotion of renewable energy sources, requires the MS to increase the share of renewable energy to 20% of gross final energy consumption and 10% renewable energy in transport by 2020 [8]. This comes along with the strategic objective to reduce the GHG emissions in the EU by 20% compared to 1990 emission levels. The RED specifies national objectives, legally binding rather than indicative targets for the share of renewable energy. Each MS has its own target for the share of energy from renewable sources and a share of 10% renewable energy in transport. In addition, the Fuel Quality Directive 2009/30/EC sets a target of a 6% GHG reduction for fuels used in transport in 2020 [26]. The RED and FQD include criteria for sustainable biofuels and procedures for verifying that these criteria are met. The RED also includes a set of provisions to facilitate the development of renewable energy, such as a legal requirement for the MS to prepare NREAPs with detailed roadmaps and measures taken to reach the RES targets and develop energy infrastructure.

2.2. Consistency with other European policies

The EU energy and climate goals have been incorporated into the *Europe* 2020 *Strategy for smart, sustainable and inclusive growth* (COM(2010) 2020) [27], and into its flagship initiative *Resource efficient Europe* COM(2011) 21 [28]. The objective of Europe 2020 is to develop: smart growth (education, knowledge and innovation); sustainable growth (a resource-efficient, greener and more competitive economy); and inclusive growth (high employment and economic, social and territorial cohesion). *Europe* 2020 includes five headline targets for the EU, among which climate and energy targets: reducing GHG emissions by 20%, increasing the share of renewables in the energy mix to 20%, and achieving the 20% energy efficiency target by 2020. *Resource Efficient Europe*, one of the seven flagships of the *Europe* 2020 (COM (2011) 21), was developed to support the shift towards a resource-efficient, low-carbon economy and to achieve sustainable growth [28]. The objectives of this strategy are in line with the objectives of the *Europe* 2020 and *Energy* 2020, for example the EU objective to reduce GHG emissions by 80–95% in 2050 compared to 1990 [6].

The *Energy* 2020 - *A strategy for competitive, sustainable and secure energy* (COM(2010) 639) set out the European Commission's energy strategy in the period to 2020 [29]. The new energy strategy focuses on five priorities: achieving an energy efficient Europe; building an integrated energy market; achieving safety and security; extending leadership in energy technology and innovation; strengthening the external dimension.

The *Strategic Energy Technology Plan (SET-Plan)* was established (COM(2007)723 final) for accelerating the development of low-carbon energy technologies, to achieve the 2020 energy and climate change goals, toward a low carbon economy [6,30]. Several European Industrial Initiatives were created to foster the development of key energy technologies: wind, solar, electricity grids, bioenergy, carbon capture and storage and nuclear fission. The *European Industrial Bioenergy Initiative* was launched to support the development and commercial deployment of advanced bioenergy technologies through building and operating demonstration and/or flagship plants for innovative bioenergy value chains with large market potential [31].

2.3. Sustainability requirements for bioenergy

2.3.1. EU sustainability criteria for biofuels and bioliquids

The *Renewable Energy Directive* includes a set of mandatory sustainability criteria [9] as part of an EU sustainability scheme and monitoring and reporting requirements for biofuels and bioliquids. Similar requirements were set in the Fuel Quality Directive (FQD) 2009/30/EC [26] on the specification of petrol, diesel and gas, together with a mechanism to monitor and reduce GHG emissions. Biofuels and bioliquids are required to fulfil all sustainability criteria to count towards EU targets and to be eligible for support. The RED excludes several land categories to be used for producing biofuels: high biodiversity value land (primary forests; areas designated for nature protection; highly biodiverse grassland); high carbon stock land (wetlands; forested areas) and peatlands. For the biomass feedstock produced in the EU, the cross-compliance rules of the Common Agricultural Policy (CAP) and the requirements for Good Agricultural and Environmental Conditions (GAECs) apply. The cross compliance regulations refer to the preservation of soil and water quality, biological diversity, careful use of fertilisers/pesticides and air pollution.

The EU sustainability scheme includes monitoring and reporting requirements. The MS must report on the impact of biofuels and bioliquids on biodiversity, water resources, water quality and soil quality, GHG emission reduction, changes in commodity prices and land use associated with the increased use of biomass. Fuel suppliers are required to report on the compliance with the sustainability criteria and on the measures taken for soil, water and air protection, the restoration of degraded land and the avoidance of excessive water consumption in areas with water deficit. Although there are no criteria for social sustainability, the

Commission must report on the impact of biofuels on social aspects and on food availability. A large number of initiatives emerged for the sustainability certification for biofuels and/or bioenergy [32]. At mid-2014, a total of 19 voluntary certification schemes have been recognised by the Commission [33].

2.3.2. GHG emission reduction requirements for biofuels and bioliquids

In the European Union, biofuels and bioliquids should meet a minimum requirement for GHG savings of 35% relative to fossil fuels. This will increase to 50% in 2017 for existing plants and 60% in 2018 for new installations. Advanced, second-generation biofuels produced from residues, non-food cellulosic material and lignocellulosic material would be double credited towards the 10% target [9]. In addition to the sustainability criteria, the RED includes rules and a methodology for the calculation of GHG emissions and provides actual and default values. The GHG emissions include all emissions from the extraction or cultivation of raw materials, from processing, transport and distribution and emissions from carbon stock changes caused by land-use change (calculated over a period of over 20 years). The GHG emissions from co-products shall be calculated in proportion to their energy content. The European Commission also provided guidelines establishing the rules for the calculation of land carbon stocks, including soil organic carbon and carbon stock in the above and below ground vegetation both for the reference and the actual land use and values for different soil types and land use categories.

2.3.3. Sustainability requirements for the use of solid and gaseous biomass

In 2010, the European Commission released a report on the sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling (COM(2010) 11). The Commission acknowledged the sustainability concerns on biomass production in terms of protecting the biodiversity of ecosystems and carbon stocks [34]. This report provided recommendations to the MS for developing national schemes for solid and gaseous biomass with the same requirements as those laid down in the RED for biofuels and bioliquids. Biomass should not be sourced from land converted from forest or other areas of high biodiversity or high carbon stock. This minimises the risk of adopting diverse and even incompatible criteria at national level, the risk of discrimination in the use of raw materials based on their final use. Small-scale producers and users (below 1 MW capacity) should be excluded from the application of sustainability criteria. Member States should keep records of the origin of biomass used in installations of 1 MW or above and monitor small-scale (mainly households) biomass use, as well as the effects of biomass use on the areas of origin. The Commission recommended the national support schemes to provide incentives to achieve high conversion efficiencies. Member States should not impose sustainability criteria to waste, which is covered by environmental rules in the waste legislation; wastes and residues should only comply with the GHG criteria. The report set out a common methodology for calculating the GHG performance, including the conversion step. The minimum GHG savings from biomass should be at least 35% compared to the EU's fossil energy mix, increasing to 50% from 2017 for existing plants and 60% from 2018 for new plants. Various initiatives have been launched to prepare sustainability criteria for solid and gaseous biomass [35].

2.3.4. Land use impact of biofuels/bioenergy development

The contribution from biofuels to the RES targets in transport is expected to be significant. The significant demand for biofuels might lead to the conversion of land to agriculture use and changes in land use. Assessing land use impacts depends on a number of factors and assumptions. One main source of uncertainty is the availability of waste and residues for energy use and the availability of land for energy crops. The amount of waste and residues depends on the future demand from different uses such as animal feed, raw material, etc. Various assumptions regarding future agricultural productivity have a great impact on the results [36,37,38]. Depending on the expected developments, the impact on land use might be significant [39]. An important constraining factor is the application of sustainability criteria, that will exclude the use of biomass that is produced under "unsustainable" conditions. The limited available biomass requires a prioritisation of its use, to those sectors where there are no other alternatives (such as aviation, etc.) or where they ensure high conversion efficiency or provide high economic value.

In addition to direct land use changes on the site of a farm or plantation, Indirect Land Use Changes (ILUC) might occur through the displacement of the previous crop to another location. The assessment of ILUC effects vary widely due to different modelling assumptions, including feedstock type, land use expansion vs. yield increase, land use dynamics [40,41]. The Commission published in 2010 a report (COM(2010) 811) to review the impact of ILUC on GHG emissions and propose actions for minimising that impact [42]. This report identified a number of uncertainties and limitations to estimate ILUC associated with modelling. It acknowledged that the impact of ILUC on GHG emissions savings from biofuels could reduce their contribution to the policy goals. An Impact Assessment (SWD(2012) 343) was conducted where five policy options were evaluated. The Impact Assessment proposed a balanced approach, including the limitation of the contribution from conventional biofuels, increase of the minimum GHG saving threshold and including the GHG emissions from ILUC, as well as additional incentives for advanced biofuels [43].

2.4. A new proposal for the amendment of the renewable energy directive

In 2012, the Commission released a proposal (COM(2012) 595 final) to amend the Fuel Quality and Renewable Energy Directives in order to take account of ILUC effects of biofuel use and to stimulate the development of advanced biofuels from non-food feedstock, which do not directly interfere with food production. The use of food-based biofuels (produced from cereal and other starch rich crops, sugar and oil crops) will be limited to 5% or to the share of such biofuels and bioliquids consumed in 2011 [44].

The Commission also proposed to include ILUC factors in the calculation of GHG savings. The GHG emission saving shall be at least 60% for biofuels and bioliquids produced in new installations. In the case of existing facilities, biofuels and bioliquids should achieve a GHG emission saving of at least 35% until the end of 2017 and at least 50% from 2018. The provisions for encouraging the cultivation of biofuels in severely degraded and heavily contaminated land do not longer apply.

This proposal provides an incentive scheme to promote sustainable and advanced biofuels from feedstocks that do not create additional demand for land. The contribution made from certain feedstock shall be considered to be four times their energy content: algae, municipal waste, industrial, agricultural and forestry waste. Biofuels produced from the following feedstocks shall be considered to be twice their energy content: used cooking oil; animal fats; non-food cellulosic material; lignocellulosic material. Biofuels produced from the following feedstock will be considered to have estimated ILUC emissions of zero: feedstock not produced from cereal, starch, sugars and oil crops; feedstock whose production has led to direct land use change. In this case, the direct land use change emission value should have been calculated in the GHG emissions. The EU Energy Council reached an agreement in June 2014 to take account of concerns about ILUC for biofuels, including on a 7% cap on conventional biofuels, higher than the 5% initial proposal [45].

The European Parliament adopted in April 2015 compromise text on addressing ILUC in the proposal for a Directive amending the Fuel Quality and Renewable Energy Directives. The adopted text proposes that food-crop biofuels should account for no more than 7% of energy consumption in transport by 2020, to accelerate the shift to advanced biofuels with low indirect land use change impacts and high overall GHG emission savings by setting a non-binding target of 0.5%, while ensuring that estimated ILUC emissions are reported [48].

2.5. Renewable energy policies in the EU and perspectives beyond 2020

In order to keep climate change below 2 °C, both the European Council and the Parliament have set the objective of reducing greenhouse gas emissions by 80–95% by 2050, compared to 1990 levels. In 2011, the European Commission adopted the *Roadmap for moving to a competitive low carbon economy in* 2050 (COM(2011) 112) and *Energy Roadmap* 2050 (COM(2011)885 final) [6,7].

The *Roadmap for moving to a competitive low carbon economy in* 2050 [20] set out key elements for the climate action helping the EU become a competitive low carbon economy by 2050. It set intermediate milestones for a cost-efficient pathway and GHG emission reductions and identified policy challenges, investment needs and opportunities in different sectors. A cost-effective pathway to reach 80%–95% GHG emission reduction objective by 2050 would be a reduction of GHG emissions of 40% for 2030 compared to 1990 levels and 60% for 2040. The share of low carbon technologies in the electricity mix was estimated to increase from around 45% today, to 60% in 2020, 75–80% in 2030, and almost 100% in 2050 [6].

The *Energy Roadmap* 2050 investigated possible pathways for a transition towards a decarbonisation of the energy system and the associated impacts, challenges and opportunities [7]. A number of scenarios to achieve 80% reduction in GHG and about 85% reduction of energy-related CO_2 emissions have been examined. Different options can contribute to the 2050 decarbonisation goal, with energy efficiency and renewable enregy playing a major role. The Roadmap includes a decrease of primary energy demand between 16%–20% by 2030 and 32%–41% by 2050, as compared to maximum levels reached in 2005–2006. Carbon capture and storage could contribute to most scenarios with a share between 19% and 32% in power generation. Storage technologies are critical to accommodate RES supply. The RES share is projected to rise substantially in all scenarios, reaching between 55% and 75% of gross final energy consumption in 2050. The RES share in electricity consumption reaches 64% in a high-efficiency scenario and 97% in a high-renewables scenario, compared to around 20% today.

The Communication "Renewable Energy: a major player in the European energy market" (COM(2012)271 final) examined the conditions for a further development of renewable energy for a medium term perspective beyond 2020. It aimed to ensure that renewable energy contributes to security and diversity of energy supply, competitiveness, and environment and climate protection, and supports economic growth, employment creation, regional development and innovation. The Communication calls for a coordinated approach in the establishment and reform of support schemes to help ensure greater consistency in national approaches and avoid fragmentation of the internal market [46].

The Communication COM (2014) 15 final on *A policy framework for climate and energy in the period from* 2020 *to* 2030 has proposed an integrated framework to drive progress towards a low-carbon economy. It aims to build a competitive and secure energy system that increases the security of energy supply, reduces energy dependence and creates new opportunities for growth and jobs. The European Council *Conclusions on* 2030 *Climate and Energy Policy Framework* endorsed in October 2014 a binding EU target of 40% reduction in GHG emissions by 2030 compared to 1990, a binding target of at least 27% for the share of renewable energy in 2030 and a 27% energy efficiency indicative target [8]. This framework will contribute to increase the investors' confidence in renewable energy and to reach the 2020 renewable energy targets.

3. Renewable energy and bioenergy projections for 2020

3.1. National Renewable Energy Action Plans and Progress Reports

The EU Member States (MS) have prepared and submitted in 2010 their NREAPs, as required by the Renewable Energy Directive, setting out their national targets for the share of renewable energy consumed in electricity, heating and cooling and in transport, and measures for achieving the national overall renewable energy targets [47].

In the NREAPs, the MS had to propose two scenarios for energy consumption until 2020: the Reference Scenario, only taking into account the energy efficiency and saving measures adopted before 2009; the Additional Energy Efficiency Scenario, including all energy efficiency and saving measures adopted and expected to be adopted after 2009. The contribution of different renewables and their targets in electricity, heating and cooling and transport in the NREAPs are based on this Additional Energy Efficiency scenario.

These plans [3] provide detailed roadmaps of how each MS expects to reach its legally binding 2020 targets for the share of renewable energy in the final energy consumption. The NREAPs include additional information to substantiate the targets and measures envisaged to reach them, including the estimated costs and benefits of the measures planned, actions for the extension or reinforcement of the existing grid infrastructure, national support schemes for renewables and the use of renewable energy in buildings.

Moreover, Member States have to prepare progress reports, every two years, on the developments in the RES against the interim targets established in their NREAPs. The reports describe the overall renewable energy policy developments in each Member State, the progress made in the use of renewable energy and their shares, their compliance with the measures set out in the Directive, in comparison with the NREAPS [9].

The first and second Progress Reports provided data for 2009 and 2010 and data for 2011 and 2012, respectively. The reports provide the data about the progress in the use of renewable energy along the trajectory towards the 2020 targets and describe the renewable energy policy developments in each MS. This study presents in the next an analysis of the progress made by the renewable energy in the 28 Member States (including Croatia, who joined the EU in 2013) with a focus on bioenergy.

3.2. Expected development of RES and bioenergy contribution

The analysis of the National Renewable Energy Action Plans shows that the use of renewable energy is projected to increase in absolute terms more than two fold between 2005 and 2020, from 4181 PJ in 2005 to about 10,255 PJ in 2020 [14,15]. The highest growth was expected to be achieved by solar, wind and heat pumps, with comparatively less increase from biomass and geothermal. According to the aggregated data from the progress reports, significant progress has been made so far, with an increase of more than 60% of total renewable energy deployment between 2005 and 2012 [3]. The renewable use in the EU was 1.9% above the NREAP projections for 2012, with a downward trend in comparison with 2010 (Table 1).

Renewable heating and cooling made the most significant progress between 2005 and 2012, followed closely by renewable electricity, while the use of renewable energy in transport was much lower. However, in relative terms, the most significant growth was made by the renewable energy use in transport sector (223%), followed by heating and cooling (60%) and electricity (50%) sectors. The use renewable energy was above the 2012 target in heating and cooling (10%) and in electricity generation (4%), while their use in transport was only 70% of the expected use (Table 2).

The European Union had a share of renewable energy source of 8.1% in the gross final energy consumption in 2005 and it is expected to reach 20.6% in 2020, in the Additional Energy Efficiency Scenario, just above the 20% target [14,15]. The RES has made a significant growth recently, to reach 14% of final gross energy consumption in 2012, which puts the EU at only 6 percentage points away, 8 years ahead from its 2020 targets [3]. The increase in the use of RES was produced in the context of lower gross final energy consumption, which played in supporting the increase in the share of RES. The renewable energy share in electricity and in the heating were both above the expected levels for 2012, while the share in transport was below (Table 3).

The contribution of different renewable energy sources is expected to change significantly until 2020. While hydro energy production would remain about constant (due to the limited potential for further development), its share in the renewable energy would decrease. The aggregated NREAPs data shows that bioenergy is expected to expand considerably, maintaining its major role as renewable energy in the energy mix in the EU until 2020. Overall, the share of bioenergy in the gross final energy consumption will increase from 5.0% in 2005, 8.5% in 2012 to almost 12% in 2020, according to the NREAPs forecast [3,14,15]. The share of other renewable sources would increase, thus changing the whole energy mix and contributing to the diversification of energy sources (Fig. 1).

The total use of biomass electricity, heating and cooling and biofuels in transport is estimated to almost double between 2005 and 2020. The bioenergy development is in general according to the NREAPs predictions (with the exception of biofuels), to be 2.3% above the expected level for 2012 (Table 4). This was influenced by the significant decrease in the use of bioliquids for electricity and heating and in the use of biofuels in transport, as result of the sustainability issues and uncertainties about future policies.

Table 1
Final renewable energy consumption [PJ].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
Hydro	1230	1245	1223	1255	1182	1278	1331
Geothermal	38	51	42	61	46	83	150
Solar	34	137	146	224	336	347	634
Marine	2	2	2	2	2	3	23
Wind	253	597	559	785	715	1109	1760
Heat pumps	25	169	183	227	288	305	514
Bioenergy	2598	3594	4127	3967	4057	4510	5841
Total RES	4181	5794	6283	6520	6643	7636	10,255

[a] Achieved, according to aggregated data of the Member States Progress reports.

Table 2
Contribution of RES to electricity, heating and in transport [PJ].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
RES electricity	1758	2352	2332	2700	2688	3247	4358
RES heat	2297	2867	3394	3121	3433	3566	4681
RES in transport	171	631	605	766	556	906	1352
Total RES	4181	5794	6283	6520	6621	7636	10,255

[a] Achieved, according to aggregated data of the Member States Progress reports.

Table 3
Total and sectorial RES share [%].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
RES heating	9.3	12.5	14.4	13.7	15.8	15.9	21.4
RES electricity	14.8	19.7	19.7	22.2	23.6	26.3	33.9
RES transport	1.3	4.9	5.0	6.1	6.0	7.2	11.4
RES	8.1	11.5	12.6	12.9	14.1	15.1	20.6

[a] Achieved, according to aggregated data of the Member States Progress reports.

3.3. Renewable electricity

The installed capacity of renewable electricity plants increased in the European Union from 170 GW in 2005 to 312 GW in 2012, which is above 7% the expected renewable capacity. Significant progress was made in most sectors, but especially in solar power, wind power and biomass [3,14,15]. The whole evolution was marked by the fast developments registered by the solar and wind between 2010 and 2012, with an increase of 41 GW (38%) in solar alone and 22 GW (26%) in wind, respectively (Table 5). The strong development in the photovoltaic and wind power production has been mainly driven by the cost reduction; photovoltaic and wind power are expected to be competitive in several markets by 2020.

Renewable electricity production increased by more than 50% between 2005 and 2012, while its share to the electricity use increased from about 15% to almost 24% in 2012, above the NREAPs projections. The renewable energy contribution to electricity generation in the EU is expected to further increase and to reach 1210 TW h in 2020, which is equivalent to about 34% of gross final electricity consumption by 2020 (Table 6). While huge progress has been made by wind and solar electricity generation, hydropower is still the main source of renewable electricity, followed by wind and biomass. By 2020, wind would become the most important renewable energy source, providing 40% of all renewable electricity, and solar would provide almost 8.5%. With a limitted grow, the share of hydro would decrease from 70% in 2005, to 30% in 2020 and the contribution of geothermal and marine energy are expected to remain marginal [3,14,15].

3.3.1. Biomass electricity capacity

The installed bioenergy power capacity in the EU almost doubled from 2005 to 2012, from 16 GW in 2005 to 29 GW in 2012, which is more than 10% above the expected capacity. However, its share in the renewable installed capacity decreased in comparison to 2010, due to the developments in wind power and solar photovoltaic capacity during the two years. For 2020, it is expected that bioenergy capacity will further increase, while maintaining its share in the total renewable capacity at around 9% (Table 7) [3,14,15].

Solid biomass is the main contributor to biomass capacity since 2005, with more than two thirds of biomass capacity, and will remain still in the same position, even with a slightly decreasing share in 2020. The installed biogas capacity increased significantly since 2005, but the highest growth was registered between 2010 and 2012 when its capacity increased by 80%, mainly due to the developments in Germany and Italy. The biogas plant capacity is well above the projections for 2012 and its share in total biomass

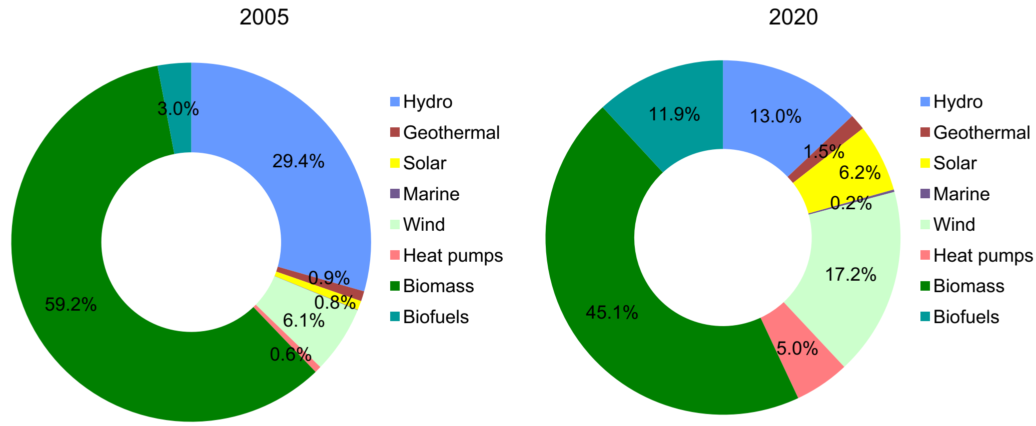

Fig. 1. Renewable energy mix in 2005 and 2020.

Table 4
Total final use of biomass in electricity, heating and cooling and transport [PJ].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
Solid biomass	2216	2667	3246	2857	3261	3191	3949
Biogas	71	166	171	204	261	275	420
Bioliquids	54	185	113	205	21	219	255
Biofuels	125	575	556	700	500	823	1216
Total biomass	2598	3594	4127	3967	4057	4510	5841
Share in energy consumption	5.0%	7.2%	8.2%	7.9%	8.5%	9.1%	11.7%
Share in RES consumption	62.3%	62.2%	65.9%	60.8%	59.9%	59.2%	57.1%

[a] Achieved, according to aggregated data of the Member States Progress reports.

Table 5
Installed RES capacity in the EU [MW].

	2005	2010	2010[a]	2012	2012[a]	2015	2020
Hydropower	110,414	113,074	103,091	115,524	105,376	119,405	127,165
Geothermal	741	816	823	881	782	1047	1623
Solar	2221	25,989	29,727	39,829	70,811	57,817	90,499
Marine	240	245	243	261	247	372	2253
Wind	40,447	85,550	84,395	107,979	106,373	143,174	210,993
Biomass	15,741	22,686	25,093	25,978	28,723	32,665	43,717
Total RES	169,804	248,359	243,371	290,452	312,313	354,480	476,248

[a] Achieved, according to aggregated data of the Member States Progress reports.

Table 6
Renewable electricity production in the EU [TW h].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
Hydro	341.6	345.8	339.7	348.7	328.4	355.0	369.7
Geothermal	5.5	6.0	5.6	6.4	5.8	7.4	11.0
Solar	1.5	20.7	23.2	39.9	71.4	61.0	101.1
Marine	0.5	0.5	0.5	0.6	0.5	0.9	6.5
Wind	70.4	165.9	155.2	218.0	198.5	308.1	489.0
Biomass	69.1	114.3	123.6	136.5	142.1	169.7	233.2
Total RES	488.5	653.3	647.9	749.9	746.7	902.1	1,210.4
Total electricity	3,284.2	3,314.7	3,226.3	3,354.6	3,138.8	3,419.7	3,543.0
RES share in electricity	14.9	19.7	19.6	22.2	23.6	26.4	33.9

[a] Achieved, according to aggregated data of the Member States Progress reports

capacity (29%) is already above the expected level for 2020 (26%). The bioliquids plant capacity has also seen a big increase until 2012 to reach a level above the one expected for 2020 [3,14,15]. However, the future developments depend on the sustainability constraints for the use of bioliquids for electricity production, since the electricity generation from bioliquids dropped between 2010 and 2012. The share of bioenergy in the renewable power capacity (Table 7) decreased from 2005 to 2012 but especially between 2010 and 2012, due to the faster developments in solar and wind. Even with a significant increase in the biomass power capacity expected until 2020, its share is expected to remain at about 9% until 2020.

The leading countries in biomass installed capacity in 2012 were Germany, Sweden, Italy and UK. Solid biomass plants are dominating in Finland and Sweden, for example, while in Germany the biogas plant capacity is above the solid biomass capacity. Significant progress is expected in many MS. In 2020, the leading countries will be Germany, UK, Italy and France. Some countries have already reached the expected installed bioenergy capacity (for example Sweden) while others are getting closer (such as Italy) (Fig. 2).

The installed capacity of biomass power plants is expected to further rise in the EU from 44 GW in 2020 to 52 GW by 2030. The installed biomass capacity increases significantly in all scenarios until 2050 analysed in the *Energy Roadmap* 2050 (COM(2011) 885) to reach 87 GW in the reference scenario and between 106 and 163 GW in different decarbonisation scenarios [7].

3.3.2. Biomass electricity production

In parallel with the increasing installed capacity, the electricity generation from biomass (Table 8) is expected to increase significantly, from 69 TW h in 2005 to 233 TW h in 2020 (almost 3.5 fold increase compared to 2005). The data from progress reports shows that biomass electricity generation is on track to

Table 7
Installed biomass electricity capacity in the EU [MW].

	2005[a]	2010	2010[a]	2012	2012a	2015	2020
Solid biomass	10,568	14,424	19,161	16,359	18,526	21,084	27,854
Biogas	2665	5433	4561	6306	8339	7944	11,232
Bioliquids	368	1039	1382	1274	1856	1438	1711
Biomass	15,741	22,686	25,093	25,978	28,723	32,665	43,717
CHP	3045	7325	14,256	8821	6900	12,736	19,327
Total RES	169,804	248,359	261,541	290,452	312,313	354,480	476,248
Biomass share in RES capacity [%]	9.3	9.1	9.6	8.9	9.2	9.2	9.2

[a] Achieved, according to aggregated data of the Member States Progress reports.

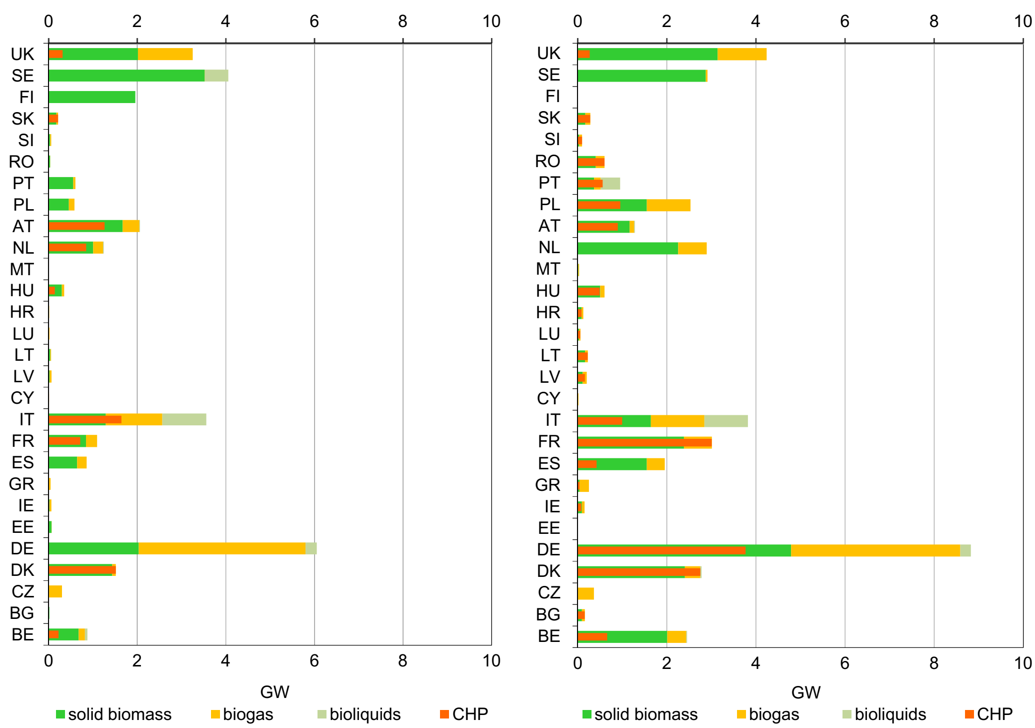

Fig. 2. Expected biomass electricity capacity in the MS in 2012 (left) and 2020 (right).

Table 8
Electricity generation from biomass in the EU [TW h].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
Solid biomass	55.1	76.7	92.8	92.0	92.4	114.0	156.2
Biogas	12.5	28.7	24.5	34.3	46.4	44.4	63.9
Bioliquids	1.5	8.6	6.4	9.9	3.2	10.9	12.7
Biomass	69.1	114.3	123.6	136.5	142.1	169.7	233.2
CHP	32.7	51.2	56.1	63.3	81.4	86.2	127.4
Total RES	488.5	653.3	647.9	749.9	746.7	902.1	1,210.4
Biomass share in RES [%]	14.1	17.5	19.1	18.2	19.0	18.8	19.3
Total electricity	3284	3315	3226	3355	3139	3420	3543
Biomass share in electricity [%]	2.1	3.4	3.8	4.1	4.5	5.0	6.6

[a] Achieved, according to aggregated data of the Member States Progress reports.

reach the 2020 target, being 3.5% above the expected level for 2012 [3,14,15]. The additional bioelectricity generation until 2020 is significant compared to the progress made since 2005, but less if comparing the annual progress in percentages and thus it could be achieved. The share of bioelectricity in renewable electricity generation increased from 2005 to 2012, despite of the progress made by other renewables. However, the progress of other renewables between 2010 in electricity generation made the share of biomass electricity to decrease during this period. The contribution to electricity made by biomass will remain at around 19% of total renewable electricity generation in 2020. Biomass electricity is also expected to reach its projected figures for 2020 for the share in overall electricity supply in the EU.

Solid biomass is the main contributor to biomass electricity, with a share expected to decrease from almost 80% to 67% in 2020. High progress is expected, in absolute values, from solid biomass; in relative terms, biogas should however increase the most. The share of biogas electricity was expected to increase significantly from 18% in 2005 to 27% of total biomass electricity generation in 2020. However, the recent developments on biogas (increase of almost 90% in the electricity production between 2010 and 2012 alone) increased the share of biogas to 32% of biomass electricity, above the expected 2020 levels. This brought the electricity production from biogas 35% above the level forecasted for 2012. Despite of earlier increase of electricity generation from bioliquids until 2010, the latest developments show that their contribution shrank to half of the level reached in 2010, due to the sustainability concerns related to their use.

The expected production of bioelectricity in 2020 looks very different among different MS, as well as the contribution of solid biomass, biogas or bioliquids (Fig. 3). The leading countries in biomass electricity generation in 2012 were Germany, UK, Italy, Finland and Sweden. By 2020, the electricity generation from biomass will increase in many MS, and the leading countries will be Germany, UK, Italy and France, with other countries following closely [3,14,15]. It is worth mentioning the large share of electricity produced in cogeneration, especially in Denmark, Sweden, Poland and Poland in 2012, which would be complemented by France by 2020.

For 2030, the biomass electricity production is projected to further increase to 360 TW h in 2050 in the reference scenario (250% increase in comparison with 2012) and up to 460–494 TW h in 2050 in different decarbonisation scenarios of the *Energy Roadmap* 2050 (COM(2011) 885) [7]. Biomass electricity contribution could rise from 2.1% share in power generation in 2005 and 4.5% in 2012 to 6.6% in 2020 to 7.3% in 2050 in the reference scenario and up to 9.3–10.9% in decarbonisation scenarios.

3.4. *Renewable heating and cooling*

The use of renewable energy in heating and cooling is expected to double between 2005 and 2020. Significant progress was made in all sectors between 2005 and 2012, bringing the contribution of renewables to heating and cooling at about 10% above the 2012 target (Table 9) [3,14,15]. The highest increase was made by biomass heating but, in relative numbers, the highest increase was made by the heat pumps and solar. The share of renewable energy in the heating and cooling sector is expected to increase from about 9% in 2005 to more than 21% by 2020. According to the NREAPs, major RES heating and cooling markets (Austria, Sweden, Germany, and France) will see further developments and new markets will emerge, such as the United Kingdom.

Biomass was the largest contributor in renewable heating and cooling since 2005. Although the biomass heating is expected to grow 1.5 times between 2005 and 2020, its share in renewable heating will decrease from almost 97% in 2005 to 80% in 2020, due to higher growth of other sources. Other renewables, such as solar thermal would increase to almost 6% of renewable heating, heat pumps should grow to 11%, and geothermal is expected to contribute 2% in comparison to rather low levels in 2005 [3,14,15].

The RES share in gross final consumption of heating and cooling could double between 2020 and 2050, reaching at least 44% by 2050 under various decarbonisation scenarios and up to 53.5% in the High RES scenario (*Energy Roadmap* 2050 (COM(2011) 885) [7]. In absolute terms, this would require an increase in the RES use for heating and cooling of 20–60%, depending on the

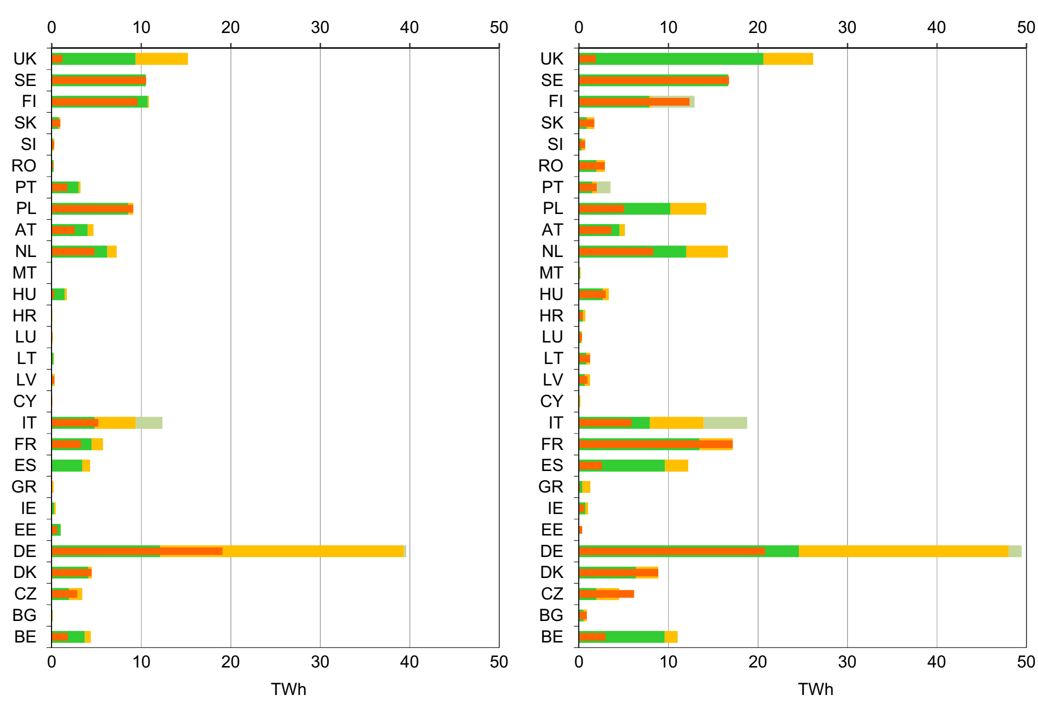

Fig. 3. Expected biomass electricity generation in the MS in 2012 (left) and 2020 (right).

accompanying measures for reducing energy use and improvements in energy efficiency.

3.4.1. Biomass heating and cooling

The main contribution of biomass to the renewable energy generation in the EU is found in the heating and cooling sector. According to the aggregated NREAPs data, the 2020 targets will entail an increase in the use of heating and cooling from biomass from 2225 PJ in 2005 to 3785 PJ in 2020. The heat generation from biomass has increased by more than 35% since 2005. Although biomass heating was almost 10% above the target in 2012, it decreased between 2010 and 2012. The share of biomass in renewable heating is expected to decrease, but its share in total heating will further increase to achieve 17% in 2020 (Table 10) [3,14,15].

The main contributor of biomass in renewable heating in 2005 was solid biomass (forest and agricultural residues, wood pellets and various waste, including municipal solid waste) with more than 90% of biomass heating at that time. Although the use of solid biomass in heating will increase, its share is projected to remain at about the same level by 2020. The most important increase, in relative terms, is expected to be registered by the use of biogas; the important progress made so far could continue to grow until 2020. The biogas share in biomass heating should increase from only 1% in 2005 to 5% in 2020. The use of bioliquids was expected to increase more than fourfold from in 2005 to 2020 with a share in biomass heating rising from only 2% in 2005 to more than 5% in 2020. During the last years, the use of bioliquids decreased significantly in all MS. District heating accounted for a small part of renewable heating and cooling in 2005 (this including also other renewables), especially in several MS where the district networks are developed (Sweden, Denmark, Austria, Finland, etc.). The progress was limited due to mixed evolution in some MS and the use of district heating was below the targets for 2012. The use of district could increase almost three fold until 2020. Significant differences among MS are clearly visible (Fig. 4) [3,14,15].

Leading countries in biomass heating in 2012 were France, Germany, Sweden and Finland. Large amount of biomass is also used in households in France, Germany, Italy and Romania. In 2020, leading countries in biomass heat are expected to be France, Germany, Sweden and Finland [3,14,15]. Significant contribution to heating is expected to come from biogas in Germany, France and Poland while bioliquids could have a large part in Finland, Portugal, Germany and the Netherlands.

On a longer term, the use of biomass for heating and cooling is expected to rise from 17.3% in 2020 to about 33% in 2050 in the High RES scenario, combining the increased use of biomass for heating with some energy saving measures to reduce the heating and cooling demand [7].

3.4.2. Biomass use in households

Biomass is largely used in households for heating in fireplaces and in stoves as firewood, but increasingly as wood pellets. The contribution of biomass in households is expected to show a limited increase between 2005 and 2020. However, the use of biomass in households has long exceeded the 2020 targets, to reach 1636 PJ in 2012, about 10% above the 2020 target. In fact, the use of biomass in households increased to 55% of the biomass used for heating in 2012, in comparison with an expected share of 40% for 2020 [3,14,15]. Leading countries in the biomass use in households in 2012 were France, Germany, Italy and Romania. In 2020, leading countries in biomass use in households are expected to be France, Germany, Italy and Austria, related mainly to a higher contribution of wood pellets. A number of 16 Member States have already reached the expected use of biomass in households for 2020.

3.5. Renewable energy in transport

The share of renewable energy in the energy used in transport in the EU is expected to grow from 1.3% in 2005 to about 11.4% by 2020, above the 10% binding target, considering multiple counting for electricity use in road transport and biofuels from wastes,

Table 9
Renewable heating and cooling [PJ].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
Geothermal	18	29	22	38	25	57	111
Solar	29	62	63	80	79	127	270
Heat pumps	25	169	183	227	288	305	514
Biomass	2225	2607	3126	2776	3046	3076	3785
Total	2297	2,867	3394	3121	3433	3566	4681
of which DH	245	341	477	389	338	482	741
of which biomass in households	1194	1278	1616	1315	1679	1359	1493
Heating	24,789	22,929	22,976	22,418	22,005	22,418	21,882
RES share in heating [%]	9.3	12.5	14.8	13.7	16.0	15.9	21.4

[a] Achieved, according to aggregated data of the Member States Progress reports.

Table 10
Total contribution expected from biomass in heating and cooling [PJ].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
Solid biomass	2017	2391	2912	2525	2943	2780	3387
Biogas	26	62	83	81	94	116	189
Bioliquids	49	154	90	170	10	180	209
Total biomass	2225	2607	3126	2776	3046	3076	3785
of which DH	245	341	477	389	338	482	741
of which biomass in households	1194	1278	1616	1315	1636	1359	1493
Biomass share in RES heating [%]	96.8	90.9	92.1	88.9	88.6	86.3	80.9
Share of biomass in heating [%]	9.0	11.4	13.6	12.4	14.2	13.7	17.3

[a] Achieved, according to aggregated data of the Member States Progress reports.

residues, non-food cellulosic material and lignocellulosic material (biofuels defined in the article 21.2 of the Directive 2009/28/EC) [9]. Considering multiple counting, in 2012, the use of renewable energy in transport in the EU increased significantly until 2012, but remained 19% below the projected use. The share of renewable energy in transport increased to 6.0% in 2012, which is just below the 6.1% target, due to the lower consumption of energy in transport (Table 11) [3,14,15].

Despite certain progress, the use of renewable energy in transport was lower in 2012 than in 2010 in several MS. The major contribution to the renewable energy in transport came presently from biofuels, but with a share increasing from 73% in 2005 to about 90% in 2020. The use of renewable electricity in transport (both in road and non-road transport) is expected to increase three fold and to reach about 3% in the total energy use in transport, in comparison with only 0.3% in 2005. In comparison with 2005, the share of electricity in comparison with the renewable energy used in transport will decrease to 10%, coupled with an increased contribution of biofuels. The majority of electricity is used in non-road transport (railways) and only 1% of this electricity is used in road transport. Multiple counting for electricity aims to promote the higher deployment of electric vehicles, this depending however on technological progress (mainly on batteries) and additional issues (availability of charging devices, costs, etc.) [3,14,15].

The leading MS in the use of renewable energy in transport in 2010 was Germany, followed by France, Italy and UK. The use of electricity in transport has also reached highest levels in France, Germany, Italy and Austria. In 2020 Germany will remain the leading MS followed by the UK and France (Fig. 5). Leading countries in the use of electricity in transport are expected to be Germany, Spain, France and Italy. According to the NREAPs, Finland will have the highest share of renewable energy in in transport in 2020 with 20% followed by Sweden with 13.8% and Germany with 13.2% [3,14,15].

3.5.1. *Biofuels*

The analysis of the NREAPs shows that the use of biofuels in transport is expected increase significantly from only 1% in the energy use in transport in 2005 to 11.4% in 2020 (Table 12). Biofuel use in transport increased to 556 PJ in 2010, but decreased to 500 PJ in 2012, 28.6% below the expected contribution of biofuels use in transport, to represent 4.6% of the energy used in transport [3,14,15].

The biofuel use in transport has been dependent on the implementation of the sustainability criteria that apply to domestic and imported biofuels as well. The sustainability of biofuels

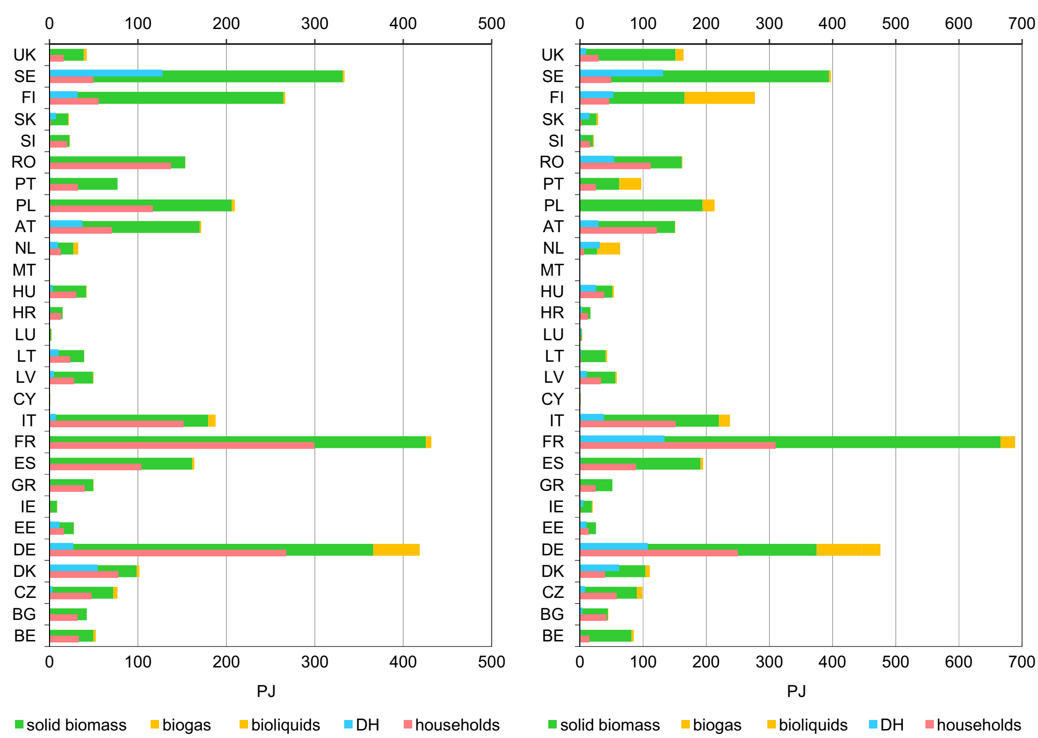

Fig. 4. Expected biomass heating and cooling in the MS in 2012 (left) and 2020 (right).

Table 11
Expected use of renewable energy in transport [PJ].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
Biofuels	125.4	575.2	555.9	699.5	499.7	822.7	1,216.4
RES electricity	45.8	54.7	47.0	65.9	55.8	83.0	135.9
of which in road transport	0.6	0.9	0.3	2.1	0.8	6.3	29.6
Total RES (single counting)	171.2	630.7	605.1	765.5	555.5	905.9	1,352.4
Total RES (multiple counting)	173.5	649.6	629.3	792.4	643	955.4	1,506.1
Energy use in transport	13,118	13,200	12,429	13,256	10,733	13,317	13,170
RES share in transport [%]	1.3	4.9	5.0	6.1	6.0	7.2	11.4

[a] Achieved, according to aggregated data of the Member States Progress reports

Table 12
Estimated contribution of biofuels in transport [PJ].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
Bioethanol/bio-ETBE	22.5	120.4	114.5	170.4	107.8	208.7	306.6
of which biofuels art 21.2	0.0	1.5	1.5	3.4	3.1	7.8	28.4
of which imported	4.9	32.3	34.5	66.6	25.7	85.7	134.7
Biodiesel	94.5	446.0	433.6	519.0	382.7	602.8	878.5
of which biofuels art 21.2	0.9	14.1	20.0	17.7	83.3	27.1	63.5
of which imported	2.2	154.4	150.9	163.9	95.7	178.3	324.3
Other biofuels	8.3	8.8	7.8	10.0	9.2	11.2	31.3
of which biofuels art 21.2	0.6	1.9	2.3	2.8	5.1	5.3	17.4
Total art 21.2	1.4	17.6	23.8	23.8	91.5	40.1	109.3
Total import	7.1	186.6	185.5	230.5	121.4	264.0	459.0
Total biofuels	125.4	575.2	555.9	699.5	499.7	822.7	1,216.4

[a] Achieved, according to aggregated data of the Member States Progress reports

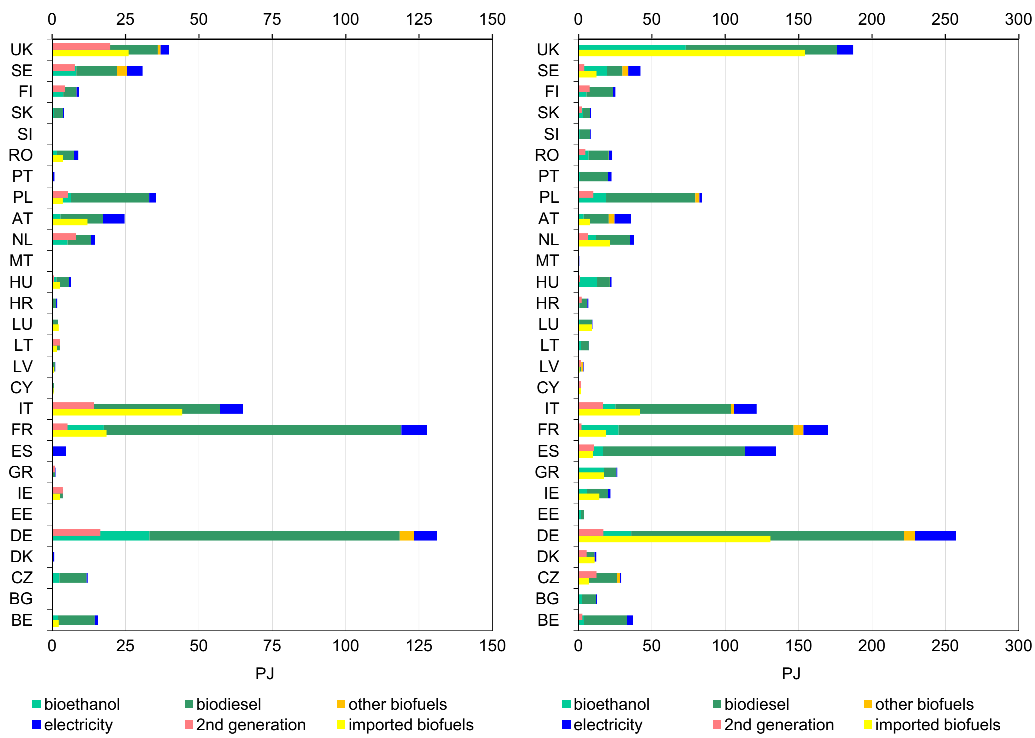

Fig. 5. Renewable energy used in transport in the MS in 2012 (left) and 2020 (right).

needs to be checked by Member States or through one of the 19 voluntary schemes which have been recognised by the European Commission since 2011 [33]. The numbers reported here do not represent the actual amount of biofuels used in transport, since in few MS (such as in Bulgaria, Estonia, Slovenia or Spain), biofuels suppliers were not able to prove compliance with the sustainability criteria. The delay on reaching the policy consensus on the ILUC effect as well as the perspectives of reducing support for biofuels have hampered the biofuels development.

The use of biofuels would reach 90% of the total renewable energy use in transport and 9% of the energy used in transport in 2020 (single counting) [3,14,15]. Contribution of biofuels to the energy consumption in transport has increased from 1.0% in 2005 to 4.6% in 2012, which is below the NREAPs expected contribution of biofuels for 2012 (Table 13). The contribution to the biofuels (multiple counting) in 2012 reached 5.4% of the energy used in transport and is projected to be 10.1% (without renewable electricity), already overcoming the 10% target imposed by the RES Directive. The use of biofuels in transport is focused on first-generation biofuels that make up more than 80% of all biofuels used by Member States in 2012. The EU is the major user of biodiesel worldwide and the greatest contribution in 2012 came from biodiesel (76%), followed by bioethanol/bio-ETBE with 22% and other biofuels (e.g. biogas/biomethane, vegetable oils, etc.) with only 2%. In 2020, first generation biofuels are still expected to provide the highest contribution to the total RES use in transport

Table 13
Estimated share of biofuels in transport [%].

	2005[a]	2010	2010[a]	2012	2012[a]	2015	2020
Share of biofuels (single counting)	1.0	4.4	4.5	5.3	4.6	6.2	9.2
Share of biofuels (double counting)	1.0	4.5	4.7	5.5	5.4	6.5	10.1
Share of art 21.2 in biofuels	1.2	3.1	4.3	3.4	18.3	4.9	9.0
Share of import biofuels	5.7	32.4	33.4	32.9	24.7	32.1	37.7
Share of RES in transport	1.3	4.9	5.0	6.1	6.0	7.2	11.4

[a] Achieved, according to aggregated data of the Member States Progress reports.

with a share of 25% bioethanol, 72% biodiesel and less than 3% other biofuels.

The leading countries in the field of biofuel use in transport in 2012 (Fig. 5) were Germany, France, Italy and UK. The leading countries in the field of biofuel use in transport in 2020 will be Germany, UK, France and Spain [3,14,15]. In all MS, the biodiesel has a highest contribution and the same is forecasted until 2020 with the exemption of Hungary and Sweden.

On long term, biofuels consumption in transport sector in decarbonisation scenarios was projected to increase to 25–36 Mtoe in 2030 and 68–72 Mtoe in 2050, in different scenarios analysed in the *Energy Roadmap* 2050 (COM(2011) 885) [7]. The share of renewables in transport (biofuels and renewable electricity) is expected to reach around 11% in 2020 in all decarbonisation scenarios and it is expected to rise to 19–20% in 2030 and up to 62–73% in 2050.

3.5.2. Biofuels from wastes, residues, ligno-cellulosic material

Biofuels produced from waste, residues, ligno-cellulosic material (biofuels defined in article 21.2 of the Renewable Energy Directive), or so-called second generation biofuels, are expected to be available at commercial scale by 2020 and have a small contribution to the biofuels used in transport. The use of biofuels article 21.2 was expected to reach a share of 9% of the biofuel use in the EU in 2020 in comparison with a share of 1.2% in 2005 [3,14,15]. Until now, article 21.2 biofuels were produced from wastes and residues. Their use increased significantly in recent years to reach 91.5 PJ in 2012, which is 285% above their expected contribution for 2012. Their share to biofuels use in transport increased from 1.2% about 18% of total biofuel use in 2012. The main contributor to biofuels article 21.2 in 2020 should be biodiesel with a contribution of 58%, followed by bioethanol with 26.0% and the other biofuels article 21.1 that count for the remaining 16%. In 2020, article 21.2 biofuels are expected to represent 7% of biodiesel, 9% of bioethanol and of 56% of other biofuels, respectively. Several countries, however, do not expect to have any contribution from biofuels from waste, residues, non-food cellulosic material and lignocellulosic material (Austria, Estonia, Greece, Lithuania, Luxembourg, Slovenia and UK) while others should have a negligible consumption (Germany, France, Ireland, Portugal). Denmark and Malta, on the other hand, expect to have the entire consumption of biofuels coming from article 21.2 biofuels (Fig. 5).

Although the contribution of article 21.2 biofuels shall be counted twice for the renewable targets in transport, their availability will depend on the advancements in the technology and cost reduction. Therefore, on short term, the majority of article 21.2 biofuels could be produced from wastes and residues. The proposal to cap the use of food-based biofuels to 7% (increased from the initial 5% proposal) [45] of the energy use in transport might influence significantly the contribution of renewable energy in transport and the use of biofuels in transport might differ substantially from the NREAPs projections.

3.5.3. Imported biofuels

The NREAPs data show that a significant amount of biofuels (459 PJ) is expected to be imported in 2020, corresponding to almost 38% of the total biofuels that will be used that year and 3.5% of the energy to be consumed in the transport sector. In comparison, the amount of biofuels imported in 2005 was almost 6% of the total biofuels used that year and only 0.1% of the energy consumed in the transport sector. In 2012, after several years of continuous increase, the use of imported biofuels in transport dropped to about 60% of their projected level in 2012 [3,14,15]. The imported biofuels still represent about 20% of the biofuels used in the EU, but with a share of only 1.1% of the energy consumption in transport in 2012. The contribution of biofuels from import in the transport sector is forecasted to increase to only 3.5% in 2020. Biodiesel will remain the main biofuel from import with a share decreasing to 78% in the total imported biofuels in 2020, while bioethanol imports will increase to reach a share of 29.3%. However, it is not clear how much biofuel should come from internal EU trade and how much should be imported as biofuels from third countries to the EU. Apart from this, some raw material (for example rapeseed, soy or palm oil) is expected to be imported and afterwards processed into biofuels within the EU.

The share of biofuels import at the level of MS is expected to vary from 0% in several countries (Belgium, Estonia, Finland, Hungary, Lithuania, Poland, Portugal, Romania, Slovenia and Slovakia) to 100% import in other countries (Denmark and Luxembourg). A number of countries should import more than 50% of their expected consumption of biofuels (Germany, Ireland, Malta, The Netherlands and the UK).

3.6. Biomass demand, supply and potential

3.6.1. Biomass demand

Biomass availability, competition between the alternative use of biomass, as well as the environmental implications related to biofuels are major concerns for bioenergy deployment. There is a limited availability of biomass that can be used for energy. Furthermore, biomass can be used not only for electricity production, but also for heat and as transport fuels. It is therefore important to analyse the demand for biomass in relation to the existing potential. We quantified the biomass required for reaching the 2020 targets for electricity, heating and transport for the whole EU and each Member State, depending of the NREAPS projections on the bioelectricity generation in Combined Heat and Power (CHP) and electricity only plants, heating and cooling, biomass used in households and biofuels used in transport. The estimation of the biomass demand was done for the different categories: solid biomass, biogas, bioliquids together with the land requirements for bioenergy production in the EU [39]. In the estimation of biomass demand, the main sources of biomass were considered in accordance with the Member States projections for the availability of domestic biomass supply, as provided in the NREAPs. The calculations were made for 2010 and 2012 to assess the biomass amount actually used for generating the energy from biomass, in relation to the amounts reported in the progress reports.

Different conversion technologies exist today [49]. Detailed information on the type of technologies likely to be deployed until 2020 as well as the plant capacities is not available, since their deployment depends on the market, the local biomass resources and local energy demand. In the assessment of biomass demand we considered a mix of technologies and plant capacities that can be used for bioenergy production and average conversion efficiencies for solid biomass, biogas and bioliquids. In the calculations, we considered as final heat consumption the energy content of biomass before conversion when used in households, services and industry and the energy content of heat after conversion in District Heating (DH) and power plants.

The results show that in the EU, total biomass primary demand to meet the 2020 targets for electricity, heating and in transport in the EU is expected to increase from 3110 PJ in 2005 to 7437 PJ in 2020. The results also show that the amount of biomass actually used in 2010 reached about 4764 PJ and about 5010 PJ in 2012. Again in 2020, the largest part of biomass demand is expected be satisfied by solid biomass, with 4.996 PJ, followed by biofuels with 1216 PJ, biogas with 887 PJ and bioliquids with 338 PJ . Fig. 6

shows the biomass demand in the EU, differentiated between solid biomass, biogas, bioliquids and biofuels.

3.6.2. Expected domestic biomass supply

The template for National Renewable Energy Action Plans under Directive 2009/28/EC [47], required Member States to assess the supply of domestically available biomass for energy production and the need for imports in all relevant sectors (forestry, agriculture and fisheries and waste). The amount of raw biomass feedstock for biogas and biofuels had to be detailed as well [47]. According to the Member States data provided in their NREAPs, the domestic biomass supply in the EU is expected to increase to meet the demand for heat, electricity and transport biofuels from around 3565 PJ in 2006 to around 5620 PJ in 2020 (Fig. 7). The aggregated values from the NREAPs show that domestic biomass supply should come from forestry with 3172 PJ, from agriculture and fisheries with 1710 PJ and 738 PJ from waste [14,15].

While the forest based biomass is expected to maintain its major role to biomass supply until 2020 (more than 55% of biomass supply), the biggest increase in supply should come from agriculture (with more than 150% increase compared with 2006), followed by the use of various wastes (with an increase of more than 130%). Depending on the total biomass demand and the domestic available supply, a share of biomass might be imported. Comparing the data from Figs. 6 and 7 a gap between the expected demand and expected biomass supply of 1817 PJ, equivalent to about 24% of the biomass demand is found. The difference between biomass domestic supply and biomass demand could come as imports of biofuels and bioliquids as well as solid biomass (wood residues, wood pellets, etc.), but, if the domestic resources would allow it, enhanced national and intra-EU mobilisation could provide a solution for filling the gap. Available potential is the subject of next paragraph analysis.

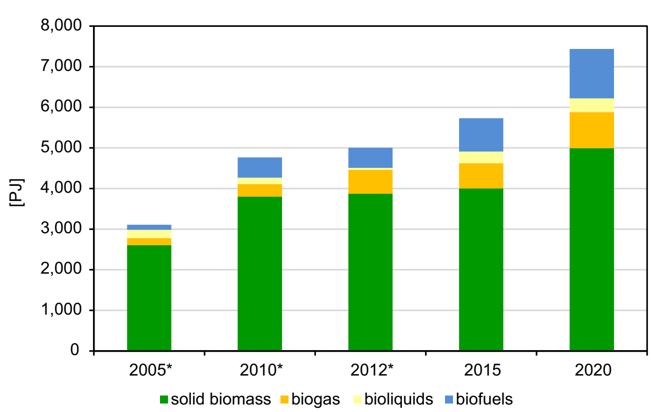

Fig. 6. Expected trend in biomass demand in the EU.

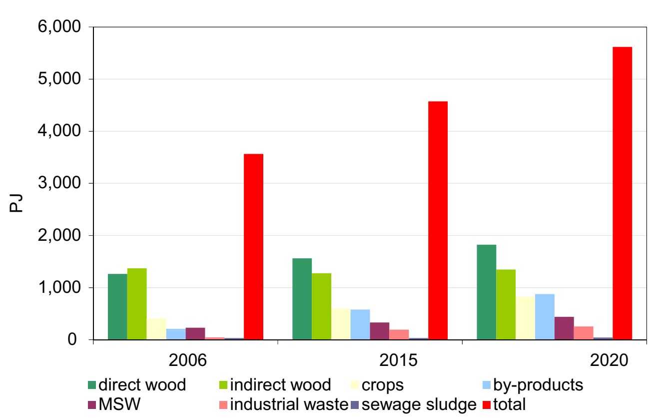

Fig. 7. Expected domestic biomass supply in the EU in 2020

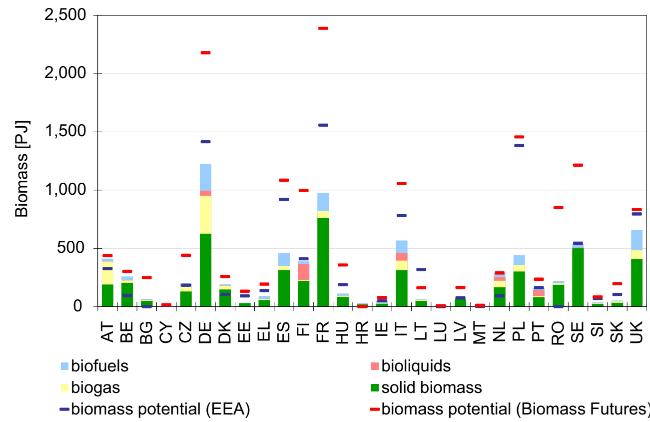

Fig. 8. Primary biomass demand in 2020 and biomass potential in the MS.

3.6.3. Future biomass demand and potential

We estimated the biomass demand for all Member States until 2020 and then compared it with the domestic biomass resources expected to be available for bioenergy production and the biomass potential (Fig. 8). Results allow to identify the potential gaps in domestic supply that can be covered by import and to adopt additional measures for increasing biomass mobilisation, depending on the existing potential.

Several studies provide estimates of the biomass potential in the EU covering forest, agriculture and waste to a different extent. The environmentally compatible biomass potential for the European Union (covering 25 Member States) was estimated by the European Environment Agency at 9839 PJ: 1641 PJ from forestry, 4007 PJ from agriculture and 4181 Mtoe from waste [50]. Another study, performed by the Biomass Futures project, shows that the biomass sustainable potential might be even larger in the EU27 in 2020, reaching 15,686 PJ, of which 7006 PJ from forestry, 6604 PJ from agriculture and 2076 PJ from waste [51]. Thus, according to both studies, the biomass potential of the European Union is large enough to ensure the biomass demand of 7437 PJ needed to reach the bioenergy targets at the EU level.

Analysing the expected biomass demand and the available domestic potential for single countries, both studies show that further development of bioenergy in the European Union is possible, especially in some Member States (Fig. 8). This reveals the extent of the expected use of domestic biomass in different MS in 2020 and that degree in which some MS could increase their contribution to the energy production from biomass. However, some biomass would be imported in any case, even if biomass potential is higher than the expected demand in 2020, since economic considerations are always the final driver for energy utilities or self-producers feedstock choice.

In several MS, such as Belgium, Denmark and the Netherlands, the biomass demand is expected to be higher than the environmentally compatible biomass potential (EEA), thus meaning they should rely on high extent on imports from other Member States or, most likely, from outside EU (Russia, Canada, etc.). In some other MS the expected biomass demand in 2020 is close to the potential (Czech Republic, Ireland, Latvia, Portugal) and thus, limited increase of domestic biomass utilisation is expected. However, in some MS the expected biomass consumption is below the biomass potential (France, Spain, Italy, Lithuania, Romania, Austria) and thus an increase of biomass use is possible. There are also Member States where the projected use of biomass in 2020 is far below the biomass potential: (e.g. Poland, Slovenia, Slovakia, Estonia, Lithuania) where significant development in bioenergy is possible also for providing feedstock for intra-EU biomass mobilisation. However, the biomass sustainable potential, provided by the Biomass Futures project, is significantly higher and all MS can rely on domestic biomass to reach their bioenergy and biofuels targets for 2020. Biomass mobilisation is a key issue, especially where the biomass demand is close to the potential.

4. Discussion and conclusions

Considering the progress made since 2005 on the deployment of renewable energy, the EU could achieve its 2020 renewable energy targets, but the progress made by renewable energy would slow down due to the reduced investments and reduction in the supporting schemes in many Member States.

The recently proposed framework for climate and energy in the period to 2030 together with the European Council Conclusions endorsing the 2030 renewable energy targets of minimum 27% will contribute to increase the investors' confidence in renewable energy and to the achievements of the 2020 renewable energy targets. The newly set renewable energy targets for 2030 would likely bring confidence on the long term perspectives of renewable energy and contribute to the achievement of the 2020 targets.

Bioenergy is the largest source of renewable energy today providing heat, electricity and transport fuels. Despite high growth rates in the photovoltaic and wind sectors, bioenergy at EU level is expected to remain the main RES contributor. Biomass is expected to contribute to almost 60% of the EU Renewable Energy target in 2020 and about 12% of the final energy use in the European Union.

Even with a reduction of earlier EU objectives in the field of biofuels for transport, there are very ambitious targets for bio-heat and bio-electricity in the EU Member States Renewable Energy Action Plans presently implemented. In the EU, carbon accounting for bioenergy is being debated and related decisions will also affect future bioenergy development.

Bioenergy production, together with building a bio-based economy, have the potential to contribute significantly to the development of a green, low carbon economy, due to the lower carbon footprint of bio-based products. The use of biomass for bioenergy and for bio-based products creates new business opportunities in agriculture, forestry and manufacturing sectors. Bioenergy production can significantly contribute to the development of rural areas and encourage creating new supply chains for biomass feedstock. The creation of new non-food markets for biomass could provide alternative income sources for farmers [52].

Increased demand for biomass for various purposes (bioenergy, bio-based products) could lead to an enormous increase in the demand for biomass, which could raise serious concerns. The availability of sustainable biomass for different uses is critical. Although about one quarter of biomass demand in 2020 is expected to be satisfied through imports from third countries, our estimates that domestic resources are likely to provide enough raw material for reaching the national targets, also through intra-UE feedstock trading. In order to realise this potential, biomass mobilisation within the EU will have to increase substantially. Building sustainable supply chains and the cost of biomass supply will be critical for the future evolution of bioenergy.

There is a significant biomass potential which needs to be exploited. Biomass import and intra-EU trade will be vital to match biomass supply and demand in different regions in Europe. The biomass demand in the EU will be covered in the next few years by a combination of the use of domestic resources and imported feedstock (or products), for example from Latin America (e.g. Argentina and Brazil for biofuels or bio-liquids), North America (Canada and the USA, in the case of pellets), South East Asia (Indonesia and Malaysia for biofuels or bio-liquids).

An important issue to monitor is the increasing competition of uses between traditional uses of biomass (e.g. food, feed and fibre), bioenergy, traditional forest industries (e.g. wood panel, pulp and paper) and growing sectors such as biomaterials and green chemistry [56]. A significant increase in the demand for biomass for bioenergy and the expected additional demand for bio-based materials will increase the competition for natural resources, in particular for land and water resources with potential negative impact on the land use patterns, biodiversity and environment. The increased use of forest and agricultural waste streams for bioenergy production could however have negative effects on soil fertility, soil productivity and biodiversity. The increased production of biomass can aggravate water scarcity in many areas of the world, because it puts additional pressure on water demand [39,57,58].

Increased demand for biomass for non-food purposes (bioenergy, bio-based products) in addition to the expected increase in food and feed demand could undermine food security and have significant impact in terms of price levels and price volatility. Although non-food crops provide an additional income for farmers, the main issue for food security is the access to food rather than food availability [59].

Several options are available to address this competition for food and non-food biomass production, such as the use of marginal and degraded land, increasing productivity, cascading use and enlarging biomass base (residues and waste, etc.). However, there are uncertainties about the degree to which the increase of agricultural production (e.g. yield improvement) can address this large increase in biomass demand and to what extent the competition can be avoided. The introduction of new technologies, through for example, the use of algae could significantly contribute at reducing competition with food, because of they have high productivity and do not compete for agricultural land. The limited availability of sustainable biomass requires biomass prioritisation and cascading use, which can bring significant improvements in resource efficiency with optimal value creation. Cascading use of biomass would contribute to minimising resource use and reducing the competition between different uses: food and feed, chemicals, materials, fuel and energy [56–58].

Within this framework, it is necessary to ensure that these expected increases in biomass use take place within a sustainable framework and biomass sustainability is thus a key issue. Several certification schemes, varying considerably in scope, were developed for a range of products and several sectors (e.g. agriculture, forestry) as a result of various concerns or specific purposes (fairtrade, environmentally sound cultivation, organic agriculture, etc.). As result of sustainability concerns related to the biofuels, several certification schemes were developed worldwide for biofuel production. The EU has also proposed MS to use the same criteria for the use of solid and gaseous biomass for energy production. These certification schemes include limited environmental, economic and social aspects, while some specific issues are not addressed. For example, the issues of indirect effects, including indirect land use changes, food availability and food security are addressed to a limited extent [32,60].

EU-wide harmonised sustainability criteria are necessary to provide reliable evidence to the general public on the sustainable use of biomass in order to increase public acceptance. Sustainability criteria should cover all types of biomass, with the same criteria for different uses of biomass (food, feed, bio-based products, bioenergy and biofuels) to avoid leakage, cover the entire supply chain and include various aspects such as GHG emissions or resource efficiency. The Roundtable on Sustainable Biomaterials (RSB) made some significant steps in this direction and expanded its scope in 2013 to cover bioenergy and bio-based products [56,61].

The future of bioenergy in the EU will also be affected by possible technological developments or cost improvements, for example in the field of torrefaction, second generation biofuels, use of algae for bioenergy or use of advanced biofuels for aviation. In the same time, bioenergy production provides good incentives for technological development to develop newer, advanced technologies. Biorefineries, for example, offers the opportunity for the co-production of both value-added products (bio-materials, biochemicals, bio-plastics, etc.) and bioenergy (biofuels, biogas, heat and/or electricity). The development of biorefineries will rely on the advancement in technology of a range of processes and achieving a breakthrough in terms of technical performances and cost effectiveness. However, a major issue for biorefinery development is related to the huge demand for biomass associated to a single large plant capacity needed to become cost effective, which huge impact on the logistics [49,53–56]. The proposal to cap the use of food-based biofuels to 5% of the energy use in transport might stimulate the development of alternative, so-called second generation biofuels from non-food feedstock (such as waste, agricultural or forestry residues), which do not directly interfere with food production.

Improved support schemes for renewable energy, coupled with the cost improvements in several technologies (mainly solar photovoltaic and wind) will drive up the progress in the renewable energy production and to contribute to the development of a low carbon economy. Stable, harmonised and sufficient support schemes are needed to improve the confidence of investors to invest in bioenergy production and in the development of biomass supply chains.

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