A calculation of the EU Bioenergy land footprint

Discussion paper on land use related to EU bioenergy targets for 2020 and an outlook for 2030

Liesbeth de Schutter and Stefan Giljum

Institute for the Environment and Regional Development

Vienna University of Economics and Business (WU)

March, 2014

Acknowledgments:

This discussion paper was commissioned by Friends of the Earth Europe.

We acknowledge the inputs by Dr. Bettina Kretschmer (Institute for European Environmental Policy, IEEP) in providing guidance in the preparation of the report and in reviewing the outcomes.

Thanks to Becky Slater for language editing.

This research has been produced as part of the Friends of the Earth Europe and Friends of the Earth Hungary project "Development Fields", with the financial assistance of the European Commission. The contents of this publication are the sole responsibility of the authors and can under no circumstances be regarded as reflecting to position of the European Commission.

Content

Executive Summary

This paper explores the land footprint related to EU bioenergy consumption and aims to contribute to the discussion on how EU bioenergy targets impact on scarce global land resources, both cropland and forest areas.

In the last decade, demand for EU bioenergy has risen significantly, largely driven by political targets and subsidies. Our calculations show that the total land footprint related to EU bioenergy is likely to expand from 44.5 Mha (an area of the size of Sweden) in 2010 to 70.2 Mha (an area of the size of Poland and Sweden combined) in 2030. This paper therefore calls for a critical view on both area requirements and environmental impacts with respect to the use of scarce natural resources for EU bioenergy purposes.

Biomass for energy
Providing 10% of global energy supply, bioenergy was the largest single source of renewable energy in the world in 2011 and provides heat, electricity and transport fuels (OECD/IEA, 2012). In developed countries, demand for bioenergy has been increasing significantly in the last decade, with the primary goal to reduce greenhouse gas (GHG) emissions in view of climate change and to become less dependent on fossil fuels (OECD/IEA, 2012, EC 2014a). As a result, pressures on land and inputs for biomass production are increasing, as are environmental impacts related to the increase in biomass demand (EEA, 2013).

Land footprint related to EU bioenergy demand
In this study, cropland and forest land requirements are calculated on the basis of EU demand forecasts for bioenergy towards 2020 and 2030. This required land area, the so-called global land footprint, includes both domestic land and land related to imports of bioenergy feedstock and end-products. Separate land footprints have been reported for sub-sectors (biofuels for transport, bio-heat and bio-electricity) and land-related biomass sources (agricultural crops and forest biomass).

Bioenergy in the EU
EU policy targets have been the most important driver of bioenergy demand in the past few years: 64% of renewable energy was derived from biomass in 2010, of which bio-heating was the most important segment with 74% of total bioenergy supply. In 2010, biofuels and bio-electricity accounted for 15% and 11% respectively (ECN, 2013). According to Member States' National Renewable Action Plans (NREAPs) (Beurskens and Hekkenberg, 2011), bio-electricity and biofuels are expected to grow substantially by 2020, indicating that high growth rates for feedstock can be expected. Although no longer term targets or incentives have yet been defined for sub-segments of bioenergy, the European Commission (EC) suggested in its 2030 energy and climate white paper that renewable energy should contribute at least 27% of renewable energy by 2030 (European Commission, 2014a).

Land related feedstock
Woody biomass is the most important feedstock, both worldwide and in the EU, as it is the most common resource for both bio-heating and bio-electricity (OECD/IEA, 2012, ECN, 2013). Woody resource includes both primary residues, mainly forest harvest residues and timber, as well as secondary biomass (by-products and waste

streams from processing industries). Secondary woody biomass is assumed to have no land footprint. The most common crops for the production of EU biofuels are wheat, maize and sugar beet for ethanol and rapeseed, soy and palm oil for bio-diesel. Cultivation of fast rotating (non-food) energy crops such as miscanthus is increasing but still limited. These 2nd generation feedstock can be used for biofuel, electricity and heating purposes. In our calculations, no significant transition towards 2nd generation crops is foreseen.

Sources and methodology for the calculations

The calculations in this study are based upon the Member States' progress reports on renewable energy (ECN, 2013) and the NREAPs providing data for the years 2010 and 2020 respectively (Beurskens and Hekkenberg, 2011). For bioenergy demand in 2030, PRIMES calculations for the NREAP variant of a study in the Biomass Futures project has been used (Apostolaki et al., 2012). Based on demand for the different bioenergy segments, we calculated the required amount of feedstock per technology pathway (in million tonnes) and – with average yields per hectare (Laborde, 2011) – the required land to produce the feedstock.

The woody biomass footprint is calculated on the basis of a technical potential approach (GEA, 2012), i.e. the maximum amount of harvest activity that can occur without degrading the productivity of the stock. The technical harvest rate in our calculations (4.4 tonnes average per hectare) is based upon the structure and age of EU forests. Imported wood from other regions is not allocated to the country of origin (with different harvest rates). Although indicating real forest area requirements, technical harvest rates don't mean that forests are sustainably managed and forest land calculations based upon this concept should therefore be considered a theoretical indicator.

Results

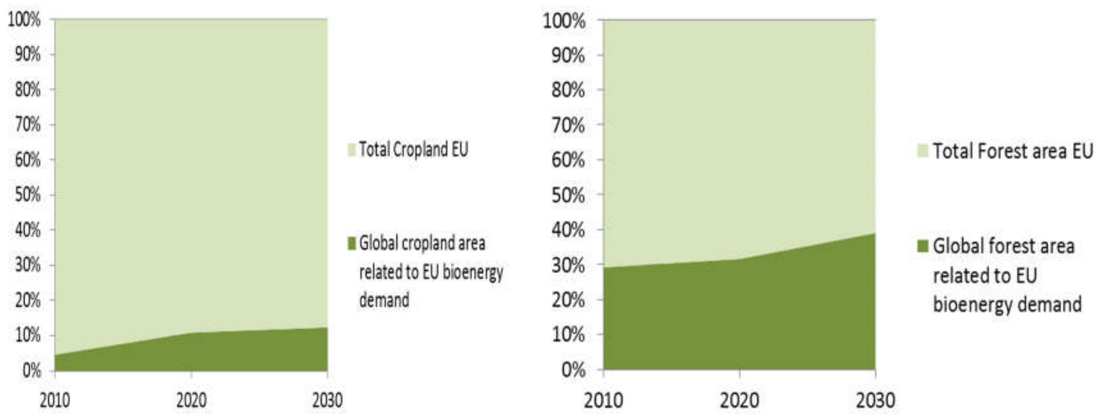
Our calculations show that the total land footprint related to EU bioenergy amounted to 44.5 Mha in 2010. By 2020, this area is projected to expand by 27% to 56.6 Mha, and expected to reach 70.2 Mha in 2030 (+58% compared to 2010). Land use requirements for biofuels will especially increase, by 130% between 2010 and 2020, in response to the 10% renewable energy target in the transport sector. Although demand for biofuels is assumed not to increase after 2020, an increase is projected in cropland for energy crops to be used in the biogas-bio-electricity pathway. In total, the majority share of the land footprint is related to wood resources for bio-heating and bio-electricity: 39 Mha in 2010, projected to expand to 55.3 Mha in 2030 (+31%).

Table 1: Land footprint calculations for EU bioenergy (Mha)

Bioenergy sub-sector	**Feedstock**	**Land footprint (Mha)**		
		2010	**2020**	**2030**
Biofuels	Ethanol feedstock	1.1	3.3	3.2
	Biodiesel feedstock	3.8	8.0	7.6
Bioenergy	Primary wood resources	7.0	10.4	13.3
	Energy crops	0.6	1.8	4.1
Bio-heating	Primary wood resources	32.0	33.1	42.1
	Total footprint	**44.5**	**56.6**	**70.2**
	Total cropland footprint	*5.5*	*13.1*	*14.9*
	Total forest land footprint	*39.0*	*43.5*	*55.3*

Based on the current cropland area of 120.4 Mha in the EU, global cropland requirements for EU bioenergy accounted for 4.6% in 2010. In 2020 and 2030, this share would more than double to 10.9% and 12.4% respectively. As for woody biomass, the total available forest area for wood harvesting is estimated at 133.5 Mha (Mantau, 2010) and the share for EU bioenergy amounted to 29.2% in 2010. In 2020 and 2030, this share is projected to increase to 31.6% and 39% respectively, while taking into account 0.3% afforestation rates in the EU.

Figure 1: The cropland footprint for EU bioenergy demand in relation to cropland availability in the EU (left) and the forest land footprint for EU bioenergy demand in relation to EU forest area (right)



Discussion

The availability and quality of reported data in the bioenergy sectors are hampered by insufficient public documentation of market developments in this sector, by inconsistencies in the Member States' progress reports (ECN, 2013) and by the fact that more exact crop areas and end-products are kept confidential by market players. As a result, the calculated land footprints contain considerable uncertainty.

Increased bioenergy demand may result in indirect land use changes (ILUC) related to policy measures to support domestic production of biomass feedstock (EEA, 2013). The use of biomass for energy purposes has various potential environmental impacts, including land degradation, nutrient pollution and increased global warming potential. These impacts are causing increasing concern. When ILUC is not taken into consideration, negative environmental impacts are likely to result in deforestation and biodiversity losses (EEA, 2013).

Lastly, the assessment of biomass feedstock and resources should take place in the context of the global macro-economy, developments in biomass markets and the EU policy outlook. Although rising energy prices are likely to support a more autonomous (cost-competitive) growth in EU bioenergy supply, firm market prices for biomass, including bioenergy feedstock, may increase costs and slow down developments and investments in the bioenergy sector. As a result, the EU framework for climate and energy towards 2030 will be crucial in determining future bioenergy demand and supply. The EC's white paper for 2030 projects a significant shift towards fast rotating plantation wood (perennial crops) as 2nd generation feedstock for bioenergy versus increased 1st generation feedstock in our calculations. However, other than in the Renewable Energy Directive (European Union, 2009), strong incentives and policy measures to promote a shift towards a more sustainable and resource efficient use of land resources for EU bioenergy purposes have not yet been specified.

To conclude: lack of sustainability safeguards and monitoring systems
Demand for bioenergy in the EU has been driven largely by political targets and subsidies. As a result, our calculations indicate a big increase in the cropland footprint between 2010 and 2020 (factor 2.3) and a forest land footprint that would require a large share of EU forests throughout the period to 2030. In 2010, biomass provided 8% of the EU's final energy consumption. If biomass energy is politically targeted to supply a strategic share of the EU energy mix, it can be concluded that the land footprint related to EU bioenergy would have to increase dramatically, causing much greater competition with other land uses and other regions.

As well as land resource use implications of expanding EU bioenergy demand, the lack of sufficient sustainability safeguards and adequate measuring and monitoring systems for bioenergy prevents an adequate protection of the environmental impacts worldwide. This study shows that such lack of measuring and monitoring systems is at least partly related to the poor and inconsistent data availability and reporting on bioenergy resources and environmental impacts by EU Member States. This particularly relates to the use of global wood resources for EU bioenergy, but also from domestic agricultural crops used for bioenergy supply.

1. Introduction: Land issues related to EU bioenergy

Bioenergy - energy produced from organic non-fossil material of biological origin - is promoted as a substitute for non-renewable (fossil) energy in order to reduce GHG emissions and dependency on energy imports. Providing 10% of global energy supply, bioenergy was the largest single source of renewable energy in the world in 2011 and provides heat, electricity and transport fuels (OECD/IEA, 2012).

Since the EU is, compared to other world regions, relatively poor in fossil energy sources and a large CO_2 emitter due to its advanced industrial development stage, its ambitions towards increased use of renewable energy sources seems a plausible strategy. Many arguments have been brought forward to promote the use of biomass in particular (e.g. security of energy supply, diversification of energy sources, reduced emissions, an alternative market for agricultural products and land rehabilitation) (European Commission, 2014b).

The EU has a target to meet 20% of its final energy consumption in 2020 from renewable energy sources. Bioenergy plays a central role in meeting this target, as evidenced by the share of bioenergy in the renewable energy, which amounted to 64% in 2010 (ECN, 2013).

However, there is an intensifying debate on possible negative social and environmental implications related to bioenergy, especially related to land competition and the effects of land use change, doubts about the low-carbon nature of bioenergy and concerns about agricultural market impacts (the 'fuel versus food' debate).

Land use and land use change for bioenergy are associated with important negative environmental and social impacts. Land use should be understood as a globally connected system where increased demand for bioenergy feedstock in one country may increase environmental pressures within or outside its territorial boundaries. These impacts affect biodiversity and the water, nutrient and carbon cycles, impacting on ecosystem functioning and resilience in diverse ways (EEA, 2013).

In this study, the land footprint associated with the 2020 EU bioenergy targets are calculated and discussed in the context of the longer term EU framework for climate and energy policies (European Commission, 2014a). Separate land footprints are reported for sub-sectors (biofuels for transport, bio-heat and bio-electricity) and land related biomass sources (agricultural crops and forest biomass).

Chapter 2 starts with an introduction to the land footprint concept, followed by a short overview of bioenergy technology pathways and the use of feedstock.

Chapter 3 presents the current state of bioenergy supply in the EU, the likely 2020 demand in line with the NREAPs and the projections for 2030 in line with the January 2014 white paper on a new EU Climate and Energy package (European Commission, 2014a).

The results of the calculations of the required feedstock for the projected bioenergy demand in 2020 and 2030 are presented as a cropland and forest land footprint in chapter 4. We also outline the data sources and scenario studies used as the basis of our calculations and, where applicable, relate the results to other studies.

In chapter 5, we discuss the results of the EU bioenergy land footprint in relation to the quality of the data, the environmental impacts and the longer term biomass market and policy contexts.

Chapter 6 concludes the major findings with respect to EU bioenergy demand and relate these to the total energy consumption in the EU.

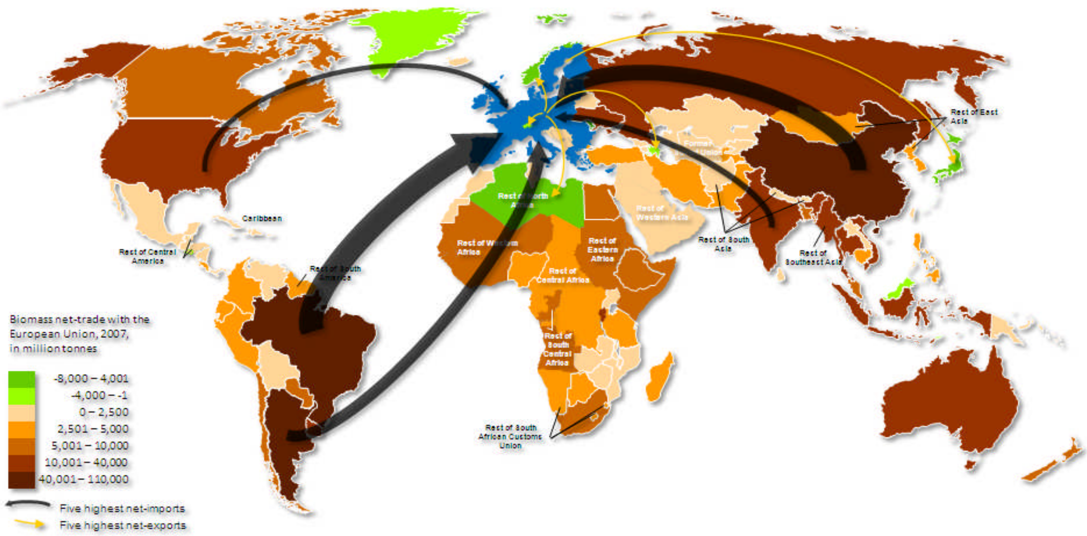
2. Land and feedstock for bioenergy

2.1 The land footprint concept

The EU's land area is one of the most intensively used regions on the globe. The EU has the highest share of land used for settlement, production systems (including agriculture and commercial forests) and infrastructure (EEA, 2010). Both the level of urbanisation (5% built-up land in 2006) as well as land used for agriculture (55% of total land) is high compared with global averages.

The EU hosts only around 7% of the global population, but produces more than a quarter of global GDP. High levels of affluence and related high levels of consumption in the EU are not satisfied with land areas available within the EU. Investigating the net-trade of embodied land of the EU with the rest of the world reveals that the EU is a net-importer of embodied land from almost all regions world-wide. The biggest flows of net-imports across all biomass-based products originate from Brazil, China, Argentina, India and the US (see Figure 2).

Figure 2: The EU's global embodied land flows (net-trade)



Source: Bruckner et al. (2012)

The EU today is a major player in global agricultural trade and is the world's biggest importing region for many products. In 2011, 44% of global imports (measured in tonnes) of fodder and feed products had the EU as their destination. The EU is by far the biggest importer of coffee, with a share of 51% in global coffee imports, and also leads with regard to other cash-crop imports such as bananas, where 37% of global trade goes to the EU (FAOSTAT, 2014).

Current and future land-related measures of the EU must therefore always be analysed in a global context, as pressures on land are continuously growing in many world regions. On the one hand, this is a result of population and economic growth, particularly in Sub-Saharan Africa and Asia, which increase pressure on, and competition for, land, for example, through changes in diets from plant-based towards animal-based products. On the other hand, regions such as Europe are contributing to this global competition over land, for example through the implementation of biofuel policies which require blending biofuels into vehicle fuels or policies that aim at substituting non-renewable materials (such as plastics) with bio-based alternatives.

This report focuses on one specific and rapidly growing component of Europe's land footprint, i.e. the land footprint related to consumption of bioenergy. As a core indicator, we apply the "land footprint" or "actual land demand" indicator, i.e. the total domestic and foreign land required to satisfy the final consumption of goods and services of a country or a region such as the EU (see Box 1 for details on the land footprint concept).

Box 1: Strengths and limitations of the land footprint indicator

The land footprint is a method of assessing the total domestic and foreign land required to satisfy the final consumption of goods and services of a country or world region. The land footprint takes a consumption-perspective and thus illustrates the actual land demand not only on the domestic territory, but also in all other world regions. By including embodied land in imports and exports (also called 'virtual land') it is thus a powerful method to calculate the total land requirements related to final consumption and/or to illustrate the dependency of countries or world regions on foreign land.

Currently, research on land footprints is very intensive in academia and statistics and a large number of publications have recently been presented on the land footprint indicator of countries and regions (for example, Bringezu et al., 2012; Bruckner et al., 2012; Kastner et al., 2011; Lugschitz et al., 2011; Statistisches Bundesamt, 2013; Weinzettel et al., 2013; Yu et al., 2013).

It should be emphasised that the land footprint as a pure area-based indicator is not able to illustrate the various environmental impacts from land use, such as deforestation, biodiversity loss, soil degradation or related GHG emissions. Indicators to address these environmental impacts are only currently being developed and only a few pilot studies have been presented (for example, Lenzen et al., 2012; VITO et al., 2013).

In the future, the use of the land footprint in combination with e.g. water, carbon and biodiversity footprints can give a comprehensive picture of the global environmental impacts of resource consumption patterns, and may help in identifying policy solutions, trade-offs and synergies aiming at a resource efficient and sustainable use of natural resources.

2.2 Bioenergy technologies and feedstock

Bioenergy refers to renewable energy coming from biological material using various transformation technologies such as fermentation, gasification, burning or pyrolysis. Biomass feedstock for this purpose originates from forest, agriculture and waste streams, with waste originating from organic household or retail waste, agricultural residues and waste products from industrial processes in e.g. the paper and pulp industry.

Depending on the biomass source, different conversion technologies are appropriate to generate a range of energy products to fuel transport, and generate heat and electricity. Conversion technologies are often categorised into conventional (e.g. currently available) and advanced (not yet demonstrated at scale and/or far from cost effectiveness) technologies, or alternatively first and second (or even third) generation technologies.

Woody resources from forests and wood processing industries is the largest resource of solid biomass, e.g. logs, bark, branches and leaves as well as sawdust. The majority share of woody resources is used for heating purposes although an increasing share is combusted to generate electricity. In this study, we have distinguished primary (mostly timber and harvesting residues) and secondary (such as saw mill residues) wood resources for the purpose of bioenergy (see Table 2 for detailed definition of woody biomass). Commonly traded products are wood chips, which can result both from residues or whole trees, and higher density pellets, often made from sawdust.

Table 2: Definitions of woody biomass for bioenergy purposes in this report

Term used in this report:	**Definition in EU Member States' progress reports:**	**Detailed definition:**
Primary wood resources	Direct supply of wood biomass from forests and other wooded land* for energy generation	a. Fellings; b. Residues from fellings (tops, branches, bark, stumps); c. Landscape management residues (woody biomass from parks, gardens, tree rows, bushes); d. Other (defined by Member State).
Secondary wood resources	Indirect supply of wood biomass for energy generation	a. Residues from sawmilling, woodworking, furniture industry (bark, sawdust); b. By-products of the pulp and paper industry (black liquor, tall oil); c. Processed wood-fuel; d. Post-consumer recycled wood for energy generation; e. Other (defined by Member State).

*excluding plantations and short rotation trees for energy purposes

Source: Commission of the European Communities, 2009

Agricultural resources used for bioenergy purposes include foremost the processing of common food and feed crops (mainly rapeseed, sugar beet, wheat, corn and rapeseed in the EU) into biofuels using conventional conversion technologies. In addition to domestic feedstock, crops such as oil palm, sugar cane or soya from other world regions are either imported as feedstock or as end-product, mainly for reasons of cost competitiveness.

A more novel generation of dedicated, non-food, energy crops include perennial energy grasses such as miscanthus, reed canary grass and others, as well as short rotation coppice from fast growing woody species such as poplar and willow. There is some potential for growing some of these on 'marginal', lower-quality lands though this usually comes with a yield penalty (Searle and Malins, 2014). Such dedicated energy crops, also called 2nd generation or lignocellulose crops, are often seen as a sustainable path to increase bioenergy supply with a limited land footprint, but it should be emphasised that, if grown on existing cropland, these crops will lead to ILUC just as conventional crops. Cultivation of dedicated energy crops is not widespread currently, due to barriers and issues posed by e.g. longer term investments, unclear technology incentives and reduced flexibility for the farmer.

The main technologies used with agricultural resources are the fermentation of starch or sugar crops into bioethanol and esterification of oil crops into biodiesel. Biogas production via anaerobic digestion for the purposes of heating, electricity generation and combined heat and power (CHP) is an increasingly important technology, largely using **biogenic waste** such as agricultural residues and food wastes. In some countries, such as Germany, fodder maize is an important energy crop for the generation of biogas, with associated land use consequences. Agricultural crop residues can also be combusted in larger (e.g. co-firing) facilities. They also have potential for liquid fuel generation through biochemical or advanced conversion technologies (Kretschmer et al., 2013), just as the dedicated energy crops mentioned above. Waste and residue streams (including secondary woody biomass) do not imply a land footprint as such and are therefore not further considered in the context of this study. However, it is important to realise that a range of existing uses rely on these resources, for example for animal bedding, composting and ploughing into the soil, which may limit the potential harvesting and collection rates for energy conversion.

For the purpose of this report, i.e. the calculation of a global land footprint related to EU bioenergy, we focus on the use of agricultural crops and primary woody resources for bioenergy purposes. For the calculations, we use commonly applied conversion factors in order to relate energy supply to energy demand (see section 4.1 for references).

3. The use of biomass for EU bioenergy

3.1 Actual use of biomass for bioenergy in the EU

Table 3 shows the total final (net) energy consumption, the renewable energy sector (RES) consumption and the biomass related energy consumption of the EU Member States in 2011. Final energy consumption and RES are actual figures (from Eurostat).The countries are listed from the largest biomass energy consumers to the smallest and Member States with a biomass share in final energy consumption exceeding 20% are highlighted in red.

Table 3: Final energy consumption, RES share and biomass share in the EU in 2011

Country	*Final energy consumption Ktoe*	*RES Ktoe*	*RES in final energy (%)*	*Biomass for bioenergy Ktoe*	*Biomass in final energy (%)*
EU-27	**1103260**	**149785**	**13,6**	**92599**	**8.4**
Germany	207093	26616	12,9	16240	7.8
France	148065	18236	12,3	12043	8.1
Sweden	32168	15452	48,0	8539	26.6
Finland	25179	8347	33,2	7076	28.1
Italy	122312	13644	11,1	6838	5.6
Spain	86532	13614	15,7	5898	6.8
Poland	64689	7050	10,9	5883	9.1
Austria	27328	8648	31,7	4566	16.7
Romania	22576	5139	22,8	3620	16.0
UK	132023	5654	4,3	3021	2.3
Denmark	14679	3690	25,1	2769	18.9
Portugal	17350	4709	27,1	2706	15.6
Czech	24643	2771	11,3	2193	8.9
Belgium	38886	2309	5,9	1639	4.2
Netherlands	50663	2141	4,2	1581	3.1
Hungary	16276	1528	9,4	1332	8.2
Greece	18835	2128	11,3	1163	6.2
Latvia	3982	1362	34,2	1099	27.6
Bulgaria	9287	1480	15,9	962	10.4
Lithuania	4696	1113	23,7	916	19.5
Slovakia	10795	1252	11,6	774	7.2
Estonia	2843	769	27,1	730	25.7
Slovenia	4951	944	19,1	558	11.3
Croatia	6181	883	14,3	445	7.2
Ireland	10800	766	7,1	321	3.0
Luxembourg	4276	298	7,0	93	2.2
Cyprus	1896	120	6,3	41	2.2
Malta	446	1	0,2	1	0.2

Source: AEBIOM, 2013 (Eurostat, AEBIOM Calculations). Note: Member States with a biomass share in final energy consumption exceeding 20% are highlighted in red.

The table above shows that 13.6% of EU final energy consumption in 2011 was from renewable sources, of which biomass derived products account for the largest share: 61.8% of RES comes from biomass, accounting for 8.4% of total net energy consumption (AEBIOM, 2013). Germany and France are the largest bioenergy consumers, whereas the Nordic states have the largest share of bioenergy in their energy portfolio, with Finland at the top ranking with a 28.1% share of bioenergy.

Table 4 shows the energy consumption levels in 2010 and the share of the Member States in the total EU market for bio-heating, bio-electricity and biofuels for transport. The countries are ranked according to the total size of the bioenergy market (consumption). With 73% of total bioenergy, biomass for heating (and cooling) purposes is by far the largest demand segment in the EU. Feedstock for this purpose consists largely of woody sources. The second important segment is biofuels, accounting for 15% of the bioenergy portfolio in 2010, and the main feedstock for this application is agricultural crops. Bio-electricity is still the smallest segment.

Table 4: Biomass-energy portfolio and market shares for the EU Member States in 2010 (consumption in Ktoe)

	Bio-heating (Ktoe)	Bio-electricity* (Ktoe)	Bio-fuels (Ktoe)	Bio-heat/ bioenergy (%)	Bio-electr./ bioenergy (%)	Biofuels/ bioenergy (%)
EU-27	***69719***	***11402***	***14419***	***100%***	***100%***	***100%***
Germany	10890	3235	3018	16%	28%	21%
France	9209	442	2717	13%	4%	19%
Sweden	7277	992	587	10%	9%	4%
Finland	6041	966	255	9%	8%	2%
Italy	4454	931	1362	6%	8%	9%
Poland	4866	654	900	7%	6%	6%
Spain	3857	388	1927	6%	3%	13%
Austria	3865	389	519	6%	3%	4%
Romania	3482	17	196	5%	0%	1%
UK	1017	1116	888	1%	10%	6%
Denmark	2314	376	230	3%	3%	2%
Portugal	2153	250	287	3%	2%	2%
Czech	1715	231	281	2%	2%	2%
Netherlands	720	607	326	1%	5%	2%
Belgium	912	406	329	1%	4%	2%
Hungary	1021	159	82	1%	1%	1%
Greece	1067	18	125	2%	0%	1%
Latvia	1057	10	19	2%	0%	0%
Bulgaria	944	5	9.8	1%	0%	0%
Lithuania	870	14	61	1%	0%	0%
Estonia	667	67	0	1%	1%	0%
Slovakia	551	71	101	1%	1%	1%
Slovenia	499	23	52	1%	0%	0%
Ireland	192	29	83	0%	0%	1%
Luxembourg	48	8	47	0%	0%	0%
Cyprus	24	5	16	0%	0%	0%
Malta	1	0	0	0%	0%	0%

*Bio-electricity: gross electricity generation from biomass, assumed to be consumed domestically.
Source: AEBIOM, 2013 (data 2010)

The table also highlights the important product market combinations, as a % of the total EU market volume. Germany is the largest market for all segments, followed by

France for bio-heat and biofuels. Sweden and Finland also have a considerable market for bio-heat and –electricity, whereas Spain and Italy are relatively large biofuel markets.

3.2 RES demand towards 2020

The Climate and Energy package adopted by the EU in 2009 presented an integrated set of climate and energy targets. For bioenergy, the Renewable Energy Directive's 20% share for renewable energy sources in EU final energy consumption is the leading target. In addition, there are specific 2020 targets for renewable energy for the transport sector (where 10% of final energy consumed is to come from renewable sources) and, as part of the Fuel Quality Directive, a decarbonisation target for transport fuels (6% reduction in GHG emissions).

In 2010, the renewables share in the EU's energy consumption was 12.7% and a little higher at 13.6% in 2011 (AEBIOM, 2013). When there was no regulatory framework at all at EU level to support renewables (1995-2000), RES grew by 1.9% per year. Between 2001 and 2010 (when indicative targets for the transport and electricity segments where in place), RES grew by 4.5% per year. However, RES would need to grow by ca. 5.5% per year between 2010 and 2020 to meet the overall 2020 target (3.7% per year for bioenergy) (AEBIOM, 2013).

According to the NREAPs, the EU is projected to surpass its 20% RES energy target in 2020 (see Table 5). The largest increase has to come from RES-electricity, where the majority is generated by hydro-power plants, although the largest growth is coming from wind power and biomass. RES-heat is projected to remain the largest sub-sector, and largely relies on woody resources for combustion. The share of renewables in transport reached 4.7% in 2010 and decreased to 3.8% in 2011 (AEBIOM, 2013).

In terms of feedstock, wood and wood waste continues to be the largest contributor to the mix of renewable energy sources in gross inland energy consumption, although its share decreased from 56% to 49% between 1990 and 2010 as other sources grew even faster (Eurostat, 2012).

Table 5: Development of RES sub-sectors between 2010 and 2020

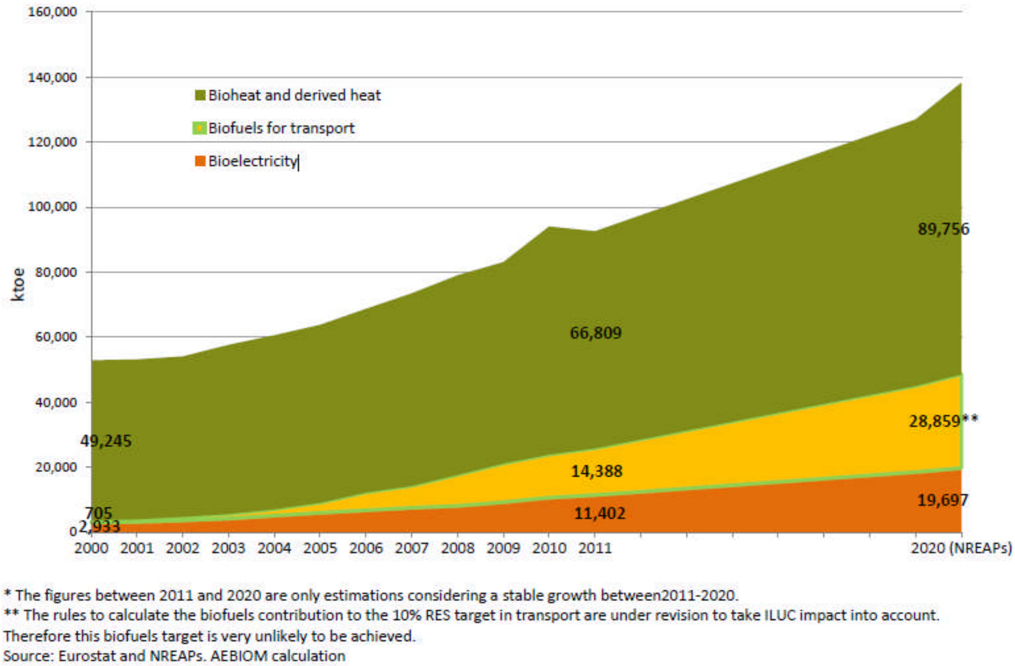
	RES 2010 (Mtoe)	RES 2020 (Mtoe)	CAGR*(%)
RES-Transport	: EU 32	32	5.2%
RES-Heating & cooling	73.5	112	4.3%
RES-Electricity	52.1	103	7.1%
Total RES	144.8	247	5.5%
Final energy consumption	1158.0	1137.3	
% RES	12.5%	21.7%	

Source: Eurostat (2012), European Commission (2013b), *Compound annual growth rate

3.3 Biomass for bioenergy in 2020 NREAPs

In the NREAPs (Beurskens and Hekkenberg, 2011), bioenergy is projected to account for almost 54.5% of the 2020 renewable energy target, with a doubling of the contribution of bioenergy (from 5.4% in 2005 to almost 12% in 2020) and a consequential increase in absolute energy contribution. However, the Member States did not indicate whether they included the sustainability criteria for biofuels in their estimates.

Figure 3: Combined, projected renewable energy targets as defined in the NREAPs (taken from AEBIOM, 2013)



3.3.1 Biomass for heat

Germany, France and Sweden are currently the largest (demand and supply) markets for biomass for heating in 2010 (AEBIOM, 2013). According to the NREAPs, biomass heat production will reach 87 Mtoe in the EU in 2020 (Beurskens and Hekkenberg, 2011), compared to 72 Mtoe in 2010 (Eurostat, 2012).

3.3.2 Biomass for electricity

The main bio-electricity markets are Germany, Italy, the UK and Finland (AEBIOM, 2013). According to the NREAPs, EU electricity power generation using biomass will increase to 20 Mtoe in 2020. In 2010, bio-electricity amounted to 10.4 Mtoe (ECN, 2013), which implies the largest growth rates for the bio-electricity sub-sector. Furthermore, there's a growing trend for biomass to be co-fired with coal or other fossil fuels in power stations.

3.3.3 Biomass for transport

The main sources of biomass feedstock for transport fuel production are maize and sugarcane/beet for ethanol and rapeseed, soy and palm oil for biodiesel. Cultivation of non-food energy crops such as miscanthus is of relatively minor importance currently. Next to domestic production, ethanol is also imported into the EU in large quantities as an end-product (ca. 0.8 Mtoe in 2010). The main supplier is Brazil, where the main feedstock is sugar cane. With respect to biodiesel, either as end-product or as feedstock, the main feedstock is soy from Argentina and the USA. A smaller, but growing, share is imported as crude palm oil from Indonesia and Malaysia (Laborde, 2011, ICCT, 2013).

The main biofuel markets in 2010 were Germany, France, Spain and Italy (AEBIOM, 2013). According to the NREAPs, biofuels (in the form of ethanol, biodiesel and bio-electricity) are projected to amount to 32 Mtoe by 2020 compared to the 14.4 Mtoe in 2010 (ECN, 2013). From these figures, it can be seen that the transportation targets, largely based on conventional energy crops, will be most difficult to achieve as an annual growth of 8.3% between 2010 and 2020 would be required (see Table 6).

Due to the ongoing legislative process to amend the Renewable Energy and the Fuel Quality Directives to take into account the ILUC impacts associated with biofuels, there is uncertainty as to the likely share of biofuels in 2020. The European Commission has proposed a 5% limit to the final transport energy demand for biofuels from food and feed crops. It looked like a 7% cap could pass through the Council, but at time of writing no agreement has yet been reached between EU energy/environment ministers let alone between Council and European Parliament.

Table 6: Bioenergy demand in 2010 and projected demand for 2020 (Mtoe)

	2010[1]	***2020[2]***	CAGR 2011-20
Heating & Cooling	71.5	***86***	1.9%
Bio-electricity	10.4	***20***	6.7%
Biofuels	14.4	***32***	8.3%
Total	96.6	***139***	3.7%

Source: [1]ECN, 2013. [2]Beurskens and Hekkenberg, 2011(NREAPs).
Note: 2010 demand for bio-heat and bio-electricity differs slightly from the AEBIOM figures in Table 4 – this is related to definitions and calculation methodologies)
CAGR=compound annual growth rate

3.4 Bioenergy towards 2030

In January 2014, the European Commission presented its vision on how to take EU energy and climate policy forward. The overarching goal of the EC's proposed policy framework (European Commission, 2014a and 2014b) for climate and energy policy to 2030 involves a GHG emissions reduction target of 40% by 2030 relative to emissions in 1990. As part of achieving this target, the EC suggests a share of renewable energy to reach at least 27% by 2030. This RES target would be binding at EU level, but not on Member States as in the current framework. How such an EU level target could be implemented in practice is unclear as of yet as there are pending discussions by European heads of states at the European Council which will be crucial for setting the direction of the future policy.

As a result of these uncertainties, the future path for biofuels and other forms of bioenergy towards 2030 is uncertain. The EC has recognised increasing pressures on biomass resources and calls for “an improved biomass policy”. It also states that biofuels from food and feed crops should not obtain public support after 2020 and suggests that bioenergy should focus on high yielding 2nd generation (perennial) crops.

4. The EU bioenergy land footprint towards 2030

4.1 Sources of data and scenario studies

Table 7 gives an overview of the main sources that have been used for the preparation of the data for the calculations of the EU bioenergy footprint in this report. The main building blocks are given by (1) the Member States' progress reports on renewable energy for the year 2010 (ECN, 2013), (2) the Member States' NREAPs for the year 2020 and (3) by two studies performed in the framework of the Biomass Futures project (www.biomassfutures.eu). The latter assessed the role that biomass can play in meeting EU energy targets while applying the sustainability criteria as defined in the Renewable Energy Directive (European Union, 2009).

Table 7: Overview of the main sources used for the calculations in this study

	2010	2020	2030
Member States' progress reports 2011 (data for 2009 & 2010)	Actual demand and supply of bioenergy subsectors, incl. solid biomass (wood)		
Member States' NREAPs 2010 (data for 2005-2020)		Forecasted demand and of bioenergy subsectors, incl. solid biomass (wood)	
Biomass Futures Deliverable 5.7 (Apostolaki et al., 2012)			Demand forecast per bioenergy subsector
Biomass Futures Deliverable 5.3		Supply shares of biofuel pathways	
Ecofys, 2013	Feedstock shares for biofuels		

The listed references are used to calculate a land footprint related to EU bioenergy demand for the different subsectors (biofuels, bio-electricity and bio-heating). The sources mentioned in Table 7 have been used to construct a scenario that is built on actual 2010 figures (progress reports), the NREAP demand projections for 2020 and the NREAP variant used in the Biomass Futures Deliverable 5.7 for 2030:

- Member States' progress reports (data for 2009 & 2010) (ECN, 2013) for the final bioenergy demand and supply in 2010, distinguished in biofuels, bio-electricity and heating and cooling;
- NREAPs of the EU Member States (data for 2005-2020), synthesised by Beurskens and Hekkenberg (2011), are used to specify the bioenergy demand and the bio-electricity and bio-heating supply projections for 2020;
- Biomass Futures Deliverable 5.7 (Apostolaki et al., 2012) for a description of the reference scenario that is based upon the NREAPs (NREAP variant), which as-

sumes the 2020 targets are met and that the legislation relating to emission reductions and the sustainability of the biomass and biofuel production is also taken into account. PRIMES scenario projections from that deliverable are used for bioenergy demand in 2030;

- Ecofys (2013) is used to distinguish the different feedstock (crops) for biofuel supply, which is needed to calculate the respective land needed for crop production. However, feedstock specifications are only available for the year 2010;
- Biomass Futures Deliverable 5.3 (Uslu et al., 2012 - calculating feedstock input for each bioenergy technology pathway) is used to calculate bioenergy feedstock shares for 2020;
- Technology conversion and biomass conversion rates are used from different sources, i.e. AEA Group (2011), AEBIOM (2013) and Elbersen et al. (2012).

4.2 Assumptions

In general, the calculations in this study are based upon a policy driven demand scenario, i.e. demand is projected to follow the projected growth as defined in the Member States' NREAPs, which have been prepared in view of meeting renewable energy targets for 2020. In this sense, the underlying assumptions for 2020 reflect the policy status quo, which might alter given the pending discussions on ILUC. After 2020, we assume no further growth for biofuels (given the uncertain future of biofuel support policy in light of announcements made in the EC's 2030 climate and energy white paper (European Commission, 2014a), discussed above) and we use the Biomass Futures D. 5.7 projections for 2030 (assuming a BAU scenario for the NREAP variant) for the bio-electricity and the bio-heat sub sectors.

For the calculations from bioenergy demand (Mtoe) to land related feedstock (million tonnes), the following assumptions have been made:

- In absence of concrete policy measures or incentives, biofuel demand is assumed not to grow after 2020. Bio-heating and bio-electricity are projected to develop according to the PRIMES projections for 2030 in Biomass Futures deliverable 5.7 (Apostolaki et al., 2012);
- Technology conversion factors are kept constant over time which can be considered conservative as technology efficiency tends to improve over time;
- Crop yields for 2020 are taken from an IFPRI study for the DG Trade (Assessing the Land Use Change Consequences of European Biofuel Policies by D. Laborde, 2011). In absence of 2010 yields, these crop yields are calculated back from 2020 with a 0.5% annual growth rate. The resulting yields are higher than reported by FAO and EU-DG Agri, which is supported by the probability that efficiently produced feedstock are exported to the world market and used for bioenergy production and by the fact that land areas have not been adjusted for multi-cropping (as is generally applied in tropical South America). Furthermore, crop yields are assumed to grow with 0.5% per year over the projected period (2010-2030), compared to a historical yield growth of 1% per year (Alexandratos and Bruinsma, 2012). Annual growth rates for crop yields have also been indicated to be negatively impacted by climate trends in a recent IPCC study (IPCC, 2014). However, as 2010 crop yields are

relatively high, cropland area calculations related to EU bioenergy may have been lower than actually required in the year 2010;

- Regarding co-products, cropland for co-products is allocated according to the physical share of the crop that is used for the co-product and deducted from the land required for the production of the whole crop;
- Only in the case of palm oil, it is assumed that biodiesel is made from crude palm oil with an average yield of 3.74 tonnes per ha (Oil world, 2007);
- Co-products of ethanol production are calculated with the following conversion factors;

Ethanol feedstock	**Co-product**	**Source**
Wheat	0.37 (DDGS)	JRC, 2013
Maize + other cereals	0.31(DDGS)	JRC, 2013
Sugar beet	0.15 (vinasse, beet pulp)	ePure, 2009

- Co-products from biodiesel feedstock (oil meals) depend on the type of feedstock and are based upon published processing technology coefficients:

Biodiesel feedstock	**Meal per ton of oilseed**
Rapeseed	0.514
Sunflower seed	0.234
Soybean	0.777

Source: Laborde, 2011

- The area of 2nd generation (dedicated) feedstock in 2010 is given by AEBIOM (2013) and amounts to 85,485 ha in 2011. This amount is included in the calculations and bioethanol conversion pathways are assumed;
- Development of 2nd generation feedstock in the bioethanol conversion pathway is defined in Biomass Futures Deliverable 5.3 (Uslu et al. 2012). A substantial increase is projected (and assumed in this study) from 0.05 Mtoe in 2010 to 1.0 Mtoe bioethanol in 2020 (factor 20);
- The area for energy crops used in the gasification pathway for bio-electricity in 2010 is estimated at 645.000 ha (or 27.5% of the energy supplied by the biogas-bio-electricity pathway) by Maiz' Europ (AGPM, 2011). Energy crops (silo maize) in this pathway are assumed to grow with the growth in demand for the total biogas segment (Apostolaki et al. 2012).
- Wood resources have been calculated according to the technology pathways as defined in the progress reports for 2010, the NREAPs for 2020 and follow the PRIMES (Biomass Futures deliverable 5.3) projections for the NREAP variant of the reference scenario in 2030;
- Total required woody biomass is split into primary and secondary wood resources, where the latter are assumed to have no land footprint (based on residues and waste streams such as black liquor);
- The split between primary and secondary wood resources is based upon EU-wood (Mantau et al., 2010) which assumes the share of primary wood resources (in total woody biomass for bioenergy purposes) to be 69%, 62.4% and 60% for respectively the year 2010, 2020 and 2030;
- The woody biomass footprint is calculated on the basis of a technical potential approach (GEA, 2012). In forestry terms this is the maximum amount of harvest activity that can occur without degrading the productivity of the stock. This concept involves maximum annual wood harvest rates that don't exceed

net annual increments based on productivity estimates from biophysical models such as GAEZ. In our calculations, an average harvest rate is calculated for the EU forest area (4.4 tonnes per ha.), based on (maximum) harvest rates for forests per Member State. This does, however, not mean that the respective forests are sustainably managed and forest land calculations based upon this concept should therefore be considered as a theoretically calculated indicator (see also section 4.4.3);

- In absence of transparent import data of woody biomass for bioenergy purposes, no distinction is made between domestic and imported feedstock, i.e. the maximum annual harvest rates for the rest of the world are assumed equal to the average EU forest rates (technology assumption).

4.3 Methodology

The methodology basically involves a coefficient calculation method where the final demand for bioenergy is calculated back into land required amounts of feedstock. Based on the data, projections and assumptions as described in the previous sections, the calculations include the following steps:

1. The starting point is the bioenergy demand (in Mtoe), for biofuels, bio-electricity and bio-heating, as defined by the Member States' progress reports (ECN, 2013);
2. In the second step, bioenergy demand (in Mtoe) is specified further and broken down according to feedstock per technology (based on Biomass Futures D. 5.3) and Ecofys (2013). So for example, it shows us the amount of ethanol produced from wheat (in Mtoe);
3. In the 3rd step, technology-feedstock pathways are converted into weight (Mton) based on energy-weight conversion factors, showing, for example, the amount of ethanol in Mton produced from wheat;
4. In the 4th step, the amount of end-product (e.g. ethanol from wheat) is translated into the original amount of feedstock required for its production by using the conversion factor (t feedstock/t end-product) for the specific technology-feedstock pathway. This step takes into account the losses that occur in the conversion of biomass to energy end-product. Co-products are not accounted for in this step, meaning that feedstock includes the whole crop/product;
5. In the 5th, final step, the land footprints for the different technology-feedstock flows are calculated, based on the feedstock requirements divided by the respective crop yields (in tonnes/hectare). This step is based upon average yields per crop and corrected for co-products.

4.4 Results

In this section, the land footprints are calculated for both cropland and forest area requirements related to EU bioenergy consumption. The results show the steps from bioenergy demand (in Mtoe) to feedstock requirements (in million tonnes) into the related land requirements (the land footprint, in Mha). The land calculations result in a global land footprint, i.e. both domestic land and land related to imported feedstock and/or end-products are taken into account. Finally, the cropland and the forest land footprint are compared to the available cropland and forest area in the EU for illustrative purposes.

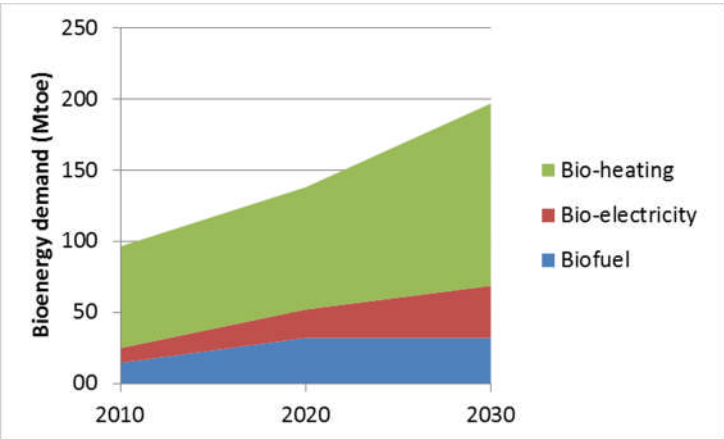
It is shown that global cropland requirements for EU bioenergy show a strong expansion path – from 5.5 Mha in 2010 to 14.9 Mha in 2030 - and that the global forest land footprint associated with EU bioenergy, with 39 Mha in 2010, is already considerable today and projected to capture the equivalent of 39% of the available EU forest area in 2030.

4.4.1 From bioenergy demand to land use

EU bioenergy demand amounted to a total of 96.4 Mtoe in 2010 (ECN, 2013). Bioheating accounts for the majority share (74%), biofuels for 15% and bio-electricity for the remaining 11% of total bioenergy consumption in 2010.

Figure 4 shows the development of bioenergy demand over time. Towards 2020, bioenergy is projected to grow by 44%, largely as a result of growth in biofuels to reach the 2020 targets. Bio-electricity and bio-heating are also projected to grow substantially (by 100% and 20% respectively). As outlined in the assumptions, biofuels are not projected to grow after 2020 in this study, given the potential phase out of support for biofuels from food crops, the potential halt to renewables and decarbonisation targets for the transport sector after 2020 and the uncertainty around the future viability of advanced biofuels. This can be considered a conservative assumption; in other words, assuming further growth in biofuel use after 2020 would increase the land footprint. However, we do assume demand for bio-electricity and bio-heating to continue which is projected to reach 204 Mtoe in 2030 (from 95 Mtoe in 2010).

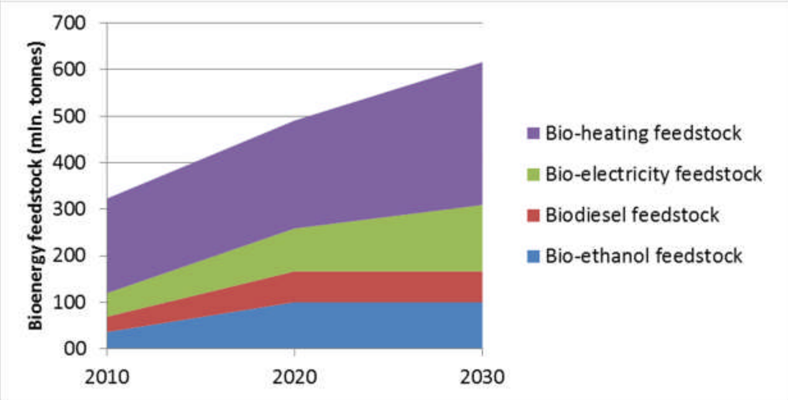
Figure 4: Development of bioenergy demand in the calculations



Source: ECN (2013), MS NREAPs (2009), Apostolaki et al (2012).

The bioenergy demand is supplied via several bioenergy technology pathways that require different amounts and different types of feedstock. Figure 5 shows the calculations of the amount of feedstock per bioenergy technology pathway (not adjusted for co-products). In line with projected demand, the largest amount of feedstock is required for bio-heating (203 million tonnes in 2010 and 307 million tonnes in 2030). Feedstock for biofuels increases from 69 million tonnes in 2010 to 170 million tonnes in 2020 and 2030. In 2010, feedstock for bioethanol and biodiesel each accounted for ca. 50% of the total feedstock required for biofuels by weight (not adjusted for co-products), whereas in 2020 (and 2030), the share of ethanol feedstock is projected to increase to 61% of the total by weight. Bio-electricity increases its land related feedstock by a factor 2.8 between 2010 and 2030, to a total of 143 million tonnes.

Figure 5: Development of land-related feedstock in the reference scenario



Source: Calculations based on Member States' progress reports (2011), MS NREAPs (2009), Ecofys (2013), Uslu et al. (2012)

In the next step, the required land area for each technology-feedstock pathway has been calculated on the basis of national or regional crop yields (Laborde, 2011). The crop areas have been adjusted for co-products. As mentioned earlier, the calculation is made from a consumption perspective, meaning that it includes land related to both domestic and imported feedstock (or end-products) and thus represents a global land footprint related to EU bioenergy demand.

Figures 6 and 7 show the global land footprint related to EU bioenergy demand (adjusted for co-products). The total required land and forest area is calculated to have been 44.5 Mha in 2010, equal to an area the size of Sweden. In 2020, this area is projected to expand by 27% to 56.6 Mha and expected to reach 70.2 Mha in 2030 (+58% compared to 2010). This would mean that, next to an area the size of Sweden, additional land area equivalent to the size of Poland would also be required to supply feedstock for EU bioenergy demand.

Land use requirements for biofuels are particularly increasing, with 130% between 2010 and 2020, in response to the 10% renewable energy target in the transport sector. Although the amount of biofuels is assumed not to increase after 2020, an increase in cropland is projected for energy crops to be used in the biogas-bio-electricity pathway. In total, however, the majority share of the land footprint is related to wood resources for bio-heating and bio-electricity: 32 Mha in 2010, projected to expand to 42.1 Mha in 2030 (+31%).

Figure 6: Required land area for feedstock related to EU bioenergy supply, adjusted for co-products

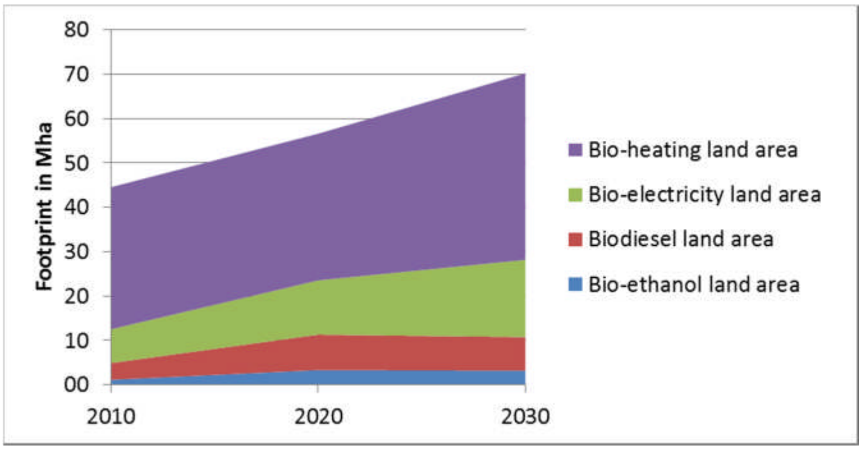
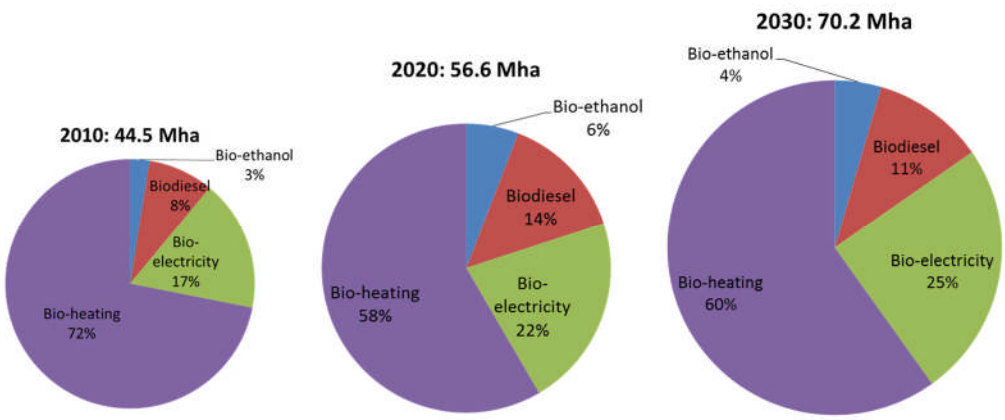


Figure 7 shows the relative shares of land area requirements related to the different bioenergy sub-sectors, as well as the development of the total land footprint over time. With 72% of the global land footprint in 2010, bio-heating accounts for the majority share of the total land requirements. This area is 100% forest area. Biofuel demand requires 11% of the total land requirements, all cropland, and 17% of the area is used for bio-electricity which involves both woody biomass and cropland. In 2020, a considerable shift towards cropland for biofuels can be noticed (20% of the global land footprint), whereas in 2030, land use related to bio-electricity increased its relative share to 25%.

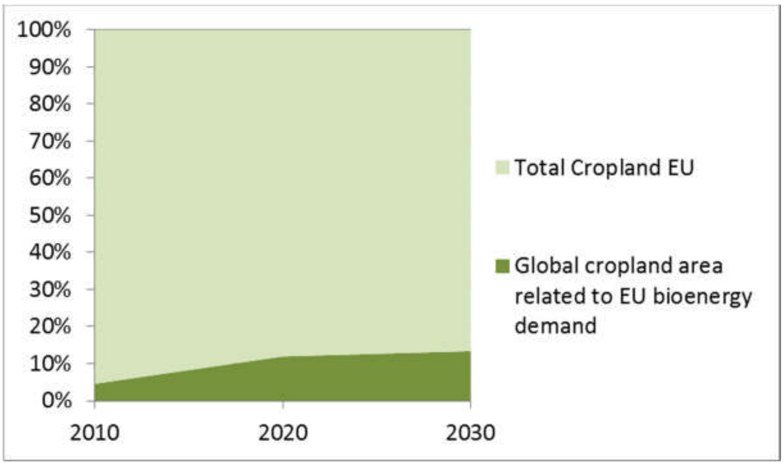
Figure 7: Relative shares in land area requirements for EU bioenergy sub-sectors



4.4.2 The cropland footprint for EU bioenergy

The total global cropland area related to EU bioenergy demand in 2010 is calculated at 5.7 Mha – which would compare to the equivalent of all the arable land in the UK. The majority share of it (72%) is related to biodiesel. Based on the current cropland area of 120.4 Mha in the EU, global cropland requirements for EU bioenergy accounted for the equivalent of 4.7% of EU cropland in 2010. In 2020, when bioenergy targets are met, the cropland footprint amounts to 14.3 Mha (in the EU and globally) and is projected to grow to 16 Mha in 2030. To illustrate this, the cropland footprint related to EU bioenergy is projected to increase to the equivalent of 11.8% and 13.3% in respectively 2020 and 2030 of the total available cropland in the EU (see Figure 8).

Figure 8: The global cropland footprint for EU bioenergy: 12% of EU arable land in 2020

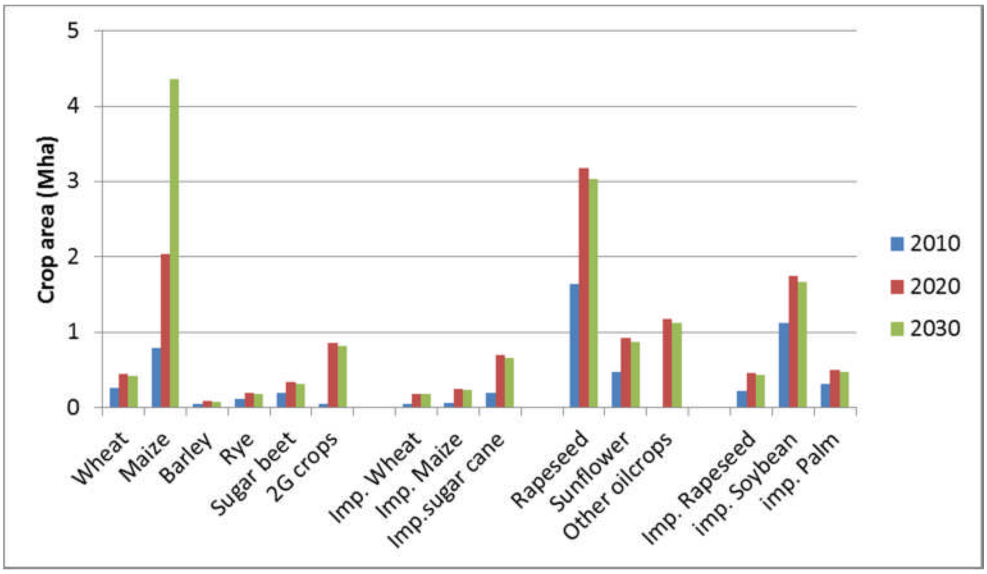


In a study for the European Commission, Ecofys (2013) calculated a required land area of 5.7 Mha for EU biofuels in the year 2010. These calculations include general assumptions regarding co-products, where it is reported that more exact information regarding co-products is likely to reduce the land requirements. The Ecofys calculations are in line with our cropland calculations in 2010 (5.5 Mha), although Ecofys does not include cropland related to the electricity pathway (where we included the 0.6 Mha of silo maize for biogas in our 2010 cropland footprint).

The cropland areas per type of bioenergy crop are shown in Figure 9 below. The areas are adjusted for co-products. Maize and rapeseed are the most common domestic crops used for bioenergy supply. Maize (0.8 Mha) and wheat (0.3 Mha) required the largest areas related to biogas and bioethanol in 2010. In 2030, (silo) maize is projected to increase substantially and 2nd generation crops such as miscanthus are projected to increase in line with the Biomass Futures supply scenario (D. 5.3) for feedstock in the biofuel pathway (Uslu et al. 2012). According to this scenario (which is used for our calculations) 2nd generation crops are projected to become the second important crop in 2020 (Uslu et al., 2012). In 2030, silo maize – as an energy crop for biogas – is projected to grow further in line with bio-electricity demand. It should be mentioned that the projected area for silo maize is currently supported by high gas feed-in tariffs in Germany, which are likely to be stopped after 2020. Furthermore, when incentives are there, silo maize may be replaced by 2nd generation feedstock.

For biodiesel, the largest domestic area is related to rapeseed (1.6 Mha in 2010), while soy – as a biodiesel feedstock - requires the largest area outside the EU (related to imports of feedstock and/or end-product into the EU): 1.1 Mha in 2010, projected to increase to 1.7 Mha in 2020.

Figure 9: Calculated areas for bioenergy crops related to EU bioenergy demand



With respect to crop areas, it should be noted that areas relate to the hectares that are sown, i.e. no adjustments are made for multi-cropping. In the EU most cropland areas yield one crop per year, whereas in Brazil for example large areas supply two crops per year, generally maize and soybeans, which may significantly reduce the land footprint related to imported feedstock or end-products.

4.4.3 The forest footprint for EU bioenergy

For the purpose of this study, we have calculated the required forest area needed to harvest the consumed amount of primary woody biomass (for bioenergy purposes) with the technical yield approach (developed by IIASA/G4M), i.e. the maximum usable harvest rate within the net annual increment of the forest. It is emphasised that a technical yield calculation of forest area is a theoretical area that is by no means comparable with sustainable forest management. The latter includes the protection of key habitats (including in commercial forests), biological diversity, forests' health and vitality, productive functions of forests, protective functions (soil and water), socio-economic functions etc. (Forest Europe, web site communication).

Calculated with a technical harvest rate of an average 4.4 tonnes per hectare, the global area for primary wood products to supply EU bioenergy demand adds up to 39 Mha in 2010 – which is equivalent to all current forest area in France, Germany, Italy and the UK together. The calculations assume secondary wood resources (ca. 40% of the total woody biomass used for bioenergy) related to industrial activities and waste do not entail a land footprint. In 2020 and 2030, the calculated forest footprint amounts to 43.5 and 55.3 Mha respectively.

In order to compare our calculations with a reference value, we calculated the area for wood resources required for energy purposes from the EU wood study (Mantau et al. 2010) based on the same harvest rate (4.4 tonnes/ha). Table 8 shows that our calculations develop more or less in line with the area allocated to energy related woody biomass demand calculated in the EUwood study (Mantau, 2010). 2010 shows the largest difference, which indicates that the actual amount of woody biomass for bioenergy may have been higher than estimated by Mantau (2010) as the amounts in our calculations are taken from the Member States' progress reports with actual data for 2010, which had not been available at the time of the EUwood study (Mantau, 2010).

Table 8: Comparison forest area calculations (in Mha)

	2010	2020	2030
EUwood (Mantau, 2010)	32.8	46.1	58.2
Calculations primary woody biomass	39.0	43.5	55.3

According to Eurostat 41%, or 178 million ha, of the area in the EU was covered with forests and other wooded land in 2010. Of the total forest area, about 75% of that is potentially available for wood supply (Mantau, 2010). The remaining area is protected by several limitations, like legal and ecological restrictions. Even within the available forest area, ownership structure and the goals of the forest owner, as well as economic and technical restrictions, reduce the real level of harvestable wood. This means that the calculated area of 133.5 Mha forest (75% of the total) available for wood harvesting in the EU can be considered an upper limit.

Figure 10 shows the global forest land footprint for EU bioenergy demand (as calculated in this study, excluding secondary woody biomass) in relation to the EU forest area available for wood harvesting in the EU. In 2010, forest area related to EU bioenergy demand is calculated to amount to the equivalent of 29.2% of the useable forest area in the EU. In 2030, this share is projected to increase to 39%. It should be noted, however, that no major shift is projected towards waste streams and/or towards high yielding lignocellulose crops to replace primary woody biomass for bioenergy purposes.

Figure 10: The global forest land footprint for EU bioenergy: 32% of EU forest area in 2020

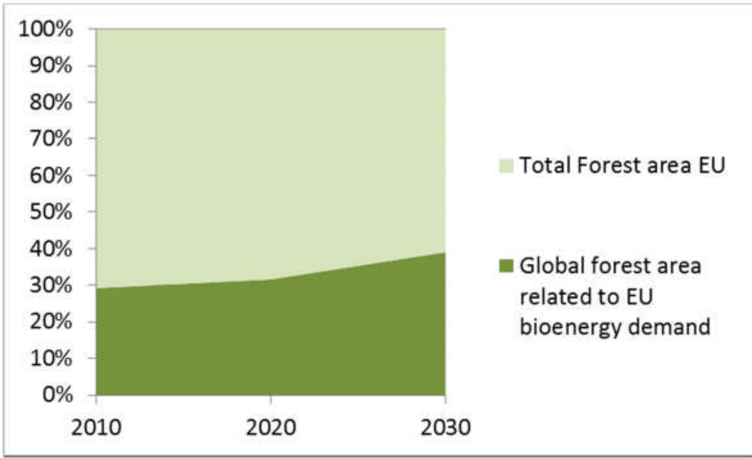
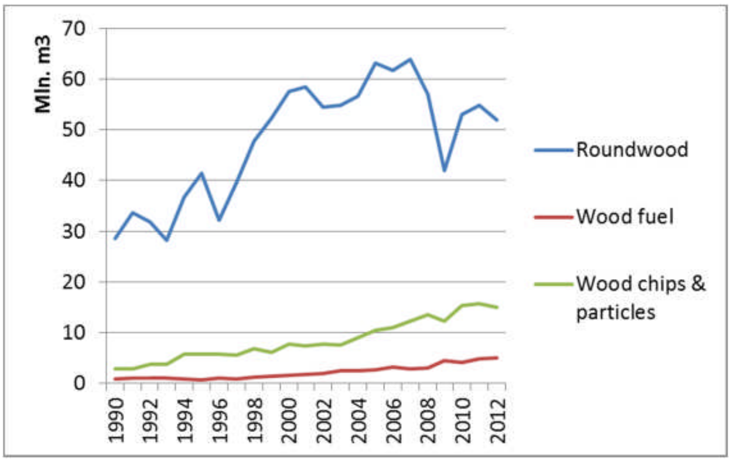


Figure 10 thus shows the global forest land footprint for EU bioenergy as if all wood is being harvested from EU forests. In reality, a share of the woody biomass is imported and imports statistics indicate an increasing volume of wood for bioenergy purposes (see Figure 11). The technical harvest rate (4.4 tonnes per hectare) in our calculations is based upon the structure and age of EU forests, which may differ from e.g. Russian, North American or tropical woods. As such, the forest land footprint in this study includes a high level of uncertainty, both related to the lack of reliable data for the amount of woody biomass used, as well as with respect to the origin of the woody biomass for bioenergy purposes in the EU.

Figure 11: Development of woody biomass imports into the EU



Source: FAOSTAT

5. Discussion

The global cropland and forest land footprint related to EU bioenergy demand, as calculated in this study, give an indication of the absolute and relative required land area in comparison to the available cropland and forest area in the EU. The calculations indicate two important issues: first, that **cropland area for EU bioenergy shows a strong increase between 2010 and 2020** (factor 2.6); and second, that the **forest land footprint represents the equivalent of a significant share of the available forest area in the EU**: 39 Mha, equivalent to 29% of the EU forest area in 2010, projected to increase to 39% in 2030. An intensification of EU forest management is also projected in the EC climate and energy package towards 2030/2050 (European Commission, 2014a), anticipating increasing harvest removals over time related to growing demand for wood products.

Land footprint calculations, as an area indicator, are **highly sensitive to the quality of reported data**. In this respect, it should be stressed that the availability of reported data in the bioenergy sectors is severely hampered by insufficient public documentation of market developments in the bioenergy sector, by inconsistencies in the Member States' progress reports (ECN, 2013), and by the fact that large processing facilities keep data on inputs, associated crop areas and end-products confidential. The latter is reported by Ecofys (2013), which mentions that the actual compositions of bioenergy feedstock per Member State are known to large processors or processor groups like ePure and European Biodiesel Board (EBB), but are kept confidential because the information is considered competition sensitive.

As for woody biomass, key sources (Member State progress reports and NREAPs) and statistical databases (Eurostat, FAOSTAT) report inconsistent and incomparable data for woody biomass resources and bioenergy. Furthermore, existing studies (such as the deliverables within the Biomass Futures project) lack a connection between woody resources, their origin, and their use in technology pathways. As a result, it has not been possible to make a sophisticated differentiation between primary and secondary woody biomass, both as an aggregate and via the technology pathway to the final energy demand. Considering the volume and growth of biomass for EU bioenergy, the lack of adequate measuring and monitoring systems of both feedstock and environmental impacts is considered a serious threat to a sustainable use of biomass for renewable energy purposes.

Use of biomass for energy purposes in developed regions is primarily targeted at reduced GHGs and a reduced dependency on fossil fuels (European Commission, 2014a, Hallström, 2011). In this respect, more intensive wood harvesting and land use changes involving the conversion of forest areas into cropland pose a **threat to a sustainable use of natural resources as well as a significant negative impact on the assumed neutral carbon balance of biomass use for energy** (EEA, 2013). As a result, there is increasing concern about the potential environmental impacts of the use of biomass for energy purposes. These include, amongst others, land degradation, nutrient pollution, water stress and increased global warming potential in relation to increasing demand for biomass (Weinzettel et al. 2013).

In the EU, forest areas have expanded in recent decades (FAO, 2012) whilst cropland area has decreased (European Commission, 2014b). Increased bioenergy demand may involve **displacement of land areas outside the EU (and increased imports) as well as indirect land use changes related to policy measures to support domestic production of biomass feedstock** (EEA, 2013). Reliance on imports is of concern because more than 30% of the net primary production that is used within the EU, including food, fuel and fibres, already comes from imported biomass or biomass products (Haberl et al., 2012, BIOIS et al., 2014). Through added biomass imports, to meet increasing EU demand for biofuels, more of the attendant climate and ecological risks of intensive agriculture would be exported to countries outside the EU.

As one of the latest prominent studies in this respect, EEA (2013) demonstrates the importance of incorporating ILUC into the analysis. **Accounting for ILUC in bioenergy policies would reduce the amount of bioenergy that can be produced sustainably**, as it worsens the GHG balance of biofuels and reduces the amount of biofuels that meet the GHG savings criteria as defined in the Renewable Energy Directive. In particular most first generation biofuel pathways are excluded, as including ILUC renders their lifecycle emissions higher compared to fossil fuels. When ILUC is not taken into consideration, negative environmental impacts are likely to result in deforestation and biodiversity losses (EEA, 2013).

Biomass for bioenergy competes with land and water resources for other purposes, mainly food and feed, but also other ecosystem services. Furthermore, bioenergy may put pressure on good agricultural and environmental practices such as fallow land and adding crop residues to the soil. As such, the assessment of biomass feedstock and resources should take place in its context. The EU context for bioenergy is formed by a macro-economic context, the biomass markets context and the policy context. The key macro-economic development relates to a projected increase in energy prices (EC, 2014a), which may render production of EU bioenergy profitable in its own right, even in the absence of strong policy drivers. From a biomass market perspective, increased demand and prices for biomass products, particularly wood, and a transition towards bioenergy will further increase competition for food and land resources on a global scale (Alexandratos and Bruinsma, 2012, Hallström et al., 2012).

Although rising energy prices are likely to support a more autonomous (cost-competitive) growth in EU bioenergy supply, firm market prices for biomass, including bioenergy feedstock, may increase costs and slowdown developments and investments in bioenergy. As a result, **the EU framework for climate and energy towards 2030 will be crucial for future bioenergy demand and supply**. In its recent presentation of the EU framework for climate and energy towards 2030, the EC continues to consider biomass for energy a key technology path towards a more resource efficient and low carbon economy in view of energy emission targets and it does acknowledge that improved biomass policies will be necessary to deliver robust and verifiable greenhouse gas savings. These policies aim to address sustainable use of land, the sustainable management of forests in line with the EU's forest strategy and address indirect land use effects as with biofuels (European Commission, 2014a).

Based on the projections of the EC, the projected 197 Mtoe final bioenergy in our calculations more or less coincides with a potential 30% renewable energy share and 40% reduction of GHG emissions in 2030 (European Commission, 2014a). However, projections in the EC's climate and energy framework include a considerably stronger shift towards fast rotating plantation wood (perennial crops) for bioenergy versus an increase in 1st generation feedstock in our calculations. As a result, cropland is projected to increase significantly in both our and the EC's calculations. Forest, waste and agricultural residues are projected to remain relatively stable in the EC's projections.

Our calculations show that meeting the EU's targets for renewable energy in 2020 and projections for 2030 require a significant transition from a business as usual scenario, i.e. increased demand for woody biomass and conventional (1st generation) crops, towards advanced biofuels based on 2nd generation energy crops. **Strong incentives and policy measures in the form of sustainability safeguards are needed to promote a shift towards a more sustainable and resource efficient use of land resources for EU bioenergy purposes.**

Conclusions

Demand for bioenergy in the EU has increased significantly in the last decade, largely driven by political targets and subsidies – and this trend is set to continue. In 2010 the global footprint related to EU bioenergy demand equalled the total land area of a country the size of Sweden. Furthermore, policy targets for bioenergy are projected to require an additional area expansion of the size of Poland by 2030. This expansion is strongly related to the EU energy targets for 2020, and assumes no further supporting measures for biofuels towards 2030.

Biomass currently provides 8% of the EU's final energy consumption. However, if biomass energy is politically targeted to supply a strategic share of the EU energy mix, the land footprint related to EU bioenergy would have to increase dramatically, causing much greater competition with other land uses and other regions.

There are currently no adequate and verifiable sustainability safeguards in place to guarantee the prevention of further ecosystem degradation from EU bioenergy consumption. In particular, land areas outside the EU territorial borders suffer from a lack of protection as systems fail to measure and monitor land use and environmental impacts related to EU bioenergy consumption.

This study shows that the lack of measuring and monitoring systems is at least partly related to the poor and inconsistent data availability and reporting on bioenergy resources and environmental impacts by EU Member States, in particular on the use of global wood resources, but also from domestic agricultural crops used for bioenergy supply.

References

AEA Group, 2011. UK and Global Bioenergy Resources and Prices – Final Report. Oxfordshire. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48059/1464-aea-2010-uk-and-global-bioenergy-report.pdf

AEBIOM, 2013. European Bioenergy Outlook 2013. Statistical Report. Brussels: AEBIOM.

AGPM, 2011. Biogas: Europe records strong production growth. Maiz'Europ Newsletter September/October 2011: http://www.agpm.com/pages/bibliotheque.php#I00050dc9

Alexandratos, N. and J. Bruinsma, 2012. World agriculture towards 2030/2050: the 2012 revision. 12. Rome: FAO.

Apostolaki E., N. Tasios, A. DeVita, P. Capros, 2012. Deliverable 5.7 PRIMES Biomass model projections. Biomass Futures http://www.biomassfutures.eu/public_docs/final_deliverables/WP5/D5.7%20PRIMES%20Biomass%20projections.pdf

Beurskens L. and M. Hekkenberg, 2011. Renewable Energy Projections (2005-2020) as Published in the National Renewable Energy Action Plans of the European Member States. ECN/EEA. https://www.ecn.nl/docs/library/report/2010/e10069.pdf

BIO IS, WU, and IVM. 2014. *Resource efficiency policies for land use related climate mitigation. Second Interim Report (updated) prepared for the European Commission, DG CLIMA*. Paris: Bio Intelligence Service at Deloitte.

Böttcher, H., S. Frank and P. Havlik, 2012. Deliverable 3.4: Biomass availability & supply analysis. Biomass Futures. http://www.biomassfutures.eu/public_docs/final_deliverables/WP3/D3.4%20Biomass%20availability%20&%20supply.pdf

Bringezu, S., M. O'Brien, and H. Schütz. 2012. Beyond biofuels: Assessing global land use for domestic consumption of biomass: A conceptual and empirical contribution to sustainable management of global resources. Land Use Policy 29(1): 224-232.

Bruckner, M., B. Lugschitz, and S. Giljum. 2012. Turkey's virtual land demand. A study on the virtual land embodied in Turkey's imports and exports of agricultural products. Vienna: Sustainable Europe Research Institute (SERI).

Commission of the European Communities, 2009. Commission Decision of 30.06.2009 establishing a template for National Renewable Energy Action Plans under Directive 2009/28/EC. C(2009) 5174-1. Brussels.

ePure, 2009. Bioethanol: producing food and fuel. eBIO newsletter November 2009: http://www.pannoniaethanol.com/files/furtherinfo/eBio_food_AND_fuel_production.pdf

ECN, 2013. Renewable Energy Progress Reports. Data for 2009-2010. Petten: ECN. https://www.ecn.nl/docs/library/report/2013/e13076.pdf

Ecofys, 2013. Renewable energy progress and biofuels sustainability. Report for the European Commission. http://ec.europa.eu/energy/renewables/reports/doc/2013_renewable_energy_progress.pdf

EEA, 2010. The European Environment. State and Outlook 2010. Land Use. Copenhagen: EEA.

EEA, 2013. EU bioenergy potential from a resource efficiency perspective, EEA Report No 6/2013. Copenhagen: European Environment Agency. http://www.eea.europa.eu/publications/eu-bioenergy-potential.

Elbersen, B, Startisky, I, Hengeveld, G, Schelhaas, M-J, Naeff, H and Böttcher, H., 2012. Atlas of EU biomass potentials. Deliverable 3.3: Spatially detailed and quantified overview of EU biomass potential taking into account the main criteria determining biomass availability from different sources. Biomass Futures: www.biomassfutures.net

Elbersen B.S., U. Fritsche, H. Eerens, K. Overmars, J.P. Lesschen, I. Staritsky, K.P. Zulka, L. Brodski and K. Hennenberg, 2013. Review of the EU bioenergy potential from a resource efficiency perspective. Background report to EEA study. Malaga: ETCSIA.

European Commission, 2013a. Green paper - A 2030 framework for climate and energy policies. Brussels: European Commission.

European Commission, 2013b. EU Energy, transport and GHG emissions trends to 2050. Reference Scenario 2013 (PRIMES). Brussels: European Commission.

European Commission, 2014a. A policy framework for climate and energy in the period from 2020 to 2030. Brussels: European Commission. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014DC0015

European Commission, 2014b. Commission staff working document Impact Assessment accompanying the policy framework for climate and energy in the period from 2020 up to 2030. Brussels: European Commission.

European Union, 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, 2009. Brussels.

EUROSTAT, 2012. Renewable energy. Analysis of the latest data on energy from renewable sources. Statistics in focus 44/2012. Brussels: EUROSTAT Environment and Energy.

FAO, 2012. State of the World's Forests. Rome: FAO.

FAOSTAT, 2014. FAO Statistical Databases: Agriculture, Fisheries, Forestry, Nutrition. Rome: Statistics Division, Food and Agriculture Organization of the United Nations (FAO).

FOREST EUROPE, UNECE and FAO, 2011. State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe. Oslo: Forest Europe. http://www.unece.org/fileadmin/DAM/publications/timber/Forest_Europe_report_2011_web.pdf

GEA, 2012. *Global Energy Assessment - Toward a Sustainable Future*. International Institute for Applied Systems Analysis, Vienna, Austria and Cambridge University Press, Cambridge.

Haberl H, Sprinz D, Bonazountas M, et al., 2012. Correcting a fundamental error in greenhouse gas accounting related to bioenergy. Energy Policy 45, 18–23 Hallström et al., 2011.

Hallström E., S. Ahlgren and P. Börjesson, 2011. Challenges and opportunities for future production of food, feed and biofuel; A land use perspective. Report No. 74. Lund: Lund University.

Hewitt J., 2011. Flows of biomass to and from the EU – an analysis of data and trends. Fern.

ICCT, 2013. Vegetable oil markets and the EU biofuel mandate. http://www.theicct.org/sites/default/files/publications/ICCT_vegoil_and_EU_biofuel_mandate_20130211.pdf

IPCC, 2014. WGII AR5, Volume 1; global and sectoral aspects: Food security and food production systems. http://www.ipcc.ch/report/ar5/wg2/

JRC, 2013. Impacts of the EU biofuel policy on agricultural markets and land use for the year 2010. Modelling assessment with AGLINK-COSIMO (2012 version). Seville, European Commission/JRC.

Kastner, T., M. Kastner, and S. Nonhebel, 2011. Tracing distant environmental impacts of agricultural products from a consumer perspective. Ecological Economics 70(6): 1032-1040.

Kretschmer, B, Smith, C, Watkins, E, Allen, B, Buckwell, A, Desbarats, J, Kieve, D., 2013. *Technology options for recycling agricultural, forestry and food wastes and residues for sustainable bioenergy and biomaterials*. Report for the European Parliament, STOA, as part of the study 'Technology Options for Feeding 10 Billion People'. IEEP: London

Laborde D., 2011. Assessing the Land Use Change Consequences of European Biofuel Policies. IFPRI, Washington.

Lenzen, M., D. Moran, K. Kanemoto, B. Foran, L. Lobefaro, and A. Geschke, 2012. International trade drives biodiversity threats in developing nations. Nature 486(7401): 109-112.

Lugschitz, B., M. Bruckner, and S. Giljum, 2011. Europe's global land demand. A study on the actual land embodied in European imports and exports of agricultural and forestry products. Vienna: Sustainble Europe Research Institute.

Mantau U. et al., 2010. Real potential for changes in growth and use of EU forests. EUwood. Final report, June 2010. 160 p. Hamburg: EUWood.

Maung T. and Gustafson C., 2009. The Economic Feasibility of Sugar Beet Biofuel Production in North Dakota. Selected Paper prepared for presentation at the Meeting of Economics of Alternative Energy Sources & Globalization. The road ahead: November 15-17, 2009. Orlando.

OECD/IEA, 2012. Technology Roadmap Bioenergy for Heat and Power. Paris. http://www.iea.org/publications/freepublications/publication/bioenergy.pdf

Oilworld, 2007. Palm oil yield in: www.americanpalmoil.com/publications/Brief%20Palm%20Oil%20Story.pdf

Ros J. et al., 2010. The contribution of by-products to the sustainability of biofuels. Den Haag: PBL.

Searle S.Y. and C.J. Malins, 2014. Will energy crop yields meet expectations? Biomass and Energy (Article in Press).

Statistisches Bundesamt, 2013. Flächenbelegung von Ernährungsgütern 2010. Wiesbaden: Statistisches Bundesamt.

Uslu, A, van Stralen, J, Beurskens, L and Dalla Longa, F., 2012. Use of sustainable biomass to produce electricity, heat and transport fuels in EU27: A model-based analysis of biomass use for 2020 and 2030.

VITO, CICERO, and IIASA, 2013. The impact of EU consumption on deforestation: Comprehensive analysis of the impact of EU consumption on deforestation. 2013 - 063. Brussels: DG Environment.

Weinzettel, J., E. G. Hertwich, G. P. Peters, K. Steen-Olsen, and A. Galli, 2013. Affluence drives the global displacement of land use. Global Environmental Change 23(2): 433–438.

Yu, Y., K. Feng, and K. Hubacek, 2013. Tele-connecting local consumption to global land use. Global Environmental Change 23(5): 1178-1186.

Appendix 1: EU wood demand for energy purposes towards 2020

J. Hewitt, 2011.

Based on 2020 demand for bioenergy, as reported in the NREAPs, Member States are projecting to increase wood consumption for bioenergy purposes by 50% to 100% (or between 100 and 200 million m3) compared to 2010. Most of the increase is likely to be for electricity generation (projected to double between 2010 and 2020), largely wood pellets, while the quantity for heating is estimated to increase by 50%. Increased quantities are likely to be used by countries with large power stations, such as Belgium, Denmark, The Netherlands and the UK, or as domestic or district heating, for example in Austria, Finland and Sweden.

The increased supply will likely come from more, or more intensively, managed domestic forests as well as from imports from Canada, USA and Russia. Domestic EU supplying (and importing) countries are listed in Table 9: EU net importers and exporters of wood products in 2010. EU imports from Brazil have also increased significantly between 2000 and 2020, and mainly include pulp based products from the paper industry. In Brazil, the majority share of wood products exports come from plantations, whereas the majority of logged tropical timber is being used within Brazil. Belarus, Norway, Switzerland and Ukraine supply a substantial volume of primary woody biomass to the EU, mainly as mill residues and logs (Hewitt, 2011).

Table 9: EU net importers and exporters of wood products in 2010

Net importers	Net exporters
Belgium	Austria
Cyprus	Bulgaria
Denmark	Czech Republic
France	Estonia
Greece	Finland
Hungary	Latvia
Ireland	Lithuania
Italy	Poland
The Netherlands	Portugal
Spain	Romania
UK	Slovakia
	Slovenia
	Sweden

Source: Hewitt, 2011

From the net importers, Belgium anticipates a 3- to 4-fold increase in energy consumption from solid biomass but there will be little change in domestic supply. Denmark forecasts steep increases in pellet imports to double its electricity generation from solid biomass. Ireland also projects large increases in energy from solid biomass. Italy is a large net importer, mainly from wood pellets (from within the EU). Spain anticipates a doubling of consumption of solid biomass for electricity generation, but is unlikely to be able to supply that without increased imports. The sustainability of wood plantations in north-western Spain has been questioned (Hewitt, 2011). The UK projects a very large increase in solid biomass for energy purposes, which largely would have to be supplied by imports. Germany used to be a net importer, but its exports show a strong increase as well. Towards 2020, Germany anticipates a considerable increase in solid biomass consumption for energy purposes.

From the net exporters, Sweden is a large net exporter of timber products and plans to eliminate fossil fuel from its economy by 2020. Finland anticipates a 50% increase in consumption of solid biomass but its production and trade in wood-based products are declining. Bulgaria reports a modest increase in woody energy consumption, but little trade is projected.

It can be concluded from the NREAPs that a large number of Member States project a significant increase in domestic consumption of woody biomass for energy purposes and that, as a result, intra-EU trade (from domestic forest inventories) is expected to decrease as a result of this. Overall, this would mean an increased dependency on imported woody biomass from outside the EU.