PBL Netherlands Environmental Assessment Agency

PBL Note

Sustainability of biomass in a bio-based economy

A quick-scan analysis of the biomass demand of a bio-based economy in 2030 compared to the sustainable supply

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Main Findings

The conversion of a fossil fuel-based economy into a bio-based economy will probably be restricted in the European Union (EU) by the limited supply of ecologically sustainable biomass. It appears realistic that, for the EU, the sustainable biomass supply will be enough to meet about 10% of the final energy and feedstock consumption in 2030. Under optimistic assumptions, this supply might increase to 20%. EU Member States, in their Renewable Energy Action Plans for 2020, already aim to apply an amount of biomass that already approaches this 10%. Therefore, from a sustainability perspective, there is an urgent need to guarantee ecologically sustainable biomass production.

In considering sustainable biomass production, land use is the most critical issue, especially the indirect land-use impacts on greenhouse gas emissions and biodiversity. The use of waste resources and agricultural and forestry residues, that does not involve additional land use, therefore, would be a sustainable option. Technically, it is possible to use these types of resources for most applications in a bio-based economy. However, it seems unlikely that, by 2030, waste and residue resources will contribute more than three to four per cent to the final energy and feedstock consumption in Europe. Moreover, many waste and residue resources currently already have useful applications; for instance, as feed or soil improvers.

These are the main findings of a quick-scan analysis carried out by the PBL Netherlands Environmental Assessment Agency and CE Delft on the sustainability of a bio-based economy.

Three priorities can be distinguished in the transition to an ecologically sustainable bio-based economy that aims to reduce the consumption of fossil fuels:

- develop new technologies, procedures and infrastructure to collect or to produce more biomass without using directly or indirectly valuable natural land;
- develop technologies to produce hydrocarbons from types of biomass that have potentially the highest sustainable supply (lignocellulosic biomass), and stimulate the application of these hydrocarbons in sectors of the economy where no or very few fossil-free alternatives exist;
- develop a system of criteria, certification schemes and enforcement for all types of biomass that aims to reduce the impact of direct and indirect land use on greenhouse gas emissions and biodiversity, to extend the current EU system that is restricted to the direct impacts of transport biofuels.

1. Introduction

The European Union (EU) and the Dutch Government consider the transition to a bio-based economy to be essential in stimulating innovation and green economic growth. Early in 2012, the European Commission will publish a European strategy towards an innovative and sustainable bio-based economy. This plan covers issues, such as research and innovation to support the transition to a bio-based economy, the sustainable use of natural resources, improved competitiveness, the creation of high-quality jobs and the transition towards a low-carbon economy. Furthermore, EU policy on increasing renewable energy (wind, solar and biomass) includes legal targets for the use of biomass in transport (biofuels).

The drive for a bio-based economy will strongly increase demand for biomass resources. At the request of the Dutch Ministry of Infrastructure and the Environment, the PBL, with the support of CE Delft, has carried out a quick-scan analysis based on the available literature on the implications of this development. This analysis was focused on the balance between supply and demand for biomass and the impact of large-scale use of biomass on net greenhouse gas emissions and the area of land required for its production. This enabled us to evaluate to what extent a bio-based economy fits within the limits imposed by sustainability.

2. The bio-based economy

The European Commission describes a bio-based economy as an economy that integrates the full range of natural and renewable biological resources – land and sea resources, biodiversity and biological materials (plant, animal and microbial) – and the processing and consumption of these bio-resources. The bio-based economy encompasses agriculture, forestry, fisheries, food and biotechnology and industrial sectors, ranging from the production of energy carriers and chemicals to buildings and transport. In this respect, a bio-based economy is nothing new. Before the industrial revolution economies were mainly bio-based. New developments comprise a broad range of generic and specific technological solutions which could be applied in these sectors to enable growth and sustainable development; for example, in terms of food security and requirements for industrial materials for future generations.

A bio-based economy, therefore, makes more widespread use of biomass to replace fossil-based resources. Moreover, a bio-based economy makes comprehensive use of biotechnology in the production of fine chemicals and pharmaceuticals, a development that is economically an important issue but which has minor impacts on the amounts of raw materials used for the manufacturing of products. In many sectors of the economy, the bulk of biomass in new applications is required for the energy supply. In addition, in a bio-based economy large amounts of biomass could be applied as feedstocks in the industrial production of synthetic materials, such as bio-plastics, and to replace cokes in iron and steel manufacturing. Moreover, a bio-based economy will use more timber in construction to replace materials, such as concrete and steel.

3. Approach

The sustainability of a bio-based economy was analysed in two ways:

- the biomass demand of a bio-based economy was compared with the potentially available sustainable supply (supply–demand balance);

- the entire production chain of energetic or non-energetic biomass products and the associated greenhouse gas emissions and land-use changes was considered.

We assume in this quick-scan analysis that the contribution made by biomass to final energy use increases in a bio-based economy; and that its application as a raw material in industrial production also increases. The magnitude of increase depends on the level of ambition. The amount of biomass is expressed as energy content (in exajoules (EJ); 10^{18} joules), whether the biomass is used as bio-energy or as bio-feedstock. This allows the substitution of fossil fuels with biomass across the various sectors of the economy to be quantified in a comparable manner. The replacement of materials with timber was not considered in this analysis.

In this paper, the bio-based economy is quantitatively defined as the share of the final energy and feedstock consumption (FEFC) that is based on biomass. The percentage of bio-based economy is the total share of bio-energy and bio-based feedstock in this FEFC. Annex A explains how this was calculated for the purpose of this quick-scan analysis.

Given a certain level of substitution in the final energy use of the different sectors of the economy, the required biomass in primary energy terms could be calculated. Due to conversion losses, the primary biomass amount is always higher than the final amount. The difference between primary and final biomass is determined by the efficiency of the conversion processes. The primary biomass required for bio-energy together with the amount required as feedstock, for this quick-scan analysis, was considered as a good approximation of the total biomass demand of a bio-based economy. This is only a rough approximation, and does not take into account other potential developments, such as large-scale replacement of concrete and steel in construction with timber.

For this quick-scan analysis, we focused on the situation in the EU27 and the global context in 2030, when the substitution of fossil fuels with biomass could reasonably be assumed to have developed more than in the present situation. We also assumed that economically viable conversion technologies applied in 2030 currently are at least in their first stage of market penetration (see Annex B). The selected biomass to fuel, power or chemical feedstock routes have relatively low land requirements per unit of final energy. For biofuels only, routes were considered that will meet the 2018 Renewable Energy Directive limit for direct greenhouse gas emissions (a 60% reduction compared to fossil fuels).

To estimate the size of the economy in 2030 and its demand for energy and feedstock, the business-as-usual (BAU) scenario of the OECD Environmental Outlook to 2050 was used (OECD, 2011, 2012). As a result of current policies, this scenario assumes already relevant amounts of biomass demand by some sectors of the economy, in particular transport and power generation (Annex C). We simply replaced a fraction of fossil fuels with biomass in the calculated results for 2030 and did not construct consistently elaborated bio-based economy scenarios. Therefore, our approach is a quick-scan analysis meant for illustrative purposes only. It aims to facilitate the discussion about the limits within which the development of a bio-based economy is sustainable and desirable policy guidance.

A series of variants of a bio-based economy scenario was used in this study (see Annex B for details). They differ in the sectors of the economy on which substitution is focused:

- power generation and heating for buildings and industry;
- transport;
- chemicals and other industrial products.

Furthermore, given current practices it appeared unrealistic to consider scenario variants based on biomass from a single source. Therefore, the biomass supply for a bio-based economy was assumed to come from various sources: crops, wood, residues and waste resources. Within the limits of what is technically feasible, biomass inputs with an accent on these different sources were considered (see Annex B for details).

For each sector, a limited number of biomass-based production chains with a good performance in direct greenhouse gas emission reduction and well-judged technical and economic feasibility were chosen. This resulted in estimates of primary biomass demand of a bio-based economy subdivided into economic sector and biomass source. An overview of the production chains considered as proxies for the purpose of this quick-scan analysis is given in Annex C.

4. Estimates of the size of the bio-based economy in 2030

The BAU scenario estimates that the final consumption of fossil fuels in Europe by 2030 will be about 70 exajoules. Fossil energy will provide 82% of primary supply for final energy and feedstock. Figure 1 shows how fossil-fuel use is expected to be divided over the different economic sectors in the EU. The contribution of biomass to the economy of 2030, according to the BAU scenario, will be 7%, mainly applied for power generation and in transport (Table 1). In addition, 7% of the total primary energy supply will come from other renewable resources (hydropower, solar and wind) and 4% from nuclear energy.

Figure 1
EU final fossil energy consumption per sector, 2030
According to OECD BAU scenario

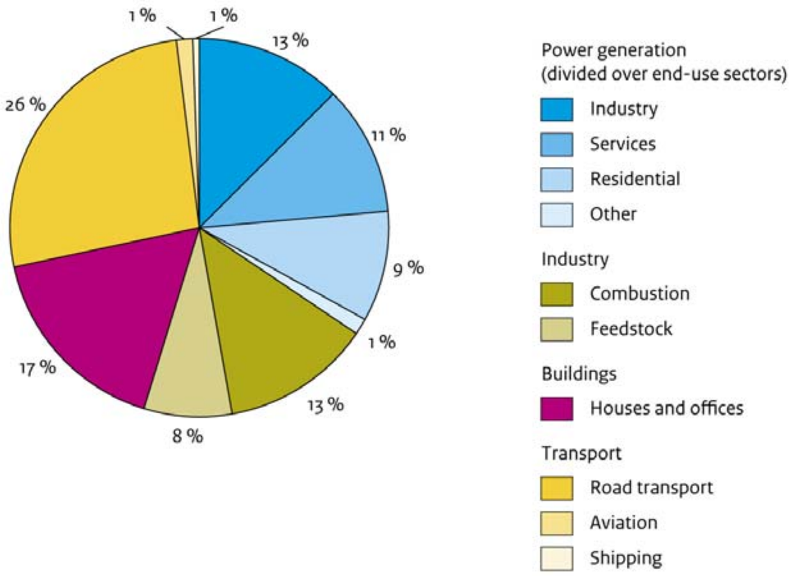


Table 1

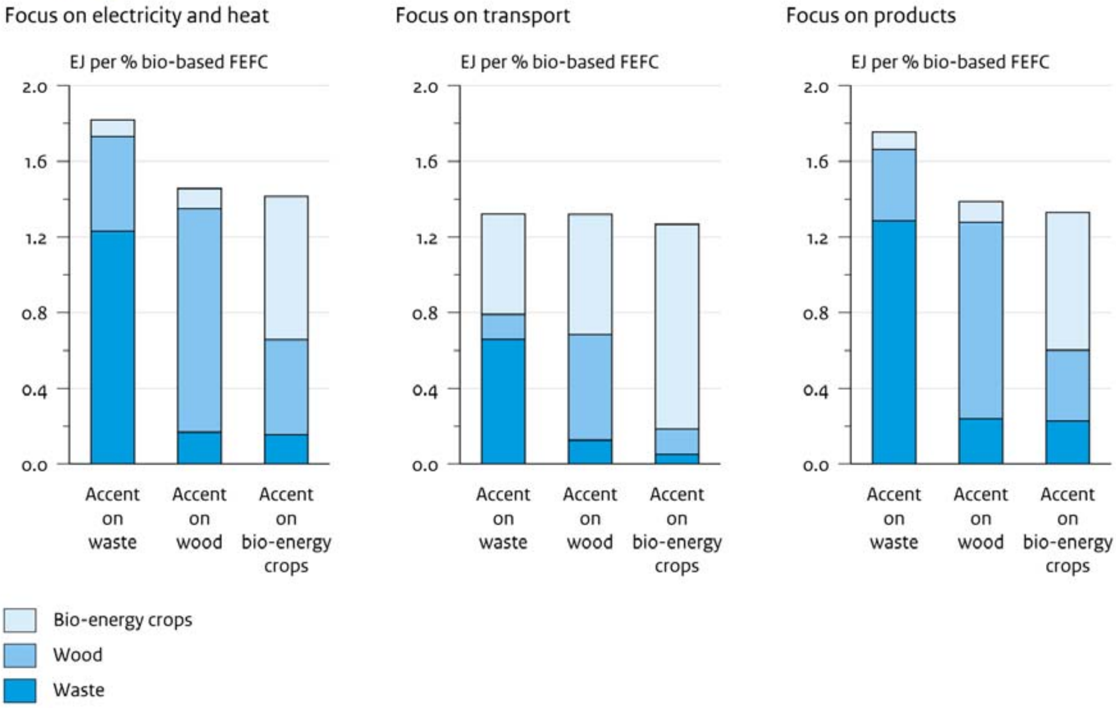
Final energy consumption (FEC) and final energy and feedstock consumption (FEFC) of biomass in the EU27 in 2010 and projections for 2020 based on the National Renewable Energy Action Plans (NREAP)

Sector	2010 exajoules	NREAP 2020 exajoules	2020 share of FEC	OECD BAU 2030 share of FEFC
Power generation	0.4	0.8		2.4%
Heat (solid biomass)	2.4	3.4		2.1%
Heat (biogas and bioliquids)	0.3	0.4		
Transport	0.6	1.3		2.2%
Feedstock		Not included		Small
Total	**3.6**	**5.9**	**10%**	**6.7%**

Source: NREAP (Beurskens and Hekkenberg, 2011); BAU scenario (OECD 2011, 2012)

Figure 2

EU primary biomass demand, in percentage of bio-based final energy and feedstock consumption (FEFC), 2030



The EU Renewable Energy Directive requires Member States to develop plans to achieve the renewable energy target. These National Renewable Energy Action Plans (NREAPs) show a large commitment to biomass by the Member States. Table 1 summarises the input of biomass in the EU planned by the Member States for 2020. This is mainly based on wood and crops.

A more bio-based economy in the future would mean more substitution of fossil fuels and an obvious rise in demand for biomass. Because of conversion losses in the production of bio-energy, the input required to substitute 1 exajoule of fossil fuel may be 1.5 to 2 exajoules of biomass.

The demand for primary biomass in the EU per percent bio-based FEFC was calculated for scenario variants taking the efficiency of the various conversion processes into account as may reasonably be expected for 2030 (Figure 2). A rough indication for the primary biomass demand by the EU for a 1% increase in the bio-based economy (of FEFC) for 2030 is 1.3 to 1.8 exajoules. Therefore, a 20% bio-based economy, for example, would require 25 to 35 exajoules of primary biomass.

5. Sustainable biomass supply

Several studies have tried to estimate the potentially available amount of biomass in Europe and worldwide for 2020, 2030 and beyond. All these studies show large uncertainties. One main source of uncertainty is the underlying assumption regarding the amount of unused agricultural land available for the cultivation of bio-energy crops, and to what extent natural grasslands contribute to this potential. In particular, assumptions regarding future agricultural productivity and future consumption of animal products have a great impact on the results. Furthermore, the uncertainty in the amounts of available waste and residue resources strongly depends on the still uncertain future demand for other applications such as animal feed and soil quality improvers.

Another source of uncertainty is the strictness in definition and application of criteria for the sustainable production of biomass. Basically, the aim of such criteria is to exclude biomass on the market that is produced under environmentally and socially harmful conditions. In practice, existing criteria mainly focus on land used for biomass production and, as yet, no single applied system of criteria exists that entirely excludes harmfully produced biomass.

The European Environment Agency has published several studies on bio-energy potentials in the European Union (EEA, 2006, 2007a, b). The data from these studies are summarised in Table 2. The amount of potentially available biomass in 2030 in the EU is estimated to be about 12±2 exajoules, depending on the strictness of application of environmental criteria. These criteria should ensure that bio-energy production develops in an environmentally-compatible way. Criteria should be elaborated for forestry and agriculture, account for biodiversity, soil and water, and be in line with current and potential future environmental policies and objectives (EEA, 2006).

Many studies show strong links between the strictness of sustainability criteria and the potentially available biomass. In the EEA studies (Table 2) the medium estimate for agriculture refers to high energy prices and high crop yields, as opposed to the low estimate, which refers to low energy prices and low yields. For forestry, the restricted cases refer to the exclusion of complementary felling in protected areas (moderate restriction, medium estimate) or, in addition, also in areas with biodiversity conservation goals (strict criteria, low estimate). Other studies with a broader

Table 2

Estimates of the environmentally-compatible primary biomass potential in the EU by 2030 according to the EEA (2006, 2007a, b) (in exajoules)*

Biomass source	Agriculture	Forestry	Waste	Total
Low estimate	4.4	1.6	4.3	**10**
Medium estimate	6.0	1.8	4.0	**11**
High estimate	8.0**	2.3	4.0	**14**

* Member States providing only small contributions to the potential in the EU27 are not included.

** Assuming a less environmentally restrictive case.

Table 3

Illustrative biomass availability for the European market based on 100–200 exajoules sustainable biomass in the world and two pro-rata criteria: per capita equality and per unit of total primary energy supply (TPES) in 2030*

Region	Pro-rata criterion	
	TPES (exajoules)	**Population (million)**
EU	80	500
World	650	8,300
EU share	12%	6%
Biomass available for the EU market (exajoules)	12–24	6–12

* TPES (fossil fuels, biomass, other renewables, nuclear) and population according to the OECD BAU scenario.

application of criteria showed a sustainable supply of biomass constrained to 40% to 80% of the estimated future technical potential (Van Vuuren et al., 2009) or even to about 10% (Van Vuuren et al., 2010). However, the future technical potential is difficult to define and highly dependent on scenario assumptions regarding trends in food and feed demand and agricultural productivity.

The EU will probably depend on the world market to supply its bio-based economy in the future. In the literature, estimates of the world supply of biomass in 2050 show large ranges, as is to be expected given the many unknowns. Based on published data, the IPCC mentions a plausible range of 100 to 300 exajoules. The low end of this range is based on pessimistic assumptions regarding the realisation of new production methods; the high end is based on optimistic expectations (IPCC, 2011). The PBL and ECN conclude that most studies support an economically feasible estimated range of potentially available sustainable biomass in the world by 2050 of 150 to 400 exajoules. However, it will take considerable effort before this potential can be fully achieved in a sustainable way (PBL/ECN, 2011). Hence, the lower end of this range provides more certainty about the sustainability of this potentially available supply and is therefore a more reliable starting point for the development of a sustainable bio-based economy. Because many new initiatives and technologies are required to realise the 2050 sustainable biomass potential, the availability of sustainable biomass on the world market in 2030 is probably lower. For 2030 we consider 100 exajoules as a realistic estimate and 200 exajoules as a quite optimistic estimate of available sustainable biomass on the world market.

Imports for the European market will mainly consist of crops and forestry products, whereas waste resources and residues with relatively high moisture contents will not be transported over long distances. Consequently, if dependent on the world market the relative contribution of waste resources in the total biomass supply will probably be smaller than if this supply were to be obtained from the EU market alone.

An increase in the bio-based economy is expected to be a worldwide development. Therefore, only a part of the globally available biomass potential is available for Europe. Just to give an idea, Table 3 allocates part of the world biomass potential to the EU according to different distribution criteria. This indicates the order of magnitude of the biomass potential for the European market.

In general, countries with large biomass resources have a more bio-based economy. Particularly in the case of a strong global climate policy, producing countries will probably tend to keep more of this supply for domestic use. In that case the world biomass supply to Europe is likely to be even less.

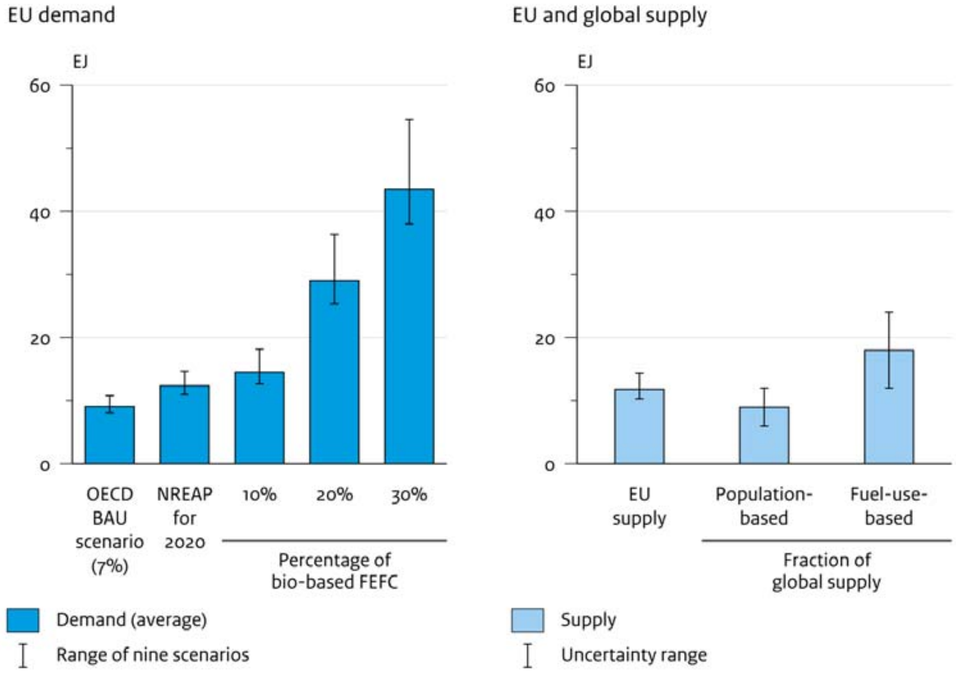
6. Comparison of biomass demand and sustainable supply

The total supply of sustainable biomass in 2030 may be enough to fulfil the demand in a 10% bio-based economy (Figure 3). The demand is in the same order of magnitude as a pro-rata share of the feasible global supply in 2030. An even more ambitious ecologically sustainable bio-based economy in 2030 is only possible if a biomass supply according to the more optimistic assessments is realised. Therefore, a highly ambitious bio-based economy increases the risk of a non-sustainable supply and overexploitation of natural resources. The commitment to biomass by the EU Member States for 2020 according to the NREAPs already approaches the demand made by a 10% bio-based economy. The sustainability of the biomass supply to realise these plans will be an important point of attention.

Our analysis shows that, based on the projected sector development and fossil fuel use to be substituted, there is some flexibility for using relatively more wood, more waste and residue resources or more crops (Figure 2). If one of these three types of biomass is preferred, technically about 50–70% of the total demand could be based on the preferred type. From a sustainability perspective, the input of waste and residue resources is preferable as it does not require extra land (see also Sections 7 and 8).

However, will there be a sufficient supply of waste and residue resources? The potential supply is limited, and the estimate for suitable organic waste resources in Europe itself is about 4 exajoules, or 30% to 40% of the total supply. The share of waste resources in imports is expected to be lower, as many of the waste resources are not traded over long distances. Therefore, even in a 10% bio-based economy, it is unlikely that the biomass supply would predominantly be made of waste and residue resources.

Figure 3
EU primary biomass demand versus potential sustainable EU and global supply, 2030



7. Direct impacts of a bio-based economy

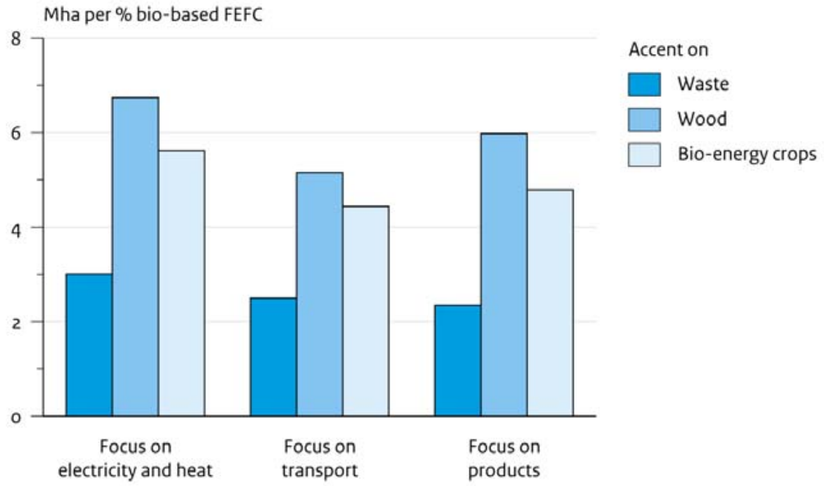
The direct effects of energy or non-energy bio-products produced in a bio-based economy are the effects that can be directly and exclusively linked to the production-consumption chain of the product. During the entire life cycle of a product resources are used (land, water and fertilizers), emissions occur, services or goods are delivered and people are working. The changes in these pools or resources are all regarded as direct effects. Technologies applied during production have an impact on these direct effects.

The most important direct effects are:

- land use (changes in land cover or land management);
- greenhouse gas emissions;
- water use;
- jobs and working conditions (change in labour market, impact on health of workers);
- profits.

Based on the present EU sustainability criteria, future direct greenhouse gas emissions from specific biofuels in traffic can be expected to be at least 60% lower than the emissions from fossil fuels, when excluding emissions related to indirect land-use change (ILUC; see Section 8). Greenhouse gas emissions are relatively large in the scenarios with large demands of crops from arable land. An important reason for this

Figure 4
Production area required for EU primary biomass demand, in percentage of bio-based FEFC, according to the bio-based economy scenarios, 2030



is the application of artificial fertilizers (the production of which requires a lot of energy), the fuel required for crop management, and the energy required for conversion technologies to produce the biofuels. It should be noted that an increase in agricultural productivity requires more fertilizers and more energy inputs. Nevertheless, for some crops, such as sugar cane for the production of ethanol, the results may be relatively good.

A more positive picture results from the scenarios focusing on the supply of wood products and waste resources. For waste this is expressly under the assumption that no other useful purposes for these flows exists. In the use of biogas from manure, the direct emission reductions can be even larger than those related to greenhouse gas emissions from the alternative fossil-fuel chain, owing to avoided greenhouse gas emissions from manure storage. However, the availability of manure is restricted.

The amount of land required for the production of biomass from crops strongly depends on the type of crops and the allocation of land use for co-products such as feed. In the scenarios presented here, maize (for green gas), sugar beet and palm oil have been selected as the primary resources. Land use for farmed wood is included.

The estimated production areas required for the biomass demand of the EU in the more bio-based economy scenarios vary between two and seven million hectares for an increase of 1% more bio-based final energy consumption. Figure 4 shows the results for the different scenarios. Even with a focus on waste and residue resources, at least 20 million hectares would be required for a 10% bio-based economy. The results can be compared with the 19 million hectares of arable land that would be available in 2030 for dedicated bio-energy crop cultivation in the EU Member States, according to an EEA agricultural scenario study. This area is equivalent to 12% of the projected utilised agricultural area of 2030 (EEA, 2006).

Comparing land requirement with available grassland and arable land in the EU clearly indicates that a 20% or 30% bio-based economy would require a significant change in agricultural production from food and feed to fuels. Indirect effects are likely to occur.

However, on a local scale the balance can be positive. For example, if degraded land can be exploited for the cultivation of perennial crops the land-use change may have positive local impacts on net greenhouse gas emissions and biodiversity.

For transport and other liquid biofuels, the present EU sustainability criteria include direct land-use change and the related effects on greenhouse gas emissions and biodiversity. There are no EU sustainability criteria for solid or gasified biomass. Therefore, direct land-use-related emissions and biodiversity losses cannot be excluded, nor can other negative impacts such as social conditions.

8. Indirect impacts of a bio-based economy: potential ecological impacts

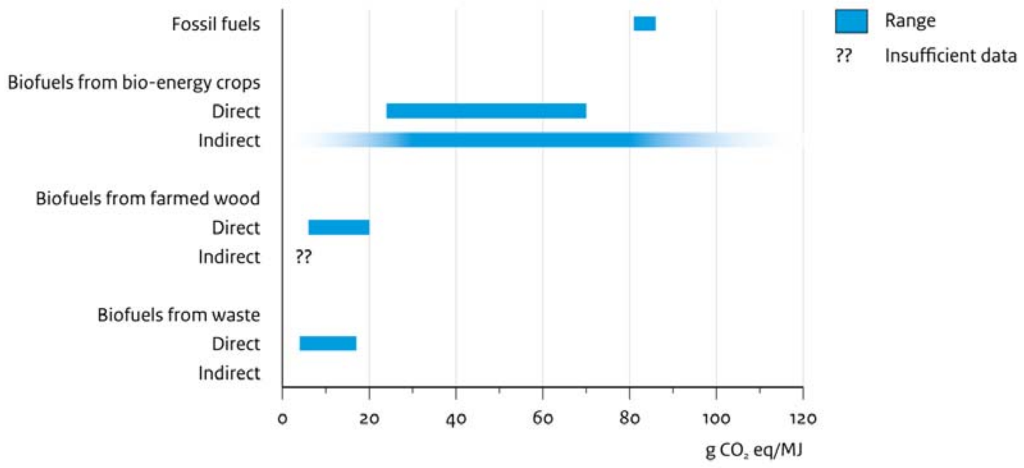
Indirect effects of energy or non-energy bio-products produced in a bio-based economy are caused by the introduction of a product, but cannot be directly linked to the production chain. Imagine a world with and without bio-products. Apart from the effects that are directly related to the production-consumption chains, there are many other differences between these two worlds. Impacts on food, feed and oil prices and related impacts on production and consumption are examples. These differences are the indirect effects. They comprise all changes in all sectors with all their consequential effects (Ros et al., 2010).

From an ecological point of view, the most severe indirect effects are related to land conversions. In particular, if existing agricultural land for food or feed production is instead used for bio-energy crops, the food and feed has to be produced elsewhere. It is very likely that new agricultural land is needed somewhere: indirect land-use change (ILUC). Deforestation cannot be excluded, but also other valuable natural areas may be turned into agricultural land. These forms of land-use change generate CO_2 emissions, as carbon from the soil and the vegetation ends up in the air. In the case of plantations for new applications of wood, ILUC and related greenhouse gas emissions may also occur.

On the other hand, an increase in the demand for crops is a stimulus for technological development, leading to the more efficient use of land through yield improvement and better use of co-products. However, there is a lot of uncertainty about these types of cause-effect relationships and the extent to which yield improvement can compensate for the increase in demand, especially in the case of a more bio-based economy. These uncertainties are reflected in the model studies that try to calculate the indirect greenhouse gas emissions. A series of calculations with different models have been executed recently for crops used for biofuels in road transport in the context of adjusting the sustainability criteria (Ros et al., 2010; IFPRI, 2011). The results make clear that the indirect emissions cannot be neglected. They may exceed the direct emissions and in some cases even the emissions of the fossil alternatives. The present sustainability criteria do not prevent these indirect emissions.

For farmed wood indirect effects are likely, but because solid biomass is not included in the present EU criteria, the model analyses mentioned above do not focus on the indirect effects of wood. For an application of waste and residue resources there are no indirect emissions. However, it should be emphasised that this conclusion is only valid for waste with no other application. For example, in the case of a shift in waste used for feed to waste used for biofuel, the feed has to be produced elsewhere, leading to ILUC.

Figure 5
Indirect (ILUC) and direct biofuel greenhouse gas emissions compared with fossil-fuel emissions from road transport



Sources: ILUC greenhouse gas emissions: Overmars et al. (2011) and IFPRI (2011); direct biofuel emissions: EU (2009; some crops do not meet the future 60% criterion).

Note on biofuels from waste: If manure is used to produce biogas, the methane emissions of manure storage can be reduced significantly, leading to total emissions reductions of more than 100%. This offset is not included in direct emissions in this figure, nor are effects due to the waste or residue resources being withdrawn from another application. Waste as biomass does not have ILUC emissions as it does not involve additional land use.

Figure 5 summarises the direct and indirect emissions for the application of biofuels in road transport. The use of crops, wood and waste resources for other applications will show other figures, but similar general conclusions. Because of the uncertainties, this short report does not include an assessment of all emissions in a more bio-based economy. The significance of indirect effects, especially related to land conversions, for sustainability is clear. If the direct and indirect emissions for biofuels based on crops are added, there is a considerable risk of an increase in greenhouse gas emissions compared to fossil fuel use. However, the indirect emissions are temporary, until a new equilibrium of soil carbon is reached. The indirect emissions shown in Figure 5 are average emissions over a 20 year period.

The impact of land-use changes goes beyond greenhouse gas emissions alone. It also influences the conservation of biodiversity. Indirect land-use change implies a short-term loss of natural area somewhere in the world. These land reclamations may lead to habitat destruction and the loss of associated plant and animal life. However, where the application of biofuels leads to a net reduction in greenhouse gas emissions this contributes to mitigating climate change in the long term. In turn, mitigated climate change may diminish biodiversity loss. The net effect of bio-energy on biodiversity is therefore a combination of difficult to compare short-term losses and long-term gains. An indicative analysis of some of the biofuels shows that it might take hundreds of years to compensate for the short-term loss. This analysis does not include the potential irreversible losses related to land-use change. Minimising overall land-use change is at least a strategy that helps to avoid loss of biodiversity (Van Oorschot et al., 2010; PBL, 2010).

Although direct land use is an important characteristic of a biofuels production chain, as far as ILUC effects are concerned, the ILUC emissions are not an unambiguous fixed characteristic of these bio-products, but a variable result of the interaction with dynamic (global) economic and physical systems. Therefore, not only do indirect greenhouse gas emissions bear a scientific uncertainty, they also vary in time. Furthermore, the higher the demand for biomass, the higher too the risk of deforestation, and therefore the relatively highest indirect greenhouse gas emissions. These facts complicate the formulation of sustainability criteria for bio-products.

9. Considerations for priority applications of biomass

Technically speaking, fossil fuels can be replaced with biomass in any application, whether fossil fuels serve as energy carriers or as organic bulk chemicals. The limited availability of sustainable biomass requires prioritisation in its application. Life Cycle Analysis is often used as a tool to calculate the ecological advantages and disadvantages (e.g. impact on greenhouse gas emissions) of specific substitutions. The applications with the highest ecological advantages can than be selected. However, regarding the pathway to a future low-carbon economy, another even more important criterion comes into view: the (future) availability of fossil-fuel-free alternatives in specific applications (PBL/ECN, 2011).

For power generation, for instance, which is an important component of the energy system, numerous non-combustion alternatives exist: solar, wind, nuclear and hydropower. Therefore, the application of biomass in power generation has a low priority. Electric engines powered by batteries or hydrogen fuel cells may replace the combustion engines of light duty vehicles in the future. However, this type of replacement is less likely for heavy trucks or shipping, and very unlikely for aviation. These will therefore require biofuels. There is a focus on electric heat pumps for heating homes and buildings, and hydrogen or electricity can be applied for high temperature processing heat in industry. The possibilities for using alternative energy sources in existing buildings and small industries are limited, and biofuels therefore have a role to play. For the fossil-free production of plastics, the use of biomass as bulk chemical is actually the only option. This survey of technological alternatives reveals biomass priority applications for which very few or no alternatives exist. In general, using the energy as well as the carbon from the biomass to produce hydrocarbons for specific fuels and chemical products has priority.

A roadmap towards a low-carbon, partly bio-based economy, should focus on stimulating these prioritised biomass applications. This will often require innovative technologies, such as gasification, the development of which is time-consuming, in some cases probably taking 10 or 20 years. Decisions on the short-term development and application of biomass technologies should ideally be in line with these long-term considerations. In particular, a policy that focuses only on setting overall policy goals for greenhouse gas emissions or renewable energy targets risks stimulating the most cost-effective short-term options at the expense of developing more sustainable and promising long-term options. Complementary technology policy can help overcome such lock-ins (Verdonk et al., 2011).

10. Innovative production of sustainable biomass

We have therefore found that a guaranteed supply of sustainably produced biomass is the main restriction to a bio-based economy. Sustainability criteria, certification schemes, compliance monitoring and enforcement for all sources of biomass help to guarantee a sustainable bio-based economy. At EU level, such a warranty is still missing for the full range of supplied biomass. Only direct effects related to the production of biofuels have so far been translated into sustainability criteria.

A complementary track to develop a sustainable bio-based economy is to support the development of technologies, facilities and infrastructure for the production of sustainable biomass. The PBL and ECN (PBL/ECN, 2011) identified some of the key areas for various types of biomass:

- Agricultural residues. Bio-refinery is a technology that enables the production of high value chemicals from crops. Remaining refuses can be applied for energy purposes. Technically and economically this development leads to the use of all parts of the crop. However, many of the residues, such as straw from wheat or bagasse from sugarcane, already have some useful applications, not in the least by leaving them on the land for soil quality reasons. Agricultural management guidance should help to avoid soil degradation.
- Forest residues. More and more residues from forests are applied for energy purposes. There are two points of particular interest with regard to this development. First, the infrastructure for collection and pre-treatment should be organised in such a way that long-distance transport of products of low-energy content is avoided. In practice, it is advisable to have pre-treatment plants in the region of forest residue collection. Second, stripping the forest floor of all residues should be avoided, as this would lead to forest soil degradation and biodiversity loss. Forest management guidance could support sustainable practices.
- Bio-energy (especially perennial) crops on degraded land. Biomass production and ecological improvement, in this case, may go hand in hand. However, the business cases are in general not very attractive. Start-up and development of this practice will therefore be a challenge.
- Aquatic biomass. The production of algae oil for fuel is a promising technology, but costs are still much too high for use as a resource for energy. More promising in the short term is the production of specific chemicals with relatively high added value from algae. More research and development is needed.

In many cases, innovative technologies (gasification or advanced fermentation) are needed to enable the conversion of these potentially sustainable types of biomass into the desired products.

In addition to these specific actions, reducing the global claim on land is a dominant sustainability factor in general. Improving agricultural productivity, reducing losses in agriculture and food wastage, and consuming fewer animal products are important drivers to achieve this (Westhoek et al., 2011).

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Annex A
To what extent is an economy bio-based?

In this paper, the bio-based economy is quantitatively defined as the share of the Final Energy and Feedstock Consumption (FEFC) that is based on biomass. Figure A.1 shows the types of energy and feedstock consumption included in the calculations. For every type of consumption, the share of bio-energy and bio-feedstock can be determined and summed up in terms of energy. The total share of bio-based energy and feedstock in the FEFC is considered the percentage bio-based.

$$\text{Share of the bio-based economy} = \frac{\text{Bio-FEFC}}{\text{FEFC}} * 100\%$$

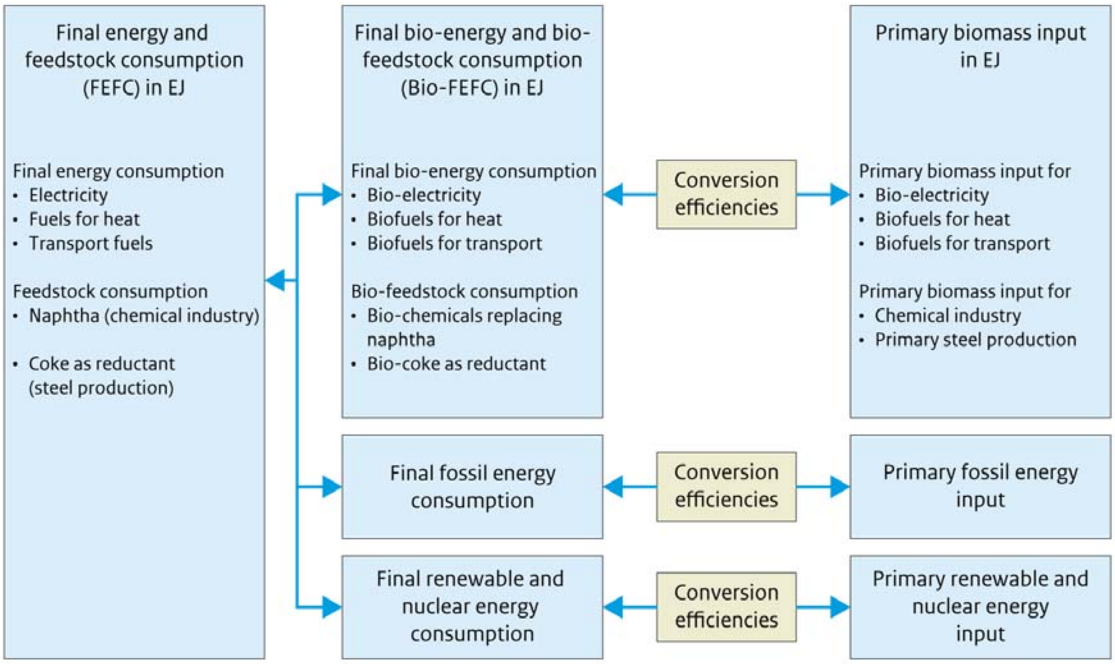
where

FEFC = Final Energy and Feedstock Consumption
Bio-FEFC = Final Bio-based Energy and Bio-based Feedstock Consumption

The primary biomass input can be calculated with the help of conversion efficiencies. These conversion efficiencies are considerably lower than one. Therefore, the primary biomass input is higher than the share of bio-energy and bio-feedstock in the final consumption (Bio-FEFC).

The same approach can be used for the share of fossil fuels and other energy resources. Because of differences in conversion efficiencies, the relative shares in the FEFC differ from the relative shares in total primary energy inputs. In general, the efficiencies for biomass use are lower than for fossil resources. Replacing one exajoule of primary fossil resources requires 1.5–2 exajoules of primary biomass. The total of the required biomass inputs is the demand made by the market, with the challenge to realise a sustainable supply for it.

Figure A.1
Types of energy and feedstock consumption included in the scenario calculations



Annex B
Underlying bio-based economy scenario assumptions

The fractions of total fuel use per sector, in the BAU scenario, substituted by biomass assumed for the three scenario variants, are shown in Table B.1. The figures presented are for the case of 30% biomass consumption in total final energy and feedstock consumption (FEFC) in 2030. This percentage includes electricity produced from biomass. For cases with other biomass shares in FEFC, substitution fractions were scaled proportionally.

For each of these scenarios we defined three variants for the primary biomass mix used per sector, each focusing on one primary biomass type (Table B.2):

- wood from fellings
- crops
- waste and residue resources (including wood residues from fellings and agricultural residues).

For each of the nine scenario variants per sector and fossil-fuel type, one of 11 technology chains of Table B.3 was chosen. This selection was based on economic viability, contribution to greenhouse gas emission reduction (excluding ILUC) and corresponding best to the main primary biomass variant (Table B.4).

Table B.1
Sectoral biomass substitution fractions of fuel use in the BAU scenario assumed in the three focus scenarios for 30% biomass consumption in total FEFC in 2030 (in %). Percentages for EU27

Sector	Electricity and heat	Transport	Products
Power generation	80	20	45
Industry - heat	40	10	60
- products	10	10	80
Buildings (heat)	30	10	30
Road transport	10	60	10
Other transport	10	60	10

Table B.2

Assumed shares of primary biomass types per sector per main primary biomass variant (in %)

Sector	Waste and residues	Wood	Bio-energy crops
Focus on waste and residues			
Power plants	50	50	
Industry	80	20	
Buildings	80	20	
Road transport	40		60
Other transport	80		20
Focus on wood			
Power plants		100	
Industry	20	80	
Buildings	20	80	
Road transport	10	20	70
Other transport	10	20	80
Focus on crops			
Power plants		50	50
Industry	20	20	60
Buildings	20	20	60
Road transport			100
Other transport			100

Table B.3

Biomass technology chains considered in the biomass scenarios

Fossil fuel	Biofuel technology route
Natural gas	Green gas from maize in anaerobic digester Fuelwood in woodstoves and local cogeneration Fuelwood in industrial cogeneration Green gas from agricultural residues in anaerobic digester Synthetic Natural Gas (SNG) from wood pellets gasification
Pulverised coal	Torrefied wood pellets from Short Rotation Coppice (SRC) or waste wood
Diesel, jet fuel	Wood based Fischer Tropsch synthesis from Short Rotation Coppice (SRC) or waste wood Hydrotreated Vegetable Oil (HVO) from palm oil Hydrotreated Vegetable Oil (HVO) from residual fats
Petrol	Ethanol from sugar beets or straw Wood based Fischer Tropsch synthesis from Short Rotation Coppice (SRC) or waste wood
Naphtha	Wood based Fischer Tropsch naphtha from Short Rotation Coppice (SRC) or waste wood Ethanol from sugar beets

Table B.4

Biomass routes selected per sector per main primary biomass type

Sector	Fossil fuel type	Most efficient / Best technology fit	Accent on waste and residues	Accent on wood	Accent on bio-energy crop
Power generation	Coal	Torrefied pellets	Torrefied pellets, waste wood	Torrefied pellets, SCR	Maize AD, green gas STAG
	Oil, natural gas	SNG	Residue AD, green gas STAG	SNG	Maize AD, green gas STAG
Industry, heat	Coal (injection)	Torrefied pellets	Torrefied pellets	Torrefied pellets	
	Light oil (s.c. naphtha)	Sugar beet ethanol	Residual wood FT	FT synthesis	Sugar beet ethanol
	Natural gas	SNG	Residue AD, green gas	SNG	Maize AD, green gas
Buildings, heat	Coal, heavy oil	Wood boiler	Residual wood	Wood boiler	Maize AD, green gas
	Natural gas, light oil	Wood boiler	Residue AD, green gas	Wood boiler	Maize AD, green gas
Road transport	Petrol	Sugar beet ethanol	Straw ethanol	FT wood	Sugar beet ethanol
	Diesel	Palm oil HVO	Residual fats HVO	FT wood	Palm oil HVO
Aviation	Jet fuel	HVO	Residual fats HVO	FT wood	Palm oil HVO

Abbreviations used:

AD = Anaerobic Digester
FT = Fischer Tropsch
HVO = Hydrotreated Vegetable Oil
s.c. = steam cracking
SNG = Synthetic Natural Gas
SRC = Short Rotation Coppice
STAG = Steam and gas

Annex C
OECD Business As Usual scenario: basic energy consumption data

For the Business-As-Usual scenario of regional demand for energy and feedstock the Baseline scenario of the OECD Environmental Outlook to 2050 was used (OECD, 2011, 2012). In this scenario additional (new) legislated policies in the European Union are not reflected, but the European Union's energy and climate package is assumed to be implemented in all policy simulations carried out in the analysis (OECD, 2011).

The total transport sector projection in this scenario has been split into road transport and non-road, notably shipping and aviation, using the shares in transport fuel consumption in 2008. Subsequently, the trends to 2030 in global shipping and aviation were taken from Den Elzen et al. (2007). For the EU only domestic shipping and aviation was included in the calculations, assuming the same trends as for the global totals.

Tables C1 and C2 show total fuel consumption in end-use sectors and for power generation in the EU27 in 2030 by fuel type and by sector in the OECD BAU scenario (excluding electricity end-use consumption).

Table C.1
EU-27: Fuel consumption in 2030 by fuel type (excluding feedstocks, traditional biofuels) (unit: EJ final use)

Fuel type	2008	2030
Coal	15.7	13.8
Heavy oil	9.4	10.4
Light oil	10.8	9.3
Gas	16.4	23.0
Other	3.7	10.2
Total fuels	**56**	**67**
30% of total =	**17**	**20**

Table C.2
Sectoral fossil fuel consumption in BAU scenario for 2030, EU and global total (unit: EJ final energy consumption)

Sector	EU		Global	
	BAU-FF	30% FF	BAU-FF	30% FF
Power generation	23	6.8	232	69.5
Industry (combustion)	8	2.5	89	26.8
Industry (feedstock)	5	1.5	44	13.3
Buildings (houses and offices)	11	3.4	61	18.4
Road transport	18	5.3	121	36.4
Aviation	1	0.2	14	4.2
Shipping	0	0.1	15	4.5
Total	**67**	**20**	**577**	**173**