Communication

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Sustainable biomass supply and demand: a scenario analysis

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Abstract: This paper provides a concise summary and discussion of key results of the study “Sustainable biomass potentials for biofuels in competition to food, feed, bioenergy and industrial material use in Germany, Europe and the world”. The scenario-analysis developed in this paper differentiates between the global level and the European Union level, providing a perspective on future trends and developments. Specifically, results of the present study provide a detailed view of possible scenarios for a sustainable supply of biomass until the year 2050, and of the development of demand in all biomass sectors: food, feed, chemicals and materials, bioenergy and biofuels. Due to this approach, one can clearly see under which assumptions global supply shortages or a sufficient coverage of demand may occur.

Keywords: Bio-economy, biomass, bioenergy, scenario analysis

1 Introduction

In this contribution, the most important results of the study “Sustainable biomass potentials for biofuels in competition to food, feed, bioenergy and industrial material use in Germany, Europe and the world” are summarised and discussed. In this study, the authors differentiate between the global level, the European Union and Germany and provide a perspective on future trends and developments. This project was funded by the German Federal Ministry for Food and Agriculture (BMEL) and the German Federal Ministry for Economic Affairs and Energy (BMWI) under grant number 22501112 resp. 12BMU011, and carried out by an expert team at the nova-Institut. The results of the study were published in August 2015.

As an outcome of the study, a modelling tool is now available with which it is relatively easy to calculate new biomass scenarios based on a varied set of input parameters. Policy makers, NGOs, associations and companies are invited to make use of this tool. All documents may be downloaded for free at www.bio-based.eu_ecology.

While the German long version “Nachhaltig nutzbare Potenziale für Biokraftstoffe in Nutzungskonkurrenz zur Lebens- und Futtermittelproduktion, Bioenergie sowie zur stofflichen Nutzung in Deutschland, Europa und der Welt” (Piotrowski et al. 2015) details all parameters, scenario assumptions and full results over 270 pages, the English short version presents only the main assumptions and results in an aggregated form.

In the version presented in this contribution, we only focus on the global and European level. Furthermore, for the global level, it contains an additional scenario (“High demand – low pressure”). This scenario has been developed in the project “Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy – A Challenge for Europe” (Mathijs et al. 2015). This project was carried out by an expert group of the Standing Committee on Agricultural Research (SCAR) as the 4th Foresight Exercise and presented to the public in October 2015. Michael Carus was part of this group as “long-term expert”.

The results of the present study provide a detailed view of possible scenarios for a sustainable supply of biomass until the year 2050, and of the development of demand in all biomass sectors: food, feed, chemicals and materials, bioenergy and biofuels. Due to this approach, one can clearly see under which assumptions global supply shortages or a sufficient coverage of demand may occur. Overall, the results show that biomass shortages will occur if biomass supply is not expanded significantly until 2050. However, such an expansion of biomass supply could have negative sustainability implications unless technology paths are chosen that substitute biomass by other sources of renewable energy.

In the following, we first present the baseline for 2011 for the world and the EU-27, followed by the description...
of explorative biomass supply and demand scenarios. Then, we explore, how well supply and demand match in these scenarios and what implications these have in terms of sustainability of biomass supply. In the concluding section, we summarise our results and formulate policy implications.

2 Global and EU-27 baselines for 2011

In order to have a solid basis for the development of scenarios for biomass supply and demand up to the year 2050, a comprehensive analysis of the current global situation and in the EU-27 in the year 2011 was conducted.

For the first time, a consistent picture of the total biomass supply on the one side and of biomass demand for food, feed, materials, bioenergy and biofuels on the other could be drawn. Biomass supply and demand was determined and analysed by origin (harvested agricultural biomass, harvest residues, grazed biomass and wood) as well as by major constituents of the biomass (sugar/starch, (hemi-)cellulose, oil/fat, protein). In an iterative process, a match was achieved between supply and demand on the basis of tonnes of dry matter and biomass constituents. The difference between biomass supply and demand as found using this method was only 6% for the global scale and less than 1% for the EU-27 – a remarkably good result given the high uncertainties of the underlying data.

The biggest challenge was the analysis of the demand for material uses, which includes thousands of applications, and has been ignored in most studies so far.

Figures 1 to 4 show the main results. In the year 2011, globally about 11.4 billion tonnes dry matter of biomass were harvested or extracted for use and processed into food, feed, bio-based products, energy carriers and biofuels (Figure 1). At the same time, demand was around 12.1 billion tonnes dry matter (Figure 2). The difference of 6% arises due to the data uncertainties. The demand for material uses is about ten times higher than that for biofuels. This may surprise those interested in the topic. However, today the share of biofuels may be higher (2%, up from 1% in 2011).

The assessment of biomass supply and demand for the EU-27 requires an integration of international trade of biomass and biomass products. Hence, we differentiate between domestic supply, imported and exported biomass. The biomass supply of the EU-27 includes domestic and imported biomass while the biomass demand includes biomass for domestic uses and exported biomass. Note that in the case of traded animal products we have converted these back to feed equivalents. Figure 3 and 4 show that biomass supply and demand match even better than for the global scale, with a difference of less than 1%. Overall, the structure of global biomass supply and biomass supply in the EU-27 turns out to be quite similar, with the exception of grazed biomass which has a much higher share globally. Accordingly, biomass demand for feed is also more strongly represented globally than in the EU-27.

**Figure 1:** Global biomass supply 2011, by biomass sources

Source Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). Statistical database of the FAO. 2014. Available at http://faostat.fao.org/site/ 339/default.aspx (Last accessed March 2015).

**Figure 2:** Global biomass demand 2011, by sectors

Source Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). Statistical database of the FAO. 2014. Available at http://faostat.fao.org/site/ 339/default.aspx (Last accessed March 2015).
Based on the baseline data shown above, several explorative scenarios have been defined for the year 2050. These scenarios highlight how under different plausible and consistent assumptions the supply and demand of biomass may develop. For about 100 parameters that significantly determine future supply and demand, different sets of assumptions have been applied. It was then calculated what these assumptions imply for the supply (by origin) and demand (by sectors) for biomass in the year 2050. The matching between supply and demand is based on a hierarchical order of uses. Only when the demand for plant-based food and animal products is globally satisfied, the demand for biomass for bio-based products is covered which, in turn, is prioritised over bioenergy and biofuels. The reason for this approach is the fact that already today, technologies such as solar and wind energy exist which provide energy more efficiently and ecologically than bioenergy and conventional systems, while in many cases there are no alternatives for certain material properties of biomass (among others protein, fat and carbohydrates).

Since the number of parameters for the scenarios is very high, this summary focuses only on an explanation of the most important ones. The long version of the study describes all parameters in detail and can be easily changed for new explorative scenarios and models.

For both the world and the EU-27, three global supply scenarios (LOW, Business-As-Usual (BAU), and HIGH) and four demand scenarios (LOW, BAU, Bio-based, and Bio-based High) have been defined. For the global level, an additional demand scenario has been defined which explores how the biomass demand from the highest scenario could be covered with the lowest pressure on ecosystems and biodiversity (“High demand – low pressure”).

### 3.1 Global supply scenarios

The supply scenario LOW is characterised by very moderate intensification of agriculture. Accordingly, we assume that no expansion of agricultural land takes place. Instead, due to soil degradation, the area used for arable and permanent crops decreases by a total of 100 million ha. Based on several studies (Bringezu et al. 2010, Qadir et al. 2014, IFAD 2013, Pimentel 2006), we concluded that in the past the loss of agricultural area due to all forms of degradation amounted to about 10 million ha per year, so from 2011 to 2050, the total loss could amount to almost 400 million ha. However, in the LOW scenario we assume a lower loss of only 100 million ha due to lower pressure on agricultural land.

Regarding crop yields, Alexandratos and Bruinsma 2012 presented assumptions for yield increases of 13 main crops or crop groups until 2050. For the LOW scenario, we assume 50% lower yield increases than projected by Alexandratos and Bruinsma 2012.
Finally, we assume that the average annual increase of the Multi Cropping Index (MCI) is reduced between 2011 and 2050 from about 0.003 to 0.001. The MCI then reaches a value of 0.91 in the year 2050.

In total, biomass supply reaches about 12.4 bn t dry matter in this scenario in 2050, so it would be only slightly higher than in 2011.

The supply scenario BAU is characterised by higher biomass production and concomitantly higher intensification and expansion of agricultural area and hence more pressure on other forms of land cover.

In the BAU-scenario we assume that loss of agricultural land due to degradation will amount to 400 million ha until 2050. However, these losses are offset by cultivation of new agricultural areas of 435 million ha. These are areas suitable for rain-fed cultivation that are not currently used for crop production and not protected. We assume that 50% of these areas were previously used as meadows and pastures, so that the area of meadows and pastures decreases by about 218 million ha. Additionally, 100 million ha of forests are converted into agricultural land. As the basis for this scenario we have assumed that the current trend of deforestation continues until 2030 and then comes to a halt as internationally declared (Council of the European Union 2009).

Overall, the area for arable and permanent crops increases globally between 2011 and 2050 from 1.55 bn ha by about 135 million ha to 1.69 bn ha.

Regarding crop yields, we assume the yields as projected by Alexandratos and Bruinsma 2012. For the MCI, we assume that the average annual increase of about 0.003 continues until 2050. The MCI then reaches a value of 0.96 in the year 2050.

In the BAU-scenario compared to the LOW scenario, we assume an increase of the utilization of primary harvest residues from 25% to 40%.

Regarding forest biomass, we assume that the effective utilization of the forests other than planted forest increases from 10% to 25% and the wood yield from planted forests increases from 8.5 cbm/ha*a to 14 cbm/ha*a. Furthermore, the area of the planted forests increases by 195 million ha.

In total, biomass supply reaches about 18.2 bn t dry matter in this scenario in 2050.

In the supply scenario HIGH we assume that loss of agricultural land due to degradation will amount to 500 million ha in 2050. However, these losses are offset by cultivation of new agricultural areas of 760 million ha. These are areas suitable for rain-fed cultivation that are not currently used for crop production and not protected. We assume that 50% of these areas were previously used as meadows and pastures, so that the area of meadows and pastures decreases by about 380 million ha. Additionally, 100 million ha of forests are converted into agricultural land, as in the BAU scenario. In total, the land for arable and permanent crops therefore increases by 360 million ha.

Regarding crop yields, we assume 25% higher yields than projected by Alexandratos and Bruinsma 2012. For the MCI, we assume that the average annual increase of about 0.003 increases to about 0.004 in 2050. The MCI then reaches a value of 1.01 in the year 2050.

Regarding forest biomass, we assume that the effective utilization of forests other than planted forest increases from 10% to 25%, as in the BAU scenario and the wood yield from planted forests increases from 8.5 cbm/ha*a to 20 cbm/ha*a. Furthermore, the area of the planted forests increases by 390 million ha compared to 2011.

Additionally, we assume an increase of the utilization of primary harvest residues from 25% to 50%. This increase in the use of harvest residues could still be consistent with a sustainable cultivation as long as long-term soil fertility is not threatened, as might be the case for humus draining crops. In many cases, countermeasures might become necessary such as the cultivation of catch crops.

In total, biomass supply reaches about 25.2 bn t dry matter in this scenario in 2050.

Table 1 shows the summary of global biomass supply in the base year 2011 as well as in the three scenarios LOW, BAU and HIGH.

### 3.2 Global demand scenarios

We formulated five different demand scenarios. All of these demand scenarios share the same assumptions regarding the demand for food and feed: The average annual growth rate of the demand for plant-based food is calculated to be about 0.7% and that of the demand for feed to be about 0.4%. Input parameters for these results were the growth of world population (from 7 bn in 2011 to 9.55 bn in 2050), a higher per-capita demand for food, a growing share of animal-based food and at the same time a reduction of global food waste from 30% in 2011 (HLPE 2014) to 20% in 2050 and an increase in feed efficiency.

Furthermore, we assumed that the global demand for energy increases by less than 1% annually while the demand for biomass for bioenergy increases by about 2% annually. These assumptions were based on the IEA-scenario ETP 2012 2°C (ETP 2DS) as described in IEA 2012. This scenario “sets out cost-effective strategies for
reducing greenhouse gas emissions in the energy sector by 50% in 2050 compared to 2005 levels” and keeping the +2 °C climate target.

Regarding the demand in material sectors, the evaluation of a large number of market studies has shown an annual global growth of 3.5% for chemicals and plastics (in Europe 1.75%) and of 3% for textiles. Other material sectors typically grow by between 1% and 2% annually. This leads to the interesting conclusion that the total demand growth for materials of 1% to 4% annually (depending on the sector) is significantly stronger than in the energy sector with 1% p.a. at the most. This means e.g. that the share of material use in petrochemistry as well as in the bioeconomy increases significantly, from about 5-10% today to about 20-30% in 2050.

Additionally, in this assessment, an increase in the global recycling rate from 15% to 25% has been taken into account. This increase in the recycling rate is also partly based on stronger cascading use of biomass.

The demand scenario LOW is linked to the supply scenario LOW, i.e. supply LOW and demand LOW exactly match. In the supply scenario LOW, only the demand for food and feed can be fully covered. The material use and bioenergy sectors can only be partially covered. Less than 20% of the available biomass is left for materials and bioenergy which is less than in 2011 (27%). That means that the demand for materials and energy has to be covered mainly by other sources (fossils or other renewables). As sustainable as the LOW scenario may appear from the agricultural side, the bioeconomy can contribute only little to cover the demand of the other sectors or to a lowering of greenhouse gas emissions.

The demand scenario BAU is linked to the supply scenario BAU i.e. supply BAU and demand BAU exactly match. Additional to the assumption of an annual growth rate of 3.5% for chemicals and plastics, we assume that the share of biomass used in the chemical and plastic industry will increase from 10% today to 20%.

Figure 5 illustrates how the global raw material demand of the chemical industry would increase until 2050 in this scenario. Due the assumptions of an annual growth rate of chemicals and plastics of 3.5% and an increase in the share of biomass in the total organic raw material demand of the chemical industry from 10% (2010) to 20% in 2050, the 59 mln t dry matter of biomass in 2010 for the chemicals and plastics industry would turn into 470 mln t dry matter in 2050.

In this scenario, biomass demand from food and feed, materials and bioenergy could be fully covered by supply scenario BAU and about 1 mln t dm of biomass would be left for other uses such as biofuels. This is about 7 times the quantity used in 2011. The IEA 2012 expects that a total of 3-4 bn t dm of biomass (equivalent to 60 EJ) would be needed for biofuels in order to reach the +2 °C climate goal (however, without taking into account the CO2-savings due to the higher material use of biomass). With 1 bn t dm, about 25-30% of this demand could be met.

The Bio-based demand scenario is characterised by a higher biomass demand for materials as well as bioenergy and biofuels. The share of biomass needed to cover the demand of the chemical and plastic industry would increase from 10% today to 40%, and together with higher growth rates in other material sectors (construction,
The fuel demand is covered mainly by solar fuels, with renewables, and especially solar energy. That means that the left over biomass demand can be covered by the BAU supply scenario.

The non-fossil demand for materials and energy is mainly covered by other renewable energies such as solar, wind and hydro energy and storage systems. In detail:

- The total material demand for the chemicals and plastics is covered mainly by solar chemicals and only to a lesser extent by complex biomolecules.
- The energy demand is mostly covered by renewables (solar, wind etc.) and less by bioenergy (same level as in 2011).
- The fuel demand is covered mainly by solar fuels, with a low share of biofuels (same level as BAU scenario).

Together with electric cars driven by renewable energies, the left over demand for fossil fuels is lower than in all other scenarios.

In total about 4.5 billion tonnes dry matter have to be substituted by solar chemicals and solar fuels in 2050. Will this be possible? From a technology point of view, it is already possible today to produce gaseous and liquid molecules such as methane, methanol, kerosene and more from CO₂ and water using renewable electricity. These products can be used as fuels or raw material for the chemical industry. The efficiency for this transformation is about 60% today and can probably be increased to about 80% by 2050.

Different technologies can be used for this transformation, for example via electrolysis and methanisation or Fischer-Tropsch, algae and biotechnology, but in the future also different kinds of artificial photosynthesis. Those technologies are also called power-to-gas, power-to-liquid or power-to-chemicals (Dena 2015).

Today, more than 30 pilot plants are running worldwide and the first commercial plants will start operation soon. The costs are higher than for fossils but almost on the same level as for biofuels.

What land area is needed to produce for example 4.5 billion tonnes of methane from power-to-gas? With existing technologies it is possible to produce about 80 tonnes of methane per ha per year in the desert (with 80,000 GJ solar radiation per ha per year). To produce 4.5 billion tonnes of methane, 57 million ha of desert land would therefore be needed. The total desert area is about 2.75 billion ha (Piotrowski et al. 2015). Therefore, about 2% of deserts worldwide would be enough to meet more than 95% of the total demand of the (organic) chemical and plastics industry and also a relevant demand for fuels.

Table 2 shows the summary of global biomass demand in the base year 2011 as well as in the five scenarios (LOW,
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3.3 Supply scenarios for the EU-27

The results for the EU-27 are comparable to the global ones, except that the respective ranges of supply and demand are markedly lower (see Table 3 and Table 4). This is on the one hand due to the lower potential for an expansion of agricultural areas and on the other hand due to a lower increase in demand in a strongly industrialised and affluent society.

The results are based on the premise that Europe will remain export-oriented and that a decrease of domestic demand will be compensated by stronger exports.
Furthermore, we consider in the scenarios the hypothetical case that only the domestic biomass supply would be available for satisfying demand. The basic idea behind this assumption is that a sustainable potential for the utilisation of domestic biomass should not be constructed by increasing on the other hand biomass imports for other domestic demand (for food, feed, material use and bioenergy).

With moderately increasing agricultural areas and increasing yields, the biomass supply would increase in the BAU scenario until the year 2050 compared to 2011 by 30% and in the HIGH-scenario, with an expansion of planted forests, by 40%. In the LOW-scenario, with no expansion of agricultural areas and only moderate increases in yields, the biomass supply would stay approximately on the same level as in 2011.

### 3.4 Demand scenarios for the EU-27

Table 4 shows the results for the four biomass demand scenarios for the EU-27. Main parameters common to the scenarios are an annual growth of the EU-27 population of 0.02%, a constant domestic per capita demand for food and a cut of food waste from 18% to 9%. Regarding the growth of demand for materials, we assume that in most sectors, annual growth rates would be approximately half as high as globally. Growth in demand for bioenergy and biofuels was based on the evaluation of the national renewable energy action plans by Bentsen and Felby 2012.

The supply scenario BAU shows that due to the relatively low import shares compared to the domestically produced biomass, even without imports, more biomass could be available for other uses, such as for biofuels, in the demand scenario BAU. Conversely, demand could hardly be satisfied and no biomass would be left for other uses in the demand scenarios Bio-based and Bio-based High.

### 4 Sustainability considerations

All biomass supply scenarios assume that the respective supply can be provided on a long-term basis so that the actual main sustainability criterion is satisfied. All scenarios first cover the demand for food and feed and can therefore also be regarded to be sustainable from this perspective since they first address the basic needs of humankind.

Under certain criteria, however, some of the global scenarios could be regarded as unsustainable. Under
the criterion of a “safe operating space”, which essentially means that the global loss of biodiversity comes to a halt in 2020, the global areas for arable and permanent crops may witness a net expansion to up to 1.64 billion ha according to Bringezu et al. (2014). This sustainability criterion is only achieved in the LOW scenario but not in the BAU and HIGH scenarios which significantly exceed the boundaries within which a sustainable development is regarded to be feasible. However, the exclusive focus on the expansion of agricultural area neglects many other factors that play a role in the evaluation of the sustainability of land use, e.g. the type of cultivation and the creation of protection zones.

It is important to also note that in the BAU and HIGH scenarios no more forests are converted into arable land from the year 2030 onwards, protection zones are not infringed upon and only those areas that do not need artificial irrigation are converted into arable land. In the forests, an expansion of naturally regenerated, non-primary forests and planted forests is assumed. The areas newly converted into arable land are mainly meadows and pastures. The area expansion in the BAU and HIGH scenarios can be realised while meeting the criteria of the currently applied certification systems for sustainable biomass and the FAO – however presumably not without accepting a negative impact on biodiversity. A challenge for future agriculture will be how to achieve higher yields while at the same time incurring fewer environmental impacts. Technologies such as precision farming will play a central role in this respect.

Furthermore, all supply scenarios are in accordance with the strategy for a sustainable crop production intensification (SCPI) of the FAO. Even in the HIGH scenario it is assumed that the increase in yields can be sustainably achieved by the improvement of production systems, the use of innovative technologies, improved and adapted plant varieties and the reduction of field and post-harvest losses while at the same time the economic participation of farmers and forest owners in developing countries could be improved.

In comparison, the evaluation on the basis of other sustainability requirements, such as the “safe operating space” is considerably more difficult. In the first instance, it appears that the LOW supply scenario fulfils the criteria since here no expansion of arable land takes place – in fact, the available arable land actually decreases due to degradation – and yield increases are very moderate. Only efficiency gains, including a reduction of the field and harvest losses, enable the biomass supply to be kept on approximately the same level as in the base year 2011.

In the supply scenarios BAU and HIGH, a relevant net expansion of land for arable and permanent crops takes place and concomitantly there is a considerable threat of a further reduction of biodiversity as well as increased emissions of greenhouse gases from agriculture. Hence, these scenarios do not appear to be sustainable at first. However, two important aspects qualify this classification:

It must be taken into account that in the scenario LOW, only the demand for food and feed can be covered – the elementary needs for material products and energy cannot be satisfied even partially by biomass. When the demand for materials and energy is not to be covered by fossil fuels either (they are depleting sources, and cause $CO_2$ emissions), then massive investments into solar and wind energy as well as storage systems and Carbon Capture & Utilization (CCU) technologies must take place. Only then it is ensured that sustainable agriculture and forestry is not counterproductive to the sustainable development of a global economy as a whole.

Furthermore, a review of future trends shows technologies and systems which could allow the supply of very large quantities of additional biomass without significantly increasing the pressure on nature and biodiversity. These include desert greening, the desalinization of marine water with solar energy and marine farming of the macroalgae kelp. In 2050, more biomass could be supplied with the help of these technologies and systems than achieved in the HIGH supply scenario through expansion of agricultural areas and intensification of cultivation.

The demand scenario High demand – low pressure even goes one step further and assumes a massive development of solar and Carbon Capture and Utilization (CCU) technologies and shows that it is possible to cover the highest demand of all scenarios with at the same time using less biomass than in the BAU scenario.

Which of the biomass supply scenarios may be regarded as sustainable depends primarily on the chosen sustainability concept and the system boundaries. According to the concept of a “safe operating space” with a special focus on maintaining biodiversity, only the LOW supply scenario may be considered to be sustainable. However, this scenario, while ensuring sustainable agriculture and forestry, also gives rise to a threat against the sustainable development of a global economy as a whole – if this development is not balanced by massively investing in renewable energy and CCU technologies based thereupon.

According to other requirements for a sustainable development of agriculture (FAO and currently accepted certification systems), the biomass supply and demand in the scenarios BAU and HIGH can also be designed
sustainably, but not without threatening biodiversity. Therefore, if biodiversity ranks high in an evaluation of sustainability, especially the HIGH scenario can no longer be considered to be sustainable.

In any case the supply scenarios BAU and HIGH – and therefore the bioeconomy as a whole – can significantly contribute to the sustainable development of the global economy and a relevant reduction of greenhouse gas emissions of the material and energy economy. In turn, climate change and related greenhouse gas emissions are one of the main causes for the global reduction of biodiversity.

**5 Conclusions**

This contribution summarised and discussed the most important results of a study that developed explorative biomass supply and demand scenarios for the world and the EU-27 until 2050. As the basis for these scenarios, biomass supply and demand were matched for the year 2011 and this matching was achieved up to good level of consistency.

The results show that, given the described assumptions, the global biomass supply will scarcely change from 2011 to 2050 in the supply scenario LOW, while it will almost double in the BAU scenario and more than double in the HIGH scenario. The range of global biomass supply in 2050 based on these scenarios will be between 12.4 billion t dm and 25.2 billion t dm. As described above, the LOW and BAU demand scenarios exactly match the respective supply scenarios. The results have shown that the LOW supply scenario would just be able to cover the demand for food and feed, but hardly any of the demand for materials and bioenergy and none of the demand for biofuels. In comparison, the BAU supply scenario could cover the demand for food, feed, materials, and bioenergy and could even leave room for an expansion of biofuels of up to 1 billion t dm of biomass.

Regarding the scenarios for the EU-27, the biomass supply scenario LOW succeeds to cover with domestic biomass the European demand for food and feed (to a larger extent than globally) as well the export demand for food. Conversely, the demand for materials and energy could only be covered by increasing biomass imports. The domestic biomass supply scenario High would be able to satisfy all demand from all sectors, not taking into account the expansion of biofuels. Also, the results do not take into account that for specific biomass components, a complete import substitution is unlikely to be feasible in all cases.

While therefore at least on a global scale, already in the BAU scenario no real shortages are predicted to occur, the biomass supply, or rather the supply of renewable carbon, can be expanded much further by exploiting the described new technologies and system optimisations which allow a higher output with less input, and at the same time reduced environmental burdens. Hence, shortages by 2050 could be largely ruled out, given that investments in new technologies are made.

Examples of such promising technologies are the greening of deserts with deep water recovered by solar energy and fresh water through desalination of marine water, the introduction of salt and heat resistant crops, large-scale marine cultivation of macroalgae, tailored fertilisation, plant protection and irrigation through precision farming, optimised crop rotation and combinations of crops, soil improvements, modern plant breeding.

Since the new technologies would reclaim new areas and use the current areas more efficiently, the pressure on semi-natural areas, protected zones, and also on biodiversity would decrease significantly. At the same time, a circular economy with strongly expanded recycling and an integrated cascading and reduction of losses in the agricultural and food chain as well as a more efficient production of animal protein (insects) can reduce the demand for fresh biomass in spite of a growing world population.

Adding to this are new possibilities for utilisation of ever cheaper solar and wind energy that do not just supply electricity and heat but also produce fuels and raw materials for the chemical industry from water and CO₂, with a high area efficiency (CCU). In terms of bare figures, the global demand of organic chemistry in 2050 could be covered by less than 2% of the deserts by CO₂ utilization.

Overall, this means that in the future, the contradiction between the creation and preservation of protection zones and natural areas on the one hand and a significantly increased biomass production and other forms of renewable carbon carriers on the other can be permanently overcome. The bioeconomy and renewable energies in conjunction with CCU technologies are able to sustainably and permanently secure global raw material supply without threatening nature and biodiversity.

Even the demand from high growth scenarios can be covered with less fossil resources and also a sustainable growth in biomass supply, if there is also a strong investment in solar and other renewables, delivering not only heat and electricity, but also almost all raw materials for the chemical industry and a high share of synthetic fuels (solar fuels).

In such a scenario, high growth can be combined with low pressure on natural resources and low pressure on the
climate. But it needs a strong commitment to, investment in, and implementation of solar, wind and other renewables, and Carbon Capture and Utilization (CCU) technologies to also produce raw materials and fuels from solar and wind.

The bioeconomy can, embedded in the right overarching strategy with a strong expansion of renewable energies and in conjunction with a CO₂ utilization, contribute to a global sustainable development.

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Dr. Piotrowski has a background in agricultural science and received his doctoral degree from the University of Hohenheim (Stuttgart, Germany) at the Chair for Rural Development Theory and Policy. He joined nova-Institute in 2008. His tasks in the Sustainability Department comprise research on land use competition, the techno-economic evaluation of novel industrial processes and market research for fossil and renewable raw materials, food and feed markets and bio-based products.

Dr. Piotrowski has been working in numerous projects, e.g. for the Joint Research Centre (JRC) of the European Commission, on the assessment of the European bioeconomy in terms of biomass use and effects on employment and value added. Due to this work he has deep knowledge in the extraction and evaluation of international statistical databases such as Eurostat, FAOSTAT, USDA and others.

Michael Carus, Managing Director, nova-Institute

Physicist, from 1983 to 1994 he worked for the IT industry, environmental institutes and the solar industry. In 1994, he co-founded nova-Institute and has been functioning as owner and Managing Director ever since. Michael has more than 15 years of experience in the field of bio-based economy, including work on biomass feedstocks, industrial biotechnology and all kinds of bio-based materials. His work focuses on market analysis, techno-economic and ecological evaluation and creating a suitable political and economic framework for bio-based processes and applications.

Michael Carus is member of the Technical Committee, CEN/TC 411 “Bio-based products”, member of the “Expert Group on Bio-based Products” of the European Commission, member of the Thematic Working Groups “Biomass supply” and “Market-making” of the “Bioeconomy Panel” of the European Commission, as well as member of the SCAR Foresight experts group “Sustainable Bioresources for a Growing Bioeconomy”.

Roland Essel, Head of Sustainability Department, nova-Institute

Roland Essel studied environmental sciences at the Universities of Trier, Edinburgh and Karlsruhe and graduated from the University of Trier in 2010. He started his career as a consultant for Taurus Eco Consulting GmbH while also working as research assistant at the chair of environmental accounting at the University of Technology in Dresden. Since May 2011 Roland Essel has been working at nova-Institute; he became Head of the Sustainability Department in 2013. He is responsible for ecological evaluation, environmental resource management and oversees, among others, projects on cascading use of biomass. Roland Essel is a member of the Society of Environmental Toxicology and Chemistry (SETAC) and is active in the CEN TC 411 working group on bio-based products.