Is biomass climate neutral and sustainable?

Only approximately 0.1 percent of the solar energy that reaches Earth is currently stored for longer periods on Earth. Of this amount, nature itself stores over 99.9 percent in the form of biomass via photosynthesis. However, "only" about 10 percent of the worldwide primary energy requirement is currently covered by this biomass.
It appears that this figure could be increased. On closer examination, however, biomass doesn't represent potential for additional usable renewable energy from a global viewpoint. That is because biomass is not necessarily any friendlier to the climate and environment than fossil energy sources are.

The limiting factors for biomass as an energy source

Energy from biomass is limited primarily by three factors:
- The lack of available land
- The necessary growth conditions
- Exceeding quantities that can be sustainably produced

The lack of available land

By nature, most (approx. 70 percent) of Earth's landmass surface area cannot be used for plant cultivation (deserts, mountains, excessively low temperatures in polar regions, salination, etc.). Add to this the fact that increasing deforestation in order to cultivate crops (animal feed plants like soybeans, or energy crops like corn and oil palms) leads to steppization and desertification worldwide (see the examples below).
The competition between food and energy crops has negative consequences for the farming structure. In Brazil, one of the world's largest agricultural producers, sugar cane cultivation for bioethanol production and soybean cultivation for animal feed production led to Brazil's transition from a food exporter to importer in 2015. In addition, large areas of primeval forests were cleared for the soybean cultivation, which also negatively affects the climate.

The necessary growth conditions

The cultivation of energy crops like corn and rapeseed involves the high consumption of drinking water for irrigation purposes, the use of herbicides, fungicides, and pesticides that are toxic to people and the environment, as well as the use of fertilizers that release greenhouse gases (N_2O). Each of these aspects is a barrier to the expansion of energy crop cultivation. If people still want to cultivate energy crops, the only alternatives would be those that can be grown largely without fertilization and spraying.

Lack of sustainability with respect to greenhouse gas emissions

Since a plant absorbs exactly the same amount of CO_2 when it grows as it releases when it is burned, biomass is climate neutral as an energy source in ideal cases. Even when the plant cannot be used directly, but additional processing steps that emit CO_2 are necessary, the use of these plants is still generally climate friendly with regard to the CO_2 balance. Examples of this are oil palms and rapeseed and their processing for use as biodiesel, or corn used to produce biogas. These plants bind almost exactly as much CO_2 when they grow as they release again when they are processed and consumed.

However, if you consider not only this CO_2 balance, but all greenhouse gases, such as the additional CO_2 from slash-and-burn clearing, N_2O from fertilization, and environmental pollution through pesticides, the climate and environmental balance is often negative. (N_2O that is produced through fertilization with mineral nitrogen-based fertilizers and from slurry is 310 times more potent as a greenhouse gas than CO_2.)
In any case, the climate balance is negative whenever more biomass is consumed than can grow back in the same time period.
For instance, when it comes to wood, this type of sustainability hasn't existed for a long time in many regions around the world. Sustainability would be ensured only if the wood were grown in "short-rotation forests" (fast-growing poplars and willows) on formerly fallow land (see photo below).

Chinese silver grass Hemp Willows and poplars

Fig. 1: Largely climate and environmentally friendly energy crops

Collage created by Dr. Michael Huber using the following images:
Chinese silver grass: From user: Markus Hagenlocher – own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=697164
Hemp: Credit: Acrocynus | Acrocynus | License: CC-BY-SA-3.0-migrated GFDL
Willows and poplars: From Lignovis GmbH – own work, CC-BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=43266976

When does the cultivation of energy crops make sense?

The cultivation of energy crops makes sense only under the following conditions:

- No competition with food crops
- Use of fallow land exclusively, without clearing of forests
- Climate neutrality throughout the entire chain, from cultivation to consumption
- No pollution for people and the environment caused by pesticides, fungicides, and herbicides (including pollution of drinking water)
- No soil destruction through erosion or steppization

Climate and environmental pollution caused by the most important energy crops					
Plant, fruit	**Raw material**	**Process or use**	**Product**	**Nitrogen requirement, (cause of greenhouse gas N_2O)**	**Use of herbicides, fungicides, pesticides**
Beet, potato, grain, corn	Plant material containing sugar and starch	Fermentation into ethanol	Fuel, ("bioethanol", fuel additive)	**High**	**High**
Sugar cane	Plant material containing sugar and starch	Fermentation into ethanol	Fuel, ("bioethanol", fuel additive)	**High**	**Low**
Rapeseed, sunflower seeds	Plant material containing oil	Pressing, extraction, transesterification	Fuel, ("biodiesel", fuel additive)	**High**	**High**
Oil palms	Plant material containing oil	Pressing, extraction, transesterification	Fuel, ("biodiesel", fuel additive)	**Medium**	**High**
Jatropha	Plant material containing oil	Pressing, extraction, transesterification	Fuel, ("biodiesel", fuel additive)	**Medium**	**Low**
Straw	Wood chips	Combustion	Heat and possibly electricity	**None**	**None**
Miscanthus (Chinese silver grass, elephant grass)	Wood chips	Combustion	Heat and possibly electricity	**Low**	**Low**
Hemp	Wood chips	Combustion	Heat and possibly electricity	**Low**	**Low**
Trees, bushes	Logs, wood chips, pellets	Combustion	Heat and possibly electricity	**Low**	**Low**
Grass clippings, plant waste	Chopped pieces	Anaerobic fermentation into methane ("biogas")	Electricity and heat (combustion in gas turbines, engines)	**Low**	**Low**
Corn, grain, beet	Chopped pieces	Anaerobic fermentation into methane ("biogas")	Electricity and heat (combustion in gas turbines, engines)	**High**	**High**

Sources for this table: Schlipf et al; Handbuch der Landwirtschaft [Farming Manual]; website of the training and research stations at the University of Bonn; website of the Bayerische Landesanstalt für Wald und Forstwirtschaft [Bavarian State Institute of Forestry]; FAO databases (Food and Agriculture Organization of the United Nations).

Example: Europe, Indonesia, and Paraguay

If one considers more than just the climate balance, environmental pollution – in particular caused by overfertilization, acidification, and erosion of soil used for agricultural purposes – has a negative impact related to the cultivation and processing of biomass. Shortages of freshwater and the steppization and desertification of large areas are currently increasing worldwide, but these situations are caused only partly by climate change. These phenomena are significantly intensified by logging and slash-and-burn clearing of rainforests, especially today for the cultivation of sugar cane and oil crops for the production of bioalcohol and biodiesel as “renewable” fuels.

Europe

In Europe and primarily in Germany, nitrogen-based fertilizers used in the increasing cultivation of rapeseed and corn has led to higher emissions of the extremely strong greenhouse gas, nitrous oxide (N_2O). Apart from this, nitrogen-based fertilization of 27 percent of Germany’s area has rendered the groundwater unsuitable for drinking water production. And in 2015, the nitrate levels of drinking water in Germany already exceeded the EU limits in 40 percent of the cases. What’s more, in the same year, urine samples from 70 percent of the German population contained traces of the herbicide glyphosate.

Indonesia

Vast areas of primeval forest were slashed and burned in Indonesia for the cultivation of oil palms. However, the amount of CO_2 and H_2O stored in the large old trees of a rainforest is so high that the CO_2 released during the clearing cannot be compensated for by the growth of the oil palms. As a result, in 2015 Indonesia released more CO_2 through slash-and-burn clearing than the total amount of CO_2 emissions in Germany. In addition, slash-and-burn clearing of rainforest areas leads to extreme air pollution through soot and other hazardous exhaust gases, like nitric oxides, aerosols, and dioxins. For instance, in autumn 2015 a 300 km cloud of smoke and smog formed in Indonesia that reached all the way to Singapore and Malaysia, forcing the temporary closing of schools there, among other issues.

Paraguay

Of the original primeval forest that still existed in Paraguay 50 years ago, only about 30 percent has been preserved; the rest has been cleared for soybean cultivation and cattle farming. Only 13 percent of coastal rainforest remains. Apart from the worsened climate imbalance, this clearing has had further extremely negative consequences. Since the forest has lost its capacity to retain water, heavy rains result in flooding and washing away of the humus layer, and drier periods result in aridification. The local climate suffers, and erosion is increased. Steppization and desertification are progressing. As a result, soybean cultivation is now no longer worthwhile in many parts of Paraguay.

Wood – good or bad example of energy from biomass?

In early 2017, the Food and Agriculture Organization (FAO) of the United Nations announced that between 2010 and 2013, 5.2 million hectares of forest area around the world were lost each year. Many forest areas worldwide are still not being sustainably managed. As we have seen from the examples of Indonesia, Paraguay, and Brazil, this is mainly due to the clearing of primeval forests in order to cultivate energy crops or feed instead. In contrast, North America, Australia, and Central Europe long ago committed themselves to sustainable forestry. Large forest areas are generally no longer cleared and, at least formally, as much forest is regrown as is cut down. Whether this level of sustainability still applies can be examined particularly well using Germany as an example.

Here, wood consumption for heating purposes has risen tremendously in the past 15 years as part of the transition to renewable energy.

Do people in Germany burn only wood that grows back?
In Germany, the demand for wood has grown significantly in recent decades. According to information from the wood-processing industry, annual consumption throughout Germany was 136 million cubic meters of wood. Of that amount, however, only approximately 60 million m^3 originate from Germany. Paper recycling has compensated for about 35 million m^3. This results in a difference of 41 million cubic meters that had to be imported for furniture and firewood. In addition to the demand by the construction and paper industries, the reason for the high consumption is primarily the increasing need for firewood. Each year in Germany, around 70 million cubic meters of wood are burned in wood chip and coal-fired power plants, but especially in private fireplaces and pellet stoves. If calculations are based on realistic consumption of three cubic meters of firewood per fireplace and year, nearly half of the timber harvest ends up in private fireplaces and stoves.
This means firewood must be imported from densely forested countries, for example, from Poland, Ukraine, and Bulgaria.
The timber harvest in these countries increased between 2000 and 2010 as follows:

- Poland + 34 %
- Ukraine + 29 %
- Bulgaria + 109 %

This doesn't include the wood from Siberia and Belarus. The ecological consequences for the forest areas of these countries are alarming. Between 2000 and 2010, the area of logging (cleared areas) in Eastern Europe increased by approximately 23 percent, in southern Europe by even more than 70 percent.

How sustainable can forestry be with such high demand?

A press release from the German “Arbeitsgemeinschaft Rohholzverbraucher e. V.” [Consortium of Raw Timber Consumers] in early 2013 states that despite the shortage of raw materials, the sustainability of forest management in Germany is not in jeopardy. Between 75 and 85 million m^3 have been sustainably harvested in German forests every year. This timber extraction is offset by timber growth of approximately 120 million m^3 annually. Forests will therefore continue to be managed sustainably since less wood is being removed than grows again. However, the same press release stated that things cannot go on in this way or else sustainability will be jeopardized.

A 2013 study by the Bund für Naturschutz [German Association for Nature Conservation] names a few reasons for decelerated forest growth:

- Too many nutrients have already been removed:
  Every time timber is harvested, nutrients are removed from the forest. In low mountain range areas that are poor in nutrients, the supply is already scarce.
- The excessive input of nitrogen impairs forest health:
  The addition of nitrogen (nitric oxides from power plants, traffic, and agriculture) leads to a deficiency of potassium, magnesium, and phosphorus in forest soils.
- Nutrient losses due to complete use of the wood.
  In the past, only the logs were removed; branches, twigs, and bark were left on the forest floor to decompose into high-nutrient humus. Today, this “kindling” is processed into readily sold wood chips as heating material. The humus layer is disappearing.

Add to this the fact that the monocultural forests of spruce and pine common in Germany are further strained by climate change. They become more vulnerable to pests, wind breakage, and forest fires, and the new growth is severely hindered by dry periods.

What does sustainable, close-to-nature forestry mean?

When timber is harvested today, wide areas of forest are generally clear-cut. This allows the cost-efficient use of forestry harvesters. This method of harvesting is particularly lucrative in relatively old forests with tall, thick-trunked fir, spruce, beech, and oak trees up to 100 or even 200 years old. The argument “what we have cut down will grow back again” isn’t really valid. After all, it takes 100 years for a 100-year-old forest to grow back again!

Sustainable, close-to-nature forest management meets the following criteria:

- **Mixed forest with various types of coniferous and leafy wood, ideally with undergrowth**
  A mixture of tree varieties adapted to a location makes the forest less vulnerable to pests and wind breakage (mixture of shallow- and deep-root trees). The capacity to store water and the breakdown of harmful nitric oxides are also generally better.

- **Mixed forest with trees of widely varying ages**
  The young trees grow up under the protection of the old trees, so to speak. The incidence of light and thus growth by means of photosynthesis improve. At the same time, the forest floor is shaded by the smaller trees and bushes, preventing an excessive rate of evaporation.

- **No clear-cutting**
  Instead, mixed cutting at different rates based on age. Young trees in particular should be cut down relatively often for thinning to prevent mutual obstruction, middle-aged trees (approximately 15 to 30 years, depending on the tree species) should seldom be felled, and old trees (100 years and older) should only very rarely be cut down.

According to the German Federal Environmental Agency, however, in 2014 only approximately 15 percent of German forests were really managed in a near-natural manner.

Fig. 2: Clear-cutting in the Bavarian Forest.

The photo above shows clear-cutting in the Bavarian Forest in which firs over 100 years old were felled. New trees won't be planted at this location, rather the forest will be left to its own resources for a "close-to-nature forest" to develop. The same procedure followed in areas affected by wind breakage and bark beetles has shown that a natural mixed forest will indeed grow back within about 15 years. However, it will take over 100 years until the same amounts of CO_2 and water have been bound in the regrown natural forest as were bound in the cleared fir forest.

What is the level of climate neutrality and environmental compatibility of other energy crops?

Examples: Biodiesel from rapeseed

Plant-based oils, especially from rapeseed, oil palms, sunflowers, and used cooking oils (deep-frying fat), can replace conventional fossil diesel fuel relatively inexpensively. However, the quality of unprocessed plant-based oils would be inadequate in terms of shelf life and winter performance, which is why they are chemically converted to technically superior substances. In many regions of the world, including in Germany, large-scale plants have been built for this purpose in the meantime. The proven process of transesterification of fatty acid glycerides in an alkaline medium is used to produce biodiesel. The oils used are compounds of plant-based fatty acids with the trivalent alcohol glycerol. These fatty acid esters are also called triglycerides. Biodiesel is produced through the transesterification of triglycerides to fatty acid methyl esters (FAME). In this reaction, the glycerol molecules are each replaced with three methanol molecules. One triglyceride and three methanol molecules react to form one molecule of glycerol and three molecules of fatty acid methyl ester. Glycerol is formed as a by-product of transesterification.
Theoretically, the amount of CO_2 released when biodiesel is burned is similar to that absorbed when the oil plants grow back. However, in reality, so much climate-damaging N_2O is released due to nitrogen-based fertilization of the plants that the climate balance of biodiesel is negative.

Example: Biogas from corn

Biogas is generally understood as mainly a mixture of methane and carbon dioxide that is produced in special biogas plants. However, equivalent gases formed as by-products – like landfill gas in landfills or sewage gas in sewage plants – are sometimes also included under this term. In

chemical terms, biogas is identical to digester gas, which is produced during anaerobic (oxygen-free) fermentation of organic material. Although other gases (such as hydrogen) may have biological origins, they are not designated as biogas.
The valuable part that is used to generate energy is primarily the methane. In addition, depending on the starting conditions, biogas contains small amounts of steam, hydrogen sulfide, ammonia, hydrogen (H_2), nitrogen (dinitrogen N_2), and traces of short-chain fatty acids and alcohols. Thanks to the compensation guaranteed by law in Germany, biogas has so far been used there mainly as fuel for small block-unit heating power plants to generate electric power and for heating purposes. In principle, purified biogas can also be fed into the natural gas network.

Biogas – from what?
Organic substances containing carbohydrates and cellulose, like manure, slurry, straw, and grains such as corn and wheat, are broken down in the absence of air (anaerobically) into methane by particular bacteria. Biogas generated in this manner can be used directly on-site with diesel engines or gas turbines to generate electrical energy. After being purified, the biogas can also be fed into the public gas network. For the process to run efficiently, concentrations, temperatures, pH values, and more must be controlled very precisely. Today there are sophisticated technologies for biogas plants of all size classes.

The following are suitable as starting substances for the technical production of biogas:

- **Fermentable waste materials containing biomass**
  like sewage sludge, organic waste, or food scraps as well as farm-produced fertilizers (slurry, manure)
- **Previously unused plants or parts of plants**
  such as catch crops, grass clippings, or a mixture of clover and grass in organic farming
- **Systematically cultivated energy crops**
  such as corn, which is predominantly used around the world. Millet and rice are also sometimes used in Asia.

Is biogas an environmentally and climate-friendly alternative?

Advantages of biogas

- Proven technology
  The generation of biogas is a proven technology that has been used for many decades, such as in the generation and utilization of digester gas in nearly all large sewage plants.
- Ideal waste recycling
  Biogas is environmentally and climate friendly if it is obtained exclusively from organic waste like slurry or excess green waste from grass and catch crops; it is contained in absolutely leakproof systems; and the fermentation residues are not spread in concentrated form.
- Available around the clock
  Unlike the wind and sun, electricity can be generated from biogas around the clock. This continuity can make a significant contribution to the stability of the power supply grid.

The construction of large, high-capacity biogas plants is generally not worthwhile for the gasification of pure waste materials. Slurry, for example, supplies only approximately 10 percent of the gas yield compared to corn. That's why over 90 percent of all biogas plants in Germany operate with corn as the main component of the biomass to be fermented. However, using corn for this purpose entails the following problems.

Disadvantages of biogas (from corn)

- Development of greenhouse gases during the intermediate storage of corn:
  Since the agricultural biogas plants operated with corn have to keep running also outside of the harvest season, the harvested corn is normally stockpiled. During the storage period, which sometimes lasts for months, the corn begins to ferment and releases the greenhouse gases CO_2 and CH_4.
- Impact on the climate due to nitrogen-based fertilization of corn:
  The nitrogen-based fertilization necessary for corn produces so much N_2O (310 times more potent as a greenhouse gas than CO_2) that the biogas is no longer climate neutral.
- Pollution of the environment due to pesticides:
  Corn is very vulnerable to pests and diseases, which is why corn cultivation causes pollution through herbicides, pesticides, and soil erosion.
- Problematic intermediate storage of the fermentation residues:
  The fermentation residues must be stored temporarily before being disposed of. These storage facilities are usually inadequately secured for financial reasons. Consequently, according to information from the Bavarian State Research Center for Agriculture, for example, leaks occurred at 657 of 2,360 total biogas plants over the past ten years, resulting in the pollution of nearby streams and the groundwater (as of the end of 2014).
- Escape of the greenhouse gas CH_4:
  Many biogas plants are not constructed to be fully leakproof for financial reasons and therefore always release some CH_4, which is 21 times more potent as a greenhouse gas than CO_2.
- Water and air pollution when the fermentation residues are spread:
  Fermentation residues are usually disposed of by spreading them on fields. However, this normally results in overfertilization. The groundwater is polluted by nitrate and the atmosphere by the greenhouse gas N_2O, which is 310 times more potent as a greenhouse gas than CO_2.
- Biogas from corn is energetically inefficient:
  The energy yield of a photovoltaic field measuring one hectare is ten times greater than a corn field of the same size.
- Biogas is generally uneconomical:
  Depending on the size of the plant, the biomass used, and the required gas purity, biogas generation cost 12.0 to 54.0 eurocents/kWh in Germany in 2015. That's two to four times higher than electricity generated from photovoltaic and wind power plants. This cost ratio also applies to Central Europe. In sunny and windy regions of the world, the prospects for biogas may be even more unfavorable if the biogas is not produced exclusively from waste materials. Unlike for photovoltaics and wind, however, for biogas there is very little potential for reducing the costs.