Extract from the series of the funding programme „Biomass energy use“

Summary of

# Milestones 2030

## Elements and milestones for the development of a stable and sustainable bioenergy strategy

Biomass
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Series of the funding programme
„Biomass energy use“
**VOLUME 18**

Summary of the report

# Meilensteine 2030

Elemente und Meilensteine für die Entwicklung einer tragfähigen, nachhaltigen Bioenergiestrategie
(Thrän et al. 2015)

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# Index

This publication is the English version of the summary of the German report „Meilensteine 2030“ (Thrän et al. 2015) which is published in the series of the funding programme “Biomass energy use”. The report describes elements and milestones for the development of a stable and sustainable bioenergy strategy.

# 1 Aim and approach

The future German energy system shall widely be based on renewable energy. In such a system, bioenergy has to fill the gaps that cannot be filled by other sources– this view has dominated the discussion in the beginning 21st century (Barzantny et al. 2009; Kirchner & Matthes 2009; German Advisory Council of the Environment [Sachverständigenrat für Umweltfragen] 2011; Schlesinger et al. 2010, 2011).
There are strong arguments for the use of bioenergy as fuel for transport and aviation or for a flexible supply of electric power, while heat can also be supplied by other forms of renewable energy. However, although biomass is a renewable source, its availability at a certain point of time is limited, especially when sustainability criteria are taken into account. Simultaneously, it is expected that the demand for biomass for food and feed production as well as for material use will continue to rise in the future. Thus, a prioritization of potential areas of application is needed (BMVBS 2010; Thrän et al. 2011; coalition agreement [Koalitionsvertrag] 2013; Majer et al. 2013).
It is commonly agreed on that the use of bioenergy has to be in line with the goals of a sustainable development. In particular, food security ranks higher than the use of biomass for energetic uses. It is further agreed on that the use of bioenergy has to be adjusted to the changing needs of the rest of the energy system and that bioenergy contribution can only be substantial if the conversion technologies improve continuously through research and development.
In the light of the manifold developments of the other regenerative, non-biogenic technologies, it seems reasonable to favour bioenergy strategies with low path dependencies, i.e. technologies that show up both in a fuel world and a flexible power and heat world.

**Research questions.** In the light of the topics mentioned above, a deeper knowledge of bioenergy technology potentials and of possible consequences of the use of such potentials is needed for the development of a stable and sustainable bioenergy strategy. To gain this knowledge, selected scenarios were created and possible technology developments for Germany until 2050 were modelled in the project “Elements and milestones for the development of a stable and sustainable bioenergy strategy – Milestones 2030”[1]. The scenarios were designed to answer the following questions:

(i) which technology options will gain relevance in the future,

(ii) which consequences does a modified use of bioenergy in Germany have on global markets

(iii) which environmental, infrastructural and social consequences are accompanied with different strategies and which actions have to be implemented until 2030 to realize the wanted supply options until 2050.

1 For more information on the project „Milestones 2030“ and the final report visit the homepage of the project: https://www.energetische-biomassenutzung.de/de/meilensteine-2030.html



**General framework.** The main scenario assumptions are:

(i) a transition in Germany towards a highly efficient energy supply based on renewable sources in 2050 (Nitsch 2008; BMU 2009; Schlesinger et al. 2010; Nitsch et al. 2010, 2012)

(ii) a global development towards an energy supply increasingly based on wood-based biofuels in 2050 (IEA 2014)

(iii) assumptions on economic development (USDA ERS 2013), population growth (United Nations 2013), technological development and on price projections for fossil fuels (European Commission 2013) as drivers of the whole economy over time and

(iv) a continuous advancement of standards for environmental protection in Germany and the EU (e.g. maximum permissible values for emissions, sustainability standards for fuels, conventions on biodiversity) and the existence of a functioning CO2 emission trading system with rising costs for CO2 emissions (European Commission 2013).

Further assumptions were made regarding global biomass potentials. Those are usually flawed and different studies give different estimates (Thrän et al. 2010, 2013). Current estimates range – under consideration of competition for land, water availability and climate change with impacts on agricultural yields – from 100 to 300 EJ global primary energy from biomass in 2050, whereof 50 EJ are already used today (Chum et al. 2011).

**Scenario setting.** For the future national bioenergy supply a total primary energy demand for biomass for energetic use of 1 550 PJ in 2050 is assumed by (Nitsch et al. 2012). A similar value was derived by calculating the theoretical share of the globally available biomass potential for Germany based on an equal per capita basis. Thus, in this study the limit for the maximal available primary energy from biomass was set to 1 550 PJ. However, no specific feedstock supply was assumed, i.e. all technologies could potentially use the full abovementioned potential. The intended use (CHP, biofuel) varies in the different scenarios. A selection of conversion pathways that have the potential for a significant contribution in the German energy system (see Table 1) and that have a potential long term relevance as well as potential for innovation was identified. As coal fired power stations will become less important on the longer run, co-firing of biomass is regarded as an option with only limited time horizon and is thus not explicitly modelled.
The increasing use of biogenic waste and residues for electricity generation was assumed to be supported by political incentives. The provision of heat without CHP was assumed to decline over time with the fuels used becoming available for other uses (CHP or fuels). The development of these plants (see Table 1) was therefore not modelled explicitly in a myopic least-cost bioenergy simulation model with endogenous learning (BENSIM) but integrated based on expert assumptions.
For the other technology options the potential global feedstock supply was analysed in more detail for transportable feed stocks with high energy density (vegetable oil, grains, wood). The electricity generation was assumed to be more flexible and demand oriented. Power generating technologies were assumed to operate with 5 000 full load hours per year. An excursus on alternative options such as power-to-gas and other storage systems is given. Infrastructural costs are considered for liquid and gaseous biofuels which are higher for gaseous biofuels.

Within the more sustainable scenarios it is presumed that an active land policy is implemented globally which avoids expansion of agricultural land into sensitive areas like primary forests or peat lands.
In sum, four scenarios (Fuel-BAU, Fuel-S, CHP-BAU and CHP-S) are analysed that represent extreme developments both in terms of energy supply and sustainability (see Figure 1). For the calculation of the scenarios the models MAGNET, LandSHIFT and BENSIM are used together with further modules for impact assessment. The models were coupled partly in a new way especially for the project.

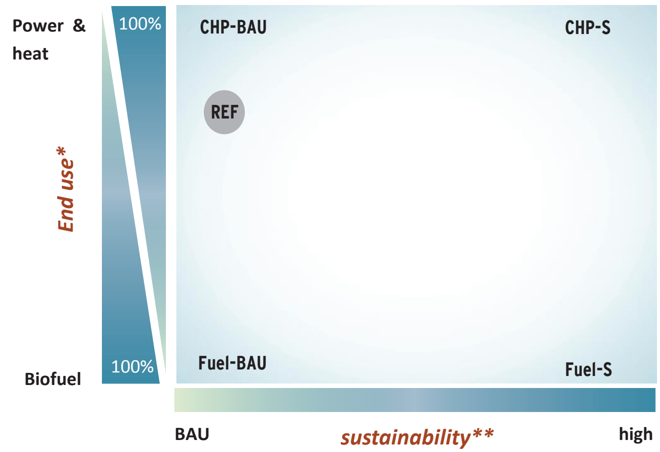
Table 1: 20 Conversion pathways selected within the project „Milestones 2030“

| | Combustion | Anaerobic digestion | Fermentation | (Trans-) esterification | Hydro-generation | Gasification |
|---|---|---|---|---|---|---|
| Electricity / Heat (CHP) | CHP (ORC) | biogas plant | – | | | small gasification (CHP) |
| | CHP (steam turbine) | biomethane plant | | | | |
| | vegetable oil CHP | small manure plant* | | | | gasification (CHP, ORC) |
| | | biowaste* | | | | |
| Biofuels | – | biomethane | ethanol (sugar beet) | FAME (rapeseed) | HVO (rapeseed) | Bio-SNG |
| | | | ethanol (wheat) | | | BtL (FT-fuels) |
| | | | ethanol (straw) | | | |
| Heat | single room heater (wood logs)* | – | | | | |
| | wood pellet boiler* | | | | | |
| | heating plant (wood chips)* | | | | | |

Abbreviations: ORC: organic rankine cycle; CHP: combined heat and power; Bio-SNG: Bio synthetic natural gas; BtL: biomass to liquid; HVO: Hydrogenated Vegetable Oils; FAME: biodiesel; FT: Fischer–Tropsch
* future energy supply is based on expert assumptions within the project

**Quality of the results.** For modelling, a variety of parameters was set based on existing studies and expert opinions, each being potentially subject to uncertainties. This is taken into account for the interpretation of the scenario results. Apart from that, the debate about the transformation of the energy system in general and bioenergy in particular has changed a lot during the last five years. The basic expectations that built the basis for this research project are not the main part of the ongoing debate any more. This underlines the need for robust options and their development
The scenario results show potential developments of economically viable technology developments within the assumed framework. The scenario assumptions are extreme assumptions. Thus, the results have to be discussed mainly relative to each other. They are a necessary tool to derive conclusions (see 3) and policy recommendations (see 4) but are no policy recommendations on their own.






* The available biomass was used up to 100 % either for the production of biofuels or for combined heat and power.
** Sustainability criteria and environmental constraints were set either low (business as usual BAU) or high (S)

Figure 1: The 4 scenarios (CHP-BAU, CHP-S, Fuel-BAU, Fuel-S) in the „Milestones 2030“ project

# 2 Results

## 2.1 Technology development

**Technology potential.** The potential for a specific technology to enter the market is derived from the levelized costs of production of the different technology options. The costs are modelled in BENSIM and are set by the development of feedstock costs, revenues for by-products as well as by learning rates. The development of the machine park towards a purposive biomass use is calculated by an annual construction and dismounting of facilities.

**Promising pathways.** Bioenergy supply from waste is expandable but limited in scope. In the BAU scenarios, oil seed based energy carriers are the least-cost option (under consideration of the modelled commodity price developments, see feedstock results), followed by biogas / biomethane. Stronger sustainability criteria flip this order. This holds true for both the CHP and the fuels scenarios, i.e., the feedstocks are relevant for both sectors. Pathways based on ligneous crops become preferable only on the long run and only under high sustainability criteria.

The picture changes if:

- certain energy carriers are prohibited due to future sustainability criteria (e.g. biodiesel from oil seeds) or
- energy carriers show qualities that are necessary for sectors where other alternatives are not at hand, and therefore are heavily pushed (e.g. bio kerosene as aviation fuel).

**Factors of influence.** The following additional factors of influence were identified through sensitivity analysis:

- If the price increases of ligneous feedstocks stay significantly under those for non-ligneous crops in the next decades, gasification based energy carriers become competitive. However, not primarily FT-fuels (BtL), but Bio-SNG (assuming a corresponding demand).
- If the power sector increasingly requires a flexible power supply, biogas and oil seed based technologies gain further advantage, due to lower investments costs.
- If the revenues from by-products increase, oil seed based energy carriers and CHP-options with higher heat output are favoured.
- $CO_2$-prices have only a small effect, as the emissions are only marginally different between the pathways modelled in this study.

**Further important factors to derive milestones.** The heat sector has not been in the focus in this study, but we expect wood-based combustion technologies to have cost advantages here. Bioethanol from sugar cane has not been included in the competition, but could have cost advantages as an import option. Co-firing of wood in coal power plants has also not been modelled, although market entry may be expected at prices for $CO_2$-certificates of above 30 Euro/t (Vogel et al. 2011). All three conversion pathways could however potentially dominate the energy sector under certain conditions and are therefore mentioned in the discussion.

## 2.2 Feedstocks

**Global and national agricultural commodity markets.** The MAGNET model calculates possible developments of quantities and prices for agricultural products taking the whole economy into account. The results show that agricultural markets are and remain dominated by the rising global demand for food and feed. However, some influence of bioenergy demand on the development can be seen for particular commodities such as oil seeds. German biodiesel demand induces imports of vegetable oils. If this demand decreases, imports of vegetable oils diminish rather than rise and the production of oil seeds in Germany rises much lower over time compared to a scenario with a high demand for biodiesel. Strongly rising prices for land indicate that land becomes a limiting factor in agricultural production. Agricultural prices rise especially in the sustainability scenarios, as there is less land available for production. The land restrictions and rising prices stimulate technological development, leading to higher yields and an intensification of production on the remaining area.
Sensitivity analyses showed that a variation of the future GDP of +10 % has a much higher influence on the results than a variation of the demand for biofuels of +20 %. While the former does influence prices more strongly than production, the latter almost only influences production.

**Wood.** The price development of wood cannot be calculated well with MAGNET. Thus, wood price development was based on expert opinions and it was supposed that wood prices will develop similar to wheat prices. Moreover, the area needed for the plantation of short rotation coppice to meet the demand for woody biomass from international fuel scenarios has been taken into account. The different ways to calculate agricultural and forestry price developments is a source for severe uncertainties, but the approach allowed us to take both sectors into account. The effect of an increasing material use of wood has been estimated and no substantial changes in the availability of wood for energetic use were observed, as an increasing material use results mainly in a prolonged cascade chain.

**Further important factors to derive milestones.** The model results show that under the assumptions made here, technologies using wood as feedstock for the production of CHP or fuels are not competitive. This brings up the question how the widely anticipated market entry for wood based fuels shall be achieved.

### 2.3 Land demand

**Global land demand.** The model results from MAGNET are allocated to arable land areas through the LandSHIFT model, considering all agricultural commodities (food, feed, fibre, material and energetic use). Land demand for 2nd generation fuels from switch grass and short rotation coppice was fed into the LandSHIFT model based on external data on yields, conversion efficiencies and on disaggregated projections for global production (ILNAS 2014). The global demand for arable land increases in all scenarios, from 1.4 billion ha today to 2.4 billion ha in 2050 in the sustainability scenarios and to 2.8 billion ha in the BAU scenarios. Increasing demands for food and feed are the main driving forces. No significant differences in global developments can be found between the fuel and CHP scenarios, as global parameters were kept identical and changes in biomass use (fuel or CHP) were only made for Germany. In the BAU-scenarios, eastern Brazil (sugar cane and beet), south western Russia (wheat) and Southeast Asia (oil seeds) experience the largest expansions of arable land. In the sustainability scenarios, a lower demand for arable land in combination with effective protection mechanisms (for primary forest and conservation areas among others) lead to less loss of natural vegetation. While almost 300 million ha of the 4.32 billion ha of forest in 2007 are cleared by deforestation until 2050 in the BAU scenarios, this trend is virtually stopped in the sustainability scenarios. At the same time, a shift in land use towards other, unprotected areas can be seen, reducing the global area of grassland and shrub land ecosystems from 5.49 billion km² in 2007 to 4.65 billion km² and 4.72 billion km² in the sustainability scenarios and the BAU scenarios, respectively, until 2050.

**National land demand.** In the fuel scenarios, a rise in land demand for agricultural production in Germany is observed from 9.35 million ha in 2007 to 11.46 million ha (BAU) and 10.04 million ha (sustainability) in 2050. In the CHP scenarios a rise to 11.72 million ha (BAU) and 11.35 million ha (sustainability) occurs. The use of pasture land develops in the opposite direction from 6.96 million ha in 2007 to 4.91 million ha (BAU) and 6.34 million ha (sustainability) in the fuel scenarios and to 4.65 million ha (BAU) and 5.02 million ha (sustainability) in the CHP scenarios in 2050. Due to legal regulations, in the sustainability scenarios no additional pasture land is converted into cropland after 2020.
Until 2030 there is a stronger rise in cropland area in the CHP scenarios compared to fuel scenarios. After 2030, less land is needed for the production of bioenergy crops in the CHP scenarios, setting free land for grazing management (as from there on no increase in production capacities but only a restructuring of the machine park is assumed). In the fuel BAU scenario an expansion of cropland is seen (due to the higher priority in LandSHIFT) at the expense of pasture land until 2050, while only 0.06 million ha of areas with near-natural vegetation (grassland, shrub land) are converted into cropland until 2030 with no further change until 2050. Due to legal regulations, no deforestation occurs.
It should always kept in mind that the results mentioned above stem from extreme scenario calculations. Due to the high preference for conversion technologies based on agricultural commodities, the calculated demand for land is much higher compared to the demand in other energy scenarios that were used as a starting point. For example, the total amount of directly and indirectly occupied arable land for biofuels in Germany and abroad equals the total national agricultural land in the BAU-scenarios. This would lead to a massively larger footprint with regard to area needed for food, feed and bioenergy. In the sustainability scenarios the demand for land is much lower (about four million ha) compared to BAU scenarios due to higher efficiencies of biogas / biomethane.
The results obtained from the extreme scenarios are evaluated in terms of their environmental impacts, food security and regional infrastructure.

### 2.4 Cumulative environmental effects

**Evaluation method.** The amount of end energy supply as calculated by BENSIM for the four scenarios is the basis for the assessment of the environmental impacts. This amount of end energy supply is presented together with the environmental impacts of the remaining fossil energy carriers for each year. It was assumed that biomass in the energy system replaces only fossil energy carriers but no other renewable ones. The development of latter was taken from (Nitsch et al. 2012). Here, two different approaches are possible to calculate the amount of total energy taken into account for the assessment and thus the amount of fossil energy. For the comparative system assessment, the effective energy was chosen that will be supplied by fossil or biogenous energy carriers in Germany in 2050 after (Nitsch et al. 2012). However, for the comparative assessment of technologies and the assessment of greenhouse gas (GHG) emissions from land use changes, a unitary amount of final energy is defined for all scenarios and all time points, namely the maximum of the available bioenergy for each sector and year. The amount of fossil energy is then the difference between the maximum of available bioenergy and the amount of bioenergy used in a particular year and scenario. This definition will be referred to as “product basket”). Through this approach, the results between the different scenarios become comparable.
In addition to the amount of end energy, also the BENSIM results for the machine park composition (number of facilities and installed capacity) and the annual production are combined with life-cycle assessments, which were calculated according to the international standards ISO 14040/14044 (German Institute for Standardization [Deutsches Institut für Normung e.V.] 2006) for the single technology options. This then results in cumulative environmental impacts (energy demand, GHG effect, acidification, nutrient input and particulate matter emissions) for the four scenarios. In the case of GHG emissions, emissions from carbon stock changes due to land use change are also calculated based on the LandSHIFT results.

**Comparison of technologies.** Based on the product basket approach the results show that energy demand declines over the years in all scenarios. This is mainly due to the declining use of fossil energy carriers, which also leads to a drop in GHG emissions. However, additional GHG emissions occur due to land use change. Especially when indirect effects are taken into account (which was only possible für the fuel scenarios in this study), GHG-Emissions may decline only slightly between 2025 and 2040 and may even stay constant despite the use of bioenergy if conditions are unfavourable. The decline in GHG emissions is highest in the sustainable CHP scenario. However, regarding acidification, the decline is higher in the other three scenarios. This means that there is a conflict of aims. The nutrient impact shows no falling tendencies but rather a slight increase in some scenarios. Thus, from a scientific and objective point of view, none of the scenarios can be clearly preferred and a rating cannot be done until additional subjective criteria are considered. If, for example, a reduction in GHG emissions shall be the major goal, then the sustainable CHP scenario performs best.

**Land use effects.** In the LandSHIFT model all land use changes are calculated that result from the future demand for food and feed, material use and bioenergy. These changes have an influence on the cumulative GHG emissions and affect biodiversity and soil quality as well (see 2.5). GHG emissions from land use changes result from changes in the carbon inventory of the soil. Their calculation is complex, especially due to indirect effects, and they have a strong impact onto the overall GHG balance of bioenergy use. Thus, within the project the effect of land use change related emissions on the scenario results has been estimated with two different approaches: on the one hand, additional GHG emissions were calculated based on the LandSHIFT modelling results (LUC approach). On the other hand, for the fuel scenarios emissions due to indirect land use change (iLUC) were taken into account based on the iLUC factors currently debated in the European Union (12 - 55 g $CO_2$ / MJ biofuel), which results in significantly higher land use related emissions. The calculated range of results underlines the need for further research in the area of land use change assessment. The results show that GHG emissions from land use change can sometimes be as high as or even higher than the sum of the emissions from cultivation, processing and use of the bioenergy carrier. GHG emissions from land use change are mainly emitted outside the European Union, in the BAU scenarios caused by a direct import of biomass, in the sustainable scenarios due to indirect effects of an increased cultivation of energy crops in Germany (see 2.3).

**Further important factors to derive milestones.** As energy carriers based on vegetable oil seem to be promising options especially in the BAU scenarios, their future conformity with the European renewable energy directive 2009/28/EC (RED) in terms of GHG emissions is an important and currently uncertain point. Therefore we also calculated how environmental effects change when the use of oilseeds and wheat is prohibited in the BAU scenarios. The prohibition results in a shift towards biomethane and biogas production, respectively. The environmental effects differ only slightly from the results of the BAU scenarios. While GHG emissions are virtually the same in 2050, a slight rise in acidification and a reduction in particular mater emissions can be observed.

### 2.5 Impacts on biodiversity and soil quality

**Indicators.** To assess the risks for biodiversity and soil quality, cultivation patterns of the years 2030 and 2050 were compared with the cultivation pattern in 2007. The use of areas that have been arable land or fallow land in 2007 has been classified as „low risk“ for biodiversity. For the use of areas that have been unused grass land, forests, primary forests, wet land or peatland, a „high risk“ for biodiversity is assumed. The risks that come along with the use of already used grass land are to be discussed for each country individually. To assess the impact of crop cultivation on soil, the soil suitability map from the International Institute of Advances System Analysis (IIASA) has been used. IIASA categories 1 to 4 were defined as soils that are well suited or agricultural use. IIASA categories 5 to 6 were defined to be less well suited and IIASA categories 7 and 8 are only poorly suited for agricultural use. For the assessment it is assumed that a poor suitability is usually accompanied with a high risk for soil quality.



**Global biodiversity risks.** The analysis shows that the global arable land area used for commodities that can in principal be used for bioenergy production is approx. 1.35 billion ha in the BAU scenarios in 2030. Of these, 80 % are areas with a low risk for biodiversity. The areas taken into cultivation after 2030 are mainly former pasture lands. Areas with middle and high risk for biodiversity are hardly taken into cultivation. Until 2050 the global area for the production of the specified commodities increases to 1.85 billion ha. During this period, the use of areas with a low risk for biodiversity declines while the use of grass land areas and to a smaller percentage also forest (with a medium risk for biodiversity) areas rises. Areas with a high risk are no taken into cultivation until 2050.
In the sustainability scenarios the global arable land area used for commodities that can in principal be used for bioenergy production is reduced to approx. 1.1 billion ha in 2030 and to approx. 1.65 billion ha in 2050. Due to the strict exclusion of sensible areas, from 2020 on, new cultivated areas are established mainly on former pasture land. Here it was taken into account that every country had to establish protected areas on at least 17 % of the total land area (including pasture land) from 2025 on. This means that at least a certain area of grass land with high biodiversity is not converted into arable land. In the sustainability scenarios intensification in the cultivation of the remaining arable land is observed. It is assumed that the impact on biodiversity of such intensification is lower than a conversion of formerly unused land. In the fuel BAU scenario in the years 2030 and 2050 as well as in the sustainable fuel scenario in the year 2030 feedstocks for bioenergy production are produced in Germany on an area of less than two million ha. In addition to this, 10 to 12 million ha are needed outside of Germany. Thus, severe land use changes in foreign countries are to be expected which will mainly affect unused pasture land and to a minor extend also used pasture land and forest.

**National biodiversity risks.** Biomass for energetic use is cultivated in Germany mainly on areas with a low risk for biodiversity. Nevertheless, a conversion of pasture into arable land with corresponding risks for biodiversity is observed as well. In the sustainable fuel scenario, almost only biomethane from cultivated crops is used in 2050 besides a minor amount of ethanol from cereal straw. For this, approx. four million ha with mainly low risk on biodiversity are used, while a conversion of peatland into arable land cannot be ruled out. It should also be noted that such an occupation of arable land leads towards a reduced production of other crops, i.e. the crops are displaced or partly substituted. We estimate these indirect effects for the fuel scenarios assuming that wheat production is displaced by biomass production for energetic use. In such a case, a supply with biomethane requires less land than a vegetable oil dominated supply.

**Soil quality.** Additionally needed land for bioenergy production is implemented to 56 % in areas with soils that are well suited or agricultural use and to 27 % in areas with soils of an intermediate suitability. 17 % of the areas used were only poorly suited. This means that a rising area demand results generally in a rising risk for soil quality. No assessment of soil quality risks was possible for areas used for cultivation of energy crops for biogas production in Germany.

### 2.6 Food security

At least 2.300 kcal per person per day are required in order to ensure healthy nutrition. In the model concerning food security, a minimum of 10 % animal source foods and 90 % plant-derived foods was taken as a basis. On the assumption that food security must always take priority, the utilisation of agricultural land for energetic purposes, among other things, depends on the extent to which biomass is needed to guarantee secure and healthy nutrition throughout the world. The modelling of food security has shown that in 2010 the number of calories that are lacking in order to meet the minimum requirements for healthy nutrition amount to less than 40 % of the bioenergy demands of the top 20 % of the richest countries. Owing to the generally positive development towards higher per capita income in poor countries, this percentage is set to drop to 7 % by the year 2050. The results of this theoretical approach are surprising in that in purely arithmetical terms – without considering access to and distribution of food – rich countries would, in the long term, theoretically only need to reduce their bioenergy demands by about 7 % in order to meet the calorie requirements of countries where hunger is prevalent. However, when evaluating these findings account must also be taken of the fact that the availability of land also involves other considerations apart from bioenergy demand, e.g. changes in eating habits with regard to the consumption of meat and dairy products may make land and / or cultivated biomass available for other uses or demands.

### 2.7 Regional infrastructure

In regional terms it is possible to integrate the scenario results into the regional situation, particularly because small-scale technologies were the results of the modelling. However, there were clear differences between the scenarios regarding energy consumption:

- In the combined heat and power (CHP) scenarios the large number of small units enables a good spatial distribution of cogeneration options. On the energy demand side, the existing CHP system will be able to absorb the amounts of energy calculated from a regional point of view. The only differences between the BAU and the sustainability scenario for the supply of regional heating in district heating networks relate to the substrate mix and the biomass supply chain. Existing and future district heating networks, on the other hand, can expect to maintain sufficient supplies of biogenic heating.
- In the fuel scenarios, however, the cogeneration option is absent. The German government's renewable heating targets would then have to be achieved by using cold district heating systems (solar thermal energy) or fossil energy sources. Local and district heating networks would also face challenges, since at present they are focusing primarily on bioenergy. Heating networks are sometimes amortised over a period of 25 years. Since a large proportion of the biogenic CHP systems will be obsolete by the year 2030, heating networks built today would be lock-in investments. The electricity output that is lacking in the fuel scenario would also have effects on the ability to use biogenic electricity as a flexible factor in the power supply system in order to balance out the fluctuating renewable energy sources. This may perhaps lead to additional costs for the electricity system. Were the fuel scenarios to occur, the impact of the dismantling of biogenic CHP systems on network stability would also have to be taken into account. From the point of view of regional integration, preserving certain proportions of bioenergy for the provision of electrical power and heating is therefore to be regarded as advantageous.

Since there is no significant demand for wood fuels in any of the four scenarios, the question arises as to whether and to what extent it would be useful to counteract the existing patterns of use on the electricity and heating market. The effort and expense involved in establishing new marketing opportunities for wood would be considerable and these would only be feasible in the very long term (development of new markets for forest owners, diversification of the wood fuel industry etc.). In addition, different ways need to be sought for presenting potential heat and energy savings (e.g. funding programmes for insulation, encouragement of the utilisation of industrial waste heat).

### 2.8 International energy markets and feedback effects

**Import potentials for Germany.** Since there is increasing demand for bioenergy sources not only for modern purposes such as fuels and electricity generation, but also for the "traditional" use of biomass for cooking and heating, particularly in developing countries, the sustainable sources of bioenergy that may be available for international trade are to be found primarily in Brazil, Canada, Russia and the USA, whereas countries such as China and South Africa may become net importers (IINAS and CENBIO 2014).

As regards the anticipated import potentials for Germany, it must be taken into account that in a global climate protection scenario where the target is to limit the global warming to 2 °C with a high level of sustainability, countries such as Canada, Russia and the USA will use bioenergy for the endogenous substitution of fossil fuels, so that their future export potentials will only be met if export is economically more attractive than domestic use. At the same time, it must be borne in mind that in countries like Brazil, Canada, Russia and the USA, and also in countries in East and West Africa, there are considerable potentials for other renewables and for improving energy efficiency, the use of which would – depending on each particular scenario – lead to export options for bioenergy while still meeting global climate protection targets.

From today's perspective, the global trade in bioenergy (solid particularly in the form of pellets, liquid in the form of fuels) will therefore be limited to a few countries, whose export potential will decline in parallel with increased climate protection efforts.

Taking these and other restrictions into account, the import proportion for Germany that can be derived from these considerations about the general availability of biomass will amount to approximately 100 PJ of solid bioenergy sources and 30 PJ of liquid bioenergy sources by 2030, rising to about 240 PJ of solid and 60 PJ of liquid bioenergy sources by 2050. To this can be added approx. 10 PJ of biomethane from non-EU states in Central and Eastern Europe by 2030, increasing to approx. 100 PJ by 2050.

**Sustainability.** A fundamental prerequisite for the future worldwide availability of biomass is the sustainability of its supply, which is currently being analysed, operationalised and implemented at various levels. This normative requirement is endorsed by numerous studies, cf. for example (Cornelissen et al. 2012; Dauber et al. 2012; GEA 2012; IEA 2012, 2012; IEA/OECD 2012). It can therefore be assumed that for the international trading of bioenergy sources in the medium term (up to 2030) binding sustainability standards will be established regarding at least the aspects of GHG balance (reduction in comparison with fossil fuels), biodiversity protection and social issues (occupational safety, land rights). Relevant voluntary schemes already exist in the form of the GBEP indicators (Global Bioenergy Partnership, GBEP 2011) and the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests (Committee on World Food Security, CFS 2012), and globally binding standards have already been drawn up for biofuels (Franke et al. 2013).

Owing to the increasing use of biomass as a source of raw materials and in "coupled" systems such as biorefineries, it will be necessary to establish global sustainability standards for the use of biomass as raw materials and as an energy source in order to avoid negative displacement effects (Fritsche & Iriarte 2014).

**Security of supply.** Security of supply is a further important issue when evaluating energy systems. Regarding bioenergy, the GBEP has presented a list of 24 indicators for evaluating the sustainability of national bioenergy policies. Among those, GBEP indicator 22 (Energy Diversity) is a comparatively simple method for approximately quantifying the aspect "security of supply" (GBEP 2011). It is done using the so-called Herfindahl Index, which is determined by establishing the share of energy sources used in meeting primary energy demand. On the basis of data from BENSIM and the results of ecological audits, the data concerning biogenic final energy supply have been integrated into the overall primary energy balance for Germany and then the Herfindahl Index calculated. The BAU and sustainability scenarios for fuels and CHP respectively, reveal very different effects on the fossil energy mix and hence on security of supply. The fuels scenarios require much smaller amounts of mineral oil (but biomass imports), whereas in the CHP scenarios there is less need for coal and natural gas but a greater need for mineral oil.

The main differences in energy diversity are between the BAU and the sustainability scenarios (around 3 percentage points in each case), whereas the differences between the sustainability scenarios for fuels and CHP are extremely small. In comparison with 2010, the scenarios for 2030 can improve energy diversity by about 7 % (BAU) or 10 % (sustainability scenarios). Thus, bioenergy has significant potential to improve security of supply in Germany.

### 2.9 The effects over time

Using the modelling approaches selected, different trends along the supply chain become evident (see Table 2).

Thus, in these scenarios it is evident that the technologies and effects that are widespread today will remain important up to 2030, whereas after 2030 the scenarios increasingly differ. The different trends give rise to different fields of action in the respective time periods. In addition, it should be emphasised that in the extreme scenarios studied here, the potential of wood is not used by innovative technologies but, instead, a comparatively high demand for arable land has been modelled. This shows, on the one hand, that a very broad evaluation of risks is possible. On the other hand, however, it is evident that the current use of wood in heating is a very robust option and a shift towards increased energetic use of wood in the sphere of electricity / heating or fuels can only be achieved with considerable effort and expense.

To summarise, it is clearly evident that with a bioenergy policy that focuses moderately or strongly on domestic raw materials – in particular avoiding the need to implement international land use policies – potential risks can be significantly reduced (and sometimes already have been; for details on changes in bioenergy policy see 1). Hence, a future bioenergy strategy should especially focus on elements relating to the improvement of quality and not so much on the question of quickly achieving what has been calculated (Nitsch et al. 2012) as the available and sustainable potential of 1 550 PJ of biomass primary energy in Germany.



Table 2: Overview of the model results over time

| | 2010 – 2030 | 2030 – 2050 |
|---|---|---|
| Global demand for biomass | Continuously growing demand, especially for food and animal feed production | |
| Land for global biomass production | Increasing biomass production on land previously not used for agriculture, including conversion of pasture, resulting in various levels of risk for biodiversity (for all uses) | Land consumption in BAU scenario encroaching more into sensitive regions (for greenhouse gas emissions and biodiversity, esp. forests and pasture); in the Sustainability scenario to a lesser extent (and only affecting pasture) with increased intensification on the lands used |
| Use of arable land in Germany | Extent of use remaining constant but with varying international balance of trade. Increase in pasture conversion, especially in the BAU scenarios | |
| Technological developments in Germany | Bioenergy plants based on agricultural raw materials (vegetable oil, biogas) in all scenarios; no prospect of new technologies for wood use up to 2030 | Bioenergy production slowly shifts towards biogas / biomethane; wood-based gasification technologies may be ready for the market. The prospects for wood-based fuels remain limited. |
| Anticipated international demand for wood for energetic utilisation (not modelled) | A high level of global demand for wood-based solid fuels is anticipated, e.g. for use in coal-fired power stations, if prices for $CO_2$ emissions permits develop appropriately | A high level of global demand for wood-based liquid fuels is anticipated, which is not, however, evident in the national technology considerations |
| Contribution of bioenergy to energy supply in Germany | Contribution expected both for electricity / heating and for fuel in the transport sector | Increasing contribution in the transport sector, because alternatives are available for electricity / heating |
| Greenhouse gases from bioenergy used in the German energy supply | Generally decreasing, but no substantial difference between the different scenarios. Owing to changes in land use there is a risk that greenhouse gas emissions will decrease only slightly or even remain constant despite the use of bioenergy. | |
| Environmental effects of bioenergy provision in the German energy supply | Where the effects on biological diversity and soil quality are concerned, the supply of bioenergy sources from domestic agriculture is considered more manageable and less risky than international supplies of raw materials. | Since installations increasingly operate on the basis of biogas / biomethane, the raw materials are primarily supplied by German agriculture and are more manageable and less risky than international supplies of raw materials. However, in this case there is an increase in nutrient input and sometimes also in acidification and particulate air pollution. |
| Food security | Moderate risks to food security due to bioenergy | Only low risks to food security due to bioenergy. |

## 3 Conclusions

Bioenergy sources derived from agrarian raw materials remain economically advantageous in all scenarios.

The findings show that the future utilisation of biomass is shaped primarily by demand for foodstuffs and animal feed. In terms of volume and price effects, a national bioenergy strategy will not significantly influence the international agrarian raw materials markets even with high proportions of imports. This only applies, however, as long as other countries develop their bioenergy strategies within the corridor of assumed international expectations. When considered in detail, the analyses conducted using the BENSIM technology model show that with the anticipated price increases for agrarian products  it is above all vegetable oil / biodiesel followed by biogas / biomethane that are the relatively advantageous energy sources for conversion systems  in Germany. Beyond the model findings, the characteristics of the two technical systems can be described as follows:

The production of **vegetable oil and biodiesel** generally has the following characteristics:

- The raw material is largely imported.
- The conversion technology for producing and utilising vegetable oil / biodiesel is state-of-the-art with comparatively little potential for innovation.
- The conversion technology for electricity generation is already very well adapted to the flexible production of electricity.
- The yields per unit area are – except in the case of palm oil – relatively moderate, but the bioenergy source is usually produced in combination with animal feed (press cake / extraction meal) and glycerol (usually pharmaceutical glycerin), which have a price-stabilising effect and which can be an important transition technology, for example against a backdrop of glycerol-based usage pathways. The price-stabilising effect can minimize the risks posed by fluctuations in prices for raw materials.

The production of **biogas / biomethane**, on the other hand, is characterised as follows:

- Owing to its low energy density, the raw material (biogas substrate) is produced largely domestically, but since the substrate is unsuitable for transportation, the land around biogas plants has to be set aside for this purpose over the long term. International biogas and biomethane trading, e.g. via the gas network, may also become interesting over the medium term (Thrän et al. 2014).
- Conversion technology also has short-term innovation potential for “flexible electricity provision” and in the medium term for obtaining new interim products for material and energetic uses, research on which is partly still in its infancy.



- The energy yields per unit area are significantly higher, albeit at the expense of greater environmental impacts in the sphere of nutrient input and partly also with regard to acidification and particulate air pollution.
- Utilisation as fuel is subject to various hindrances and is expected to be relevant only for selected transport sectors.

A harmonised international land use policy is a prerequisite for a sustainable bioenergy policy in Germany.

For evaluating the raw materials basis, differences are evident in particular between a global sustainable land use policy and the maintenance of current requirements. The findings show that if measures to prevent changes in land use in protected areas and other sensitive environments were to be imposed from the year 2020, the effects on biological diversity and soil quality – particularly in the global context – would be much smaller. Although with domestic biomass production the risks to biological diversity and soil quality are estimated to be less severe, the indirect effects resulting from the displacement of other field crops by biogas substrates can only be roughly estimated (e.g. under the simplified assumption that only wheat is displaced) and these could be quite different in reality. If bioenergy from energy crops were to be further expanded, greenhouse gas emissions from direct and indirect changes of land use could be on the same scale as emissions arising from the cultivation, supply and use of bioenergy sources or may even exceed these and significantly influence the overall result. If changes of land use in forests, peatland and other sensitive environments were to be prevented at world level from 2020, greenhouse gas emissions would be lower after 2020 but the effect would not be visible until after 2040, since the high emissions of the earlier period (in each case written off after 20 years) would continue to have an impact for a long time.
Conversely, this means that as long as there are no international land protection standards, the utilisation of new areas should be carried out in a much more moderate way than those modelled in the extreme scenarios. Technologies based on domestic raw materials are still preferable for “soft” reasons (risks to biological diversity and soil quality, manageability). When expanding these technologies, particular attention must be paid to indirect effects which it has only been possible to estimate roughly within the context of this project. At the same time, sustainability standards for liquid bioenergy sources, which have been established over the past few years, should continue to be tested internationally and expanded as appropriate to other biomass sectors. As a first step, binding sustainability standards should also be extended to gaseous and solid bioenergy sources and definitions of good practice / sustainability requirements in forestry, and for forests with a high degree of biodiversity, should be drawn up.

Elements for a bioenergy strategy can be derived from the extreme scenarios.

The generation of heat from wood is currently the most important bioenergy source in Germany, Europe and throughout the world. The aim of the four extreme scenarios was to investigate the pathways, with the aim of developing more sophisticated technology pathways. The scenarios drawn up on the basis of price expectations clearly show that without sectoral standards, the investigated technology pathways for the use of domestic or imported wood for electricity generation or as fuel will only be able to attain (relatively modest) significance over the medium term; and then not as an input material for liquid fuels but rather in the sphere of small or medium scale gasification technologies. The generation of heat from wood-based raw materials could therefore continue to play a relevant role for a considerably longer period. The calculated scenarios are only partly compatible with the current and expected availability of raw materials (e.g. Majer et al. 2013; Mantau 2012; Thrän et al. 2011).

The following have been identified as important **elements in a bioenergy strategy**:

- For further expanding the utilisation of residual materials, there are still potentials in the agriculture and forestry sectors. Among the fuels which have so far not been ready for launching onto the market, the production of ethanol from (domestically produced) straw may become marketable in the medium term. From the point of view of environmental protection, however, this type of use is less positive in comparison with the possible generation of electricity and heat from straw (Keller et al. 2014).
- Increased demand for bioenergy from energy crops leads to direct and indirect changes in land use, which in turn results in changes in carbon stocks from which greenhouse gas emissions derive. The calculation of these effects is complex and their detailed analysis would go beyond the scope of this study. However, it has been possible to show here that – depending on the methods adopted – the overall reduction of greenhouse gas emissions through the use of bioenergy (compared with the use of fossil energy sources) can be only slight, or even completely absent, owing to changes in land use. The future bioenergy strategy will require a robust calculation and investigation of these effects – not only for bioenergy but also for other forms of utilising biomass. The monitoring of land use, changes in land use and the associated carbon balances and greenhouse gas effects is an important prerequisite – not only for bioenergy policy but also for the further development of the bioeconomy as a whole. Until this is done, the utilisation of bioenergy should be improved particularly in terms of quality, and there should only be very moderate expansion in the sphere of energy crops. This conclusion also derives from the other environmental impacts identified, such as particulate air pollution, acidification and nutrient input, which can increase through the use of bioenergy. Appropriate framework standards – ideally for the utilisation of biomass as a whole – should be introduced in order to ensure that the conversion of the energy system does not lead to an increase in negative environmental impacts. As well as attaining the climate protection goals, it should also be ensured that the targets set in the sphere of water, soil and air pollution control (e.g. EU Water Framework Directive [Directive 2000/60/EG, 2000] or the National Emissions Ceilings for Certain Atmospheric Pollutants [Directive 2001/81/EG, 2001] and the sustainable use of resources [e.g. a circular economy]) are also achieved.
- Germany should give preference to efficient domestic bioenergy production – whether in the fuels sector with biomethane or in the electricity / heating sector with biogas – over a strategy of importing sometimes less efficient biofuels, since this is associated with a lower level of risk to biodiversity and soil quality at world level. It has, however, only been possible to estimate roughly the indirect effects of the displacement of other field crops by biogas substrates, and these may turn out to be much greater in reality. This should be taken into account when developing a strategy.
- The supply of heating on the basis of wood is also a robust bioenergy option in the medium and long term. It should be gradually developed further, taking account of regional supply structures, emissions standards and user preferences. Through the launching of gasification technologies onto the market, Germany should steer the development of wood-based heating towards combined heat and power generation (small and medium-sized units).
- When $CO_2$ -prices are high, a market-driven demand for (mainly imported) wood for co-combustion in coal-fired power stations may temporarily occur (IEA-ETSAP and Irena 2013; Vogel et al. 2011). Given the higher risks associated with imported raw materials, the temporal limitations on their use (assuming that in the medium term coal-fired power stations will play a sharply declining role in electricity generation) and, on the other hand, the very high potential demand during the relevant period, the co-combustion of wood in coal-fired power stations is a matter that will soon require a clear strategy as regards the desired quantities and the proportion of imports. Sustainability standards for solid fuels can provide a framework for their use when $CO_2$-prices are high.
- Germany should develop a post-EEG (Erneuerbare-Energien-Gesetz = Renewable Energies Act) strategy for biogas and biomethane plants. This will require a detailed analysis of the existing plants as to the availability of useful heat sinks for CHP operation and infrastructural potentials for converting biogas and biomethane plants (e.g. proximity to the existing natural gas network), as well as sectoral analysis to determine the mobility sectors in which biomethane should be used in future.
- A bioenergy strategy must be closely coordinated with the agriculture sector. This includes the future status of the production and use of energy crops as well as the sectoral utilisation of vegetable oil / biodiesel / biomethane as fuels.

- Biodiesel is a low-cost, liquid bioenergy source which, however, reveals little potential for innovation. The existing production capacities should not be further increased – neither, however, should they be decreased in the near future because the production of fuel results in important ancillary products (animal feed and glycerol) and because the question of the volume and need for liquid bioenergy sources for a sustainable energy transition has not yet been settled (see next point).
- An open point remains: the targeted development of high-quality liquid bioenergy sources for selected fields of application (e.g. aircraft fuel). This should be developed on the basis of the long-term goal. Long-term support is therefore needed for BTL fuels, both through R&D measures and through market launch instruments, because in all scenarios such fuels are considerably more expensive than the alternatives. For the transport sector, however, the transition towards renewable energy sources requires that other aspects be taken into account in addition to the supply of biofuels.

As well as the conclusions primarily affecting national bioenergy policy, two further areas arise at international level:

- the implementation of ambitious sustainable land-use policies
- the monitoring of international quantity expectations for FT fuels with regard to the assumed influencing variables (e.g. investment costs, prices for raw materials, achievable greenhouse gas emissions)

On the basis of these conclusions, the four extreme scenarios which serve to present a certain range of developments and thus provide scope for interpretation, can be interpreted synoptically. Figure 2 provides a summary relating to the development of bioenergy by presenting indicative trends for Germany up to the year 2050. It is based on the modelling results (extreme scenarios) and their extensive interpretation, as well as on the developments viewed in qualitative terms and on other recent studies.

**Opening up potentials:** By 2030 the contribution of bioenergy to the energy supply, to the security of supply and the achievement of the targets for reducing greenhouse gas emissions should have been stabilised at today's level (approx. 700 PJ/a final energy consumption), thereafter perhaps increasing moderately, depending on the type and extent of future land use policies. The targeted utilisation of agricultural residual materials (such as the potential of using straw for the production of ethanol) and biogenic local waste products can be implemented particularly in the regional context or as part of a circular economy. Through further improvements in efficiency, the biomass required as primary energy input will decrease in relation to the energy output and it will be possible to ensure compliance with the potential levels that are regarded as sustainable (Nitsch et al. 2012, and estimate of potentials in this report) even if there is a moderate increase in the supply of final energy from biomass.



**Utilisation options:** The use of biomass for generating energy will change to varying extents in the different sectors. The generation of heat alone, particularly using single room combustion plants and heating networks, but also by industry, will continue to play a significant role. This is due, on the one hand, to the very moderate demand for wood for innovative technologies and the well-established regional and local raw materials supply structures and also, on the other hand, to the investments in district heating systems that have already been made. At the same time, there is also a need for change in this area, towards increasing efficiency and reduced emissions. Gasification technologies and, where relevant, other small-scale systems for combined heat and power generation can bring about the necessary innovations in the system. In addition to the involvement of decision makers at local government level, the supply of biogenic heating requires support as part of a national heating strategy.

Clear signals are necessary for the further development of the technologies and concepts for combined heat and power generation, incentives for which have been provided and projects implemented on the basis of the Renewable Energies Act (EEG). These investigations have shown that not only CHP- stations based on waste wood but also demand-actuated biogas plants can make a contribution to electricity provision. For the realisation of these options, however, there is a need for a clear "post-EEG" strategy, otherwise the range of existing installations will be significantly reduced and the potentials for contribution to the system will remain unused. Parallel to this, the partial shift from existing local biogas electricity conversion units to biomethane processing plants offers the possibility of very flexible utilisation both of the electricity supply (with mandatory use in CHP- stations or highly efficient gas and steam power stations) and of its use as fuel. Against this background, biomethane should be strategically (further) developed.

Furthermore, there is a need for a differentiated biofuels strategy – among other things because of the potential use of biomethane in the transport sector. This should also take account of stability in the supply of biofuels on the basis of agrarian raw materials in order to meet the standards of the existing regional or decentralised structures and synergies for the supply of animal feed. In the biofuels strategy for the period after 2030, the advantageousness of the fuel options should be determined, on the one hand, by stable demand for biofuels in selected fields of application (e.g. aircraft fuels, agriculture), and the potential for systems which combine the production of biofuels with material use, on the other. Such a fuels strategy would, however, certainly require lasting and reliable framework conditions in order to be implementable on the market.

In addition, from 2030 there are likely to be stronger shifts between the electricity, heating and fuels sectors as well as in relation to other renewable energies, although it is unlikely that these will fundamentally alter the relative advantageousness of the elements identified here. The option of co-combusting wood in coal-fired power stations may lead to a short-term increase in wood consumption if prices for $CO_2$-emissions certificates increase, although the present low certificate prices mean that this risk is currently thought to be only slight.

This synopsis is the source for the 10 milestones described below.

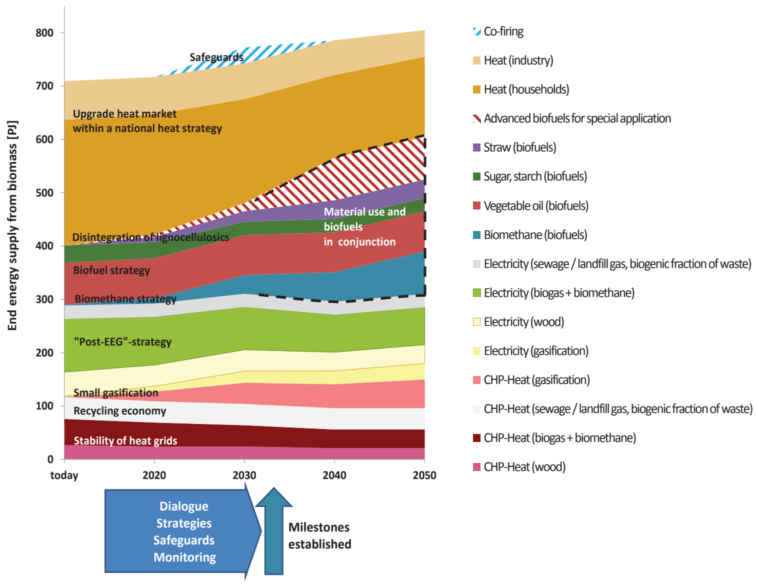



Figure 2: Indicative trends in bioenergy up to 2050 as a synthesis of the project "Milestones 2030"



## 4 Milestones 2030 – recommendations for action

The bioenergy strategy will be implemented in the various fields at different rates. Ten important milestones that must be achieved by 2030 are listed below:

**Milestone 1: Sustainable land use is essential.**

A prerequisite for the sustainable use of biomass in 2030 is the rapid definition and implementation of ambitious international goals for the protection of sensitive environments such as primary forests, peatland, wetlands, woodlands and pasture with a high level of biodiversity, e.g. as part of a global agreement on protected areas modelled after the resolutions of the Convention on Biological Diversity (CBD). At national level the effective protection of permanent pasture would appear to be appropriate. These protection efforts will alter the volume of agricultural production, will involve intensified cultivation of the land used and extend much further than its utilisation for bioenergy purposes. Germany should therefore take up the initiative at international level or further intensify existing initiatives which cover both sustainable land use and aspects of the anticipated intensification of land use. Instruments for the protection of sensitive environments which are already being implemented concerning biofuels should be considered with a view to their transferability.

**Milestone 2: Monitoring of land use, carbon inventories and greenhouse gas emissions has been established within the framework of the bioeconomy.**

In this way, the development of greenhouse gas emissions as a result of changes in land use and their effects on the desired targets in the energy system can be regularly checked and the strategy adjusted.

**Milestone 3: Development strategy for biogas / biomethane (post-EEG strategy) has been implemented.**

For the existing biogas and biomethane plants, a firm utilisation strategy has been developed on the basis of the characteristics of such plants. This must be closely coordinated with agriculture, must take account of their increasing use as fuels and be based upon the current number of plants in operation. The more precise specification of biomethane as a fuel is therefore an important prerequisite (see Milestone 7). According to the current state of knowledge, the use of biomethane as a fuel requires not so much the construction of additional biogas plants as rather their conversion for that purpose. In addition, the potentials of the individual plants need to be considered in more detail and in each case it is necessary to estimate for which plants or combinations of plants an additional processing stage is appropriate, where flexibilisation can provide longer-term added value, and where such conversion does not appear appropriate. For flexible electricity generation on the basis of biogas cogeneration units, the conversion of existing plants (flexibilisation) up to 2030 has already been largely completed.

**Milestone 4: Heat generation from biomass increasingly involves innovative concepts ("upgraded heat recovery") and has been taken into account as part of a heating strategy.**
Heat generation from biomass is a robust utilisation option. However, it requires constant further development to meet future demand structures (lower specific heating needs, combination with other renewables, higher comfort expectations), emission requirements and expansion towards combined heating / cooling and power systems (see also Milestone 5). In this connection Germany needs a heating strategy which combines bioenergy in the form of heating networks and CHP plants using waste heat from industry and efforts towards greater energy efficiency. With the aid of instruments for area planning and urban development (urban land-use planning), a heating system register should be drawn up for the whole of Germany taking account of demographic effects. This should define focal points for the construction of heating networks with flexible, regenerative energy sources.

**Milestone 5: Gasification technologies are available.**
The transition from heat generation alone to combined heat and power generation (see Milestone 4) should be supported by means of market launch programmes and specifically targeted research. These technologies have a great deal of export potential. In principle this also applies to Bio-SNG where there is sufficient demand.

**Milestone 6: Guidelines for the co-combustion of wood have been drawn up.**
With higher prices for $CO_2$-emissions, larger amounts of wood would be co-combusted in coal-fired power stations for economic reasons. In order to have a steering influence on this utilisation option with regard to its environmental compatibility and sustainability, the necessary framework conditions must be created early on. These include the introduction and implementation of suitable sustainability standards or solid fuels at national level. In the long term, the significance of co-combustion will decline as the proportion of coal-generated electricity decreases.

**Milestone 7: A differentiated biofuels strategy has been implemented.**
In the transport sector there will be subsectors in which the use of biofuels will make an efficient contribution towards climate protection. It is necessary to identify these and underpin them with robust long-term strategies, also with regard to the systematic use of sustainable raw materials and especially residual materials, since the so-called new technologies (e.g. on the basis of lignocellulose) will not be able to establish themselves on the market in the foreseeable future without long-term and purposeful support. Cornerstones of a biofuels strategy are (i) a clear hierarchy of goals to be achieved by the utilisation of biofuels, (ii) on the basis of that, the identification of priority areas of application, (iii) the technical, economic and environmental analysis of potentials for combined production of biofuels and other bio-based products, (iv) the integration of this into an overarching mobility and fuels strategy and the establishment of appropriate regulatory mechanisms.



**Milestone 8: Lignocellulose decomposition of straw is established on the market and has been prioritised among the utilisation options.**
Lignocellulose decomposition offers a wide range of options for the use of straw and other residual materials. This needs to be flanked by corresponding R&D activities. The use of straw as an element in future fuel strategies has been evaluated in detailed analyses. The supply should be based on German and European raw materials. Domestic production and imports of ethanol from residual materials requires comprehensive guidelines in order to protect soil fertility.

**Milestone 9: The treatment of waste within the circular economy has been organised.**
The exploitation and best possible use or recycling of local waste (esp. biodegradable waste, waste wood, sewage sludge) requires further support and legislative guidance in accordance with the principles of a circular economy. Regarding efficient energetic waste treatment systems, with particular attention being paid to the bioeconomy and cascade processes, it is necessary to adjust infrastructures so as to enable the sorting and utilisation of assorted biomass.

**Milestone 10: Bioenergy should be established in partnership.**
The use of bioenergy is one element in the transition to an economy that is increasingly based on renewable resources. In order to fulfil this task successfully, partnership concepts are becoming increasingly important. This includes, for one thing, close coordination with agriculture, and for another the further development of combined material and energetic concepts, both in the sphere of wood utilisation and, in the case of agricultural products, their processing and utilisation, but also the necessity for the careful treatment of limited resources in general. It is also recommended that there should be a high degree of commitment on the part of politicians, in Germany and elsewhere, in order to combat hunger in the world and to implement positive case examples for bioenergy and food security. Finally, the increasing combination of material and energy use is an important element, in particular for the achievement of the efficient use of residual materials. However, this process is ongoing and can only reach an interim level by 2030.

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