Journal of Sustainable Energy & Environment Special Issue (2011) 1-10

Biomass for Energy in Germany
Status, Perspectives and Lessons learned

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After the tragic accident within one of the nuclear power plants in Japan in early 2011, biomass as an environmentally friendly source of energy is more and more discussed as the great white hope under the various renewable energy sources. This is justified by the fact that biomass contributes already with more than 10% to the global energy demand. Against this background, the goal of this paper is it to analyze the status, the perspectives as well as the lessons learned from the increased use of biomass within the German energy system. This analysis shows that a significantly increased use of biomass is possible with existing technology. Nevertheless, the frame conditions to support such an increased use of biomass within the highly developed German energy system have to be carefully designed and arranged in an integrative way taking technical constraints, environmental demands and economic necessities into consideration.

1. Introduction

The global energy system will continue to grow significantly in the years to come especially due to the strongly increasing energy demand of the emerging economies (like China, India, Brazil). Following the current developments, most likely this worldwide strongly growing energy demand will be covered to a major extend by fossil fuel energy. Crude oil, natural gas and especially coal are easily accessible and still characterised by huge resources, well-known production and conversion technologies, existing infrastructure and comparably low costs. In addition, possible alternatives to replace oil, gas, and coal to a fully extend are not available on the short term. Nevertheless, some options to provide useful energy from renewable sources of energy are already market mature and others are still under development.

Due to this foreseeable development, it is likely that the emission of greenhouse gas (GHG) – and especially CO_2 – will continue to grow in the years to come. As a consequence it can be expected that the GHG reduction goals issued by various governments within the ongoing Kyoto-process will not be fulfilled on a global scale.

Nevertheless, various governments have implemented measures for the development of alternatives for covering the energy demand with significant lower GHG emissions. These measures are aiming in most cases for a significantly increased use of renewable sources of energy. For example, the German government has issued several acts in recent years to promote and support the use of renewables for the provision of heat, electricity and transportation fuels. The most important measures in this respect can be summarised as follows.

a) An act on the use of renewable sources of energy within the electricity sector (i.e. the Erneuerbare-Energien-Gesetz (EEG; electricity-feed-in law)).

b) A decree with the goal to promote renewables to cover the heat demand especially within domestic households (i.e. the Erneuerbare-Energien-Wärme-Gesetz (EEWG; renewable-energy-heat-law).

c) A law to promote the use of biofuels (i.e. Biokraftstoffquotengesetz; biofuel quota law).

In addition to that, many regulations have been adapted to allow an easier implementation of systems and plants for the use of renewable sources of energy.

Currently biomass is the most important renewable energy carrier. Within the global energy system biomass contributes with roughly 10% to cover the given primary energy demand. But, there are huge variations of the actual use within different countries. In some countries, the contribution of biomass is significantly more than 50%; in developing countries, where a high share of people lives in rural areas with a lack of (expensive) fossil fuels, wood fuels are still the most widely used energy carrier. In other countries, bioenergy contributes to the overall energy system with a couple of percent and even less. In Germany, for example, biomass accounts for approx. 7.2% of the primary energy demand. Nevertheless, in all countries biomass is significantly more intensively used compared to all other renewable sources of energy (there are some exceptions due to some national specialities like e.g. hydropower in Norway).

Against this background, the goal of this paper is it to analyse and assess the status of the use of biomass for energy within the German energy system. Based on this and the experiences made in recent years some conclusions are drawn. For this reason, the German energy system is presented first. Then the various options to provide useful energy from different biomass resources are discussed. In the following, the potentials are analysed before the current applications of the various options to use biomass for heat, electricity and fuels within the German energy system as well as their development are presented. Based on this the experiences gathered during recent years in using biomass are discussed (i.e. lessons learned). Finally, the most important findings are summarised.

2. German Energy System

Within the Federal Republic of Germany, the primary energy consumption summed up to approx. 14 EJ in 2010 [1] (for comparison: worldwide primary energy consumption in 2009 ca. 523 EJ including hydropower and biomass (roughly 55 EJ) [2]). The order of magnitude of the primary energy consumption in Germany has been more or less stable throughout the last two decades. During these 20 years, the energy demand varied between 14 and scarcely 15 EJ; the only exception has been the year 2009 with roughly 13.5 EJ due to the economic crisis in 2008.

Altogether crude oils contribute roughly one-third (33.7%) and natural gas one-fifth (21.8%) to cover this primary energy demand. Additionally, hard coal and lignite provide 12.1 and 10.8%, respectively; thus, coal cover roughly one-fourth of the German primary energy consumption. Compared to this, the use of renewable sources of energy is low. Hydropower, wind energy, and photovoltaics contribute with 1.5% and the other renewables (mainly biomass) with 7.9% within the energy system; i.e. the overall use of renewables within the German energy system is scarcely one-tenth. This is slightly less compared to the use of nuclear power (i.e. 10.8%). Fig. 1 illustrates these different contributions.

The primary energy consumption of 13,463 PJ in 2009 feeds a final energy consumption of 8,714 PJ (2009 [1]). Industry, transportation and households have used this final energy to a similar share of 25.9, 29.1 and 28.6%, respectively. The sector business, trade and services consumed the remaining 16.1%.

In 2007, 26.1% of the final energy consumption has been used to provide space heating. Another 5.0% has been used for the provision of hot water, 23.1% for process heat, 2.4% for lightning, and 43.4% for mechanical energy [3]. Under the assumption of similar shares in 2009 3,782 PJ of final energy were needed to provide mechanical energy primarily within the transportation sector, 2,013 PJ for process heat, and 2,710 PJ for space heating and hot water provision.

This overall energy consumption was responsible for carbon dioxide emissions of roughly 700 Mio. t in 2009 (for comparison: world wide CO_2-emissions 31,098 Mio. t in 2009 [1]). Approx. 22% are caused by the transportation sector, 15% by the household sector, 47% by the energy industry and the remaining rest by other industry sectors as well as small consumers.

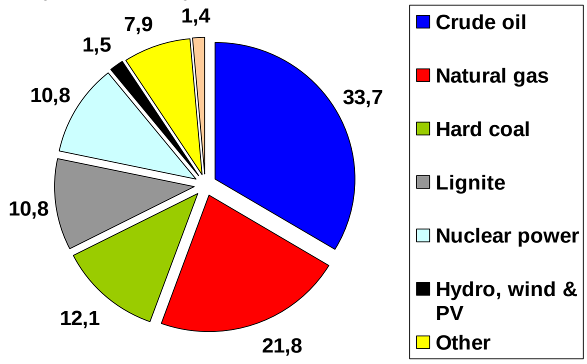

Figure 1. Primary energy consumption in Germany (2010; values in % referring to the overall primary energy consumption of 14 EJ) [1].

3. Possibilities to Use Biomass for Energy

Bioenergy is generated in a multistage supply chain starting with the collection of residues, by-products or wastes resp. the cultivation of energy crops. This biomass then undergoes a variety of mechanical processing, storage and transportation steps – depending on the local conditions and the desired final product – and maybe industrial conversion processes to produce secondary solid, liquid and/or gaseous energy carriers or biofuels. These fuels can be used to meet the given demand for different forms of useful energy (i.e. mostly power and heat, but also liquid or gaseous transportation fuels) (Fig. 2).

The different possibilities to provide secondary energy carrier with more promising fuel characteristics compared to mechanically treated biomass (i.e. wood chips, wood logs, pellets) can be subdivided in options based on heat induced processes, on biological processes and on physico-chemical processes. These different options are discussed briefly below (see [4]). Beforehand, the provision of biomass free conversion plant is analyzed (see [4]).

3.1 Biomass Conversion Routes

A conversion route describes the pathway from the production of the energy crops respectively the provision of residues, by-products and/or wastes at the place of origin up to the provision of the biomass in a predefined form at the gate of the conversion plant, the provision of secondary energy carrier (e.g. solid, liquid or gaseous fuel, district heat), the provision of final energy (e.g. heat, electricity) or the provision of useful energy (e.g. heat, power). Thus, a conversion route covers the overall life cycle from the production resp. the genesis of the organic matter (i.e. the primary energy) up to the provision of the secondary, useful or final energy.

The overall goal of such a conversion route is to meet a specific, in parts strongly varying demand of final or useful energy with a predefined degree of supply security. To reach this goal appropriate conversion plant(s) with a reliable technical performance are needed as well as the necessary amount of biomass in a predefined quality.

Each conversion route consists of the steps biomass production (i.e. energy crops) resp. genesis (i.e. residues, by-products, and wastes), provision of the organic material and/or the bioenergy carrier, final or useful energy provision as well as the utilization and/or disposal of the resulting residues and/or wastes. Each of these different life cycle phases is again composed of different technical processes. For example, biomass production requires among others a preparation of the seedbed, the distribution of fertilizer as well as plant protecting agents and various cultivation measures.

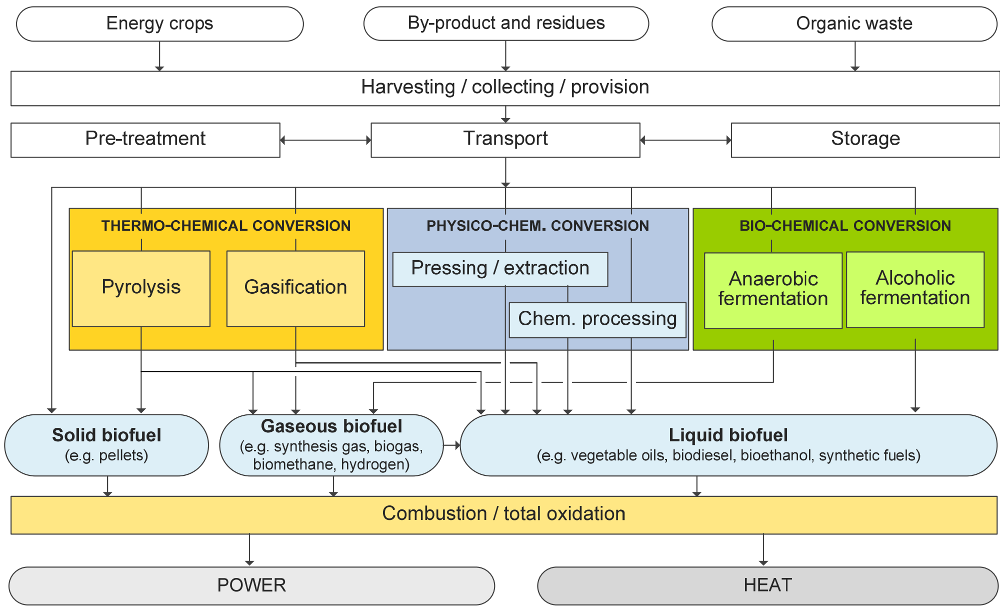

Figure 2. Possibilities to provide heat and/or power from biomass [4].

Because different life cycle stages of a biomass conversion route normally do not take place at the same location, the existing distances have to be overcome by various transportation duties (e.g. truck, pipeline, conveying belt). In existing biomass conversion routes, the decision for a specific transportation option is mostly chosen based on economic aspects.

Thus, the design of a specific conversion route is very much defined by the frame conditions fixed by the available biomass (supply side) and the requested provision of the final and/or useful energy (demand side). Additionally technical, economic, and environmental (as well as administrative and/or legal (and emotional resp. social)) aspects influence the arrangement of such a route. Besides, the biomass availability varying throughout the different seasons of the year has to be taken into consideration. In addition, the energy demand is changing over the time. Based on this an adequate provision concept has to be realised. Consequently, certain storage options (e.g. wood chip storage, heat storage) have to be included in the entire chain.

Furthermore, the conversion route matching all these demands has to be economic viable under the frame conditions defined by the investor and the government. It has to receive the required legal authorization (if applicable) and – last but not least – should be socially and emotionally acceptable at least by the people living close to the plant. Hence, different players with a very different background and understanding (like farmers, power plant operators, investors) have to communicate and interact successfully with each other as well as with the representatives of the local regulatory authority to create a successful project.

Thus, technical as well as various non-technical aspects define such a biomass conversion route. This makes the set up of new chains often interesting, exciting and demanding.

3.2 Conversion Options

The conversion of biomass (i.e. organic material of very different origin) into solid, liquid and/or gaseous secondary energy carrier can be realised based on a thermo-chemical conversion, on a bio-chemical conversion and/or on physico-chemical processes. These conversion processes are in most cases the "heart" of such a conversion route. Below, these various options are explained.

Thermo-chemical conversion. Solid biomass can be converted into useful energy or into secondary energy carrier using conversion processes based on heat.

During "classical" combustion for provision of heat and/or electricity biomass is fully oxidized basically with oxygen from the surrounding air by releasing heat. Various chemical processes are realized during this full oxidization. They are executed in parallel at the same place. The chemical reactions can be influenced to a certain degree to minimize the creation of unwanted substances harmful to humans and the environment by setting the frame conditions defined by the involved combustion technology.

Alternatively, the full thermo-chemical conversion can be split up. In this case, the underlying chemical processes take place at different locations and at different points in time. To realize this, solid biomass is mixed under certain conditions (pressure, temperature etc.) and high temperatures clearly below the stoichiometric concentration with an oxidizing agent (e.g. air, water). Under these circumstances, the solid biomass is converted into solid, liquid and/or gaseous secondary biofuels to be used as an energy carrier at another place and date. The chemical processes executing the conversion are based on the same fundamental reactions as realised during combustion. However, the composition of the resulting secondary energy carrier varies depending on e.g. the involved technology, the selected process parameters, the catalyst involved (if applicable), and the type of biomass used.

In gasification as one of these options, solid biofuels are converted as completely as possible into an energy-rich producer gas (or synthesis gas; i.e. into a gaseous secondary energy carrier). After expensive cleaning processes, the gas can be used directly without any further chemical transformation e.g. in an engine, a turbine, or even a fuel cell to provide heat and/or electricity. Alternatively the gas can undergo a subsequent synthesis process to be converted into a liquid or gaseous biofuel with clearly defined properties (e.g. Fischer-Tropsch diesel, synthetic natural gas (bio-methane), hydrogen) e.g. for the use within the transportation sector.

In pyrolysis, another option, solid biomass is converted solely by the (short- or long-time) application of heat into solids (charcoal), liquids (bio crude oil), and gases (e.g. CO, H_2, CO_2).

- In fast pyrolysis processes, a maximum yield of liquids (i.e. bio crude oil) is desired. The by-products – e.g. combustible gases and charcoal – can be used e.g. to provide the energy needed for the conversion process and/or as a raw material (e.g. active coal as a filter medium). The produced bio crude oil has to be refined and/or conditioned. Afterwards it can be utilized as liquid fuel within engines and/or turbines.
- The goal of slow pyrolysis processes is to convert solid biomass into charcoal. This solid carbon can then either be used as a more pleasant source of energy (e.g. for daily cooking in developing countries and for leisure activities (barbecue) in industrialized countries) or as a raw material (e.g. active coal filter).

Thus based on a thermo-chemical conversion – beside the provision of heat and electricity – also solid, liquid and/or gaseous secondary energy carrier can be produced directly and/or indirectly.

Physico-chemical conversion. This conversion pathway is used to produce liquid biofuels from biomass containing oils and fats (e.g. rape seed, oil palm fruits, and sunflower seeds). The oil is separated from the seed e.g. by pressing and/or extraction. The necessary process technology is well known since centuries. Afterwards, the crude vegetable oil is cleaned to meet predefined product standards. The cleaned oil can then be used as an energy source in its straight form (if the engine is able to burn such a relatively inhomogeneous fuel characterized by considerable differences from e.g. conventional diesel fuel) or after a chemical treatment respectively conversion (e.g. trans-esterification with methanol to FAME). Alternatively the vegetable oil can be treated with hydrogen (i.e. hydrogenation to HVO) or processed together with crude oil in conventional crude oil refineries to provide a fuel with characteristics complying the requirements for the existing transportation fuels (basically diesel fuel or kerosene).

Bio-chemical conversion. In this group of conversion processes, groups of microorganism split the organic material into fragments and compose new chemical compounds. The most important options are the alcoholic fermentation and the biogas production.

- During alcoholic fermentation, sugar, starch and cellulose contained in some types of biomass are transformed into ethanol. Therefore, the sugar is needed to be available in a watery solution. For these reasons, starch and celluloses have to be converted to sugar. Then the alcoholic fermentation takes place, where biocatalysts convert the sugar molecules to bioethanol and carbon dioxide. Afterwards the ethanol needs to be distilled and dehydrated. The pure ethanol can be used in IC engines and/or turbines in its pure form or as a blend with conventional gasoline (e.g. E5, E10).

o During anaerobic fermentation, organic matter is converted into biogas. This gas is a mixture of roughly 50 to 60% methane and 40 to 50% carbon dioxide. The process is performed by various groups of bacteria active within a certain temperature window (e.g. 35 to 40°C) able to degrade organic macromolecules via different intermediate steps into gases. These gases leave the solution of water and biomass where this process takes place. This gas has to be cleaned (e.g. sulphur, water). Afterwards it can be used in combined heat and power (CHP) generating units to produce electricity and heat. Alternatively, after further processing, upgrading, and – where necessary – distribution through the existing natural gas grid, a use in vehicles designed for the use of natural gas is easily possible.

4. Bioenergy Potential and Use in Germany

Below the biomass potential as well as the current bioenergy use in the Federal Republic of Germany is discussed.

4.1 Biomass Potential

In general, for the energetic use of biomass a wide range of different resources is available (e.g. forest wood, straw, cereal, liquid manure). These biomass potentials are derived from the agricultural and silvicultural primary production resp. from the industries that follow on the primary production as well as from the respective waste management (i.e. when organic material leave the production process resp. the end user).

The total amount of available biomass to be used as a source of energy considering given technical restrictions is characterised by the technical potential. In addition to technical restrictions, structural and environmental constraints (e.g. nature protection areas, biotope network areas) as well as the given legal framework (e.g. legitimacy of hygienic precarious organic waste for use in biogas plants) are taken into consideration for its estimation. Such restrictions may reduce the available biomass potential comparable to technical aspects.

Table 1 shows the technical biomass potential for Germany based on the criteria mentioned above. Residues, by-products and waste are differentiated in herbaceous biomass (e.g. straw, landscape conservation material), wood (e.g. forest residual wood, industrial residual wood) and other biomass (e.g. excrements, organic industrial waste). The forest potentials include the wood not used as a raw material (i.e. firewood, forest residual wood) and the share of the annual incremental growth, which is currently unused.

Furthermore, there are energy crops, which can be cultivated as annual or perennial cultures on agricultural land for the exclusive energetic use.

Taking the current demand for food and fodder into consideration, an available land area of about 2 Mio. ha can be assumed for biomass production within Germany. On this land area, different types of plants can possibly be cultivated for different purposes.

o Thermo-chemical conversion: mixed cultivation of different lignocellulosic plants for the provision of solid biofuels.

o Physical-chemical conversion: rape-seed cultivation.

o Bio-chemical conversion: two-culture-system for the production of substrates for biogas production, cultivation of input products for the ethanol production.

The method explained above leads to an estimation of an upper border, since in practice the selection of suitable cultivation cultures is significantly reduced due to the given local conditions.

However, the biomass declared (e.g. herbaceous biomass, energy crops) can be used only once (either thermo-chemical or bio-chemical or physico-chemical). Thus the entire fuel potential amounts to approximately 1,000 to 1,300 PJ/a (approximately 8% of the present German primary energy consumption).

Changes are expected in the years to come. These variations might be small for residues, by-products and waste, whereas a clear increase is expected for energy crops – due to presumably declining land area requirements for the production Thus an increasing biomass potential – and hence an increasing importance of cultivating energy crops – is likely in the future. Due to this development, the entire biomass potential might increase to approximately 2,000 PJ/a in the year 2020. Additionally improvements in the seeds for the energy crops can even lead to higher yields and thus higher potentials. Improved environmental and nature protection requirements (e.g. expansion of organic farming) might lead to a decrease of the agricultural area available

Table 1. Technical biomass potential within Germany [5].

	Mio. $t_{raw\ material}$/a	PJ/a	PJ/a	PJ/a
Herbaceous residues, by-products and waste				
Straw	9.3	130	38 – 63	–
Grass from pastures etc.	2.6 – 4.0	37 – 56	15 – 23	–
rural conservation material	0.9 – 1.8	11 – 22	8 – 16	–
Total	12.8 – 15.1	178 – 208	61 – 102	–
Wood residues, by-products and wastes				
Forest residual wood	13.7	169	–	–
Thinning	10	123	–	–
additionally available wood	10.7	132	–	–
demolition wood	6	78	–	–
industrial residual wood	4	58	–	–
landscape conservation wood	0.46	4	–	–
total	45	563	–	–
Miscellaneous residues, by-products and waste				
excrements and litter	162	–	96,5	–
harvesting residues	7 – 14	–	9.1 – 18.3	–
wastes from industries	3.1 – 4.7	–	6.4 – 12.2	–
organic urban waste	7.6	–	12.5	–
Total	180 – 188	–	124 – 139	–
Gas from purification plants		–	19,5	–
Landfill gas		–	15 – 21	–
Total residues, by-products and wastes		741 – 770	219 – 282	–
Energy crops on 2 Mio. Ha		365	236[a] – 252[b]	103[c]
Total amount		1,106 – 1,135	455 – 533	103

[a]biogas substrates, [b]ethanol from sugar beets (additionally biogas substrates (95 PJ/a) would be usable energetically) [c]vegetable oil resp. FAME from rape seed (additionally straw (125 PJ/a) and whole grain (65 PJ/a) would be useable energetically)

and thus downsize possible potential increases. Even then, an increase of the potential is expected [5-6].

4.2 Biomass Use

Biomass is used in Germany for the provision of heat and electricity as well as transportation fuel. Below the current use within these three markets is discussed in detail (see [7-8] and especially [9]).

4.2.1 Heat Provision

In Germany currently approx. 290 PJ of solid biofuels are used for heat provision in systems with 1 MW thermal capacity and below. This small-scale heat market is dominated by the use of wood logs provided outside the "classical" commercial energy markets. So far, most of this wood energy is retrieved from forests covering roughly 31% of the area of Germany; here a limited commercial market has been developed in recent years. Additionally, solid biofuels (i.e. wood logs) are also produced from various other primary sources (like old fruit trees, roadside trees, garden trees, park trees) and secondary sources (like residues from sawmills and the wood processing industry). The high market importance of wood logs within the small-scale heat market can be explained with relatively low costs and the fact that the end user can (and does) contribute to the fuel provision lowering the fuel costs even further; this is one of the main reasons for the big share of wood logs coming from informal markets.

Furthermore, wood chips and wood pellets have a certain market importance. Especially the latter was characterised by a considerable market growth during recent years. In 2010 roughly 63 pellets factories produced approx. 1.75 Mio. t of pellets (Fig. 3). The installed production capacity has shown a significant growth throughout recent years. Overall, the installed capacity accounts for roughly 3.25 Mio. t (Fig. 3). For pellet production, wood powder available as a waste product from sawmills and other wood processing industries is used currently. Additionally fresh wood coming directly from the forests serves in an increasing manner as a feedstock for pellet production. Compared to the approx. 1.75 Mio. t of pellets produced in 2010 (Fig. 3), the domestic consumption added up roughly to 1.2 Mio. t. The surplus of ca. 0.55 Mio. t exceeding the domestic market has been exported to other European countries. Thus, Germany is still a net pellet exporting country.

The pellets applied as an energy carrier in Germany have been used for heat provision in ca. 140,000 pellet boiler (Fig. 3) mostly with an installed thermal capacity below 20 kW. However, with an increasing tendency also combustion units with a higher installed thermal capacity (up to 5 MW) have been implemented in recent years.

Compared to the small-scale heat provision discussed above, the production of thermal energy with installed capacities above 1 MW is only of limited importance for Germany at the time being. Nevertheless, there are several units under operation providing heat for small-scale district heating networks and/or large consumer (like public swimming pools, schools, hospitals). Due to the legal frame conditions (i.e. feed-in law (EEG)), such district heating systems are realised as CHP-units to a considerable amount (see next chapter).

4.2.2 Electricity (and Heat) Provision

Electricity (and heat) from biomass is provided by combustion of solid, liquid, and gaseous biofuels. All these different options are found on the German market as units for the provision of electricity only as well as systems providing heat and electricity within a coupled process (i.e. CHP). Below these different options are briefly discussed.

Solid biofuels. In 2010 261 biomass fired power resp. CHP-plant with an overall installed electrical capacity of 1,240 MW and a potential yearly electricity generation of 8.4 TWh have been under operation in Germany (Fig. 4). Additionally another eight plants with altogether 250 MW are installed within the pulp and paper industry providing roughly 1 TWh. Additionally heat and electricity is generated from the organic waste fraction. Assuming a similar development as in recent years approx. 4.8 TWh of electricity have been produced in existing waste incineration plants mostly based on a coupled process (i.e. CHP). In 2010 approx. 14.2 TWh of electricity as well as a considerable amount of heat have been produced from solid biomass in Germany.

The plants subsidised based on the German electricity-feed-in act (Fig. 4) have used about 7.7 Mio. t (dm) of solid biomass.

- Circa 56% of these plants use natural wood only. This sums up to approx. one third of the overall used solid biomass for electricity resp. CHP generation. The average installed electrical capacity of these 145 plants (i.e. scarcely two third of the overall installed plants) is 2.9 MW. Moreover, a considerable amount of these plants provide additionally heat to be used e.g. for feeding district heating systems and/or large consumer. Due to the legal frame conditions (i.e. feed-in law) and the limited amount of fuel available within a cost-efficient manageable catchment area such plants are still installed to a certain extend (Fig. 4). Within such plants also "innovative" technologies are used (e.g. Organic Rankine Cycle; in 2010 79 plants based on this technology have been under operation).

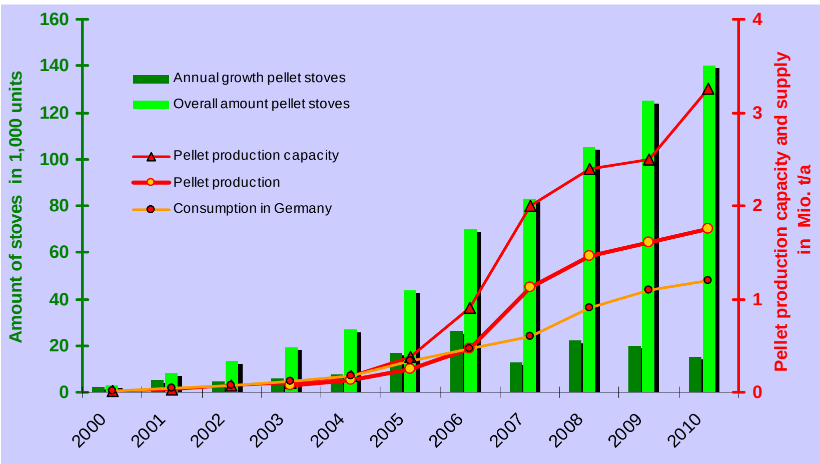

Figure 3. Yearly and overall installed pellet fired heating units as well as the overall pellet production capacities and pellet production in Germany (data according to [9]).

o Another 15% of the plants use natural wood and additionally demolition wood of the classes AI and AII (i.e. only slightly contaminated). These plants are usually characterised by a medium installed capacity.

o The remaining 39% of the plants use additionally class AIII and AIV demolition wood (i.e. highly contaminated waste wood). Due to the valid challenging emission regulations and the resulting necessary expensive flue gas treatment systems, these plants show an average installed electrical capacity of 8 MW. In these plants, the demolition wood available in Germany is fully used. Therefore, it is not likely that new plants using only highly contaminated demolition wood will be installed in the years to come.

Liquid biofuels. In 2010 approx. 1,850 engine based CHP-units using vegetable oil or FAME have been under operation. With an overall installed electrical capacity of 415 MW within these units about 2.0 TWh of electrical energy has been provided to be fed into the grid. Additionally the heat is used to a certain extend allowing for an economic viable operation. For this purpose, vegetable oil with a fuel energy content of roughly 21 PJ has been used.

Gaseous biofuels. By the end of 2010 about 5,700 biogas plants with an installed electrical capacity of ca. 2,130 MW have been under operation in Germany (Fig. 5). These plants allow for an electricity generation of roughly 15.8 TWh; in spite of the newly installed plants the electricity feed-in has only been at around 14.7 TWh. Parallel to this approx. 22 to 25 PJ of coupled produced heat has been provided. Besides, with a decreasing tendency due to the legal prohibition of dumping organic matter on landfills, there is an electricity generation of approx. 1 TWh from landfill gas produced from old landfills. Additionally, 0.9 TWh of electricity has been produced in roughly 700 sewage gas plant (overall installed electrical capacity ca. 160 MW). Overall, approx. 16.6 TWh of electricity have been provided based on an anaerobic fermentation of organic material in Germany.

Within the "classical" biogas plants operated mostly within the agricultural sector, mostly agricultural substrates are used. Due to the legal frame conditions, most widely spread agricultural residues (like animal manure) and/or energy crops (like maize silage) are digested. Additionally also organic waste materials from other parts of the overall economy are used in an increasing way due to growing prices for "classical" agricultural substrates. In most cases, part of the heat provided by the gas engine resp. the CHP-unit is used to heat the biogas substrate. A surplus heat usage outside the borderline of the biogas plants is only sometimes realised because usually there is no heat sink available close to the location of the biogas plant (e.g. on a farm).

Beside the direct electricity (and heat) provision at the location of the biogas plant, more and more biogas plants upgrade the produced biogas to natural gas quality to feed the resulting biomethane into the natural gas grid. Once within the gas distribution grid, it can be used easily in a CHP-unit located at a spot where the heat can be used entirely and/or within the transportation sector in commercially available CNG-vehicles. In 2010 about 48 biogas plants with grid injection have been under operation realising a feed-in of methane of about 2.54 TWh.

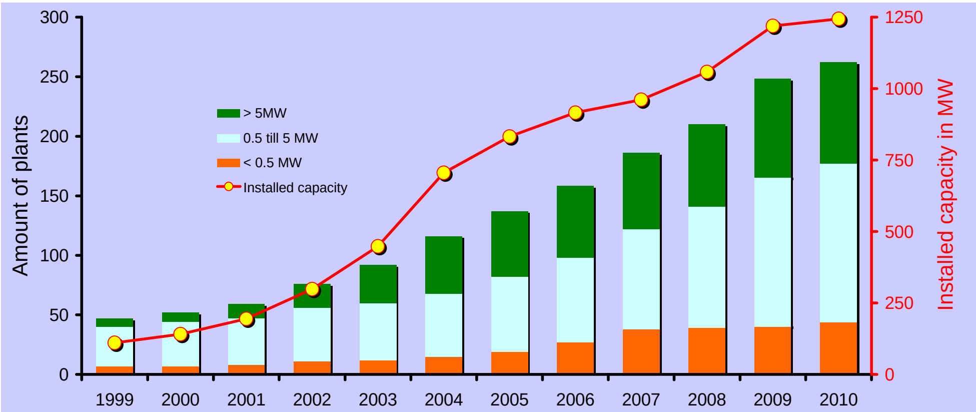

Figure 4. Overall installed power and CHP-plants fired with solid biofuels (data according to [9]).

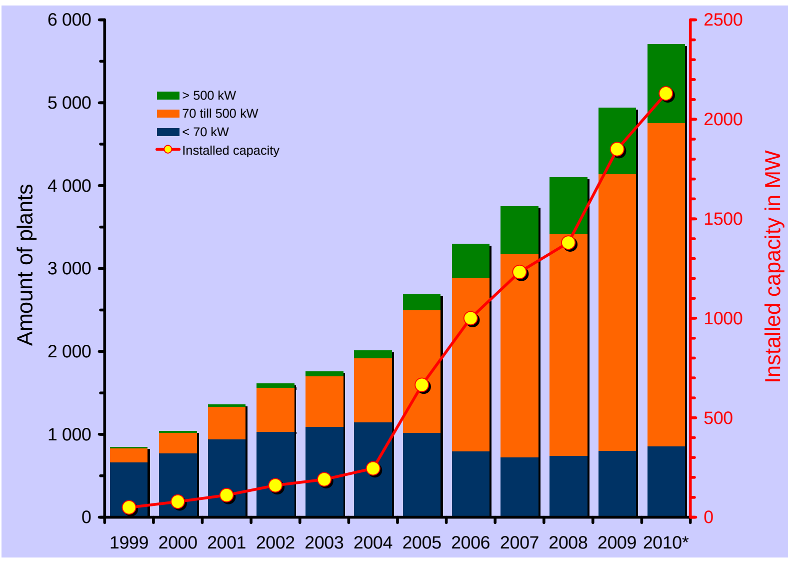

Figure 5. Amount and installed capacity of agricultural biogas in Germany (data according to [9]).

4.2.3 Provision of Transportation Fuels

In 2010 the transportation sector used approx. 3.7 Mio. t of biofuels. This represents about 123 PJ. The FAME and bioethanol-production capacities are within a range of 5.0 and 0.88 Mio. t, respectively (Fig. 6).

Biodiesel – here mostly FAME based on rape oil (i.e. RME) – contributes with ca. 79% to this overall use (i.e. 2.6 Mio. t or 97 PJ). FAME has been sold as an additive to conventional diesel fuel (ca. 89%) and as a fuel on its own (ca. 11%). The use of FAME within the German transportation sector has been slightly decreasing in recent years due to respective changes within the legal framework. This trend seems to be stopped and the amount of Biodiesel sold in Germany in 2010 has shown a small increase (Fig. 6).

Another 19% of the biofuels sold on the German markets comes from bioethanol (23.8 PJ). Ethanol is used within two pathways. One option is the further processing to Ethyltertiärbutylether (ETBE) for the substitution of Methyltertiärbutylether (MTBE) produced from fossil fuel energy. Another possibility is the use as a substitute for gasoline with a maximum share of 5 or 10% (i.e. E5 or E10).

The remaining 2% are crude vegetable oil used with a fast decreasing share in some niche markets (e.g. tractors driven by crude vegetable oil). 2010 ca. 0.06 Mio. t or 3.8 PJ have been used.

Other options do not have any significant market importance yet. The only technically mature option is the provision of biomethane for the use in CNG-vehicles. Nevertheless, this option does not contribute with a noticeable amount within the overall energy resp. transportation system. Reasons are the limited importance of vehicles driven with natural gas in general and the limited available (expensive) biomethane within the grid.

4.2.4 Summary

Fig. 7 shows a summary of the overall energy provision from biomass. According to this in 2010 roughly 835 PJ of primary energy from biomass has been used within the German energy system (roughly 6% referring to the primary energy consumption in 2010; see chapter 2). Based on this primary energy input 32.9 TWh of electricity, 469 PJ of heat and 123 PJ of fuels have been provided. Referring to the end energy consumption this represents a share of approx. 7 to 7.5%.

5. Experiences gathered and Lessons learned

The explanations in chapter 4 have shown that the use of bioenergy in Germany has increased significantly in recent years. This development is triggered by a broad amount of different aspects and steered by various measures. Below only some of these aspects are enumerated.

o GHG reduction goals issued by the German federal government based on the targets defined by the Commission of the EU.

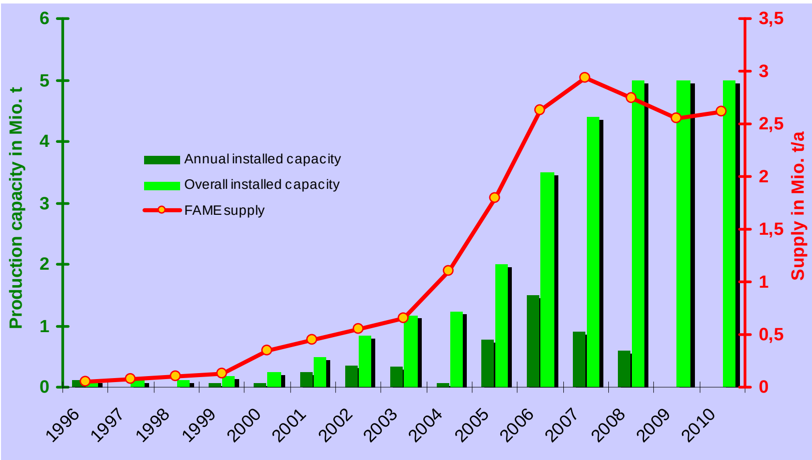

Figure 6. Production capacity and sold amount of FAME in Germany (data according to [9]).

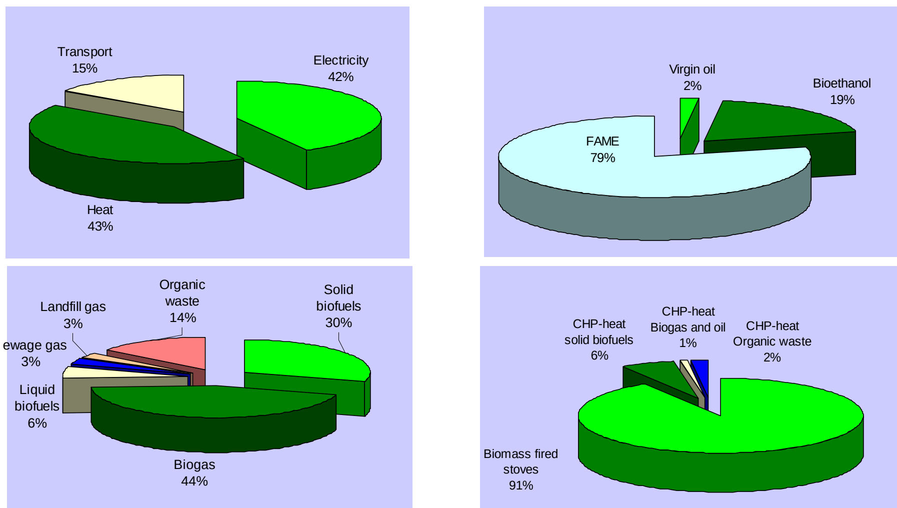

Figure 7. Overall bioenergy use in Germany (top left: share of the overall used bioenergy used within the three different sectors; top right: share of different types of biofuels within the transportation sector; bottom left: share of different biomass sources within the electricity sector; bottom right: share off different heat sources within the heat market) (data according to [9]).

o Electricity feed-in law with fixed reimbursement rates and an unlimited amount for electricity to be fed into the public grid.

o Biofuel quota law with a defined biofuel quota based on the targets defined by the Commission of the EU.

o Decree for an increased use of renewables within space heating.

o Disconnection of the gas delivery between Russia and Ukraine (and thus also to Germany) in winter 2007/08 as well as in winter 2008/09.

o Increase in the crude oil price level in 2008 up to roughly 140 US$/bbl.

These and other aspects have significantly influenced the development of the bioenergy market in Germany in recent years. During this development, for example the following experiences have been gathered.

o The electricity-feed-in law has triggered a significant increase in the production of electricity from biomass. This proves true for the provision of electricity from solid biofuels as well as from biogas. Without this governmental measure, the electricity production from biomass to be fed into the public electricity grid would probably be negligible as it has been until this decree was put into force. Independent from this recent development, the wood waste produced within the wood processing industry has been used already since years for a combined heat and electricity production needed by industry to power their production facilities and to get rid off the wood waste.

o Due to the market expansion triggered by the legal frame conditions, biomass conversion technologies already available on the market have been technically improved. This applies especially to biogas plants where the average time-space yield has been raised considerably within the last decade to an amount unthinkable 10 years ago. Nevertheless, such an impressive technical development and such a success story have not taken place at conversion plants based on thermo-chemical gasification neither at the small nor at the large scale. There are two explanations for that: a) the legally bounding feed-in tariffs are too low to compensate the risk using a technology not market mature yet or b) the investors do not find budding units and systems on the market promising an economic operation with a high number of full load hours (i.e. a kind of hen and egg problem). Probably the truth is somewhere in between.

o Due to the market introduction of the different conversion technologies supported by defined feed-in tariffs more efficient plants – and thus cheaper plants referred to the installed capacity – with significant increased installed capacities have been developed. At the same time, the technological and environmental demands to be fulfilled by these plants – and thus the overall costs – have been increased amongst others due to public demand and/or the claims of local citizens' initiatives (i.e. local NGO's). Overall, the cost reduction due to the legally supported market introduction is partly compensated resp. over-compensated. Therefore, as a more general development, the biomass conversion systems available on the market have become significantly better from a technical and environmental point of view – but not necessarily cheaper in absolute and relative terms.

o The introduction of legally defined feed-in tariffs for electricity from demolition resp. contaminated wood induced a not foreseen price development. Wood waste costing considerable money to get rid of is converted into a valuable fuel (i.e. a fuel product) with a relatively high market price. Therefore, the economic profit possible due to the feed-in law has been skimmed of by the traders dealing with the wood waste and not by the companies using the wood waste as a fuel for electricity generation. Because of this development, the market prices for solid biofuels from demolition wood resp. contaminated wood waste are now within a range allowing the power plants only a marginal profitable operation when using this fuel based on demolition resp. contaminated wood. Consequently, some power plants operating under the scheme of the electricity feed-in law have been shut down already due to economic problems.

o The legal frame conditions support the operation of CHP-units for efficiency reasons (i.e. GHG reduction reasons) with an extra promotion of heat produced within a coupled process. In spite of this special incentive of originally 0.02 €/kWh and now roughly 0.03 €/kWh a significant share of the conversion plants using either biogas or solid biofuels as an energy carrier are still designed and operated with no or only a very limited use of the available (waste) heat. One reason for this is that the locations for biomass-fired plants are mostly not defined primarily by criteria related to the heat use. Additionally, the implementation of a district heating system is too expensive in most cases and/or considerable heat sinks are too far away. Not until biomass-based fuels especially for units fired with solid biofuels became more and more expensive in recent years, plants with relative low electrical capacities have been installed in an increasing way at locations where a certain heat usage is possible. However, this applies only to a very limited extend to biogas plants. For this reason the recent amendment of the feed-in law allows to claim for the special heat incentive mentioned above also if legally defined new heat consumers are installed at the plant location. This offer has been widely accepted by the biogas operator to maximise their economic benefit. Nevertheless, it is questionable if e.g. the drying of the digested slurry allowing claiming for this incentive makes sense from an economic and environmental point of view. If the available biomass due to the limited available amount should be used most efficiently (i.e. CHP to maximize the overall conversion efficiency) stronger incentives would be needed to "motivate" the plant operator to use the heat in an environmental sound and energy efficient way.

o The pellet market has increased dramatically within the last 10 years in Germany from basically zero around the year 2000 to more than 1.75 Mio. t in 2010. In the early years of the last decade, only wood powder available as a waste / side product from sawmills has been used as a feedstock within pellet production facilities. Nowadays this potential is basically fully used and competition is given with e.g. the wood composite industry. Therefore, additionally fresh wood from the forests is used for the provision of pellets. But also this forest wood competes with wood to be used as a raw material for the wood processing industry as well as the pulp and paper industry. The consequence of this ongoing development is an increasing competition between the energy markets and the markets for wood as a raw material. The market price is growing due the fact that the (public) forest industry does not increase the production in the necessary range (although that this would be possible as clearly demonstrated by the private forest owners) and an extended wood import from other European countries would be too expensive. Thus the resulting raise in price is supported by the structure of the German state controlled forest industry, which acts not very flexible in this respect. So far, only privately managed forests have increased their production considerably within the last decade. Beside the increasing demand for wood for pellet production another reason is the strongly growing demand for wood logs.

o The possibilities to expand biogas production in Germany are limited a) by the available organic residues (like animal manure, organic waste fraction) as well as b) the available energy crops (like maize silage, corn-cob-mix silage) due to a priori limited agricultural land (and the impossibility to transport biogas feedstock over long distances because of the relatively high water and thus low energy content and the thus resulting high specific costs). The potential of the former possibility is comparable low and already used to a considerable amount; nevertheless, this option will be more widely used in the years to come. The potential of the latter option is limited by the accessible agricultural land not needed for food and fodder production and/or any other high value purpose (currently ca. 650,000 ha; the overall agricultural land in Germany is 11.8 Mio. ha). This share not needed for food provision is very much influenced by e.g. the Common Agricultural Policy (CAP) within the EU, the land requirements for other energy crops (like rape for Biodiesel production), and the production intensity as well as the food and fodder demand. According to the current situation, the potential of producing energy crops is used already to a considerable extend. Consequently, the biogas production cannot be increased significantly in the years to come. Thus, the expectation for the industry producing biogas plants is considerably decreasing markets. Due to the valuable experiences gathered in the past, the biogas plants produced in Germany are well developed and from a technological point of view leading on the world markets. If the biogas plant producing industry is willing to grow even further there is the urgent need to sell their plants on the global energy markets. Due to the subsidised market in Germany, the conditions abroad are less promising in most cases. Therefore, this industry has to become more competitive.

o Parallel to the increasing contribution of biomass within the energy system due to the legally defined incentives, the political discussions about the pros and cons of biomass as a source of energy have gained more and more importance within energy and environmental politics in Germany. This appears true independently from the discussion about the proc and cons of the use of nuclear power ongoing especially in Germany. The increasingly emotional and highly controversial public and political discussions focuses among others on the following aspects: a) competition issue (i.e. food-or-fuel-debate), b) environmental issues (e.g. greenhouse gas emissions within the life cycle of biogas production, odour emissions from biogas plants, particulate matter emissions from boilers fired with solid biofuels), c) indirect land use change (e.g. biofuel production on cleared rain forest land in Brazil), and d) sustainability aspects. The discussions about these points are still ongoing. Therefore below only a short summary of the status can be given.

a) Competition issues. Due to the limited available land useable for biomass production the amount of organic matter to be produced in a sustainable way is a priori limited on a global scale. Even if this border is not reached yet (and will not be reached within the next decades) with a fast and strongly growing demand for biomass the prices on the national and global markets will rise. Moreover, the biomass demand from the energy sector is over proportional growing globally due to the relatively high fossil fuel price level probably continue to be noticeable above 100 US$ in the years to come. Additionally the markets for food and fodder are right now characterised by a strong growth. The growing world population and the increasing welfare (e.g. China, India, Brazil) triggers the consumption of more food in general and more meat in particular especially within the emerging markets (like China and India). To cover the demand for more meat significantly more cereals are needed as fodder; already today more than 50 and 70% of the cereal production is used for meat production worldwide and in Germany, respectively. However, growing prices will enforce a growing production limiting the price increase. Within such an adaptation process, the prices might fluctuate strongly till a new equilibrium has been found. We are currently facing this situation.

b) Environmental issues. The justification for subsidizing an increased use of biomass for energy is given by environmental advantages associated with the use of bioenergy. If – due to new (serious or less serious) research results – this precondition is not valid any more, additional (very) controversial discussions will start (and have started already). One typical example for such a situation is biogas production from energy crops. The question is still not fully answered if biogas production from maize silage is truly a promising option from a GHG reduction point of view. Because new and not yet verified measurements have shown that for badly managed plants the methane leakage within the overall system might be significant and thus exceeding the GHG emissions from e.g. electricity from coal. For this reason, it is advisable to ensure that there is always accompanying research carried out by neutral research groups tackling the open and controversial discussed points.

c) Indirect land use change. If virgin land (e.g. rain forests, natural grassland) is converted into agricultural land, the net greenhouse gas balance might be negative. For this reason, the discussion about the pros and cons especially of biofuels is very much focusing on the question if due to an increased biomass or biofuel use in Germany somewhere else throughout the world virgin land (e.g. rain forests in Brazil or Indonesia) is converted into agricultural land and thus the GHG savings are converted to GHG emissions. Against this background, the current discussion is focusing on how to verify, quantify and control this effect, how to assess the consequences, and how to develop globally acceptable avoidance strategies. This discussion is still ongoing.

d) Sustainability aspects. It belongs to common sense worldwide that an energy provision from biomass makes only sense if biomass is produced in a sustainable way. However, the discussion how to define and how to measure sustainability is still not at an end (and will probably never come to an end because sustainability is very much influenced by the societal valuation changing over time). Nevertheless, the EU-Commission has issued a sustainability decree defining some sustainability indicators to be fulfilled if the used biofuel shall be accounted to the quota. Based on this decree, environmental standards are significantly higher for biomass to be used as a feedstock for energy compared to the same biomass to be used within the food and fodder market and/or the markets for raw materials. The consequence is that badly and not sustainable produced biomass is sold to the food and fodder markets and well-managed biomass goes into the energy markets. Nevertheless, for the first time ever sustainability criteria, which are to be improved in the years to come, have been introduced into the market. This can be seen as a tremendous step forward to a more sustainable agricultural production. Yet, there is an urgent need to transfer these criteria also to other products of the agricultural and forestry primary production in the following years to avoid so called leakage effects.

6. Final Considerations

Biomass is the most important renewable source of energy used by humans so far. Within the global energy system biomass contributes with roughly 10% to the given energy demand and in Germany the share is slightly above 7%. In addition, according to the political goals biomass shall make a significantly larger contribution within the energy system of the future. This is justified by contributions to GHG reduction and to a more secure overall energy system. Against this background, the goal of this paper is it to analyse the current use of biomass within the German energy system and to assess the experiences made in recent years during the significantly increasing use of bioenergy within the energy system. The main finding can be summarised as follows:

o The German energy system is characterised by a primary energy consumption of roughly 14 EJ and an end energy consumption of scarcely 9 EJ. Biomass contributes already with a share of ca. 6% to cover the primary energy consumption and contributes to cover the end energy demand with 7 to 7.5%.

- Thus, the energy provision from biomass is market mature. Nevertheless, the establishment of new provision chains is challenging because various and very different players have to be convinced to collaborate within an economic viable way. The development in Germany has shown that this is a demanding process usually performed successfully.
- 2010 roughly 835 PJ of primary energy from biomass has been used within the German energy system. Based on this primary energy input 32.9 TWh of electricity, 469 PJ of heat and 123 PJ of fuels have been provided. This biomass represents GHG savings of approx. 61 Mio. t (2010). Referring to the overall energy based GHG emissions in Germany of ca. 730 Mio. t (2010) this represents between 8 and 8.5%.
- To achieve this considerable increased use of biomass manifold political measures have been implemented in recent years by the German federal government. The most important measures have been the feed-in law for electricity (Erneuerbare-Energien-Gesetz, EEG), the renewable heat law (Erneuerbare-Energien-Wärme-Gesetz, EEWG) and the biofuels quota act (Biokraftstoffquotengesetz). Beside these measures, additional decrees on very different levels (i.e. regional up to European level) in very different areas have triggered this development.
- The development in Germany has shown e.g. the following characteristics:
  - If a biomass conversion technology has already been available on the market the legal frame conditions supported the further development of this technology (e.g. biogas technology). New and not market mature technologies have not been further developed (e.g. gasification technology).
  - Due to the market introduction of the different conversion technologies legally supported more efficient – and thus theoretically cheaper – plants have been developed. In parallel, the technological and environmental demands to be fulfilled by these plants have been increased – and thus the overall costs. Hence, the achieved cost reduction is compensated resp. over-compensated. Therefore, in general the biomass conversion systems have become significantly more efficient but not necessarily cheaper.
  - The significantly increased use of biomass has caused competition effects within the markets. The results have been growing market prices for the biomass feedstock. Therefore, bioenergy markets have to be developed within a long-term process to avoid strongly fluctuating prices. Nevertheless, a certain competition cannot be avoided and triggers due to the resulting price increase to agricultural and forestry primary production.
  - To achieve public acceptance of a wider use of bioenergy within the energy system the biomass has to be provided in a sustainable way. For this reason globally accepted and easily verified sustainability criteria are needed to be implemented for the overall agricultural and forestry production.

Altogether, the German example has shown that a strategy to use biomass more intensively within the overall energy system is possible and successful. A significant contribution to GHG reduction can be achieved and the security of energy supply can be increased.

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