Chapter 1
Sustainable Bioenergy Production: An Integrated Perspective

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Abstract Energy from crops, wood and biological residues should always be viewed together with other renewable energy sources, such as wind and hydro power, photovoltaic power, concentrated solar power, solar heating, etc. All of them and the introduction of efficiency measures allow to attenuate climate change as well as the future shortage and increasing price of conventional fossil and nuclear energy sources. Bioenergy has several advantages that make it strategically important: It can provide heat, electricity as well as liquid and gaseous fuels; it can be stored and used when needed; and it can balance fluctuations in the electricity grid.

Owing to widespread malnutrition and a rapidly growing global population with increasing calorie and livestock product requirements, estimates of the potential areas where energy plants could be grown vary widely. A reduction in livestock production on fertile soils, in harvest and postharvest losses and in the waste of food would open up large areas for more sustainable farming as well as for energy crop production. Bioenergy should not lead to monoculture; instead, it should increase biodiversity in agricultural areas and enrich the landscape, thereby improving the

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population's acceptance thereof. Owing to the state-of-the-art technology, greenhouse gas savings – especially from biogas production for combined power and heat plants – can be quite a bit higher than 70 %. The nutrients that are recycled back into the fields with the digestate maintain soil fertility and save money.

In addition, this chapter discusses the application of Germany's Renewable Energy Source Act and the resulting National Biomass Action Plan. Moreover, it highlights the quota system and feed-in tariffs as promoters of the successful expansion of renewable energy forms.

Keywords Bioenergy potential • Efficiency • Greenhouse gas • Meat versus bioenergy • Biodiversity • Feed-in tariff

1.1 Arguments for Renewable Energy Production

Together with population growth, energy and water shortages, declining arable land and forests, soil degradation, climate change, ocean acidification, decreasing resources and food insecurity are the major challenges of the twenty-first century. To counter these unfavourable trends, concerted actions have to be taken to achieve climate stabilisation, to conserve biodiversity, soil, and forests, to ensure the availability and quality of water, economic and social development, human well-being, global security and a secure, low-carbon energy supply, all of which should be focussed on sustainable development on a local, national, and international level.

Today, fossil fuels (crude oil, natural gas, coal and uranium) account for approximately 85 % of the global primary energy production (DERA 2011). In the next few decades, renewable types of energy, including wind, water, solar power and bioenergy, have to become the major energy suppliers, because:

- The reserves and resources of fossil energy sources (especially natural oil and gas) are nearly depleted, even if shale gas and unconventional oil resources are included in these reserves. Depending on the underlying models and estimations of the global consumption of oil and gas, and on technical improvements and prices, oil production may have passed its global peak or will do so in the near future. This has important consequences for the supply and price of fossil energy sources.
- As implied by the name, renewables, which are based on solar energy, will be available as long as the reactor sun gives off energy; that is, for several billion years to come. It has taken just two centuries for man to seriously deplete the earth's fossil fuels formed over millions of years in the sediments of the outer earth crust.
- Under optimal circumstances, renewables' CO_2 emissions are far lower than those of their fossil fuel counterparts, such as coal, oil and gas. The increase of renewable energy sources counteract the climate change by reducing greenhouse gas emissions.
- Municipalities save on fossil fuel costs, create jobs, collect taxes and lease revenues by installing renewable energy systems (Mühlenhoff 2010).

Strong efficiency measures should be in place when transforming energy systems into renewables. In 2009, 80 % of the emitted greenhouse gases in Europe originated from the energy sector (Boßmann et al. 2012). However, this sector has a strong potential for decarbonisation as it offers a variety of technologies ranging from carbon-neutral electricity generation by means of highly efficient energy conversion processes to energy saving options (Boßmann et al. 2012). Europe's building sector has the highest final energy saving potential. The electricity and petroleum sector has the highest potential for financial benefits. By 2050, the overall final energy demand could be 57 % lower than the baseline projection, which translates into cost savings of about 500 billion EUR per year (based on the 2005 value) (Boßmann et al. 2012). This will increase supply security while decreasing Europe's external fuel bill and enhancing its competitiveness in the global economy. Therefore, the European Union's Energy Roadmap's target is to reduce greenhouse gas emissions by at least 80 % by 2050 (Boßmann et al. 2012). With regard to heating, house insulation and the functionality of stoves and furnaces should be improved. More effective electricity devices should be used to reduce the waste of electrical power. With regard to bioenergy, additional efficiency measures include the energetic use of organic wastes and plant residues as well as the energetic recycling of used materials, such as furniture, construction wood, fibres, etc., which may be reused or co-fired at the end of their useful live (see 'Cascade use' in Box 1.1; WBGU 2008). Generating electricity from biogas should always involve the use of 'waste' heat for household or industrial processes, such as drying. Thus, combined heat and power (CHP) plants can offer double the total usable energy (FNR 2009; FNR/GIZ 2010; see Box 1.1).

The energy transformation of fossil into renewable energy can also promote sustainable development and better incomes in developing countries if similar supporting transformations occur within the political, economic and social systems, and the local, national and international authorities support them (WBGU 2011).

Box 1.1 Bioenergy Glossary

Sources: modified from REN21 (2012), WBGU (2008, 2011), IEA (2011).

Biomass is any organic living or dead material of biological origin, excluding fossil fuels or peat. Biomass comes in solid or liquid forms. Examples are wood, energy crops derived from dedicated plantations, wastes, organic residues from industrial and municipal sources and manure. These materials can be converted into biofuels, biogas or biomethane.

Bioenergy/Biomass energy refers to the final or useful energy derived from biomass. *Traditional bioenergy* is produced by burning solid biomass, including agricultural residues, animal dung, forest products, gathered fuel wood and charcoal. These types of biomass are often burnt inefficiently in open fireplaces, stoves, or furnaces to provide heat energy for cooking, comfort, and small-scale agricultural and industrial processing, usually in rural areas of developing countries. The emission of air pollutants during burning often cause

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health hazards due to incomplete combustion. In 2008, it was estimated that 2.7 billion people were dependent on biomass for cooking (Chum et al. 2011). Therefore, about 85.6 % of global bioenergy is used in a traditional way (WBGU 2008). *Modern biomass energy* is derived from solid, liquid, and gaseous biomass fuels used, for example, for heat and power generation (space heating and electricity) as well as for transportation. Modern bioenergy involves burning biomass directly or converting it into more convenient fuels, for example, through the pyrolysis and gasification of solid biomass to produce liquid and gaseous fuels, the anaerobic digestion of suitable biomass materials to produce biogas, the transesterification of vegetable oils to produce biodiesel, and the fermentation of sugars to produce ethanol.

Biofuels comprise a wide range of liquid and gaseous fuels derived from biomass – including the liquid fuels bioethanol and biodiesel as well as biogas. Biofuels can be combusted in vehicle engines as transport fuels and in stationary engines for heat and electricity generation. These fuels can also be used for domestic heating and cooking. Today, *first-generation biofuels* are mostly used. These include sugar cane ethanol, starch-based ethanol, biodiesel, fatty acid methyl ester (FAME) and straight vegetable oil (SVO) as well as biogas/biomethane. Feedstocks typically used for the production of liquid biofuels include: sugar cane and sugar beet, starch-bearing grains, like corn and wheat, oil crops, like canola and palm, and, in some cases, animal fats. *Advanced or second-generation biofuels* comprise different emerging and novel conversion technologies that are currently in the research and development, pilot, demonstration or early commercial phases. Advanced biofuels include synthetic biofuels, such as Fischer-Tropsch diesel, biomethane and biohydrogen, which is produced by thermochemical processes, such as gasification and pyrolysis.

Biodiesel is a diesel-equivalent, processed biofuel used in diesel engines of cars, trucks, buses and other vehicles. It can also be used for stationary heat and power generation. Through the process of transesterification (a chemical process that removes the glycerine from the oil), biodiesel is produced from oilseed crops, such as soya bean (*Glycine max*), rapeseed (*Brassica napus*; cultivar canola), oil palm (*Elaeis guineensis*) and, from other oil sources, such as waste cooking oil and animal fats.

Bioethanol, which is mostly used as a gasoline substitute, is produced by fermenting any biomass high in carbohydrates with the aid of yeast or bacteria. Today, ethanol is made from starches and sugars (usually corn, sugar cane, or small cereals/grains), but second generation technologies will produce it from cellulose and hemicellulose. Small amounts of bioethanol can be used to substitute gasoline for use in ordinary spark ignition engines (stationary or in vehicles), or can be used in stronger blends (usually up to 85 % ethanol, or 100 % in Brazil) in slightly modified engines (flexible fuel vehicles).

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Biogas/Biomethane: Biogas is a mixture of methane and carbon dioxide produced through the anaerobic bacterial degradation of organic matter (fermentation), such as agricultural and food industry wastes, sewage sludge, biological remnants in municipal waste and – especially in Germany – purposely cultivated energy crops (after ensiling). The digestion (biological transformation) of organic material into biogas occurs in a fermentation plant. The methane is the fraction of biogas that can be utilised for energy recovery. Biomethane is nearly pure methane, which is separated from biogas by removing carbon dioxide, hydrogen sulphide, siloxanes, water and some other impurities. Biomethane can be injected into natural gas networks and used as a substitute for natural gas. Biogas and biomethane can be burnt to produce heat and power. Biomethane can also be used as a fuel for cars.

Greenhouse gases are those gaseous constituents of the atmosphere that, due to their selective absorption of thermal radiation, cause warming of the lower atmosphere. The primary anthropogenic greenhouse gases are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Other greenhouse gases are traffic-caused ozone (O_3) and industrial gases, such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF6) and the ozone-depleting chlorofluorocarbons (CFCs).

Carbon dioxide (CO_2) is a naturally occurring greenhouse gas. It is a product of burning fossil energy carriers and biomass. Deforestation, wetland transformation (peat, swamps, etc.) in agricultural areas, other land-use changes and industrial processes, such as cement production, all lead to additional CO_2 emissions.

Methane (CH_4) is a greenhouse gas emitted mainly from livestock and rice cultivation. It is the principal component of natural gas and biogas.

Nitrous oxide (N_2O) is a persistent greenhouse gas, which is mainly emitted by nitrogen fertilisers in agriculture, the livestock sector (primarily cows, chickens and pigs) and by the burning of fossil fuels.

Carbon dioxide equivalents ($CO_{2\ eq}$) are a measure of the degree to which a mixture of gases contributes to global warming. With the aid of a conversion factor, the global warming potential of non-CO_2 greenhouse gases is expressed as the quantity of CO_2 that would cause the equivalent warming effect. For example, in a 100-year time horizon, methane (CH_4) will trap a lot of heat, warming up the lower atmosphere 25 times and nitrous oxide (N_2O) 298 times more than the same amount of CO_2. The calculation of $CO_{2\ eq}$ makes it possible to include all greenhouse gases in one unit and allows for a comparison of their individual impacts on global warming.

Cascade use refers to a strategy seeking to use resources, or products made from such resources, for as long as possible within the economic cycle. The

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material passes through as many phases of use as possible. This approach boosts the overall value creation and improves environmental performance. In the case of biomass, cascading can mean that the biomass is first used as an industrial feedstock, after which its energy content is recovered at the end of the product cycle. For example, furniture or wood used in construction can be co-fired in a heat or power plant at the end of its service life.

Combined heat and power (CHP)/Cogeneration plants are facilities that not only generate electricity during the combustion of fuel, but their waste heat can also be used for space heating purposes (as in district heating systems) or for heat/cool-dependent production processes in industry.

Ecosystem services are the benefits people gain from ecosystems. These include supply services, such as food, water or energy, regulatory services, such as carbon sequestration, protection against flooding, or against the spread of disease, cultural or recreational services and support services, such as nutrient cycles, as well as seed and pollen dispersal, all of which maintain the Earth's life-support systems.

Energy is the ability to do work. It comes in different forms, including thermal, radiant, kinetic and electrical energy. *Primary energy* is the energy embodied in natural resources, such as coal, natural gas, biological materials and other renewable sources. *Final energy* is the energy that is available to the final consumer in a usable form (such as electricity from an electrical outlet), where it can provide services such as lighting, refrigeration, etc.

Energy crops are cultivated to extract energy from their biomass. This may involve using either a specific part of the crop (e.g., maize grain or vegetable oil extracted from seeds), or the entire above-ground biomass (e.g., field crops or grass used for biogas installations, woody species, such as poplar or willow for heat and power production). For more information, see Chap. 6.

Energy efficiency or energy conversion efficiency is the ratio between the useful energy output of an energy conversion machine and the expended energy input. It answers the question of how much input energy should be applied to produce a certain amount of electric power, mechanical work, heat, fuel, etc. The ratio is always smaller than one.

Joule/Kilojoule/Megajoule/Gigajoule/Terajoule/Petajoule/Exajoule: A joule (J) is a unit of work or energy and is equal to the energy expended to produce one watt of power for one second. A kilojoule (KJ) is a unit of energy equal to one thousand (10^3) joules; 1 megajoule (MJ) = 1 million (10^6) joules; 1 gigajoule (GJ) = 1 billion (10^9) joules; 1 terajoule = 1 trillion (10^{12}) joules; 1 petajoule = 1quadrillian (10^{15}) joules; 1 exajoule = 1 quintillion (10^{18}) joules. One barrel (159 l) of oil can store approximately 6 GJ of potential chemical energy.

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Land-use changes (LUC): The term land use refers to the human use of an area of land for a certain purpose, while land-use changes refer to changes in such human use. These include logging, afforestation, sealing, drainage, the conversion of cropland to grassland (and vice versa), or the conversion of cropland to fallow land. Land-use changes can take place directly, for instance, when forests are cleared and the land is used to cultivate energy crops. It is more difficult to identify land-use changes induced by indirect mechanisms. When food crops are replaced with energy plants, the agricultural production that previously took place on this cropland has to take place elsewhere. We refer to such situations as indirect land use change (ILUC)

Pellets are a solid biomass fuel produced by compressing pulverised dry biomass, such as waste wood and agricultural residues. Pellets are usually cylindrical in shape with a diameter of around 1 cm and a length of 3–5 cm. They are easy to handle, store and transport; they are used as fuel for heating and cooking applications as well as for electricity and combined heat and power generation.

Renewable energy includes solar, wind, hydro, oceanic, geothermal, biomass and other sources of energy derived from “sun energy”, which is thus renewed indefinitely as a course of nature. Forms of useable energy include electricity, hydrogen, fuels, thermal energy and mechanical force. More broadly speaking, renewable energy is derived from non-fossil and non-nuclear sources in ways that can be replenished, are sustainable and have no harmful side effects. The ability of an energy source to be renewed also implies that its harvesting, conversion and use occur in a sustainable manner, i.e. avoiding negative impacts on the viability and rights of local communities and natural ecosystems.

Short-rotation plantations (SRPs) refer to the cultivation of fast-growing tree species (e.g., poplar and willow) on agricultural land to produce biomass. The concept derives from coppicing, a method traditionally used to produce firewood. The rotation period extends from the growth period until the trees are cut; its duration thus depends on the use of the wood. For pulpwood or for woodchip production, the trees are harvested after 3–5 years. The below-ground root mass remains in the soil, enabling the growth of coppice shoots the following year.

Transformation refers to the initiation and progression of an active transition or a change. The German Advisory Council on Global Change (WBGU 2011) uses the term great transformation as “the modification of both the national and the global economy within planetary guard rails in order to avoid irreversible damages on the Earth system and its ecosystems, and the impact of these damages on human kind”. Such guard rails prevent the mean global temperature from increasing more than 2 °C above the pre-industrial level, protect soil and biodiversity, etc., in order to avoid risks and catastrophies and to preserve the Earth systems resources and services and secure humankind’s natural life support system and sustainable development. While transformation is primarily

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focussed on the analysis of social, economic, cultural, and political changes, it must also consider sustainable technological and ecological/environmental improvements to ensure a sustainable future. In a broad sense, the WBGU (2008, 2011) regards transformation as a chance to achieve the sustainability goals of mitigating climate change by shifting from fossil fuel to renewable energy sources and to overcome energy poverty in developing countries.

Watt: A watt is a unit of power that measures the rate of energy conversion or transfer. Power is the rate at which energy is consumed or generated. For example, a light bulb with a power rating of 100 watts (W) that is switched on for one hour consumes 100 Watt-hours (Wh) of energy, 0.1 kilowatt-hour (kWh), or 360 kilojoules (kJ).

1.2 Bioenergy – Pros and Cons

Biomass, especially wood, was the first energy form applied by man. It has been used since just after the Ice Age (10,000 BC) and is still the most important heat supplier in developing countries. IEA (2011), however, estimates that 1.3 billion people have no access to electricity and 2.7 billion people are without clean and effective cooking facilities. Of these people, 84 % live in rural areas. In 2008, their traditional use of biomass, mainly wood, dung, etc. amounted to 8.5 % of the global final energy consumption (REN21 2012), or 10.2 % of the primary energy supply (Chum et al. 2011).

1.2.1 Bioenergy Pros

Bioenergy has three main advantages over other renewables:

- *Reservable*: Bioenergy is easy to store and can be used as required. It can therefore balance the fluctuation of wind and solar power (regulating energy).
- *Different usable forms*: Plant material can be used in a solid (e.g., wood), liquid (biodiesel and bioethanol) or gaseous state (biogas); the liquid and gaseous states are easily obtained through chemical transformation processes.
- *Versatility*: The different states can be used for heat and power production, or as fuel for mobility and other purposes. The other renewables produce mostly electricity.

Bioenergy production has additional advantages:

- *Promotes biodiversity*: Energy plant cropping may increase the biodiversity of arable land if energy plantation concepts are realised as double cropping during the year, or as the cultivation of plant mixtures instead of monocultures. Weeds can also be used if they do not lower yields in general. In addition, short-rotation cropping or agroforestry can be incorporated into energy crop farming (see Chap. 6).

- *Ensuring good yields*: These diversification concepts ensure energy plants' yields, decrease soil erosion and increase the attractiveness of the environment by providing more diversified landscapes.
- *Element recycling for fertilisation*: If remnants of the energetic use of crops, such as the residual digestate from biogas plants or wood ashes, are recycled to the areas from which the plants were taken, a nearly perfect recycling of the elements is possible (except for nitrogen). This fertilisation can be done when the growing plants need nutrients. It saves money and fertiliser resources (an important example is phosphorous, whose extraction maximum should be reached in 2030; Cordell et al. 2009; Gilbert 2009).
- *Monetary advantages*: Bioenergy offers local farmers new income opportunities, which could also reduce rural exodus and alleviate poverty, thereby decreasing the gap between the rich and the poor in developing countries (WBGU 2011). Bioenergy production can also decrease dependence on imported fossil fuels, thus improving countries' foreign exchange balances and energy security. Furthermore, it can expand access to modern energy services and bring infrastructure, such as roads, telecommunications, schools and health centres, to poor rural areas (GBEP 2011; WBGU 2011).
- *Job creation*: The introduction of bioenergy may create new jobs. Growing, harvesting and distributing bioenergy feedstock are specifically very labour-intensive. Additionally, biomass, biofuels and biogas production have created approximately 2.5 million technological jobs globally (REN21 2012).

To ensure bioenergy's sustainable production, the Global Bioenergy Partnership created 24 sustainability indicators with clear advice on how to handle them (GBEP 2011). Stakeholders and decision makers should be encouraged to use them as an analytical tool and facilitate decisions on and planning for sustainable bioenergy development. These indicators are based on interrelated environmental, social and economic pillars. The pillars comprise indicators, such as greenhouse gas and pollutant emissions, the productive capacity of the land and ecosystems, water availability, biological diversity, land-use changes, access to land, jobs, labour conditions, social development, human health and safety; efficiencies in bioenergy, production, conversion, distribution and end-use; as well as economic, technological, and logistic development and energy security.

1.2.2 Bioenergy Cons

Despite these benefits, the use of bioenergy has some limitations:

- *Land use conflicts and food-fuel competition*: The production of energy plants on farmland leads to a competition for arable land for the production of food and animal fodder.
- *Monoculture*: The production of only one high-yield plant, such as maize, in consecutive years leads to an area poor in biodiversity, decreases the landscape's

attractiveness, degrades soils through humus losses, increases the erosion risk and requires substantial fertilisation.

- *Acceptance*: In Germany, the increase in maize for energy use has decreased the acceptance of bioenergy production. Moreover, the comfort of people who live near a biogas plant might be affected due by increased traffic during the harvest season.
- *Greenhouse gas balance*: The greenhouse gas balance is not neutral, especially if the strong greenhouse gas methane escapes from fermentation plants during biogas production. Furthermore, the intensified application of nitrogen to increase energy crop yields produces the very strong climate gas nitrous oxide (N_2O).
- *Emissions of toxic compounds*: The ineffective burning of wood or charcoal in developing countries, but also in old fireplaces in industrialised countries, emits toxic compounds into the atmosphere.
- *Financial implications*: Besides breathing life into rural economies and the creation of new jobs, the competition for land increases the price of comestible goods if the production of food plants decreases due to increased energy croplands. Additionally, the rent for farmland may increase.

Some of the limitations described above, such as the environmental implications, should be compared with the conditions arising from the burning of oil, gas, or coal. In the following section, we examine how some of the emerging conflicts can be de-escalated.

1.2.3 Evaluating and Reducing Emerging Conflicts

1.2.3.1 Land Use Conflicts and the Food-Fuel Competition

To date, the amount of crops used for energy production is still small. In 2008, about 74 % of the world's agricultural production, which totalled about 10 billion tonnes, was allocated to animal food (fodder), while 18 % was used for food, only 3.7 % was used for energy and 4.3 % for biomaterial production (Raschka and Carus 2012). In that year, 260 million hectares (ha) of the 1,445 million ha of arable land were used for food, 1,030 million ha were used for animal feedstuff, 55 million ha were used for energy crops and 100 million ha were used for biomaterial production (Raschka and Carus 2012).

It is difficult to expand the area suitable for agricultural use, since agriculture has already cleared or converted 70 % of the grassland worldwide, 50 % of the savannah, 45 % of the temperate deciduous forest and 27 % of the tropical forest biomes (Foley et al. 2011). This conversion of land for agriculture has tremendous impacts; it reduces habitats and biodiversity, depletes the humus in soils, soil fertility, the freshwater available and the water quality. In turn, critical ecosystem services are being depleted. It is hard to find areas for the production of energy plants that do not compete with the production of food, fodder or plants for the material or industrial sectors. In addition, the prevailing natural resources used by man have already exceeded the Earth's carrying capacity (Rees 2006; WWF 2012). The pressure will increase further in the near future, as agricultural production needs to increase by 60 % over the next 40 years to meet the rising food demand (OECD/FAO 2012).

On a global and a national scale, the estimates of the bioenergy potentials that are available as part of a future sustainable energy supply are very contradictory. This is because the estimates depend on many parameters with unknown influences (e.g., Chum et al. 2011; Haberl et al. 2011). Therefore, the following questions need to be answered:

(a) How can the efficiency of crops, irrigation, nutrient supplies and cycling be increased in order to close the yield gap (see Chaps. 5 and 6)?
(b) To what extent does increased CO_2 fertilisation influence yields?
(c) To what extent will fertiliser (especially phosphorus) be available in future?
(d) How will soil degradation by means of salinisation, erosion, pollution, etc. develop?
(e) How accurate is the evaluation of degraded and marginal land's potential?
(f) Will improvements in management and technology, including the improved use of biomass (plant residue and cascade utilisation), lead to more efficient systems for agriculture or for consumers?
(g) What will the growth rate of the global population be?
(h) How will the competition between bioenergy and animal feed or bio-based material production develop?
(i) How will rising temperatures, changing rainfall patterns (amount and distribution) and the increased frequency of extreme events influence cultivation and plant yields?

Owing to these constraints, bioenergy could be a bridging technology for the transformation from fossil-based energy systems to future energy systems potentially based on wind and solar energy.

Chum et al. (2011) describe some of the difficulties of providing a global outlook for bioenergy potentials in 2050. They estimate that, in the median scenario, bioenergy will contribute 120–155 EJ/year to the global primary energy supply and can contribute up to 265–300 EJ/year in the highest deployment scenarios. This upper limit decreases to approximately 100 EJ/year if policy frameworks and enforcing mechanisms are not introduced, or if there is strong competition with biomaterials. These numbers should be compared to the total global primary energy supply, which was 492 EJ in 2008.

The German National Academy of Science (Leopoldina) estimates that, in Europe (EU25) and Germany, the potential for bioenergy is negligible, that it will only meet a small percentage of the country's primary energy needs and that it will mainly rely on waste (Haberl et al. 2012). The same authors furthermore assume that almost all the biomass that can be sustainably harvested worldwide will be required for human food, animal feed, construction materials, or as a basis for chemicals, leaving very little room for the use of biomass as an energy source, apart from wastes.

In contrast, by means of model calculations Zeddies et al. (2012) estimate that, in Germany, 2.4 million ha of land are available for 2020 for bioenergy production in addition to the 2.1million ha that are already being used for energy crops (out of 12 million ha of arable land in Germany). By 2050, this area could increase to 7.5 million ha even if 2.4 million ha are used for food export. Since they believe that it will be possible to obtain enough land to provide food security, the authors estimate that, by 2050, 200–300 million ha of land will be globally available for energy crop production.

Fritsche et al. (2012) estimate that advanced biofuels (see 'Biofuels' in Box 1.1.) could cover up to 70 % of the fuel demand for all modes of transportation in Germany by 2050, bearing in mind that fuel demand will be significantly reduced by then and that biofuel demand will be met without land use competition or additional imports. According to these authors, biofuels will be produced either from residual biomass, or from agricultural areas that have been made available for the production thereof. This biofuel production ought not to have a negative impact on biodiversity, nor lead to the conversion of pastureland or meadows into cropland. Additionally, this production ought not to reduce Germany's self-sufficiency in food supply.

The world's technical and sustainable biomass supply potentials as well as the expected demand for biomass (primary energy), which are based on global energy models and estimates of the world's total primary energy demand in 2050 (see Chap. 3), are shown in Fig. 1.1. The current world biomass use and the primary energy demand are shown for comparative purposes.

In addition to bioenergy, there are other competitors for food and fodder production areas: The replacement of all organic compounds in Germany's chemical industry will require yields from 58 % of the country's arable land, while the replacement of lubricants with bio-lubricants will require a further 11 % thereof (Bringezu et al. 2009).

On a global scale, the production of animal food (meat, milk and eggs) is by far the most restricting factor with regard to the availability of fertile arable land area for organic farming or energy crop production. Animal food production covers 1,030 million ha of farmland – about four times more than vegetable food production (Raschka and Carus 2012). Livestock production covers an additional 3,550 million ha, which are mostly used as pasture and grazing lands. Meat production is growing strongly. It has tripled between 1970 and 2009 from about 100 million to 300 million tonnes per year (OECD/FAO 2012).

A more specific description of the real land use conflicts does not cover food-energy competition, but meat-energy competition. While grazing land that is unsuitable for food production may ensure additional calories and proteins for people, highly productive areas used for animal feed are a net drain on the potential global supply of food (Foley et al. 2011) or bioenergy. Global meat consumption differs quite dramatically: In about 20 developing countries, the yearly meat

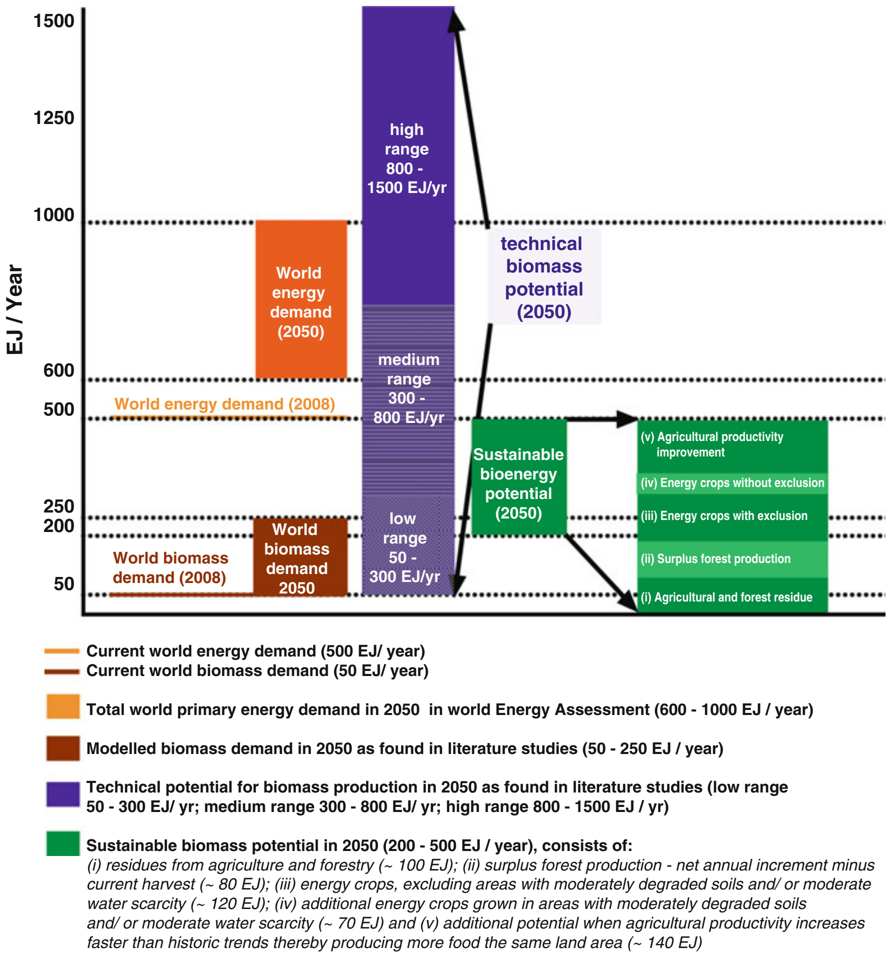

Fig. 1.1 Visualization of the technical and sustainable biomass supply potentials, expected demand for biomass (primary energy) based on global energy models, expected total world primary energy demand in 2050 (Bauen et al. 2009) and current world biomass use and primary energy demand (Dornburg et al. 2008; figure modified from Bauen et al. 2009)

consumption per capita is below 10 kg compared to an average of 80 kg in developed countries. Additionally, meat consumption in developing countries is increasing constantly (FAO 2012).

1.2.3.2 Land Use Change Through Meat Production

The expansion of land for livestock development has been the main driving force behind deforestation in, for example, Latin America and the Caribbean, while overgrazing is prevalent in other regions (FAO 2012). In Argentina and Brazil, for example, soya beans are cultivated to provide proteins for industrial livestock farming in European countries, such as Germany. To meet the requirement to generate 62 % of Germany's energy from vegetal food products, about 10 million tonnes of carbon are harvested from biomass every year. In contrast, annually, the feeding of animals to produce meat, milk and egg products requires about 53 million tonnes of carbon from plant biomass, which are either harvested or grazed, as well as about 9 million tonnes of imported carbon (about 5.4 million tonnes from soya beans and soya bean products, 2.3 million tonnes from rapeseed and 1.2 million tonnes from maize) (Haberl et al. 2012). Between 2008 and 2010, Germany used approximately 7 million additional ha of land outside Europe, thereby virtually increasing Germany's agricultural area from 17 to 24 million ha (Bringezu et al. 2009; Witzke et al. 2011). If the production of meat were to be reduced, the cultivation of other food products, such as protein-rich plants, would have to increase to ensure balanced human diets. However, this would require a much smaller area than that which is currently used for livestock production. The meat footprint of the average German is more than 1,000 m^2 (including 230 m^2 for soya production in overseas areas). This means that more than 8 million ha are used for meat production alone. Moreover, in Germany, 60 % of the grain and 70 % of the oilseed plants are used as fodder (Witzke et al. 2011).

1.2.3.3 Environmental Impact of Intensive Meat Production

Besides consuming much of the land and water resources, intensive animal husbandry or factory farming leads to many other problems:

1. Domestic animals emit large amounts of the greenhouse gases, methane and nitrous oxide.
2. Fields become overfertilised with manure.
3. Surface water becomes contaminated with nitrate and phosphate (causing eutrophication).
4. Nitrate and ammonia filter into the groundwater (posing a threat to human health when used as drinking water).
5. Pharmaceutical ingredients (hormones, antibiotics, etc.) are transferred from animals to the water.
6. Ammonia is released into the atmosphere where it is transformed into nitric acid, which in turn acidifies rainwater and soils.

In Germany, approximately 2 of the 11.7 tonnes of CO_2-equivalent emissions that are annually released per capita, are released during the production, processing, packaging, transport, marketing and consumption of agricultural products. An additional 0.5 tonnes of CO_2-equivalent emissions are annually released per capita due to land use changes. In the value-added nutrition chain, 204 million tonnes of CO_2 equivalents are annually emitted in Germany. About two-thirds of these greenhouse gas emissions can be attributed to animal products (meat, milk, eggs, etc.) and one-third to plant products (Noleppa 2012). In addition, importing soya material as a cheap source of protein for animal feed is an important aspect of factory farming in Europe. Approximately 85 % of the world's total soya production is used for animal feed. The international production of soya beans has increased by a factor of 2 over the last 30 years; in South America, it has increased by a factor of 4, with the strongest growth in Argentina and Brazil. These two countries are currently also the largest producers of soya beans (Reenberg and Fenger 2011).

Germany uses approximately 2.6 million ha of land outside the European Community to satisfy the need for soya products for livestock production (Witzke et al. 2011). In Brazil and Argentina, soya cultivation has expanded to land previously used for grazing or for natural habitat. This leads to direct land use changes by affecting the local savannahs and to indirect land use changes by exerting pressure on the tropical rainforest of Amazonia causing negative effect on the global carbon dioxide budget and on biological diversity (Barona et al. 2010; Reenberg and Fenger 2011). Additionally, the majority of soya bean crops in the USA and South America are genetically modified (GM) and become part of the meat and milk production, even in countries like Germany, where GM food is not accepted on the market. Another aspect is animal welfare: Nearly 75 % of the world's poultry production, more than 50 % of its pork production, and 60 % of all egg production occur in large-scale intensive industrial production systems (FAO 2009). Factory-farmed animals are usually confined to small pens, cages, sheds, or indoor stalls. They therefore mostly do not have access to pastures, fresh air and sunlight, and are unable to perform many of their natural behaviours (MacDonald 2012).

All of these arguments suggest that high meat consumption needs to be questioned. The reduction of meat production will:

- ease the pressure on the land areas used by man,
- open up space for a more ecological agriculture or for bioenergy plants,
- reduce emissions of greenhouse gases,
- reduce mostly inhumane industrial livestock farming,
- improve people's health and food security, and
- may lower the cost of basic food.

Greatly altered human behaviour is a prerequisite for change and is a crucial challenge. Creating awareness of the consequences of the disproportionate consumption of animal products is one of the prerequisites for a sustainable future.

Besides the meat-fuel competition, the following aspects also influence the availability of land areas:

1.2.3.4 Postharvest Food Losses and Food Wasting

Postharvest food losses occur during threshing, grading, packaging, transport, storage, processing, distribution and marketing, or due to biological or chemical contamination and deterioration. Between one-fifth and one-half of produced food is estimated to be lost early in the supply chain segments (the dominant form in developing countries), or wasted at the consumer end (the dominant retail and household levels in industrialised countries), globally amounting to about 1.3 billion tonnes per year (Parfitt et al. 2010; Grethe et al. 2011; Gustavsson et al. 2011). Every German throws away an average of more than 80 kg of comestible food every year (Noleppa and von Witzke 2012; Kranert et al. 2012; Noleppa 2012). This equates to 25 billion EUR, 2.4 of the 16.9 million ha of agricultural land and to 40 million tonnes of CO_2 equivalents per year.

1.2.3.5 Health Aspects

Between 1980 and 2008, the worldwide prevalence of obesity (overweightness) almost doubled (WHO 2012). By 2008, 10 % of men and 14 % of women in the world were obese. The reasons for this include a higher consumption of calories and increased consumption of animal products, salt, sugar and processed and fried foods. From a health perspective, significant reductions in meat consumption in the OECD would be preferable (McMichael et al. 2007; Witzke et al. 2011). In Germany, the adoption of more healthy, less animal-biased nutrition would release 1.8 Mio ha of productive land (Noleppa and von Witzke 2012) and would lower greenhouse gas emissions by 27 million tonnes per year (Noleppa 2012). A stronger awareness of the health aspects and optimal portion sizes of meat, egg and dairy in people's daily diet not only helps fight obesity, but also opens up areas for food and fodder production.

1.2.3.6 Land Deals for Bioenergy Production

Land deals (grabbing) with Africa, Latin America and Southeast Asia for the large-scale production of food, cash crops and biofuels have increased in recent years. Domestic and transnational companies, governments and individuals' land grabbing quickly escalated after the increase in food prices in 2007–2008 – especially in sub-Saharan Africa. In many cases, this has led to the expropriation or displacement of rural populations and to an increase in food prices in these countries. Countries' institutional infrastructure may be ill equipped to handle an upsurge in investor interest. Together with weak land protection rights, this may lead to uncompensated land loss due to the land users' exiting businesses or land being given away or sold at well below its true social and economic value. Over 46 million ha of large-scale farmland acquisitions or negotiations were announced between October 2008 and August 2009 (Deininger and Byerlee 2011). To compensate for the negative effects, we have, amongst others, formulated the following principles for responsible agro-investments:

- respect land and resource rights,
- ensure food security,
- ensure transparency,

- ensure that all the affected people are consulted and that they participate in all the important decisions,
- safeguard social sustainability by making investments that have a desirable social and distributional impact, and
- promote environmental sustainability by minimising and mitigating the risk and magnitude of the negative impacts.

If these principles are followed, there is a chance that countries with large tracts of currently uncultivated land suitable for cultivation, or with large gaps between potential and actual yields, may increase their outputs and welfare. Private investors may then provide their farmers with knowledge, technology, infrastructure, market access and relevant institutions.

To summarise, energy crops should only be cultivated in areas in which the food demand has been satisfied and crops can be produced without their having a harmful impact on the forests, wetlands, nature conservation areas, etc. Bioenergy production should not jeopardise food security, but rather strengthen it. Food security and environmental sustainability have to be integral parts of energy crop production. It should also be taken into account that, for millennia, bioenergy (especially in the form of heat), together with food and water, has been essential for human survival and that many people in developing countries still rely on it.

1.2.3.7 Monoculture and Acceptance

There is a strong movement against bioenergy in Germany. This is especially due to many people's unwillingness to accept the increase in maize crops (a high productivity energy plant) – a process to which they refer to as 'Vermaisung' (a verb formed from the German noun "Mais" (maize)). This is mainly because the plants grow up to 2.5 m, blocking people's views. However, crop rotation, inter-cropping, double cropping and introducing agroforestry or short-rotation cropping can enhance the landscape's appearance, thus increasing people's acceptance of energy cropping. Other concepts for increasing biodiversity through energy plants are described in Chaps. 6 and 7.

1.2.3.8 Greenhouse Gas Balance (GHG) and Other Environmental Impacts

Agriculture contributes 30–35 % of global greenhouse gas emissions. In particular, land use change – in the form of deforestation, grassland transformation, methane emissions from livestock and rice cultivation, nitrous oxide emissions from fertilised soils and unsustainable water withdrawals – contributes to this (Foley et al. 2011).

Theoretically, bioenergy is carbon dioxide-neutral. Crops and trees take up carbon dioxide (CO_2) from the atmosphere and water (H_2O) from the soil and transform it by turning the external energy source sunlight into organic compounds (simplified CH_2O) and oxygen (O_2). This process is called photosynthesis. The very simplified reaction is:

$$CO_2 + H_2O + \text{sunlight (h}\nu) \rightarrow CH_2O \text{ (biomass)} + O_2.$$

Inversely, biomass can be oxidised (e.g., the burning of wood) and thus produce carbon dioxide, water and energy. Another way to produce energy from biomass is to include the intermediate step of producing methane or liquid biofuel, which can be burnt in a second step. In the case of methane, biomass is fed into an anaerobic digester (biogas plant). During several stages, bacteria systematically transform the biomass into methane (CH_4) and carbon dioxide. This is done according to the following simplified reaction:

$$2\ CH_2O \rightarrow CH_4 + CO_2.$$

In a gas burner or engine, the methane can be oxidised by air oxygen to carbon dioxide and water, releasing energy:

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O.$$

In the end, all the carbon that plants take from the atmosphere is quantitatively released back into the atmosphere. This process is completely carbon-dioxide-neutral and produces no additional greenhouse gas.

Criticism of the greenhouse gas balance, especially with regard to biogas production, arises due to:

- methane leaks in biogas plants,
- the release of greenhouse gases (methane and nitrous oxide) during and after the application of nitrogen fertiliser and the liquid biogas digestate to soils and
- the direct and indirect land use change of forests, grasslands and wetlands.

Methane and nitrous oxide have a strong warming potential. According to Haberl et al. (2012) and of EMPA (2012), bioenergy generated from specially grown energy crops instead of waste or plant residues (domestic and industrial organic waste, manure, straw, wood remnants, etc.) releases more CO_2-equivalent emissions for the production of bioethanol and biodiesel than fossil fuel combustion does. The reasons for this are the application of nitrogen fertilisers, which produce nitrous oxide, as well as direct and indirect land use change, which releases CO_2, etc.

An exception is the production of biogas from crops and grass that have a slightly more favourable greenhouse gas balance than the production of biodiesel and bioethanol (EMPA 2012). A systematic review by Liebetrau et al. (2012) reveals that, under typical conditions in Germany, the generation of electricity from biogas emits 70 % less greenhouse gas than the production of conventional fossil electricity. If the technical installation is optimised and biological and crop residues are used, this percentage can increase to 90 %. The energetic use of biomass in stationary combined power and heat plants is economically and ecologically more advantageous than the production of liquid fuels (Bringezu et al. 2009). A mid-class car would be able to travel 67,000 km with the biogas fuel produced from one ha of land, while it would achieve 41,000 km with biodiesel (including its by-products) produced from the same amount of land, and only 36,000 km with bioethanol (valid for agricultural yields in Germany; FNR 2012). Biogas fuels therefore have a much better greenhouse gas balance.

On the other hand, land use changes in terms of forests or grasslands transformed into croplands for energy crop production have a very unfavourable greenhouse gas balance. Replacing forested areas with, for example, oil palm plantations will lead to substantial greenhouse gas emissions and considerable biodiversity losses. Conversely, if degraded areas are transformed into cropland for energy plants, such as oil palm, jatropha, sunflowers, etc., the plants and the soils could act as a carbon sink. However, the land use change argument can not be applied to countries in which biomass crops are produced on already existing farmland. These countries would not have to cut down forests or transform grassland and wetland into arable land, nor does the argument apply to countries where wood for energy is gathered from forest residues or offcuts from the wood processing industry.

The EMPA study (2012) lists additional negative environmental impacts, such as the eutrophication and acidification of soils and water, which increase their toxicity (e.g., contaminating them with nitrates and ammonium), the enrichment of toxic particulate matter in the air during biomass burning, the depletion of water resources in scarcity areas and the consumption of fertilisers. If, on the other side, greenhouse gas effects are considered in addition to these harms, the environmental sustainability of traditional biomass production is clearly better than conventional oil and gas utilisation.

Therefore, areas' individual greenhouse gas balance and their real environmental impact should be estimated. Bioenergy systems' impact assessments should be compared to those of replaced systems, which are usually based on fossil fuel combustion, but also to the impact systems of replaced crops cultivated for food or fodder. The digestion of manure in biogas plants is much more environmentally friendly than storing it in a container and applying it directly to fields. The digestion process significantly reduces manure's methane, nitrous oxide, ammonia and its unpleasant smell. Moreover, using the residues of a fermentation plant will decrease the need for additional fertilisation, because the nutrients are quantitatively recycled. This digestate can be applied to the farmland from which the crops were originally harvested. The negative environmental impact of the extraction, transport and processing of fossil oil and gas should also be considered when calculating environmental damage. The assessment should also include water consumption and pollution, methane emissions installations, transport, accidents, such as oil spills, oil tanker collisions, etc. Embodied energy (= the total amount of energy used for buildings, machines, fertiliser, pesticides, transport, etc. in order to produce something) should also be taken into account when assessing the impact of bioenergy. A total life cycle assessment, including the direct and indirect impacts, is necessary to compare the production and use of bioenergy and fossil energy.

1.2.3.9 Emissions of Toxic Compounds During the Combustion of Biomass (for More Information, See Chap. 13)

There is a lack of systematic comparative studies of toxic emissions from fossil fuel and bioenergy sources. It can be assumed that the burning of biogas and biomethane for heat and power generation emits similar, but negligible, amounts of harmful substances as natural gas. The situation regarding biofuels and fossil liquid fuels, which are burnt in engines or in household oil heaters, may be slightly different: Fossil oil contains a higher concentration of vanadium, molybdenum, nickel, cobalt, zinc, copper and sulphur (Jungbluth 2007) than liquid biofuels do. Liquid fossil fuel has a higher emission rate of these elements when burnt if they are not removed when the oil is processed. The emission of critical organic substances is assumed to be low in both biofuels and fossil oil if optimum burning conditions prevail. When burnt to generate heat and electricity, the emissions of the solid fuels lignite and coal can be compared with emissions from the burning of wood. As a former plant material, coal contains critical elements such as antimony, lead, cadmium, cobalt, copper, nickel mercury, sulphur, selenium, vanadium, zinc, thallium, uranium and tin (for data on coal, see Dones et al. 2007; for data on biomass, see Chaps. 13 and 14). Coal can be additionally enriched by these elements during the diagenesis process (when it is transformed from plant material into coal) and often by means of secondary inputs through formation water. This accumulation of elements is the reason why coal burning leads to a significantly higher emission of critical elements than wood burning if the emission is not reduced through filters. To compare the emissions, they have to be related to the produced energy, because the heating value of dry wood fuel is approximately half of that of hard coal. There has been no systematic comparison of the harmful organic compounds emitted from coal and biomass burning.

Since biofuels are often wet and contaminated and inefficiently burnt in small, traditional stoves – especially in poor households in developing countries – indoor air pollution (chiefly organic emissions, such as black carbon) is also a concern (Chum et al. 2011). In 2008, 2.7 billion people were estimated to be dependent on biomass for cooking. In total, indoor, air-pollution-related diseases cause 1.6 million additional deaths and casualties, including those of 900,000 children under five, and a loss of 38.6 million DALYs (Disability Adjusted Life Years) per year. Cleaner fuels and more effective and safer stoves that produce fewer emissions are beyond most of these households' reach. Advanced biomass cooking appliances include biomass gasifier-operated cooking stoves that run on solid biomass, such as wood chips and briquettes. These appliances have significantly lower emissions and are far more efficient than the traditional biomass cooking stoves (three-stone fires) that are still widely used in developing countries. Switching from traditional to modern bioenergy reduces the death and disease count from indoor air pollution significantly, frees women and children from having to collect fuel wood and reduces deforestation (GBEP 2011; Chum et al. 2011).

The local environmental and social impacts of activities (e.g., coal mining) and their effects on the surrounding areas (landscape destruction, water pollution through elutriated sulphuric acid and elements as well as emissions such as methane) should also be taken into account when comparing renewable and fossil energy sources (for coal, see Dones et al. 2007). These kinds of impacts are negligible in the case of regenerative bioenergy sources. Furthermore, the residues from coal and lignite burning (ashes) should be deposited in landfills, or, for example, used as an additive for cement production. The residues from bioenergy generation, however, can be recycled back into the areas from which the biomass was harvested: Fermentation plant residues can be recycled back into the farmland and grate ash residues can be recycled back into forests.

The emission situation regarding nuclear energy differs greatly from energy generation from organic materials. Energy from nuclear power is assumed to have very low emission rates of critical substances; however, there are important risks: The mining and processing of the uranium ore, as well as the reprocessing treatment of the spent nuclear fuel rods may release radioactive radiation (the Chernobyl accident, April 1986). Moreover, operating errors, equipment failure, natural catastrophes, such as earthquakes or tsunamis (the Fukushima accident in March 2011), as well as the consequences of landslides and floods may release radioactive material from nuclear reactors and should thus be taken into account. In addition to these risks, none of the 31 countries with nuclear power plants has as yet found an optimal solution for the ultimate storage of nuclear waste.

1.2.3.10 Financial Implications

While bioenergy production might contribute to increases in food prices, its impact is less severe than that of weather conditions, changes in food demand, production efficiency and increasing energy costs (Zeddies et al. 2012). While benefitting farmers, increases have adversely affected the poor, food security and nourishment in developing countries. On the other hand, bioenergy provides these countries with opportunities to progress with regard to rural developments and agricultural growth, both of which lead to job creation. If sustainability frameworks are properly designed, implemented, monitored and adhered to, they may help minimise negative socio-economic impacts and maximise the benefits of bioenergy production, particularly for local people (Chum et al. 2011; WBGU 2011). The real implications of bioenergy have to be investigated individually with regard to each form of bioenergy.

1.3 Bioenergy in Germany

In 2007, Germany's government established the German Integrated Energy and Climate Change Programme. Its main objectives are to ensure a secure, economically efficient and environmentally friendly energy supply. At the same time, the

Box 1.2 Important renewable energy implementations in Germany

1. The Renewable Energy Sources Act (EEG) 2012:
   - passed on 1 January 2012, replacing the previous acts of 2009 and 2004
   - most effective funding instrument at the German government's disposal
   - purpose: To further increase the share of renewable energies in electricity generation by 2020 as part of an integrated energy and climate protection programme
   - internationally observed as exemplary law.
2. The Renewable Energies Heat Act (EEWärmeG) 2008:
   - goal: to increase the percentage of renewable energies in heat supply to 14 % by 2020
   - purpose: to promote renewable energies in the heat sector
   - to achieve the sound management of fossil resources and decrease dependency on energy imports
   - to facilitate the sustainable development of energy supply and
   - further develop technologies to generate heat from renewable energy sources.
3. The Biomass Ordinance 2001 specifies:
   - which substances are recognised as biomass
   - which technical processes may be used for electricity generation
   - which environmental standards have to be met.
4. The Biomass Electricity Ordinance (BioSt-NachV) and Biofuel Sustainability Ordinance (Biokraft-NachV) 2009:
   - implements the EU's Renewable Energy Directive (RED) regarding the sustainability criteria for biomass and
   - specifies the legal and technical rules for recognising certification systems and certification bodies.

programme is supported by on-going legislative initiatives (e.g., the Renewable Energy Source Act, see Box 1.2) that aim to create more competition in the energy markets and offer new regulations for emissions trading.

One of the programme's initiatives is the National Biomass Action Plan, which provides a holistic solution for increasing bioenergy's contribution to Germany's total energy supply. Bioenergy is considered a means with which to mitigate the effects of climate change, to secure energy supply and enable the sustainable development of societies. It has also helped Germany increase its domestic value creation, especially in rural areas.

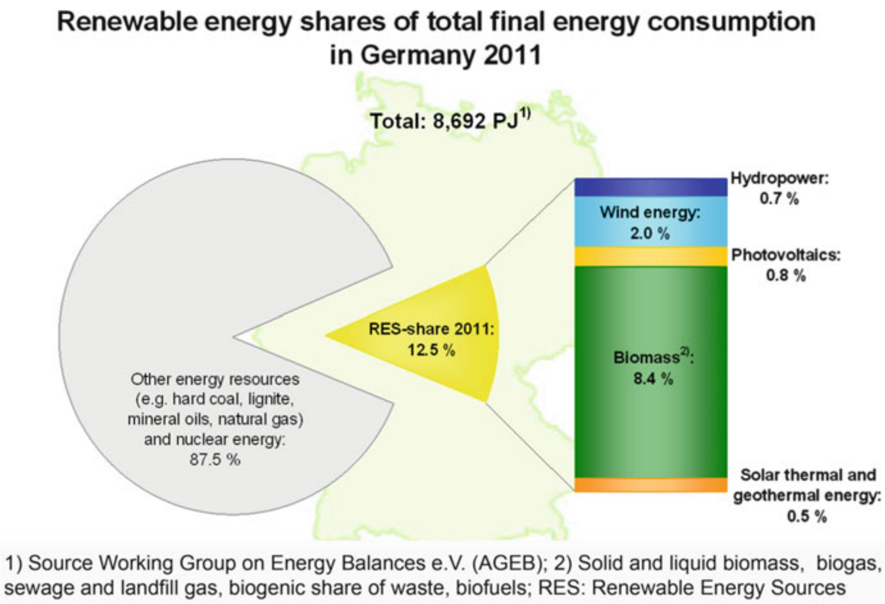

Fig. 1.2 Shares of renewable energies in relation to the total final energy consumption in 2011 (Source: BMU-KI III 1 based on working Group on Renewable Energy-Statics (AGEE-Stat) and Centre for Solar Energy and Hydrogen Research Baden-Württenberg (ZSW), according to AGEB (BMU 2012c); deviations in the totals are due to rounding; 1 PJ = 10^{15} J; as at: July 2012; all figures provisional)

The National Biomass Action Plan will be integrated into the German government's Renewable Energy Action Plan according to the requirements of the EU Renewable Energy Directive. The main goals are to:

- increase the percentage of renewable energy in electricity production to at least 30 % by 2020;
- use biofuels to further reduce greenhouse gas emissions in the transport sector; from 2015, biofuel quotas will be based on net greenhouse gas reductions rather than set relative to their energy content.
- increase the percentage of biofuels in the overall fuel consumption to reduce the net greenhouse gas emission by 7 % by 2020 (equivalent to approximately 12 % energy content).
- increase the percentage of renewables-generated heat from the current 12 % energy content.

Bioenergy met 8.2 % of Germany's final energy consumption needs in 2011 (BMU 2012c; Fig. 1.2). This amount will have increased by 2020 due to the targets stated in the EU Climate and Energy Package in April 2009 and in the German Integrated Energy and Climate Change Programme, which was launched in August 2007. Biomass is the most important contributor to the renewable energy mix (Fig. 1.2). Nuclear power's contribution to the energy mix has decreased by 30 % due to Germany's decision to abolish it. In contrast, owing to governmental subsidies, the total renewable energy supply (electrical and thermal power) grew by 9 % in 2011, which shows an

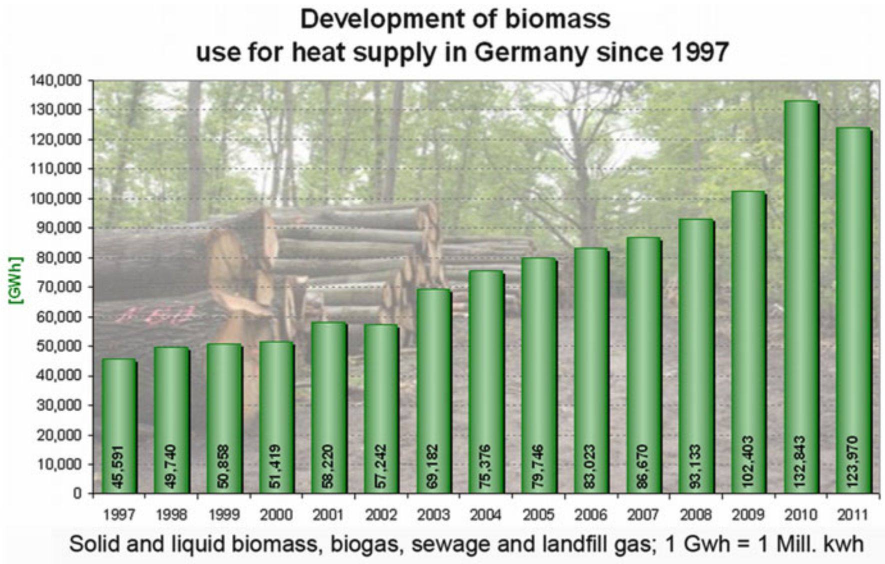

Fig. 1.3 Development of biomass use for heat supply in Germany since 2007 (Source: BMU-KI III 1 based on Working Group on Renewable Energy-Statics (AGEE-Stat); image BMU/ Brigitte Hiss; as at: July 2012; all figures provisional (Source BMU 2012c))

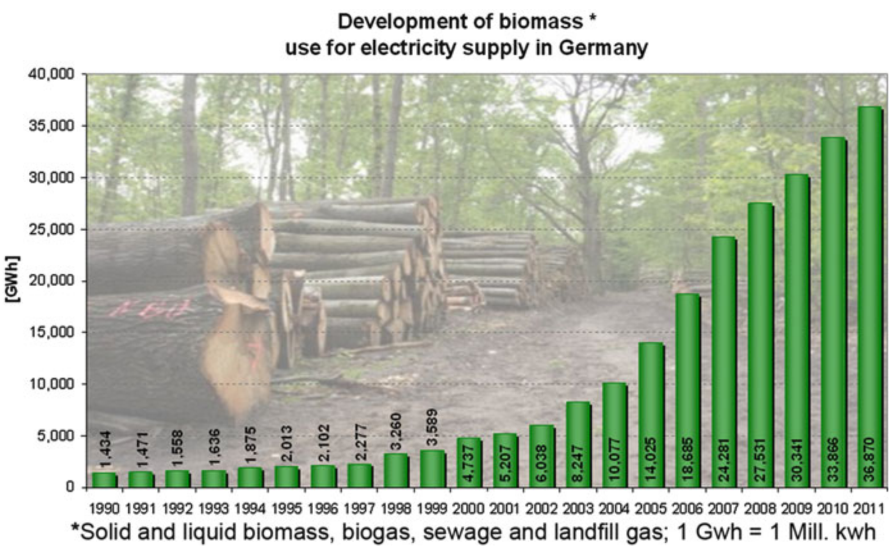

Fig. 1.4 Development of biomass use for electricity supply in Germany since 1990 (Source: BMU-KI III 1 based on Working Group on Renewable Energy-Statics (AGEE-Stat); image BMU/ Brigitte Hiss; as at: July 2012; all figures provisional (BMU 2012c))

impressive increase in the development of renewable energies to 12.2 % of the total final energy consumption. Figures 1.3 and 1.4 demonstrate the development of biomass use for the respective supply of heat and power over the last few years.

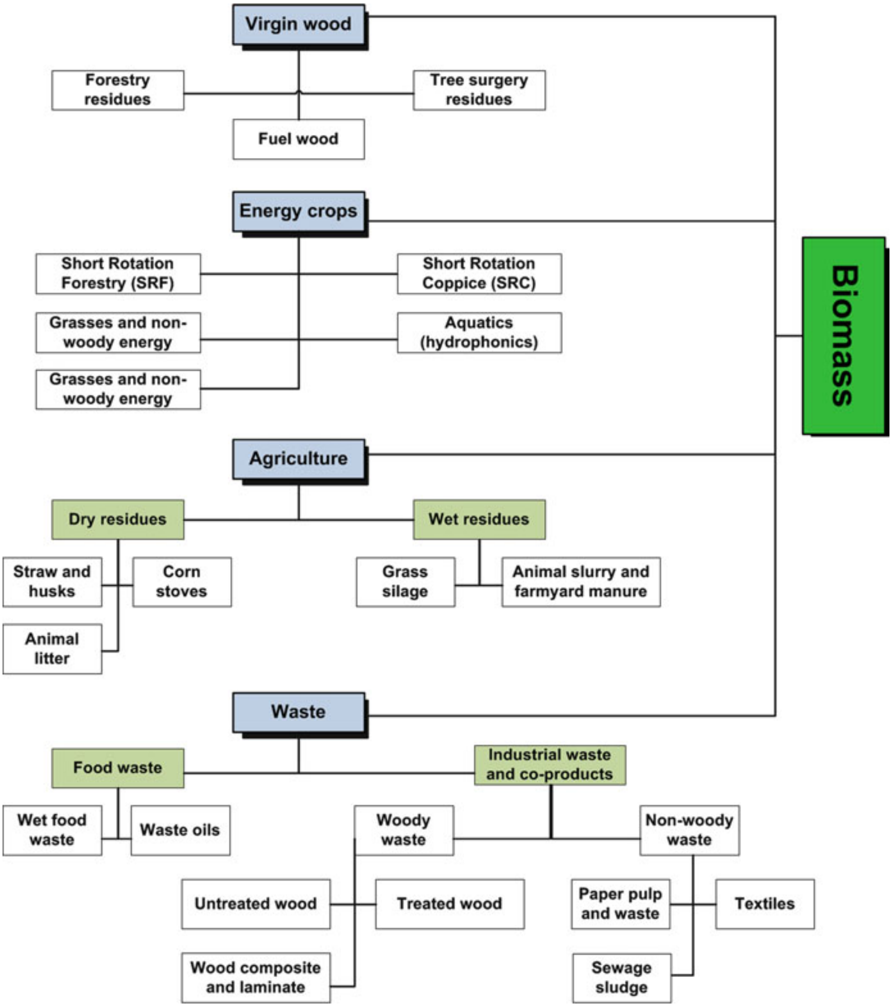

Fig. 1.5 Sources of biomass for the production of bioenergy (modified from Ladanai and Vinterbäck 2009)

The German Biomass Action Plan specifies the potential of biomass use in Germany and reveals Germany's strategies to promote bioenergy use in the heating, electricity and fuel sectors. Depending on the raw material used, biomass is a manifold energy source. Moreover, it can be used in many different technologies: wood is mainly used for heat production, biogas for both heat and power generation, while oil seed is used as biofuel in power stations.

According to Fig. 1.5, wood, agricultural sources (mostly energy crops) and wastes are the main sources of biomass (for an explanation of the biomass sources, also see Box 1.1). Figure 1.6 shows the ways in which heat, power and fuels are generated from biomass.

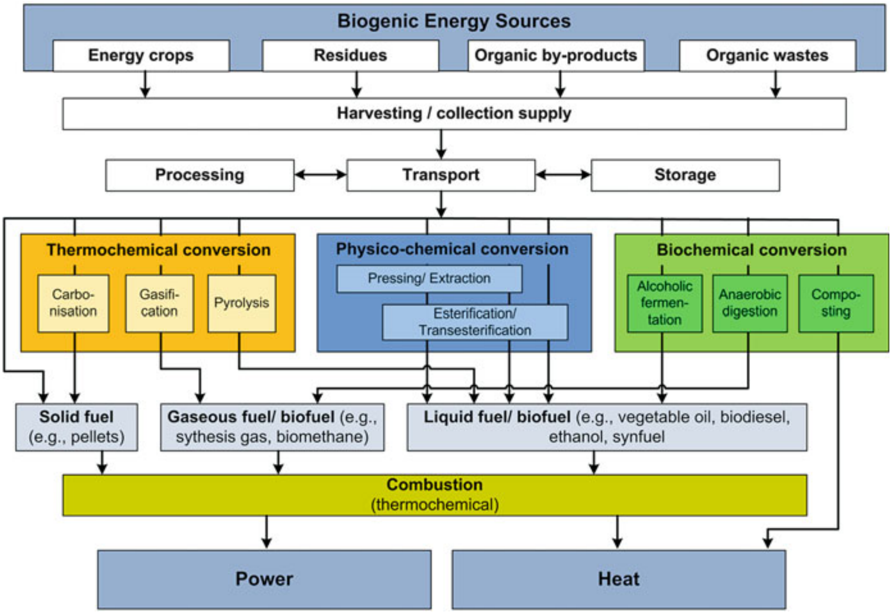

Fig. 1.6 Ways to provide heat, power and fuels from biomass (Modified from FNR/GIZ 2010)

1.4 The Promotion of Renewable Energies: Quota Systems and Feed-in Tariffs

According to the European Union's targets, renewable energy sources should comprise 20 % of the total energy supply by 2020 (European Commission 2012). At this stage, fossil energy production is still more cost-effective than renewable energy production. All countries should therefore have financial support schemes in place in order to "facilitate a sustainable development of energy supply, to reduce the costs of energy supply to the national economy, also by incorporating external long-term effects, to conserve fossil fuels and to promote the further development of technologies for the generation of electricity from renewable energy sources" (BMU 2012a).

All the individual countries in the EU have different goals and methods to achieve such schemes. Thus, each country also has its own means of promoting the development of its renewable energy sector. There are two general instruments that can be used to promote the use of renewable energies in the electrical power sector: the quota system and feed-in tariffs.

1.4.1 Quota System

Some European countries, including Great Britain, Sweden, Belgium and the Netherlands, have applied the quota system. The system requires energy operators and energy supply companies to share the quota of renewable energies to be contributed to the total electrical power supply. Therefore, each company is expected to contribute a specific percentage of electrical power generated from renewable energy sources to the power grid. The federal government defines this quota, which therefore varies from country to country. In some cases, the sharing quota depends on the type of renewable energy source, i.e. there might be different quotas for wind power and photovoltaic power.

The quota scheme rewards operators with certificates or penalises them, as this is known to stimulate the market and therefore reduce the total cost of changing the energy system. The reward and penalising approach is aimed at specifically promoting renewable energy systems with the lowest operating costs. In turn, this will facilitate access to markets without federal supply systems. Energy operators and energy supply companies can guarantee their quota if they produce the power themselves, or if they buy certificates from renewable installation companies. These certificates are therefore available on the market. Those energy supply companies that cannot guarantee a fixed quota, are penalised. The calculation of the certificates' prices and the penalties' amount differ significantly from country to country. These calculations are, however, the key factors for the success of the quota system and determine whether or not renewable technologies will be developed and will achieve their energy production targets.

The quota system not only applies to the electrical power sector, but also to the production of liquid biofuels. Fuel companies have to guarantee a certain percentage of biofuel in their gasoline. This percentage has been increased over the years to support the biofuel industry and to systematically reduce dependency on fossil fuel.

1.4.2 Feed-in Tariffs

Sijm (2002) defines feed-in tariffs as follows: "Usually, this term refers to the regulatory, minimum guaranteed price per kWh that an electricity utility has to pay to a private, independent producer of renewable power fed into the grid". Feed-in tariffs have been enacted in 50 countries, including Germany, Austria, Denmark, Canada and China. They have three key functions:

- To prioritise the connection to the grid system
- To appoint long-term contracts for electricity generation
- To base the purchase price on production costs.

1.4.2.1 Feed-in Tariffs in Germany

Feed-in tariffs were enforced in Germany in 1991 (BMU 2000). The Renewable Energy Sources Act (EEG), in which the feed-in tariffs are defined, was implemented in 2000. In order to address certain developments in the energy sector, including the federal decision to change the whole energy system from fossil-based to renewable-based production, the Act was amended in 2004, 2009 and 2012. The following key elements were added to the Renewable Energy Sources Act (BMU 2004):

- The prioritisation of the purchase and transmission of electricity
- The guarantee of a consistent fee – generally for a 20-year period – minus a degression rate
- The nation-wide equalisation of purchased electricity and the associated payable fee.

The main intention of the Act is to guarantee a high investment security for 20 years and to guarantee a tariff system that covers more or less all the installation and running costs over the 20-year period. This reduces installation companies' investment risks, because grid operators have to pay fixed tariffs for the feed-in of electricity from renewable energy sources. Moreover, the Act supports the installation of renewable energies and influences the quality of the production (e.g., of bioenergy) by adjusting the tariffs accordingly.

In principle, the fee that the grid operators have to pay depends on the energy source and on the installation size. Innovative technologies receive an additional bonus. Differentiated fee systems apply to bioenergy (see paragraph below). The fees generally depend on the materials used (bioenergy: variety of plants, wood, manure, etc.), the installation size and the installation type. The grid operators can take the additional expenses set by the Renewable Energy Sources Act into consideration in their charges for the use of the grid. Therefore, the total costs are apportioned to the electricity consumer.

A yearly degression rate, which depends on the energy source, reduces the costs. The reduction rate of all types of renewable energy varies if the costs of the technology decrease. The costs, for example, of installing photovoltaic systems have been reduced by about 65 % over the last few years (BSW 2012). Therefore, the degression rate was reduced several times between 2010 and 2012.

Since 2009, operators have had the opportunity to sell energy directly on the market at the price that the spot market determines plus a compensation payment. This firstly reduces the costs of the tariff-in scheme and facilitates entrance to the market. Furthermore, in 2012, a flexibility premium was established for bioenergy as it has the capacity to generate electricity on a demand basis. The aim of this is:

- to feed in electrical power when there is a high electricity demand, thus
- to reduce the amount of electricity that needs to be stored and
- to stabilise the grid by reducing the generation of power from biogas plants if too much electricity is generated by wind and solar power.

Figure 1.7 illustrates the share of the renewables according to different consumption schemes. It is noteworthy that electricity consumption is increasing continuously. In 2011, wind, photovoltaic, bioenergy and hydropower already provided 20.3 % of the gross electricity consumption. The percentage of wind and photovoltaic power also shows a rapid increase.

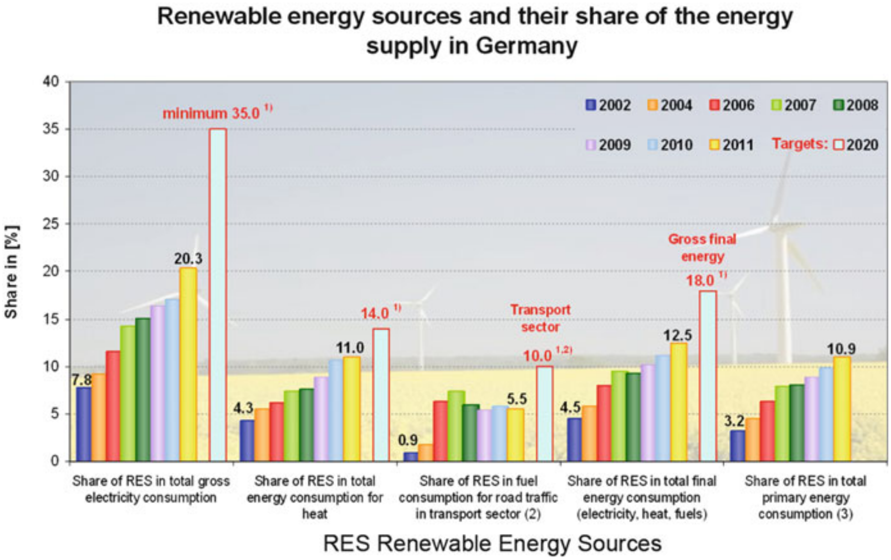

Fig. 1.7 Renewable energy sources and their share of the energy supply in Germany (Sources: Targets of the German Government, Renewable Energy Sources Act (EEG); Renewable Energy Sources Heat Act (EEWärmeG), EU-Directive 2009/28/EC, Total consumption of engine fuels, excluding fuel in air traffic, calculated using efficiency method; Source: Working Group on Energy Balances e.V. (AGEB)) (Source: BMU-KI III 1 based on working Group on Renewable Energy-Statics (AGEE-Stat); image BMU/Brigitte Hiss; as at: July 2012; all figures provisional (BMU 2012c))

1.4.2.2 Feed-in Tariffs in the Bioenergy Sector

The Renewable Energy Sources Act (EEG) has set different fees for the use of bioenergy, depending on the input material used. The biomass ordinance "regulates which substances are classed as biomass, the substances for which an additional substance-based tariff may be claimed, which energy-related reference values are to be used to calculate this tariff and how the substance-based tariff is to be calculated, which technical procedures for electricity generation from biomass fall within the scope of application of the Act and which environmental requirements must be met in generating electricity from biomass" (BMU 2012b). As mentioned above, the EEG promotes the quality of bioenergy production. Since 2012, bonuses are only paid if 60 % of the electricity is generated from combined heat and power plants, or if manure is used to generate 60 % of the electricity in biogas installations. Furthermore, maize, including corn-cob mixes, may not comprise more than 60 % of input substances in biogas installations (BMU 2012a).

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