Chapter 2
Demand for the Flexible Provision of Bioenergy Carriers: An Overview of the Different Energy Sectors in Germany

Martin Dotzauer, Karin Naumann, Eric Billig, and Daniela Thrän

Abstract Today bioenergy is the most important renewable energy carrier in Germany and yet it is mostly provided constantly as a base load, for example most biogas plants are in constant production at full load. In numerous ways, bioenergy could be a flexible option to satisfy the fluctuating demand for electricity, heat and transport fuels. In the power sector, biomass is a short-term option to meet the increasing need for flexible power generation, while wind or solar power are characterized by an alternating feed-in. Biogas plants in particular are ideal for providing power on demand for a stable electricity provision with a high percentage from renewables. The heat sector is well established for heat only provision, but has to integrate future combined heat and power concepts. Therefore, an optimal alignment between heat and power generation is required, if a high overall performance is to be achieved. Furthermore, the general decrease in heat through efficiency measures will change the way in which heat will be generated with more versatile load curves where flexible energy provision is favoured. In the transport sector flexibility is necessary in the form of a varying feedstock basis for consistent liquid biofuel products. For example, bioethanol could be made from sugar beets or cereals, where sugar, or starch converted into sugar, is processed by fermentation into alcohol. Second generation bioethanol is based on cellulose enzymatic split into single sugar molecules. Additionally, biomethane as a potential substitute for natural gas can be applied in different sectors and is predestined for flexible energy provision. A local and temporal decoupling of energy source generation, the well-established gas grid

M. Dotzauer (✉) • K. Naumann • E. Billig
Deutsches Biomasseforschungszentrum GmbH – DBFZ,
Torgauer Str. 116, 04347 Leipzig, Germany
e-mail: martin.dotzauer@dbfz.de; karin.naumann@dbfz.de; eric.billig@dbfz.de

D. Thrän
Department of Bioenergy, Helmholtz Centre for Environmental Research – UFZ,
Permoset Straße 15, 04318 Leipzig, Germany

Deutsches Biomasseforschungszentrum – DBFZ, Torgauer Straße 116,
04347 Leipzig, Germany

Bioenergy Systems, University of Leipzig, Grimmaische Straße 12,
04109 Leipzig, Germany
e-mail: daniela.thraen@ufz.de

D. Thrän (ed.), *Smart Bioenergy*, DOI 10.1007/978-3-319-16193-8_2

and the interchangeability with natural gas are all aspects that support this. It is expected that the different markets for power, heat and fuels will be more closely linked by the mid term. Here, some additional combinations of bioenergy with other renewables (i.e. power-to-gas) can provide flexible energy in different sectors additionally.

2.1 Introduction

Since the use of renewable energy sources has been recognized as playing a major role in counteracting climate change, in many countries the direction and design of the energy policy framework has been adapted in favor of promoting renewable energies, leading to ambitious targets for renewables to account for a larger share in the overall energy mix. Furthermore, in terms of the provision, use and integration of bioenergy, the specific political framework conditions are very relevant. Today, biomass is applied for the provision of electricity, heat and transport (see Chap. 1). Bioenergy is already highly relevant in all three final energy sectors and in terms of the transition targets for energy systems, the different markets are affected in different ways. Additionally, the substitution of natural gas with biomethane is of increasing interest, because it enables the renewable carbon carrier to be applied in many different fields. In this chapter, the four energy markets (electricity, heat, transport fuels and biomethane) are described, including the regulatory frameworks, their significance for renewable energy provision, the spatial impacts on particular markets as well as the necessary technical requirements.

The analysis focuses on the market situation in Germany, also including the European conditions. Germany is a country with a high population density and a high energy demand from different industries. In 2012 the total primary energy consumption in Germany amounted to 13,757 PJ. Germany has very little fossil energy resources of its own. The most important sources for energy provision are mineral oil (33.0 %) and natural gas (21.5 %), which are mainly imported. Between 1990 and 2012, the share of renewable energy within the German energy system has increased more than tenfold – from 1.3 % to 11.6 % of primary energy consumption

Table 2.1 Status quo and targets for the transition towards renewable energies and bioenergy in Germany (Based on [1] and [2])

	Status of renewables in 2010/2012	Renewable energy target 2020	Bioenergy target 2020
	Share of renewables in the final energy demand (%)	Share of renewables in the final energy demand (%)	Share of bioenergy in the renewable energy section (%)
Electricity generation	16.8/22.6	38.6	22.8
Heating and cooling	9.8	15.5	78.7
Transport	5.8	13.2	Almost 100

[3]. The German national renewable energy action plan (nREAP) of 2010 includes commitments to targets for renewable energies and for bioenergy in various energy sectors by 2020 (Table 2.1). By 2020 the share of biomass is expected to account for almost 10 % of the total final energy consumption (8,859 PJ) in Germany [4]. Thereby, biomass shall contribute with 22.8 % to the electricity sector, 78.7 % to the heating and cooling sector and almost exclusively provide for the transportation sector with almost 100 % [2].

2.2 Electricity Market

2.2.1 The Political Framework

The provision of electricity from renewables is backed up by Europe's Renewable Energy Directive [5], which sets targets for renewable energy in gross final electricity consumption of at least 20 % by 2020. National targets are not specified there, but the methodology to create national energy action plans describes how to determine overall targets in different sectors.

The national regulatory framework for the provision of renewable electrical energy in Germany is first of all determined by the Renewable Energy Sources Act ("Erneuerbare Energien Gesetz" – EEG) [6]. The EEG Act first became effective in 2000. The EEG Act supports the provision of electricity from biomass in "bioenergy-only"-plants with a power capacity of up to 20 MW. The two main features are the feed-in priority for electricity from renewable power plants and a system of guaranteed feed-in tariffs for different technologies as well several plant sizes. Both aspects ensure that renewable electricity has an advantage over power from nuclear and fossil fuels and thus strongly support market access. The reward system for biomass plants considers the year that operations started, the scale of the conversion plant and the type of biomass used for production. Furthermore, there are several kinds of additional rewards, for example for upgrading from biogas to biomethane, for coupling out of heat for external use and for innovative technologies, which have been integrated by amendments in 2004, 2009 and 2012.

With the amendment of the EEG in 2012 a more market-oriented operation of power provision from biomass was targeted. Therefore, a new reward concept was implemented to support the direct marketing of electricity through the market bonus. The market bonus counterbalances the distribution between spot market prices and the general fixed reward. It is set to the difference between the average monthly price and the fixed reward. Under direct marketing a management bonus is provided as an incentive and to compensate the distribution costs. Additionally, biogas plants can receive a flexibility bonus, when they have the ability to shift the power feed in. The flexibility bonus enables plants to operate below full capacity, to regulate their power according to fluctuant prices on spot markets as well as fluctuating demand [7].

2.2.2 The Market Situation

In 2012 the share of renewable energies in the electricity market grew to account for 22.6 % of Germany's energy mix as shown in Fig. 2.1. Although bioenergy has a relatively small amount of installed capacity (10 %) among the renewable energies compared to wind or solar power, due to its high full load hours (about 7,500) it has a relatively high percentage (31 %) of overall renewable power feed-in.

The provision of renewable power generation from biomass includes electricity generation from biogas, solid fuels and liquid fuels and is carried out in combined heat and power installations as well as in electricity-only installations. The co-combustion of biomass in fossil-fuel plants is not supported and therefore only plays a minor role. The generation from biogas accounts for almost two thirds of all installed capacity and even more of the produced energy (Table 2.2). Biogas plants are evenly distributed across Germany, many of which are representative of the average plant size (0.41 MW). Here, decentralised combined heat and power units using biomethane have been included. A greater focus on the biomethane market on the whole will be provided in Sect. 2.5.

Solid fuel plants provide around one third of the installed capacity and a little less of the produced energy. The average plant size of 2.9 MW results from a large variety of installed capacities in the portfolio of plants.

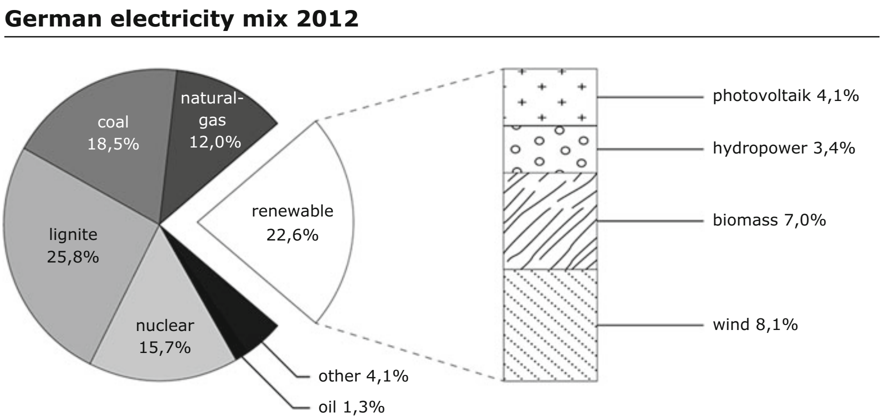

Fig. 2.1 Germany's electricity mix in 2012, share of power produced (Source: Agency for Renewable Energies [8])

Table 2.2 Biomass plants' statistics 2012 [9]

	Count	Capacity	Average size	Feed-in
	[n]	[MW]	[MW]	[TWh]
Biogas	7,400	3.1	0.41	23.1
Solid fuels	540	1.6	2.9	8.4
Liquid fuels	1,050	0.17	0.16	0.25

Even though liquid biomass could be operated as flexible as or even more flexibly than biogas, it has not played such an important role in the recent development of flexible bioenergy provision. A global perspective of the liquid biomass sector is given in Sect. 2.4.

2.2.3 Future Markets for Electricity from Biomass

The transition of power generation from more renewables also leads to different supply patterns: Historically speaking, the electricity supply in Germany could be divided into the base load supply from power plants running 8,000 h per year and the peak load supply that was only added at times of higher demand. The highest demand for power typically occurred during the daytime in winter, peaking in the late afternoon (Fig. 2.2, left). Typically, the base load supply was provided by coal and nuclear power plants, whereas the peak load supply came from natural gas installations. With the increasing supply from wind and solar power, the supply pattern changed to variable proportions of wind and solar power and a remaining demand to be covered by flexible and controllable power plants – the so-called residual load. Due to the sunlight dependency of solar power, the residual load is at a minimum during noon (Fig. 2.2, right), and can also become negative on sunny day, when the demand for power is generally low (i.e. on Sundays or holidays). Future markets for renewable electricity will therefore have to focus on an efficient supply of the residual load from biomass and other flexible provision options.

So far biomass plants have been running 8,000 h per year, but within the announced change in renewable power provision from the feed-in priority with fixed tariffs to a more market-oriented model, the question is really which markets would

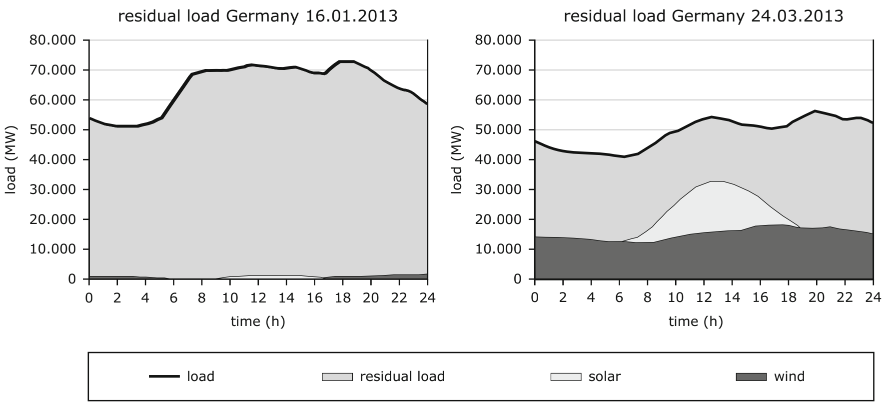

Fig. 2.2 Recent residual loads in Germany under different consumption and renewable feed-in patterns [10]

be most suitable for the different biomass plants. Electricity markets are sub-divided into energy-only markets for the trade in energy and markets for control reserve (see also: https://www.entsoe.eu/fileadmin/user_upload/_library/publications/entsoe/Operation_Handbook/Policy_1_final.pdf and https://www.regelleistung.net/ip/action/static/marketinfo)

Energy-Only Market Electricity markets in Central Europe and Germany can be subdivided into electricity that is traded "over the counter" (OTC) or through power exchanges that are organised markets (PXs). There are two main segments in power exchanges for electricity. The future market, for advance trading for up to 6 years ahead is located at the European Energy Exchange (EEX) in Leipzig [11]. The relevant spot-market for short-term trading is located at the European Power Exchange (EPEX) in Paris. For a flexible provision of electrical energy, the relevant market is European Power Exchange, where electricity is traded within a one-price auction. The order is structured by individual hours for day-ahead trading [12]. There is also an intraday market with quarters of hours, but normally this is too quick for biogas plants to react to price signals and to schedule their production accordingly. To participate in these markets a certain amount of power has to be provided.

Markets for Control Reserve Besides the energy supply, some electricity is also needed to provide a secure power-supply infrastructure. For network operation, control reserve is necessary to balance forecast errors for power generation and consumption, because of the need for an anytime equilibrium of feed-in and the delivery of electrical energy. Control reserve is needed at the top level of network topology in the distribution network. In Germany, there are four distribution network operators that enable the demand for control reserve to accumulate in an announcement. A distinction is made between primary control reserve, secondary control reserve and the minutes reserve [13].

In the upcoming transformation of electrical power production in Germany and Europe, wind and solar power have also gained importance. The main reason for this can be said to be a largely absent marginal cost of production because wind and solar power have no fuel costs at all. On the other hand, these two types of renewable energies are produced erratically and not always in line with demand patterns. For this very reason a range of flexibility options are required, for example: demand-side management, network expansion, energy storage and flexible power plants [14]. From a short-term perspective, flexible power could be met from fossil and renewable sources, but from a long-term perspective this task should be transferred exclusively to renewable power plants.

2.2.4 Options for Integrating Biogas into the Future Power Supply

Biogas plants are technically predestined for this challenge, because they provide a storable energy carrier (biogas), converted into engines showing a short response time for changing demand. Furthermore, the ability to serve control reserve as well as other system services makes them a versatile and rapidly realizable component of the future energy system [15].

Fundamentally, a flexible operating biogas plant is based on balancing the installed capacities of biogas production and biogas conversion into electricity, by converting a continuous energy provision from fermentation to an alternating mode of operation of the combined heat and power (CHP) provision with a higher amplitude in a shorter period of time (Fig. 2.3).

Depending on the demand of the energy market and marketing there are different options for this flexibilization from several minutes to seasonal shifts, requiring different adjustments to the concepts of the biogas plant (Table 2.3). In terms of marketing it has to be taken into account that biogas plants are usually too small to participate on their own in this marketplace, but specialized marketers have started to pool several biogas plants to contribute to the spot market. Additionally, for control reserve, several requirements have to be fulfilled to meet the pre-qualification for participating in this market. Because of the minimal size of bids (also for control reserve), biogas plants are pooled together to reach a minimum size, by marketers. For the moment, the main reasonable products to serve are negative secondary control reserve and both positive and negative minute reserves [16].

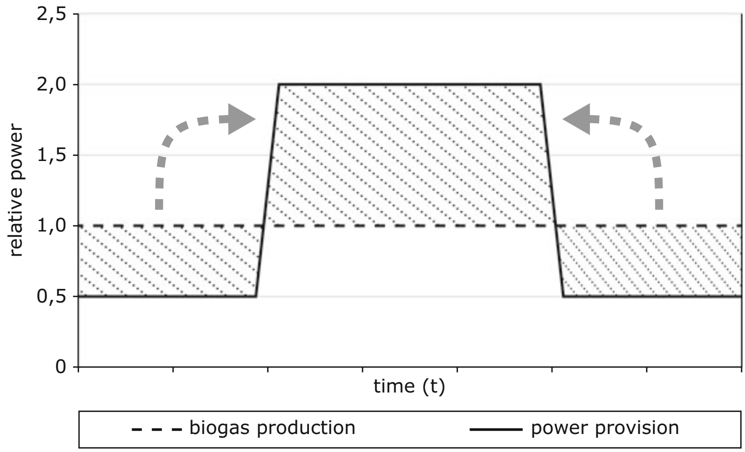

Fig. 2.3 Flexible mode of operation of biogas plants

Table 2.3 Different kinds of flexible power for biogas

Provision/Shift	Marketing	To balance	Additional technical demands
Up to 5 min	Secondary control reserve	Net frequency	Control gateway
5–15 min	Minute reserve	Net frequency	Control gateway
15 min – 6 h	Intraday	Forecast error	Gas storage
6–24 h	Day ahead	Residual load	CHP-capacity, heat storage
1–7 days	Day ahead	Macro weather situation	Feeding management
7–90 days	Day ahead	Seasonal demand	Feeding management

For the conception of flexible power generation from biogas different technical options are available and under development (discussed in Chap. 5).

2.2.5 Options for Integrating Solid and Liquid Biofuels into the Future Power Supply

Liquid biofuels could also be used in stationary engines, producing heat and power (CHP). In Germany, more than 2,000 CHPs using vegetable oils were installed in support of Renewable Energy Resource Act until 2012 (renewable energy law). Currently, approx. half of them are still operating with vegetable oils. Due to increasing prices, a large number of plants are not operating or have been converted to alternative renewables or fossil fuels [9].

CHPs are adapted for the flexible provision of heat (e.g. residential buildings, schools, market-gardens) as well as the demand-driven provision of electricity and are able to operate with vegetable oil as well as other liquid bioenergy carriers such as used cooking oil, animal fat, pyrolysis oil, biodiesel and bioethanol or solid and gaseous bioenergy carriers. Liquid biofuels can be stored easily and converted in standard diesel engines. As a result, they can provide flexible power for a comparatively high number of applications as biogas can. Liquid biofuels however are regarded as one of the options for the transition of the transport sector and because of this possible feedstock competition, the provision of electricity might not play a major role in the near future [17].

The thermo-chemical conversion of solid biomass plants could also contribute to flexible power generation. At the moment there are a lot of uncertainties about the theoretical potential and the determining factors that influence the flexible power provision of solid biomass plants, so that their contribution is expected to be more for the mid-term or long-term power adjustment strategies. A more detailed description is given in Chap. 4.

At the moment support schemes are neither envisaged for liquid nor for thermochemical conversion for greater flexibility among German renewable energy resources [18].

2.3 Heat Market

2.3.1 The Political Framework

In line with the European Renewable Energy Directive, Germany's national renewable action plan aims to increase the renewable energy share for heating from 9.1 % in 2009 to 15.5 % in 2020 [2]. This aim is supported by a combination of different regulations, including increasing energy efficiency and building insulation [19], integrating renewables for heat supply in new buildings [20] and investment support for low emission bioenergy stoves and boilers at different scales and for the district heating infrastructure [21]. The development of heat provision from biomass does not depend so much on support schemes but on emission control regulation, especially for the small-scale sector. The framework background tightens the emission protection enactment, which stipulates minimum energy efficiency and the lowering of emission limits for carbon monoxide and particulate matter [22]. Therefore, it becomes more expensive to adhere to strict limits, resulting in additional technical and economic expenses.

2.3.2 The Market Situation

In 2012 Germany's heat generation was covered by 10 % (or the equivalent of 144 TWh) from renewables [23]. A major proportion of that was contributed by solid biomass, see Fig. 2.4, with liquid and gaseous fuels playing only a minor role. Heat provision from biomass is mostly used for residential heating applications for a temperature level range of between 60 °C and 110 °C. Statistically, heat generation for industrial purposes from biomass, well above 100 °C today has a negligible impact [24]. The common form of usage in households is for small to medium stoves or boilers within the range of a few kilowatts to 100 kW. Heat generation on a larger scale above 100 kW includes heat generation solely for process and general heating purposes, as well as combined heat and power generation for electricity and heat provision.

2.3.3 Development Trends

The development of heat provision from biomass is influenced by the improvement in building insulation, emission reduction targets for biomass stoves and boilers, market conditions for combined heat and power installations based on biomass,

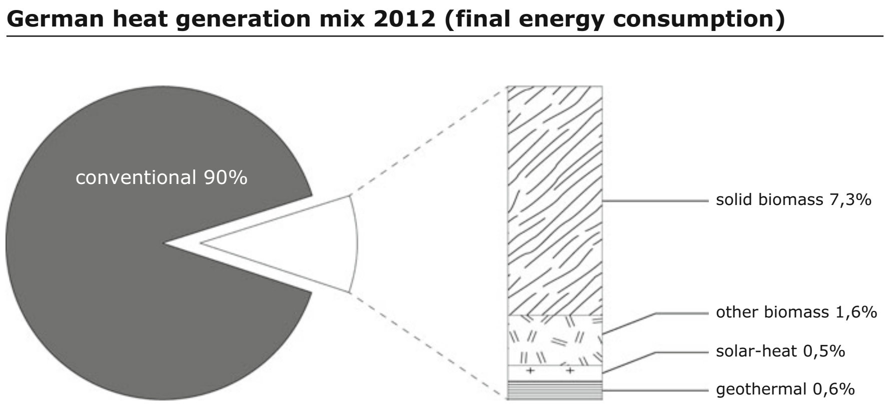

Fig. 2.4 Renewable energy provision for heating in Germany in 2012 (Data by [9])

targets for renewables in the heat sector and the market development of renewable heat provision from other sources (heat pumps, solar collectors etc.):

For the mid-term, it is presumed that a 45 % decrease for all heating sectors can be reached if ambitious restoration targets can be realized [25]. Most savings can be achieved in the building sector. For a current inventory of buildings it is supposed that most of the heat is needed for space heating and that the hot water supply is of minor relevance. If in the future, restoration and thereby insulation levels are improved, the demand for heating will generally decrease. This would also lead to a lower seasonal demand trend, with a more constant need shown for the amount of hot water usage. Furthermore, mixes with other renewable heat sources such as solar heat, geothermal heat, heat pumps and the conversion of excess electrical energy from power to heat will all increase [26]. Experiences from the past lead to the expectation that the transition in the heat sector will take place much slower than in the electricity sector. Today, the relative primary energy demand in Germany has an average of 260 kwh/(m^2*a), which is in line with the energy efficiency guidelines for new buildings (according to the EnEV 2009) that stipulates the use of less than 80–90 kWh/(m^2*a) [27].

2.3.4 Flexibility

The heat demand in the residential sector is characterised by seasonal, weekly and daily shifts. In case of a sole heat generation, the flexible heat provision covering exactly this demand is already state of the art. When compared with electricity, the storage and distribution is easy using hot water tanks, so called buffer-storage systems. Nevertheless, the specific demands and costs increase with decreasing heat provision capacities, which are expected in the future. In the case of a combined heat and power generation from biomass, it is usually the plant size and operational mode that are adapted to the demand characteristics of the heat sink. If CHP is going to change to a flexible power-guided operation mode, then it can be expected that there will sometimes be a mismatch between heat and electrical demand patterns. In this case, two different approaches are available for these conflicting goals. The first option is to add a secondary heat source to the given application, bridging emerging gaps in heat provision. This is state of the art in many concepts, where biomass serves the basic thermal load and already a pool of stoves or boilers act together to provide an all-season supply with variable demand. The second option is to install heat storage to counterbalance temporary mismatches. Both options require an individual strategy to quantify the particular need of additional demand and storage capacity respectively. A third way could be to create an integrated management that automatically takes into account both electricity and heat demand patterns [28].

2.4 Biofuels Market (Transport Sector)

Biofuels in the transport sector are characterized by a wide range of technical options with different maturity and market implementation stages. With regard to the actual market, biodiesel (fatty acid methyl esters – FAME), bioethanol and hydrogenated vegetable oils (HVO) have been introduced onto the market and will be described in the following. Additionally, biomethane can be used as a transport fuel, which is covered in Sect. 2.5.

2.4.1 The Political Framework

Numerous countries have defined national targets and mandates to increase the use of biofuels over recent years. The motivation of governments for setting such targets and implementing mandates consists mainly of (i) the desire for less dependence on importing fossil fuels, (ii) the security of supply and national added value and (iii) climate protection. The priority of these goals differs between countries and regions.

The European Union in particular has pursued an ambitious biofuel policy, adopting the relevant directives in 2009 to ensure a renewable fuels quota in the transport sector of 10 % (energy content) until 2020 in all member states [29]. In addition, specific sustainability criteria for biofuels have been defined. Biofuels and bio liquids taken into account for the quota should meet the specific requirements for the cultivation area and the cultivation practise for energy crops and a minimum of greenhouse gas emissions savings from the overall process chain (also see Sect. 3.3.2).

More sustainability requirements are discussed, for example social standards and emission factors to take into account the effects of indirect land use change.

There is also the possibility of double counting fuels from residues and waste materials [29]. The status of implementing the European Directive in national law differs between Member States. Therefore, the full impact has not yet been achieved [30].

Currently in Germany biofuels are to substitute 6.25 % (energy content) of the fossil diesel and petrol in the transport sector. In 2015 this regulation will be replaced by a quota for greenhouse gas reductions, which requires a 3 % reduction in greenhouse gas emissions from total fuel consumption using biofuels, 4.5 % from 2017 and 7 % from 2020 [1].

Different national and international standards define the minimum quality of current biofuels like e.g. biodiesel (FAME/HVO) and fuel ethanol or pure vegetable oil, bio-methane and Dimethylether. Thereby, a blending of fossil fuels with biofuels varies greatly depending on the market, e.g. in Brazil there are 18–25 % blends of ethanol in petrol [31] and a rapidly rising share in flex fuel vehicles (a tenfold increase in sales over the last 10 years, more than three million in 2013 [32]).

2.4.2 The Market Situation

The biofuel sector grew strongly over the period 2000–2010 –not only worldwide but also in Germany. Since 2010 output has increased moderately. Furthermore, a huge part of installed production capacity remains unexploited. So far, fossil fuels are largely substituted by bioethanol and biodiesel (Figs. 2.1, 2.2, 2.3, and 2.4). America is the focus of fuel ethanol production (in the U.S. primarily from corn and in Brazil primarily from sugar cane). In 2012 5 % of global production was realized in the European Union (mainly from cereals and sugar beet). Biofuels are globally traded, with imports of 1–2.5 million tons FAME and some 100,000 t to Europe over the last 3 years [32]. The global raw material base for biodiesel was composed of 28 % rapeseed oil, 32 % soybean oil, 22 % palm oil and 13 % animal fat and used cooking oil.

In Germany, pure vegetable oil and pure FAME (B100) represented a large proportion for energy consumption in the transport sector until 2008. From 2009 this decreased rapidly due to modified tax regulations and rising international prices for vegetable oils that were particularly used for trucks and agricultural machinery. In 2012 5.4 % (of energy content) of the transport fuels were substituted by 83.4 PJ/y biodiesel and 33.9 PJ/y bioethanol [33]. The domestic production included 101.1 PJ/y FAME and 16.8 PJ bioethanol [34]. Smaller amounts of biomethane were also used (see Sect. 2.5).

In 2011 approximately 3 % of the global transport energy was provided by biofuels. Their production volumes and the overall demand of the transport sector in 2011 are summarized in Figs. 2.5 and 2.6.

Current research and development activities focus on second generation biofuels from waste and residues and lignocellulosic biomass. At the same time, bioethanol and biodiesel consumed as a blend in road and rail transport has increased. The utilization of alternative fuels in further transport sectors such as shipping or aviation are increasingly under discussion [10].

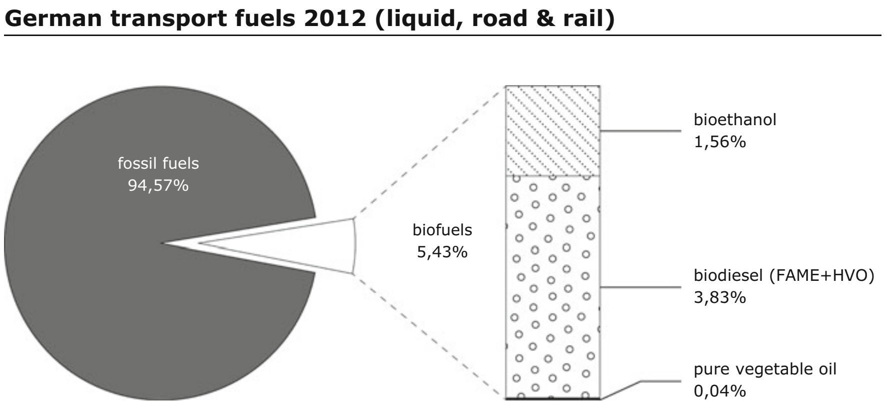

Fig. 2.5 National use of transport fuels in %, 2012 (Data from [21])

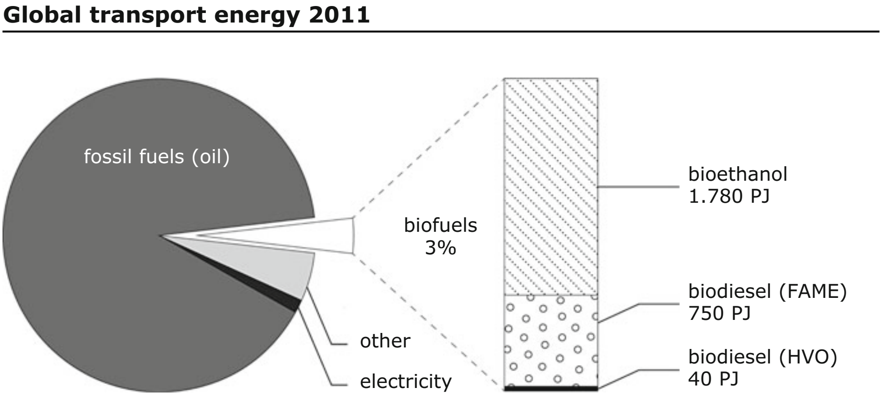

Fig. 2.6 Global energy demand of the transport sector, 2011 [6, 35]

2.4.3 Development Trends

The changeover of the biofuels quota in 2015 in Germany is associated with a number of uncertainties. On the one hand, the sub-mandates for biodiesel and ethanol fuel no longer exist. On the other hand, costs for reducing greenhouse gas emissions instead of purely the biofuel costs themselves will become important for shaping the market. Additionally, the publication of the proposal amending the renewable energy directive and the fuel quality directive in 2012 [36] as well as the policy framework for climate and energy [37] have caused great uncertainty regarding the political framework for biofuels after 2020.

By contrast, the transport sector in particular depends on propulsion systems that rely on carbon energy sources. Therefore, biofuels have a medium-term significant relevance in the transport sector, as well as other alternative fuels. Resource availability is of key importance for the specific alternatives. For example the use of biojet fuels in commercial aviation has received considerable attention in recent years. Consequently, almost all major commercial airlines and also some military sectors (i.e. in the USA), are heavily involved in testing and developing biojet fuels. Given the nature of the high quality drop-in fuels required in aviation, conversion technologies for the provision of jetfuels from biomass are rather limited, but not the main obstacle. Major advances are also necessary in terms of logistics, regulatory frameworks, quality assurance and the adoption of appropriate sustainability certifications, because any kind of biojet fuel market will become a global one [38].

2.4.4 Flexibility

Biofuels are suitable for storage and transportation over long distances in a similar way to fossil fuels. Biofuels and the majority of their feedstocks are traded on international markets as renewable energy sources as well as commodities (ethyl alcohol).

Thereby, the provision of biofuels is not coupled with utilization regarding the spatial and temporal scale.

The flexibility of biofuel production in terms of space and time is not as relevant as the flexibility of providing heat and electricity. The production of biofuels implies the conversion of biogenic raw materials to biogenic energy carriers generated by different technologies. Normally the raw materials, intermediate products and completed biofuels are suitable enough for storage and transport and therefore these commodities can be traded internationally. The production of biofuels is to a large extent decoupled from their utilization; thereby a systemic flexibility occurs regardless of the conversion technology.

Nevertheless, more flexibility will be more important within the production process with regard to the use of various raw materials in multi-feedstock plants. For the mid-term perspective, the coupled production of various products in one plant/bio-refinery will also be an interesting option for developing bioeconomy approaches. For certain resources commitment has already been shown. These circumstances enable an optimized operation of the plants regarding adjusted input and output depending upon the availability and the prices of raw materials as well as the demand and the revenue from products. Chapter 7 deals with technical options and requirements for a flexible production of liquid and gaseous biofuels.

2.5 Biomethane Market

Biomethane is defined as methane produced from biomass [35], with properties close to natural gas. When produced by thermal conversion (e.g. gasification), the methane-rich product gas is normally referred to as biobased synthetic natural gas (bio-SNG), whereas when it is produced by biological processes, including landfills, the initial product is raw biogas which must be cleaned (normally called upgrading) to reach the high methane content that is referred to as biomethane from biogas upgrading. Both processes can produce up to 99.9 CH_4 rich gases. Currently, the biochemical process is common practice, whereas thermochemically produced gas is still at the research and development stage. Focusing on the market aspects, this chapter will concentrate on biomethane produced by the biochemical process. Section 8.3 gives a more profound insight into the two different possibilities for producing biomethane from biochemical and thermochemical conversion.

2.5.1 The Political Framework

So far there is still no consistent biomethane strategy, certification and technical minimum standard in the European Union. Therefore, the situation regarding the biomethane market with its boundary conditions distinguishes between the member states, but it is still at a very low level – with Germany as the largest producer in Europe.

The German government has set the target of annually injecting 6 billion m^3 of biomethane into the natural gas grid by 2020, or 10 billion m^3 by 2030 respectively [39]. It is promoted for two markets: on the one hand biomethane is used for electricity, incited by the Renewable Energy Source Act (EEG), and on the other hand the fuel market, incited by the Biofuel Quota Act (BioKraftQuG).

Technical standards for biomethane ensure that the physical properties of the natural gas are met when it is injected into the grid. Primarily, they depend on the in-situ properties of the locally-used natural gas that the biomethane will substitute. In Germany, natural gas is distributed in two different gas qualities, low-gas (L-gas) and high-gas (H-gas) as a result of the different natural gas origins (mainly the North Sea and Russia). The specific national directions determine the gas standards for the upgraded biogas for injection into the gas grid. When used as a fuel, the DIN-51624 (automotive fuels – compressed natural gas) is applied. To pave the way for a European trade and exchange of biomethane, uniform product standards are being discussed intensively [40].

2.5.2 The Market Situation

In 2012 the consumption of natural gas in Germany amounted to 3.3 million TJ (equivalent to ~90 billion m^3 of natural gas), which is an increase in 4 % compared to 2011. Around 90 % of the natural gas used in Germany is imported from Russia, Norway and the Netherlands, see Fig. 2.7. With 21.5 %, natural gas covers more than 1/5 of the total energy consumption in Germany. Although the total energy

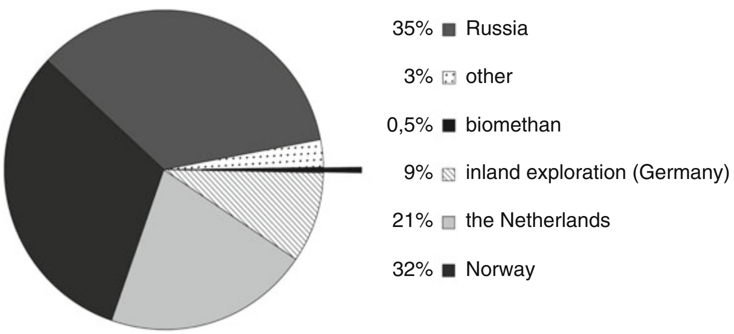

Fig. 2.7 The origin of natural gas in Germany [41, 42]

consumption has been declining since 1990, a slight increase in natural gas consumption during this time can be observed. Hence, the relevance of natural gas as an energy provider is also increasing. Natural gas is used for heating, electricity production and transport in the private, industrial and public sector. Furthermore it can be used in the chemical industry for other purposes. Because it is used for heat, the consumption of natural gas fluctuates depending on the seasons and the weather. Therefore, big gas storages, mostly underground are used [41, 43, 44].

In Germany the first biogas plants that were upgraded to biomethane were implemented in 2006. Since then a steady increase in these plants can be observed. At the end of 2012 120 biogas plants for biogas upgrading were in operation [9]. The majority of these plants injected the gas produced into the national gas grid and only a small percentage of plants directly delivered the biomethane to gas filling stations. About 413 million m^3 STP (standard temperature and pressure) of biomethane were injected in 2012 [42]. This accounts for approx. 0.5 % of the annual natural gas consumption in Germany.

2.5.3 Development Trends

With a further transition of the German energy system towards more renewables intended, an increasing importance of natural gas and a further development of the infrastructure are given. So far the development of biomethane injection over recent years has been slower than the pace required meeting the targets for 2020 and 2030. Some additional plant capacities for biomethane production and injection are in the planning and construction phases [45], but the supporting schemes for use in the electricity and fuel markets are currently under amendment and therefore uncertain [46].

Bio-SNG, as an alternative method for producing renewable methane from biomethane, is still in the development stage, see Sect. 8.3. Despite several research projects for an optimized production, so far no commercial plants are in operation.

2.5.4 Flexibility

As a result of the chemical and physical properties of natural gas and biomethane as well as their similarity, numerous flexibility properties are feasible. One major advantage is that biomethane benefits from natural gas storage in the gas grid itself as well as in several underground storages [44]. Therefore, it is eminently suitable, because of sufficient experience of natural gas, for peak and demand-driven loads for heat and electricity provision. However, up to now this potential has not been used.

2.6 Cross-Sectoral Markets from Power to Heat, to Gas and to Liquid

With growing shares of renewable energies, in the future the individual energy sectors (electricity, mobility, heating) will merge more and more together. An initial point would be the electricity sector, because of its universal characteristic to make every known kind of final energy out of it. Two example forces are the introduction of e-mobility and the promotion of heat pumps. Another one is that with increasing shares of photovoltaic and wind power, it is foreseen that there will be periods with an excessive power feed-in in relation to the actual demand.

In line with the projected expansion of fluctuating energy sources for the year 2032, it is expected that there will be an amount of excess energy between 2 % and 18 % of annual solar and wind production. Great uncertainties are still caused by technical incentives for the realisation of flexibility options for fossil power plants and the transformation of biomass plants from base load operation to alternating production [47]. The current situation is characterized by a moderate but growing amount of excess energy caused by network congestions (Table 2.4).

To make such overshoots available for the energy supply in the future, the conversion of power into heat, gas and liquids is being intensively discussed and tested in Germany.

The first option which is already at the point of market entry is the technology of so-called power to heat (P2H), which is simply a way of producing heat from excess energy [48]. For example, biogas plants which serve negative control power could use this option to serve negative loads while keeping their thermal output for connected heat sinks. In this case, the P2H is dimensioned at half of the installed capacity of the power provision unit, so that if there is a request for negative power, the plant can switch down to half load and the produced electrical power is directly and within the P2H converted into heat. Consequently, the plant can then serve a full power hub, by maintaining thermal generation and a faster reaction to recalls in both directions in case of a total switch off.

In the distant future, the so-called power to gas technology (P2G) could be suitable to transform excess power into gas [49]. In a first step, electrical energy is used for electrolysis to produce hydrogen. This hydrogen can be used as it is or could be further transformed into synthetic methane or liquid fuels like methanol (power to liquid – P2L) [50]. This technology is under development and could be an option in the future to substitute fossil fuels in mobility applications which have

Table 2.4 Excess-energy in the German power network (Data source: German network agency [16])

	2009	2010	2011	2012	2013
Excess energy [GWh]	74	127	421	385	555
Share of renewable feed-in [%]	0.10 %	0.16 %	0.41 %	0.29 %	0.44 %

a mandatory need for chemical energy storage, for example aeroplanes or heavy load transportation.

If the renewable gas from electrolysis is injected into the gas grid, the tolerable content of hydrogen in such grids will be limited for technical reasons, then it should be necessary to convert hydrogen, together with carbon dioxide into synthetic methane [51]. Biogas plants, especially those who separate raw biogas into biomethane and a CO2 rich offgas, can also provide a renewable carbon source (see also Sect. 2.4.).

2.7 Conclusion

Bioenergy is a relevant and well established energy carrier for power and heat provision and as a substitute for fossil transport fuels. With regard to their development towards smart flexible systems, the demand of the different markets is different in terms of both quality and dynamics:

The German power market is in a dynamic transition towards renewables and already needs flexible power to balance the volatile wind and solar power and stabilise the power grid. On the other hand, relevant renewable energy installations in the form of biogas plants and power generation plants from solid biofuels might build the basis for a flexible power generation based on biomass. For biogas market incentives have also been established in the form of the Renewable Energy Sources Act in 2012, with the flexible premium to provide incentives for investments in flexible power generation. The flexibilisation of power provision from biomass can therefore be seen as an interesting and promising short-term option for this transition.

By contrast, the transition of the heat market towards renewable energies has been much slower and the characteristics for the future demands on bioenergy in this sector are not that well defined yet. Improved insulation is expected, combined with a decreasing specific heat demand on the one hand and an integration of additional renewable heat supply units on the other. In terms of long term development, the future heat provision from biomass might be faced with smaller conversion units and additional flexibility.

For the substitution of fossil fuels in the transport sector and for natural gas applications, fuel provision does not depend on varying frame conditions demanded by a flexible provision. Here, the challenge for future demand is more in the field of sustainable resource availability and the stepwise production and implementation of different products for matter and energy uses in biorefineries. Moreover, biomethane has not yet been fully implemented on the market.

In the future, the sectoral analysis of power, heat, transport and gas markets will only deliver half of the picture because all market segments are expected to merge. As a result, some of the flexibility needs can be shifted between the different sectors. Especially for example of the upper excess electrical energy can be converted into thermal or chemical energy and meet some of the demand for heat or fuel consumption. Biomass, especially biogas, can link the sectors by providing the renewable carbon source for the provision of renewable gases as chemical energy storages. It can also provide the option to balance long-term fluctuations in power production, and seasonal storage functionality, which could not be covered by conventional flexibility options or common storage technology. From today's perspective this can be regarded as a second step of the transition, based on flexible technologies and concepts, which are described in the following chapters.

References

1. BImSchG, BImSchG – Bundes-Immissionsschutzgesetz in der Fassung der Bekanntmachung vom 26 Sept 2002 (BGBl. I S. 3830), zuletzt geändert am 3 Nov 2011
2. NREAP Germany, National renewable energy action plan in accordance with directive 2009/28/EC on the promotion of the use of energy from renewable sources (Berlin, 2010)
3. AGEB, *Auswertungstabellen zur Energiebilanz für die Bundesrepublik Deutschland 1990–2012* (Arbeitsgemeinschaft Energiebilanzen e.V, Berlin, 2013)
4. Federal Republic of Germany, National renewable energy action plan in accordinace with directive 2009/28/EC on the promotion of the use of energy from renewable sources (Berlin, 2010)
5. EU, Directive 2009/28/EC of the European Parliament and of the council – 2009/28/EC (2009). The European Parliament and the council of the European Union
6. EEG 2009 — Gesetz für den Vorrang Erneuerbarer Energien (2012)
7. N. Szarka, F. Scholwin, M. Trommler, J.H. Fabian, M. Eichhorn, A. Ortwein, D. Thrän, A novel role for bioenergy: a flexible, demand-oriented power supply. Energy **61**, 18–26 (2013)
8. Agency for Renewable Energies, www.unendlich-viel-energie.de, chart, 2013, accessed 2014
9. J. Daniel-Gromke, V. Denysenko, P. Sauter, K. Naumann, M. Scheftelowitz, A. Krautz, M. Beil, W. Beyrich, W. Peters et al., *Stromerzeugung aus Biomasse* (BMU, Leipzig/Berlin/Halle/Kassel, 2013)
10. K. Naumann, K. Oehmichen, M. Zeymer, *Monitoring Biokraftstoffsektor*, *DBFZ Report* (Nr. 11) (Deutsches Biomasseforschungszentrum, Leipzig, 2014)
11. EEX, *Power Terminmarkt*. https://www.eex.com/de/produkte/strom/power-terminmarkt. abgerufen am 11 Mar 2014
12. EEX, *Power Spot Market*. https://www.eex.com/de/produkte/strom/power-spot-market. abgerufen am 11 Mar 2014
13. Regelenergie.net, *Allgemeines zur Regelleistung – Technische Aspekte*. https://www.regelleistung.net/ip/action/static/techaspects. abgerufen am 11 Mar 2014
14. U. Leprich, E. Hauser, K. Grashof, L. Grote, M. Luxenburger, M. Sabatier, A. Zipp, *Kompassstudie Marktdesign Leitideen für ein Design eines Stromsystems mit hohem Anteil fluktuierender Erneuerbarer Energien* (2012)
15. R. Mackensen, K. Rohrig, H. Emanuel, *Das regenerative Kombikraftwerk* (ISET, Kassel, 2008)
16. S. Bofinger, M. Braun, C. Costa Gomez, J. Daniel-Gromke, N. Gerhardt, K. Hartmann, D. Kirchner, T. Reimann, Y.-M. Saint-Drenain; u. a., *Die Rolle des Stromes aus Biogas in zukünftigen Energieversorgungsstrukturen* (Fraunhofer-Institut für Windenergie und Energiesystemtechnik IWES, Hanau, 2010)
17. D. Thrän, O. Arendt, J. Ponitka, J. Braun, M. Millinger, V. Wolf, M. Banse, R. Schaldach, J. Schüngel, S. Gärtner, N. Rettenmaier, K. Hünecke, K. Hennenberg, B. Wern, F. Baur, U. Fritsche, H.-W. Gress, Meilensteine 2030 – Elemente und Meilensteine für die Entwicklnug einer tragfähigen und nachhaltigen Bioenergie, Energetische Biomassenutzung No. 18, 2014
18. EEG 2012 — Gesetz für den Vorrang Erneuerbarer Energien (Erneuerbare-Energien-Gesetz – EEG)Konsolidierte (unverbindliche) Fassung des Gesetzestextes in der ab 1. Januar 2012 geltenden Fassung*

19. EnEG, Gesetz zur Einsparung von Energie in Gebäuden (Energieeinsparungsgesetz – EnEG, 2013)
20. EEWÄrmeG, Gesetz zur Förderung Erneuerbarer Energien im Wärmebereich (Erneuerbare-Energien- Wärmegesetz – EEWärmeG, 2011)
21. BAFA, *Heizen mit erneuerbaren Energien – Marktanreizprogramm*. http://www.bafa.de/bafa/de/energie/erneuerbare_energien/. abgerufen am 17 June 2014
22. I. Hartmann, V. Lenz, M. Schenker, C. Thiel, M. Kraus, M. Matthes, U. Roland, R. Bindig, W.-D. Einicke, *Katalytisch unterstützte Minderung von Emissionen aus Biomasse-Kleinfeuerungsanlagen*, *DBFZ Report Nr. 6* (DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Leipzig, 2011)
23. D. Böhme, T. Nieder, T. Rüther, P. Bickel, *Entwicklung der erneuerbaren Energien in Deutschland im Jahr 2012* (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Berlin, 2013)
24. C. Viehmann, T. Westerkamp, A. Schwenker, M. Schenker, D. Thrän, V. Lenz, M. Ebert, DBFZ, *Ermittlung des Einsatzes biogener Festbrennstoffe im GHD-Sektor* (Unveröffentlichter Endbericht) (DBFZ Deutsches BiomasseForschungsZentrum gemeinnützige GmbH (DBFZ), Leipzig, 2011)
25. J. Nitsch, T. Pregger, T. Naegler, D. Heide, D.L. de Tena, F. Trieb, Y. Scholz, K. Nienhaus, N. Gerhardt; u. a.: *Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global*. http://www.erneuerbare-energien.de/fileadmin/ee-import/files/pdfs/allgemein/application/pdf/leitstudie2011_bf.pdf. abgerufen am 24 Apr 2013
26. W. Schulz, C. Brandstätt, A. Hagemeister, T. Holzfuss, J. Gabriel, *Flexibilitätsreserven aus dem Wärmemarkt* (Fraunhofer-Instituts für Fertigungstechnik und Angewandte Materialforschung IFAM, Bremen, 2013)
27. U. Bigalke, H. Discher, H. Lukas, Y. Zeng, K. Bensamnn, C. Stolte, *dena-Gebäudereport 2012* (dena, Berlin, 2012)
28. E.-M. Klotz, M. Koepp, G. Steudle, *Maßnahmen zur nachhaltigen Integration von Systemen zur gekoppelten Strom- und Wärmebereitstellung in das neue Energieversorgungssystem* (Prognos AG, Berlin, 2013)
29. European Parliament; European Council (Hrsg.), Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (2009)
30. L. Pelkmans, N. Devriendt, L. Goovaerts, P-P. Schouwenberg, *Prospective Study: Implementation of Sustainability Requirements for Biofuels and Bioenergy and Related Issues for Markets and Trade* (Final Report) (IEA Bioenergy, Paris, 2012)
31. S. Barros, *Brazil Biofuels Annual Report 2013*, *GAIN Report* (Nr. BR13005) (USDA Foreign Agricultural Service, Sao Paulo, 2013)
32. F.O. Licht, World Ethanol & Biofuels Report Bd. 2008–2013 (Informa plc, London)
33. BAFA, *Amtliche Mineralöldaten* (Bundesamt für Wirtschaft und Ausfuhrkontrolle, Eschweiler, 2013)
34. Destatis, *Wirtschaftsbereiche – Energie – Erzeugung – Statistisches Bundesamt*. https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/Energie/Erzeugung/Tabellen/Biotreibstoffe.html. abgerufen am 3 Sept 2012
35. ISO 16559:2014: Solid biofuels – Terminology, definitions and descriptions (Abstract ISO 16559:2014)
36. European Commission, Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (2012)
37. European Commission, A policy framework for climate and energy in the period from 2020 to 2030 (2014)
38. M. Seiffert, D. Thrän, *The Potential and Role of Biofuels in Commercial Air Transport-Biojetfuel* (IEA Bioenergy, London, 2012)

39. GasNZV, *Gasnetzzugangsverordnung (Gas Network Access Ordinance)* (Verordnung über den Zugang zu Gasversorgungsnetzen, 2012)
40. DENA, press release: Biogas registers combine to form network – International cooperation to drive biomethane trade forward (2013)
41. BAFA, *Entwicklung der Erdgaseinfuhr in die Bundesrepublik Deutschland – Bilanzen 1998–2012* (Bundesamt für Wirtschaft und Ausfuhrkontrolle, Eschborn, 2013)
42. BNetzA, *Biogas-Monitoringbericht 2014* (Bundesnetzagentur, Berlin, 2014) http://www.bundesnetzagentur.de/cln_1411/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/ErneuerbareEnergien/Biogas/Biogasmonitoring/biogasmonitoring-node.html;jsessionid=113ACF9D35D31A4367B2E9771FE3496E
43. AG Energiebilanzen, *Auswertungstabellen zur Energiebilanz für die Bundesrepublik Deutschland 1990 bis 2012* (Arbeitsgemeinschaft Energiebilanzen e.V., Berlin, 2013)
44. EEK, *Underground Gas Storage in Germany, Erdöl, Erdgas, Kohle (EEK)* (Urban-Verlag AG, Hamburg, 2013)
45. DENA, *Branchenbarometer Biomethan – Daten, Fakten und Trends zur Biogaseinspeisung* (Deutsche Energie-Agentur, Berlin, 2013)
46. EEG, Entwurf eines Gesetzes zur grundlegenden Reform des Erneuerbare-Energien-Gesetzes und zur Änderung weiterer Bestimmungen des Energiewirtschaftsrechts – Draft Law, 2014
47. W-P. Schill, *Integration von Wind- und Solarenergie: Flexibles Stromsystem verringert Überschüsse*, *DIW Wochenbericht* (Nr. 34) (DIW, Berlin, 2013)
48. H-M. Groscurth, S. Bode, "Power-to-heat" oder "Power-to-gas"?, arrhenius Institut für Energie- und Klimapolitik (2013)
49. M. Jentsch, T. Trost, M. Sterner, Optimal use of power-to-gas energy storage systems in an 85% renewable energy scenario. Energy Proc. **46**, 254–261 (2014), 8th International Renewable Energy Storage Conference and Exhibition (IRES 2013)
50. R. Meyer-Pittroff, *Power-to-Liquid (Methanol) zur Energiespeicherung* (Technische Universität München, München, 2013)
51. N. Grimm, I. Zoch, U. Weiß, *Integration erneuerbaren Stroms in das Erdgasnetz* (dena, Berlin, 2012)

http://www.springer.com/978-3-319-16192-1

Smart Bioenergy
Technologies and concepts for a more flexible bioenergy provision in future energy systems
Thrän, D. (Ed.)
2015, VIII, 181 p. 46 illus., Hardcover
ISBN: 978-3-319-16192-1