Chapter 9
The Potential of Flexible Power Generation from Biomass: A Case Study for a German Region

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Abstract Energy scenarios and roadmaps indicate that intermittent renewable energy sources such as wind power and solar photovoltaic (PV) will be crucial to the power supply in the future. However, this increases the demand for flexible power generation, particularly under conditions of insufficient wind and/or solar irradiation. Among the renewable energy sources, bioenergy offers multiple end-use in the form of power, fuel or heat. Biomass-based power combines the advantages of being renewable, exceptionally CO_2 neutral and supporting demand-oriented production.

This chapter analyses four energy scenarios for Germany, focusing on the relevance of flexible bioenergy therein. Depending on how the scenarios are constructed, the range of biomass potential in the energy system is 1,180–1,700 PJ/a. The following sections of the chapter investigate the potential of flexible power generation from biomass on a regional scale (50 Hertz grid) starting with a description of the current state of bioenergy generation in the region and its potential for supplementary heat provision. We model the contribution of flexible biogas and solid biomass power using a minimization of daily residual load variance as a goal function. Two points in time are modeled – 2011 and 2030 to include the current and projected

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installed capacity from wind and solar PV. The results indicate that depending on the framework conditions, flexible bioenergy inclusion can reduce the daily variance in the residual load by >50 % compared to a non-flexible system. We conclude that flexible bioenergy has significant potential to contribute to balancing the power system with increasing shares of intermittent sources such as wind and solar PV.

9.1 Introduction

The previous chapters focused on the need for flexible bioenergy generation, resource availability, sustainability and environmental impact issues. This was extended by an overview of the available technologies and their potential for flexible energy generation from solid, liquid and gaseous biomass.

In this chapter, the potential for flexible power generation from biogas as well as solid biomass and its effect on the power supply system are demonstrated for a case study region – the area of the 50 Hertz transmission grid operator. The first section introduces some prominent examples of national energy scenarios. We focus on the role of bioenergy and the handling of fluctuations in the power supply within these roadmaps of energy transition. We demonstrate that there is still no silver bullet in sight at the moment and that several options remain possible. In Sect. 9.3 the study region with its current state of bioenergy use and its potential for supplementary heat use are illustrated. This forms the basis for the calculations in Sect. 9.4 which presents a numerical analysis of the contribution of biomass to flexible power generation in the study area followed by conclusions in Sect. 9.5.

9.2 Long-Term Potential for Flexible Bioenergy Generation

The biomass potential as discussed in previous chapters shows the upper limits for bioenergy provision. Further, it was explained that biomass is currently the only renewable source that contributes to all energy sectors e.g. power, heat and fuel and that bioenergy can be generated on demand with a short response time, enabling the balance of variable renewable sources (vRES) such as wind and solar photovoltaic (PV). However, from the scientific as well as the political perspective there is currently no consensus about the preferable end-use or function of biomass in the energy system.

Since the infrastructure of energy is fairly expensive and it is usually expected that it will serve for long time periods, e.g. up to 50 years for lignite or coal power plants, decision-makers usually base their decisions on sound scientific evidence. Scientific tools commonly used for the development and description of future energy systems are ‘Energy Scenarios’. Energy scenarios at the national and/or international level have been developed and published since the 1970s [8]. By content, energy scenarios cover the impacts of individual political decisions on regional

Table 9.1 Overview of energy scenarios

Study title	Year	Name/Abbreviation	Institutes
Klimaschutz: Plan B 2050 – Energiekonzept für Deutschland [4]	2009	Greenpeace	Eutech Energie und Management GmbH
Modell Deutschland Klimaschutz bis 2050: Vom Ziel her denken [9]	2009	WWF	Institut für angewandte Ökologie ÖKO-Institut e.V., Prognos AG
Energieszenarien für ein Energiekonzept der Bundesregierung [12]	2010	BMWI	Prognos AG
			Energiewirtschaftliches Institut an der Universität zu Köln (EWI)
			Gesellschaft für Wirtschaftliche Strukturforschung mbH (GWS)
Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global – Leitstudie 2011 [11]	**2012**	**Leitstudie**	Deutsches Zentrum für Luft- und Raumfahrt (DLR)
			Institut für Technische Thermodynamik, Abt. Systemanalyse und Technikbewertung
			Fraunhofer Institut für Windenergie und Energiesystemtechnik (IWES), Ingenieurbüro für neue Energien (IFNE)

and national energy systems up to changes and developments of the global energy supply system [8].

In order to get the full picture of the potential of bioenergy for flexible power generation, it is important to consider existing energy scenarios. Energy scenarios exist for Germany at the national scale [10, 14]. Some of them also consider a high share of fluctuating renewable resources; four of those recent and most prominent scenario studies (see Table 9.1) are briefly presented here.

9.2.1 *Potential and Sector-Wise Distribution Under the Scenarios*

Table 9.2 gives an overview of the expected sustainable primary energy potential of biomass under the scenarios. The results of the studies are relatively similar to one another in the range of 1,180–1,700 PJ/a, if import is excluded. This could be partially due to the fact that most of the scenarios (Leitstudie, Greenpeace and WWF) were basically based on the same fundamental literature [5].

The primary energy potential of bioenergy is distributed to different end-uses, separated into fuel for transportation, heat and the power supply. In 2010 about 30 % of the primary energy consumption was used for power, about 60 % for heat

Table 9.2 Sustainable bioenergy potential under the scenarios

	Leitstudie	BMWi	Greenpeace	WWF
Potential	[PJ/a]	[PJ/a]	[PJ/a]	[PJ/a]
Residue	800	NA	NA	700
Import	0	500	0	500
Others[a]	750	1,700	1,180	500
Total	**1,550**	**2,200**	**1,180**	**1,700**

NA not applicable

[a]E.g. energy crops, short rotation coppice, forest biomass

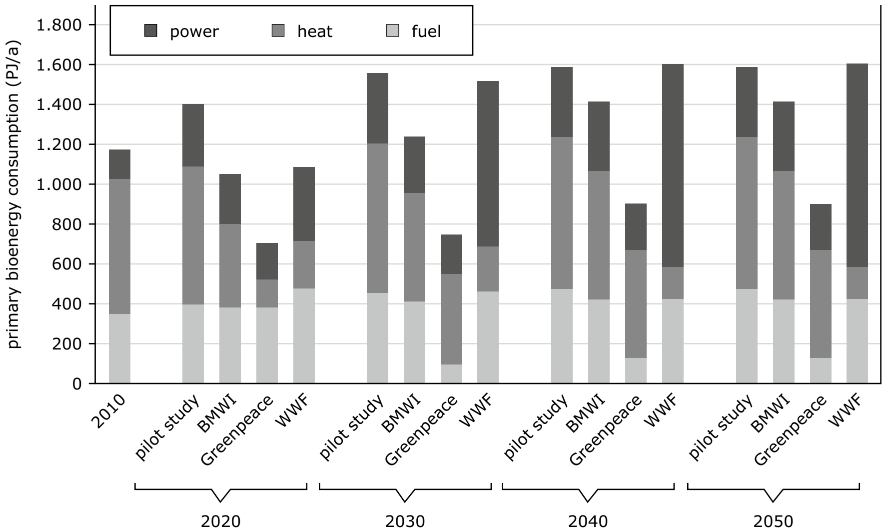

Fig. 9.1 Comparison of primary bioenergy consumption under relevant national scenarios (Based on personal communication with Julian Braun, DBFZ, 2013)

and 10 % for fuels [11]. However, under the scenarios, different development pathways with respect to the sectorial distributions of biomass are enumerated. This is basically due to a difference in the definitions of the sustainable application of biomass under framework conditions.

In Fig. 9.1, the contribution of primary bioenergy to the three sectors for a reference year 2010, as well as for the years 2020, 2030, 2040 and 2050 are displayed for comparison. Here, total and sectoral primary bioenergy consumption is compared under different scenarios. As it can be clearly seen in the figure, the scenarios differ with respect to power, heat and fuel consumption. The Greenpeace study which has a stronger focus on ecological aspects consistently allocates a lower (~ one-third) primary energy consumption of biomass compared to the other studies.

Against the above background, it can be concluded that only a small proportion of biomass is considered for power generation in the future. The following paragraphs clarify how the afore-mentioned studies deal with fluctuations and the specific role of bioenergy.

9.2.2 Flexible Power Generation Options Under the Scenarios

To compensate for fluctuations in feed-in from intermittent sources such as wind and photovoltaic, three options have been considered under the afore-mentioned scenarios: demand-side management, storage and instantaneous generation. Under the scenarios these options have been treated differently. In the following paragraphs, we discuss an instantaneous generation of power on demand, henceforth referred to as 'guaranteed capacity'.

Within the BMWI study, 50–70 GW guaranteed capacity has been calculated for the generation of balancing power. The largest contribution (~88–91 %) is provided by natural gas power plants and Carbon Capture and Storage (CCS) coal power plants. Biomass only contributes with 6 GW guaranteed capacity. However, full load hours of 6,500–6,800 h indicate that biomass plants operate in base load mode and are not managed for demand-oriented functioning.

As [11] shows, the expected guaranteed capacity is 68–77 GW. The main fraction of balancing power is foreseen to come from Combined Heat and Power (CHP) plants ─ both fossil-fuel driven as well as those fired by gaseous biofuels such as Biogas or Biomethane. Two pathways are considered in [11] with respect to the use of biogenic gaseous energy carriers. Firstly, the feed-in into the existing natural gas net for power and heat generation in large CHP plants and secondly the on-the-spot conversion to power whenever balancing power is required. For the latter option, modifications of existing bioenergy plants are necessary e.g. an increase in the installed capacity and storage capacity. The effects of a flexible on-the-spot conversion concept on the power system will be highlighted in the case study in Sect. 9.4.

The Greenpeace study mentions the challenges of tackling fluctuations in wind and solar PV, but it does not provide explicit quantifications. The WWF study calculates a guaranteed capacity of 59–61 GW depending on the scenario assumptions. This guaranteed capacity is separated into contributions from renewable sources plus imports (23–27 GW), conventional sources (mainly natural gas) and storage (34–36 GW). It does not explain however the exact contributions of the individual renewable energy sources.

Conclusively, a comparison of the studies on various scenarios shows that the role of biomass is more diverse than that of the other renewables but has not been discussed in detail along with its implications. The role of biomass in these studies is seen as ranging from base load operation mode for mainly heat and power production to a flexible source for balancing fluctuations in intermittent renewable sources (e.g. wind and solar). To use the specific advantages of bioenergy for balancing power grids, more information about the effect of flexible generation from biomass is needed. For such a smart bioenergy provision to be integrated into the overall energy system it is important to consider the regional framework condition, including the current state of bioenergy plants in operation, the demand for power and heat and the electricity grid situation. In the following (Sect. 9.3), we present a discussion of the current state of bioenergy plant distribution and the heat potential thereof followed by Sect. 9.4 which gives an example of the system effects of flexible power generation from biomass as a case study of the 50 Hertz Grid operator area in eastern Germany.

9.3 Regional Aspects of Bioenergy

This section introduces the study region for which flexible power generation from bioenergy has been modelled in the following sections. The study was conducted in eastern Germany. Geographically, the region covers seven German federal states (Hamburg, Berlin, Brandenburg, Saxony, Saxony-Anhalt, Thuringia, Mecklenburg-Western Pomerania) covering a total area of 109,340 km^2. The area is operated by 50 Hertz Transmission GmbH, which functions as the Transmission System Operator (TSO) serving about 21 % of the German population [15] (Fig.9.2).

In a classical energy supply chain, centralized systems played a major role. However, a high level of integration makes centralized systems vulnerable to changes within the supply chain. Decentralized systems, as a model of supply infrastructure, are less vulnerable to the availability of remote generation and transmission networks [6]. Furthermore, the demand for flexible power generation in a changing energy system with a high proportion of intermittent renewable sources (wind and solar PV) reaches the limits of possibilities offered by centralized fossil fuel power plants. Centralized systems are usually developed to operate at nominal capacity throughout the year which does not allow them to follow the high load gradients demanded by the feed-in of intermittent renewable sources. Flexible bioenergy is therefore emerging as a good option due to two main advantages (i) utility in decentralization mode and (ii) the ability to follow load gradients (e.g. power generation from biogas). However, the introduction of flexibility concepts to the bioenergy sector is also highly dependent upon regional or local aspects of energy production. Spatial aspects of current infrastructure are also crucial for establishing flexible energy systems at regional scales.

In the selected 50 Hertz region, the total number of plants (including biogas, solid biomass and biofuel plants) is 1,773 (2011). The total installed capacity in the region is ~1,365 MW with an average of 769 kW. The spatial distribution of these plants is shown in Fig. 9.3 while Table 9.3 shows the distribution of plants.

CHP plants primarily serve electricity production, however, heat, which is a by-product of the process may also be used e.g. for district heating. When introducing

Fig. 9.2 Transmission Network Operators in Germany

flexible options it is relevant to address the potential of district heating from biogas, since both flexibility and heat demands have temporal dimensions. Further, the spatio-temporal consideration of heat sinks in the design and implementation of flexible plants may be valuable in reducing storage requirements.

A further investigation into the biogas facilities installed in Saxony showed that currently these plants are driven by electricity demand and provide base load, thereby using only a minor proportion of the produced heat [7]. Results indicated that the total heat supply potential from biogas plants in the region is around 290 GWh (i.e. ~15 % of the heat demand in the region could be potentially fulfilled from bioenergy plants). The study identified a strong limitation due to a lack of demand centers around the plants with respect to housing infrastructure. About 40 % (194 GWh) of the heat that was theoretically available for supply faced geographical constraints for further use in district heating systems, because the plants are located too far away from the demand centers. However, in certain cases heat provision can act as a constraining factor for flexible power generation.

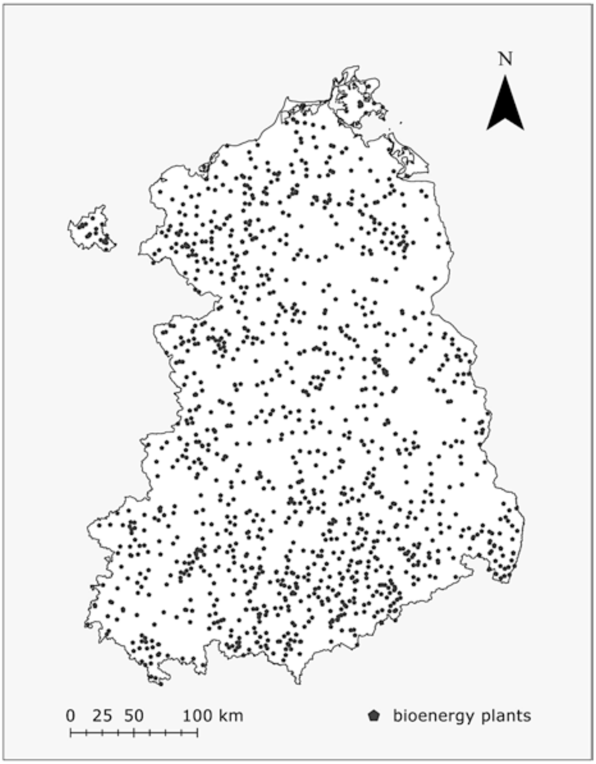

Fig. 9.3 Regional distribution of bioenergy plants

Table 9.3 Distribution of bioenergy plants in the 50Hertz grid region

Range of installed capacity (kW)	Number of plants	Total installed capacity (MW)
<500	1,006	307
501–1,000	643	391
1,001–3,500	81	137
3,501–45,000	10	46
5,001–10,000	17	108
>10,000	16	373
Total	**1,773**	**1,364**

Based on [1]

9.4 Complementing Variable Renewable Energies with Flexible Bioenergy

In the following paragraphs, the effect of flexible power generation from bioenergy to balance fluctuations in the electricity supply is demonstrated as a case study. To assess the balancing potential on fluctuations from variable renewable energy sources such as wind and solar photovoltaic (PV) as well as fluctuations of power demand, flexible bioenergy power generation is modelled for one of the four German power transmission grids, operated by 50HertzTransmission GmbH (50Hertz). Based on 3-year time series data for demand and feed-in from wind and solar, the effect of flexible bioenergy power production can be compared to current non-flexible bioenergy power generation. Residual Load (RL), calculated as the difference between the demand and supply from wind and photovoltaic forms the basis for modelling bioenergy power provision.

Since both demand and feed-in from wind and solar PV fluctuate, the compensation of the RL has to balance out these fluctuations for a stable power supply system. In contrast to non-flexible power production from bioenergy, flexible bioenergy generation is expected to contribute to the balancing of the power system, especially in cases of substantial shares of fluctuating renewable energy sources without any major power storages, e.g. large pumped hydro-storage systems.

Apart from assessing the effects of either flexible or non-flexible bioenergy power generation we also provide a scenario for the projected increase in installed capacities from wind and solar PV for 2030. The framing conditions for 2030 (installed capacities, annual energy power production and power demand) are adapted versions of [11]. Table 9.4 presents a comparison between 2011 and 2030 parameters. Two bioenergy technologies (biogas and solid biomass) are modelled, because they account for more than 90 % of the installed bioenergy capacity in the 50Hertz grid (see Sect. 9.3).

9.4.1 Model Description

Based on the time series data from 2009 to 2011 [3] the RL is calculated from the capacity given in Table 9.4 by a proportional scaling of the feed-in from wind and solar PV power plants. Feed-in from all bioenergy plants was simulated for two modes: (i) non-flexible power production and (ii) flexible power production. The

Table 9.4 Scenario conditions for the case study

	Year 2011		Year 2030	
	Capacity (CAP)	Annual energy production	Capacity (CAP)	Annual energy production
	[MW]	[TWh/a]	[MW]	[TWh/a]
Wind	11,719	18	17,979	41
Solar	4,070	3	10,005	9
Bioenergy	1,460[a]	9	2,435	15
Solid biomass	861[a]	5	1,552	9
Biogas	599[a]	4	883	6
Total	**17,249**	**30** (~36 % of demand[b])	**30,419**	**65** (~76 % of demand[b])

[a]Based on the average demand from 2009 to 2011 of 84 TWh, capacity for 2011 from 50Hertz plant data [2], capacity for 2030 derived from [11]

[b]Demand for 2030 falls by 10 % as projected by [11], 6.8 TWh of energy from wind and solar are considered to be excess energy in 2030

differences between non-flexible versus flexible power generation from bioenergy have been studied with a minimum temporal resolution of 1 h. The results from these simulations were compared to estimate the contribution of either mode to the reduction in fluctuations of RL.

To capture the effect of non-flexible bioenergy power production on RL, a constant feed-in of bioenergy is subtracted from the original RL resulting in a new RL after compensating for bioenergy ($RLB_{(t)non\ flex}$). In this case the value of "const" is equal to 1 so that no flexible operation of the bioenergy power generation capacity is possible.

$$RLB_{(t)nonflex} = RL_{(t)} - const * \left(CAP_{solid} + CAP_{biogas}\right) \quad (9.1)$$

CAP = installed capacity of either solid or biogas plants.

In the case of flexible power generation, the power production is enabled to adapt to RL fluctuations by allowing the optimization algorithm to modulate the power generation. This is realized by introducing the modulation factor "m" which scales the power generation of the capacity from bioenergy plants, so that a minimization of daily variances in RL is achieved [13]. This modulation forces power generation from bioenergy to contribute to the balancing of the power supply and demand by shifting flexible power generation from times of lower RL to times of higher RL.

On a daily basis, power from bioenergy is provided at times of high RL and reduced at times of relatively low RL throughout the time series from 2009 to 2011. As the flexible operation is modelled in sequence for the two different technologies (solid biomass and biogas), the resulting RL after the introduction of flexible bioenergy generation from $RLB_{flex\ solid}$ and $RLB_{flex\ biogas}$ is $RLB_{flex\ combined}$:

$$RLB_{(t)flexsolid} = RL_{(t)} - m_{(t)solid} * CAP_{solid} \quad (9.2)$$

$$RLB_{(t)flexcombined} = RLB_{(t)flexsolid} - m_{(t)biogas} * CAP_{biogas} \quad (9.3)$$

$$min\,variances\left(m_{(t)solid}; m_{(t)biogas}\right) = \sum_{t=1}^{24} RLB_{(t)flexcombined} \quad (9.4)$$

The "variances" as a function of the two modulation factors "m(t) solid" and "m(t) biogas" are subject to minimization in this modelling for the 24 h of each day throughout the time series.

The details of the parameterization of the model are described in the following paragraphs. The key technical parameters are provided in Table 9.5.

The operation of solid biomass and biogas capacity is modelled in sequence to improve the combined effect of the different flexibility potential from both bioenergy technologies. Setting the more dynamic biogas capacities second after the less dynamic solid biomass capacities should ensure that the characteristics of both technologies are not operated in a conflicting way but rather in a complementary

Table 9.5 Technical parameters for the flexible operation of power generation from solid bioenergy and biogas plants

	Bioenergy technologies	
	Solid biomass	Biogas
Modulation of power output	0.5–1 in 2 h time steps (0.5–1.2 for 2030)	0–2 in 1 h time steps
Operational constraints	Constant daily energy production	Constant daily energy production
	No storage limitations for input materials affecting operation	On-site biogas storage equivalent to 12–24 h in biogas production
	Reduced daily production (−20 %) during summer from April to October	Reduced biogas production (−25 %) on weekends assuming feeding management
Energy production	Annual Energy Production (AEP) remains constant for either non-flexible or flexible operation. AEP from biomass in 2030 taken from [11]	

interplay. The parameterization and operation of either technology is explained in the following:

1. Solid Biomass Plants: The combined installed capacity from solid biomass plants is first modulated from 0.5 to 1 (0.5 to 1.2 in the 2030 case) for every 2 h time step of the time series, meaning that the combined installed capacity from solid biomass plants is multiplied by the modulation factor and subtracted from the RL time series. A modulation factor of 0.5 is applied as the minimum modulation factor as heat demand from CHP production and standard conversion technology currently does not allow for a power output below 0.5 or 50 % of the rated power. The lower heat demand in summer is taken into account by a reduction in daily energy production by 20 % compared to the operation during winter.
2. Biogas Plants: The combined installed capacity from biogas plants is modulated from 0 to 2 on the basis of the RL after the feed-in from solid biomass plants (as above). The maximum modulation factor of 2 points out that the installed capacity can provide twice the power output to allow for a more flexible production compared to the current almost constant modulation factor of 1. The constraint of a maintained overall daily production together with the modulation factors of 0 to 2 implies a maximum storage capacity on site for 12–24 h, although no detailed storage modelling is performed.

   On weekends with a generally lower power demand, the daily production of biogas and consequently power and heat production is reduced by 25 % assuming a feeding management of the biogas digester.

Since the most common operation mode in bioenergy plants is CHP, the given parameterization of the modeling allows for bioenergy plants to operate throughout the year to maintain a high utilization of heat without the necessity to deploy increased heat storage facilities.

9.4.2 Results

The results presented in this section correspond to the capacity provided in Table 9.4 (1,460 MW in 2011 and 2,435 MW in 2030 for bioenergy). The calculations were based on the time-series of 2009–2011 for RL and feed-in from wind and solar PV. The combined results from a flexible operation of solid bioenergy and biogas capacity are presented in Table 9.6.

The results demonstrate that flexible bioenergy production improves maximum and minimum RLs and variance in daily RL for both 2011 and 2030 cases. The flexible bioenergy generation enables a significant reduction of the variance in daily RL by 56 % for 2011 and 54 % for 2030 compared to the non-flexible reference. This leads to a significant reduction in load variations for the remaining non-renewable power generation system. It reduces the maximum RLs compared to a non-flexible operation by 7 % (2011) and 12 % (2030) compared to the 2011 level for non-flexible operation selected as the reference (100 %). As a result, this directly contributes to reductions in power plant capacity to provide the remaining residual power production. Likewise, the minimum RL or excess power is reduced, avoiding power production at times when power generated from wind and solar already completely meet the demand for power.

A closer look at the temporal operation patterns for the flexible bioenergy plants reveals that the modulation of power output adapts to the short-term production patterns of variable renewable energy sources as well as fluctuations in demand. As shown in Fig. 9.4, the power production of the solar PV installations

Table 9.6 Overview of the results from simulated flexible and non-flexible bioenergy power generation in the case study

	Year 2011		Year 2030	
	Non-flexible operation	Flexible operation	Non-flexible operation	Flexible operation
Variance in daily residual load	100 %	Reduced by 56 %[a]	100 %[a/**]	Reduced by 54 %[a]
Maximum residual load (deficit power)	12,499 MW (100 %)	11,651 MW (reduced by 7 %[a])	10,343 MW (100 %[a])	9,047 MW (reduced by 12 %[a])
Minimum residual load (excess power)	3,980 MW (100 %)	3,352 MW (reduced by 16 %[a])	13,536 MW (100 %[a])	12,538 MW (reduced by 7 %[a])
Bioenergy power production in times of excess power	176 GWh/a	118 GWh/a	11,010 GWh/a	10,021 GWh/a
Avoided bioenergy power production in times of excess power by flexible operation	–	58 GWh/a (reduced by 33 %)	–	990 GWh/a (reduced by 9 %)

[a]Percentages compared to "non-flexible" values
[**]The high levels for 2030 figures are caused by fluctuation from increased vRES capacities

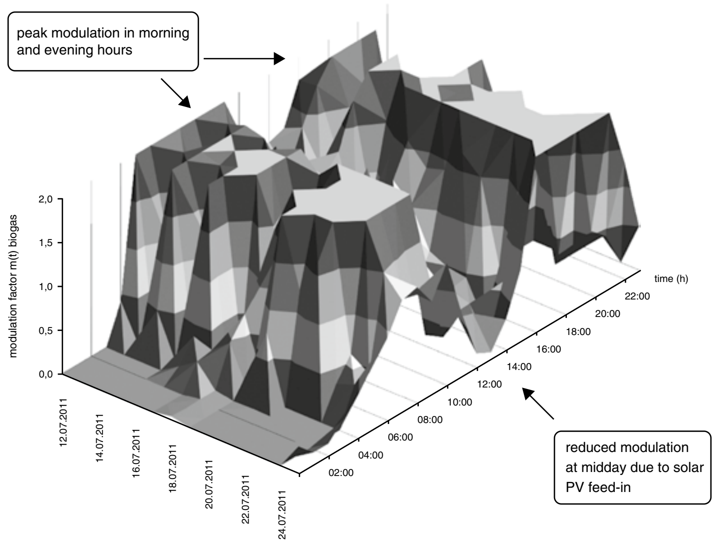

Fig. 9.4 Example for the modulation of biogas power generation in high insolation conditions

(4,070 MW/10,005 MW in 2011/2030) is responsible for the reduced RL at midday in high insolation conditions, leading to a low utilization of flexible bioenergy power production. Bioenergy power generation is instead shifted to provide maximum power production in morning hours and late evening hours when high demand cannot be met by solar PV.

Figure 9.5 depicts seasonal patterns of the effect of flexible bioenergy production on average daily RL before (solid lines) and after (dotted lines) the feed-in from flexible power production. The resulting RL shows a significant reduction in the average daily RL amplitude compared to the original RL.

Figures 9.6 and 9.7 show the duration curves for the simulated time series projected for 2011 and 2030. These duration curves are created by ordering all hourly RL values of the 3-year time series in a descending order, so that the highest RL value is located on the very left of the graph and the lowest value on the right side.

As shown by the duration curves, the flexible operation of bioenergy plants in the modelled set-up allows for a limited shift of power production (grey area between solid lines of the RL) from times of lower RL on the right side of the duration curve to times of higher RL on the left. This not only helps to reduce negative RL (excess power) from renewable energy, but also reduces maximum positive RL (deficit power), enabling a reduction in non-fluctuating plant capacity, which is currently mostly driven by fossil fuels.

The comparison of the duration curves of the RL in 2011 and 2030 reflects how a substantial increase in capacity for wind and solar power has an impact on the RL distribution. The overall duration curve shifts so that instead of a mere 120 h per year of negative RL (excess power) for 2011, over 2,000 h of negative RL per year are calculated for 2030. The maximum negative RL (excess power) over the 3 year

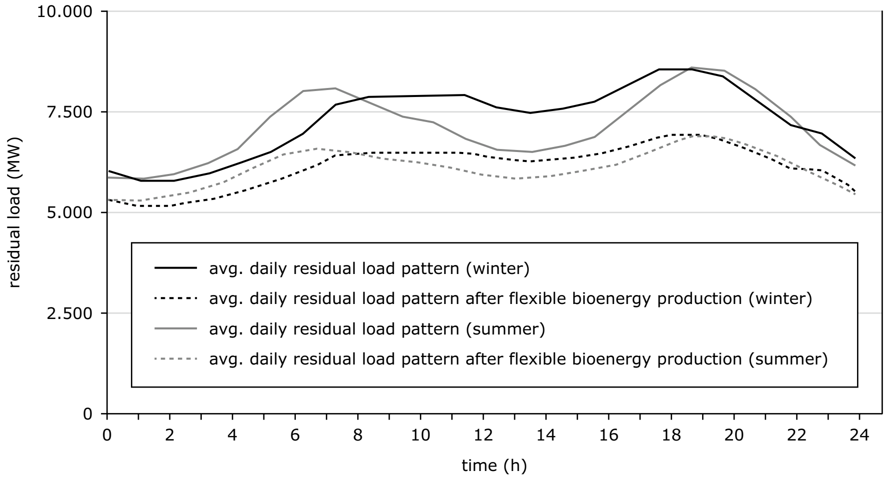

Fig. 9.5 Reduced amplitude in average daily RL after flexible bioenergy power generation, differentiated for winter and summer (2011 installed capacity) (Note: typical reduction of RL at noon in summer time, caused by high solar PV feed-in)

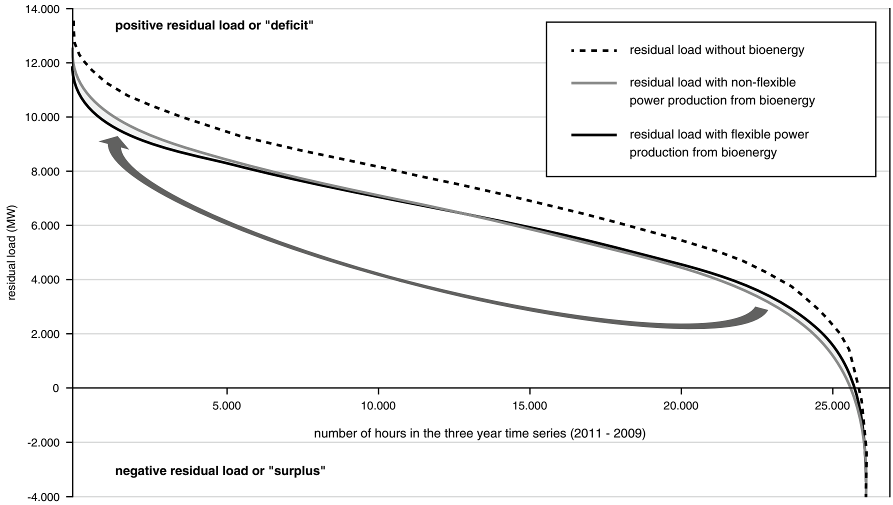

Fig. 9.6 RL curves for the 50Hertz grid network with flexible and non-flexible bioenergy (2011 installed capacity, 3-year reference period)

time-series increases from 3,980 MW (2011 capacities) to 13,536 MW (2030 capacities) (see also Table 9.6). This reflects an overall increase in capacity of variable power production from wind and solar PV. For flexible bioenergy, the consequence is that the demand for flexibility to complement these increased fluctuations will likewise increase. For example, power production from biomass has to be increasingly shifted over longer periods when prolonged periods of high power production from wind and solar are already serving the power demand.

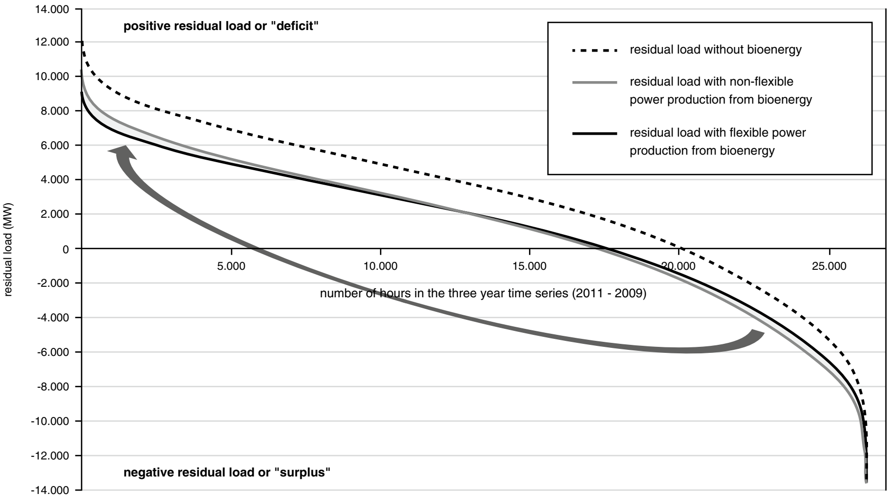

Fig. 9.7 RL curves for the 50Hertz grid network with flexible and non-flexible bioenergy (2030 installed capacity, 3-year reference period)

Of the 15,000 GWh/a of energy from biomass in 2030, about 3,500 GWh/a are shifted from times of low RL on the right side of the graph to times of high RL. Of these 3,500 GWh, about 990 GWh/a are shifted from times of negative RL so that bioenergy is not produced in times of fulfilled demand by wind and PV but shifted instead to times of positive RL. The remaining 2,510 GWh/a are produced even though wind and PV provide sufficient power to supply demand.

9.4.3 Discussion

This chapter investigated the potential of flexible bioenergy as an option for balancing fluctuations in the power grid resulting from load patterns and increasing vRES shares. The results from this regional case study indicate that flexible bioenergy can contribute positively towards balancing power grids.

Based on available renewable energy scenarios, an increase of vRES capacity (wind and PV) from 2011 to 2030 was modelled for the Eastern German region. The limited installed capacity of bioenergy in this case study (1,520 MW/2,435 MW from bioenergy in 2011/2030) is far too low to fully balance fluctuations of vRES capacity (15,789 MW/27,984 MW of Wind and solar PV in 2011/2030). However, the introduction and operation of flexible bioenergy capacity to balance fluctuations in RL (as shown in this case study) through the hourly modulation of capacity to minimize daily RL variance has been verified as an effective measure to balance short-term fluctuations. The simulation revealed a reduction in variability of more than 50 % compared to the reference case of non-flexible operation for both 2011

(56 %) and 2030 (54 %) (see Table 9.6). Modest improvements from flexible operation were identified in terms of maximum excess power and deficit power over the course of the 3-year simulation period, providing additional benefits for the power grid.

According to the simulations presented here, in 2011 the proportion of excess power or negative RL in the system was negligible (176 GWh/a). The modelling results indicate that 58 GWh/a of bioenergy generation could be shifted to compensate positive RL. By the year 2030 an increased share of vRES (see Table 9.4) and excess energy (11,010 GWh/a) in the system is expected. As for the modelling results, from the 3,500 GWh/a that would have been generated from biomass without a flexible operation in times of excess, 990 GWh/a could be shifted by flexible operation. To unlock the remaining 2,510 GWh/a and enable an additional shifting of bioenergy in 2030, greater flexibility is needed.

Therefore, these results indicate that flexible bioenergy provision in the short-term is an effective measure to balance a renewable system (with negligible excess energy), but that future (e.g. 2030) flexibility options will need to be complemented by additional flexibility options and further investments, i.e. in gas and heat storage.

Both, solid biomass power plants and biogas plants were taken into consideration, but with different assumptions about their flexibility. Solid biomass power plants are constrained in their modulation range (0.5–1.2). Although this limits their flexibility potential, power production may run at nominal capacity for long time periods as long as a sufficient stockpile of biomass is available for any addition to the base modulation factor of 1. By contrast, biogas plants with increased generator capacity can be modulated more dynamically than solid biomass plants (modulation factor 0–2). One of the factors that currently restricts flexible generation is the limited capacity to freely regulate biogas production as it is based on anaerobic digestion processes (see Chap. 5).

In general, flexible biogas plants with biogas storage on-site of 12–24 h are well suited to complement the daily production pattern of solar PV at times of high solar irradiance. As no such regular, semi-deterministic production pattern exists for wind power which has a greater dependence on high and low pressure weather systems over Germany prevailing typically for more than 12–24 h, the selected modelling setup is not sufficient to address the means of balancing long-term fluctuations from wind energy. One option to address this shortcoming is to link biogas plants to the natural gas grid to make use of the huge storage potential of the existing gas grid (see Chap. 5). This can overcome the limitations of on-site storage for biogas to cope with the long-term variability in RL.

While some inflexibility is presumably caused by restrictions of the modelling in this case study, as the applied optimization routine is restricted to daily load fluctuations and falls short of inter-daily shifting of power production from bioenergy. However, the flexibility of the biomass technologies which are used in the modelling as well as the operational constraints from combined heat and power operation limits the flexibility in the setup that was investigated.

It is worth mentioning here that this study used RL as a ‘known input parameter (from the data)’ which by contrast is only partially predictable in real-time plant operation. However, the above results for 2011 and 2030 are based on a set of ex-post data (measured/reported/calculated) specific to the 50Hertz region, implying that the optimization results and conclusions hold true for the set of input data used. The main benefit of using this approach is that it clearly illustrates the advantages of ‘flex’ bioenergy over using non-flexible bioenergy. Furthermore, results from the 3-year time-slice (RL and RES feed-in) and the applied modelling in this study provides a range of the calculated potential of bioenergy flexibility, allowing for a reduction in daily RL variance of up 56 %.

This case study strongly indicates that the adoption of flexible bioenergy has the potential of supporting the energy transition in Germany. In addition to demonstrating the technical options for flexible bioenergy as presented here, a detailed techno-economic feasibility assessment should be carried out to get the full picture. Innovations and/or adaptations to technologies need to be integrated into the current modelling process as and when required. Flexible bioenergy also needs to be adequately supported by policy, especially by specific incentives that promote flexible bioenergy and framed by sustainability requirements for the feedstock supply. In summary, flexible bioenergy does not necessitate additional bioenergy production but focusses on improving the use of bioenergy that has already been produced, while quantifying the future role of bioenergy in the energy sector can greatly benefit flexible bioenergy provision.

9.5 Conclusion

A transformation of bioenergy provision from a stand-alone provision to integrated systems can be realized on a regional level. A deeper analysis of the East German region showed that it is possible to start changing the existing installation to support the transition of the energy system in the immediate future. By enabling a flexible power provision from biomass, this will result in a higher value of the electricity provided, a reduction in the overall RL to be covered by fossil fuels, while neither the demand for biomass nor the combined heat supply are significantly altered.

For a description of future pathways towards a renewable energy supply, the options for flexible power provision from biomass should be included. So far, the available scenarios do not or not fully consider these and therefore assume higher RLs as well as more energy from fossil fuels. There is a need to adapt these scenarios –not only in terms of modified bioenergy provision but also in terms of economic effects: flexible bioenergy provision calls for much greater technical effort and leads to higher specific provision costs while the reduction of RL has a clear potential for cost reduction in the mid-term.

From the calculations in the case study, an increased negative RL can be expected while at the same time increasing the potential of bioenergy to reduce the fossil RL. Hence, in the long term, a flexible power generation from biomass has the potential of becoming a major contributor to the power supply. However, the results also show that the capacity of power provision from bioenergy is far too low to fully balance fluctuations of the vRES capacity. Consequently, if renewable power provision is to be directly integrated into the energy system, the optimization of power provision from bioenergy is only one aspect. Hence, this case study can be regarded as a starting point for a systematic optimization, which will inevitably lead to some additional potential and challenges for future developments:

1. Today the contribution of flexible power provision from solid biofuels is limited due to the currently installed technologies. Whereas new technologies will be available that support future flexibility –especially the provision of synthetic natural gas (SNG) and/or the power generation in gasification units –with the potential of a wider modulation. In this case, the flexibility of solid biofuels and biogas might be comparable in 2030. This has not been considered in the case study, because so far it cannot be estimated when and how those technologies will be in place on the market.
2. The case study focused on short term flexibility with a shift of electricity provision within 24 h (modulation rate of 0.5–2). Increasing this modulation and also including longer term flexibility might provide additional potential to balance fluctuations in the power system. The previous chapter showed how additional technical options are being developed to provide mid- and long-term flexible power.
3. Not only the electricity generation from biomass needs to be optimized with a view to system integration, but also the fluctuating energy carrier wind and solar PV can contribute to reduce fluctuations in RL, by taking into account spatio-temporal feed-in patterns and advancements in wind and solar PV technology [15]. Hence, the additional installation of renewable power capacity should be framed by integrated planning, considering those aspects as soon as possible.
4. Heat provision also has some additional effects on flexible power provision: on the one hand, CHP concepts require dedicated heat supply concepts for mid- and long-term flexible power provision. On the other hand, the availability of excess energy might lead to additional power-to-heat concepts as a second pillar for heat supply in an energy system mainly based on renewables. Both aspects have not been tackled here and need further investigation.

In terms of an efficient reduction of greenhouse gases, today's possible "no-regret-options" to reduce fossil-based power generation by adapting the existing biogas plants should be realized soon. Therefore, adjusted framework conditions are necessary to make investments in the additional power conversion unit (second CHP-engine) of the biogas plant feasible. This will be discussed in detail in Chap. 10.

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