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The role of bioenergy in the German "Energiewende"—whose demands can be satisfied by bioenergy?

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Abstract

The transformation of the energy system and especially the electricity system into a renewable-based system requires systemic changes of the different system components. The planned progressive decommissioning of fossil- or nuclear-based power plants implies that renewable-based power plants need to take over their functions. This article examines the possible role of bioenergy-based plants during the different phases of the energy system transformation.
Our findings provide strong evidence that bioenergy can supply the necessary balancing and ancillary services in order to guarantee system stability and security of supply while simultaneously covering electricity and heat demand. Only in a later stage of the transformation process, it seems to be necessary to operate in a mainly demand-oriented mode.
Besides the economic dimension, the political and scientific debate must take the various systemic and environmental impacts of bioenergy into account to maintain the ability of bioenergy to serve the energy system. The economic points of failure of the recent policy are being pointed out and it is shown that recent legislation is expected to lead to a decrease of the installed bioenergy power.

Introduction: bioenergy as a part of bioeconomy

Within the European goal of 40% reduction of greenhouse gas (GHG) emissions until 2030, renewable energies (RE) should deliver 27% of the total energy supply, and the share in the electricity sector should increase at least to 45% in 2030 [1]. This energy transition is a historical challenge. The German word "Energiewende" has become a common expression in many other countries for the challenge that Germany has set itself; by 2050, Germany wants to:

– Reduce its GHG emissions by at least 80 to 95%
– Produce 60% of its final end energy consumption by renewable energy sources
– Produce 80% of its gross electricity consumption by renewable energy sources

So far, bioenergy forms the most important renewable energy source in Europe and Germany with a share of more than 60% and more than 70% respectively [2] of the total RE. Nevertheless, the sustainability of bioenergy is strongly discussed because the land, used for primary biomass production, could be used for food and fibres as well. For this reason, sustainability standards are put in practise, e.g. to protect biodiversity [3] or generate energy from forestry [4]. Furthermore, in Germany, a new policy framework is set up to reduce the use of biomass for power production in Germany [5].

Nevertheless, bioenergy has an important place in the field of bioeconomy [6]. The European Commission defined the bioeconomy sector as one of the most innovative sectors in rural areas [6]. Besides food and fibre, bioenergy is one of the three pillars of bioeconomy, and the development of this sector in Europe has been significantly increasing. From 2000 to 2013, the bioenergy-based power generation increased from 34.1 TWh up to 149.4 TWh within the EU [7]. A similar development is known for the thermal bioenergy sector. Only biomass consumption within the mobility sector has been stagnating since 3 years for different reasons (e.g. tax regulations and quota systems). Bioenergy thus represents a new field of income for rural areas. This

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development lowers the need for the 'old EU agricultural incentive policy' like the set-aside rules.

Besides the Energiewende, another transition is taking place leading to enhanced competition between the different biomass resources: the transition from fossil oil-based materials to renewable materials like bioplastics for chemicals or fibreboards for the construction sector. The use of these biomaterials further reinforces the development of the bioeconomy sector.

These short examples show the versatile role of bioenergy and outline the material, societal, technical and economic dimensions of its use as well as potential conflicts among these dimensions [7]:

- The *material dimension*: It principally refers to the availability of goods like raw materials, agricultural land or woody biomass. The availability of these goods for the bioenergy sector is largely interdependent with the objectives of food security and biodiversity. Some of these issues can be mitigated e.g. by strict cascade use of biomass and the use of organic residues for energetic purposes solely.
- The *socio-political dimension*: This dimension covers on the one hand the availability of the organic resources and the conflicting interests between their different uses. On the other hand, the changing use of the landscape and emissions implied by the energetic use of biomass may generate a decreasing acceptance of bioenergy. In order to maintain or even to increase the current level of acceptance, different points have to be clarified: At first, this concerns a yet missing consensus on the role of biomass in the energy mix (Fig. 1). Furthermore, existing controversies about the use of organic products or problems with emissions and land use changes have to be addressed directly and in weighing them with the goods offered by bioenergy (not only different forms of energy but also important contributions to regional added value and employment). These controversies may be addressed and resolved via innovative governance processes including sincere participation processes. A legislative paradigm shift from a general public disposal order to a resource efficient system with a compulsory biomass cascade use is a further option to regain public acceptance of bioenergy.
- The *technical dimension*: The use of biomass for energetic purposes is driven by technical innovations while trying to maximise energy efficiency. The technical dimension is highly depending on a societal commitment to use biomass in the medium and long terms. The commitment to a long-term utilisation is crucial for creating sufficient incentives to look for technical innovation through research and through industrial investments resp. realisation. For the electricity and heating sector, reliable incentive schemes or even obligations for efficient combined heat and power generation are needed. The systemic and efficient integration of bioenergy to balance variable renewable energy (VRE) generation needs the extended heat grids and the appropriate regulations to create a reliable and significant pool of flexible combined heat and power (CHP), with integrated seasonal heat storages or switches between heat and power generation (methane or biogas) or storages.
- The *energy market dimension*: As already mentioned above, energy markets and their rules also need to be adapted to the growing role and diversity of renewable energies. Chapter 2 deals with these aspects.

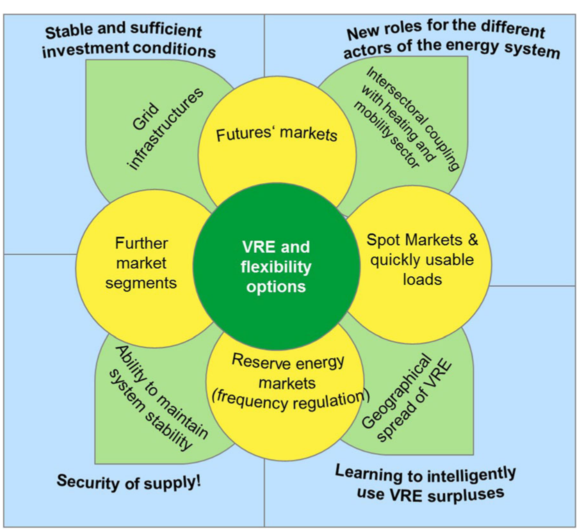

Fig. 1 Challenges for the electricity system during the system transformation [13]

When taking these dimensions into account, it becomes clear that an increase of bioenergy is limited by competition between materials, social and technical challenges and the energy market.

This article is focusing on opportunities and constraints of bioenergy within the German electricity market, as an example for the energy transition in Europe. An overview of findings from the authors' projects, funded by the German government [5], the German Renewable Energy Association and Greenpeace Energy eG [8] and the German Biogas Association [7], is given. This article does not claim to reflect all related literature and provides no transnational comparison of the role of bioenergy.

Basic concept of bioenergy flexibility

For a couple of years, for many reasons, the Energiewende has been defined 'simply' producing 'renewable kilowatt hours' of electricity, heat/cold or as vehicle fuel. Currently, the share of renewable-based energy is continuously rising while production costs for renewable technology are generally declining. Therefore, people get more and more aware of the many other challenges of the Energiewende [8]. Exemplary for the electricity sector, Fig. 1 displays the challenges to be faced for the functions, structures and processes in the electricity system.

Renewable energies need to find an adapted place in the different energy markets[1] as illustrated by the yellow blossom leaves. These mutual challenges of market integration and market adaptation are being discussed in the upcoming sections. The existing material infrastructure of the electricity system in particular and the energy system in general have to be adapted: This adaptation is focusing on the intersectoral coupling with the heating (and cooling) sector, the geographical spread of variable and flexible renewable power plants, the need to maintain system stability and different adaptations of the existing grid infrastructure (as illustrated by the green leaves).

Finally, the energy system transformation needs significant processes of behavioural changes of the different stakeholders and even societal changes. As the future energy system will be based strongly on variable energy sources (with the use of wind and photovoltaic (PV) for electricity production and solar thermal energy for direct heat and cold production), producers and partly also the consumers will have to learn new roles in managing the surpluses at times where they are not immediately needed. These societal challenges also imply the question of maintaining security of supply in the long run which cannot be guaranteed without the necessary stable and sufficient investment conditions (as shown in the blue frames).

While the outer parts (green leaves and blue frames) need actions by many different actors (politicians, regulators, grid operators, all kinds of companies, banks and citizens), the questions of market integration and market adaptation are strongly (but not exclusively) linked to actions by power producers and energy traders themselves. During the upcoming phases of the energy system transformation, the distinction between variable and flexible renewable energy sources will become of growing importance. Their roles should be more and more diverging concerning the following aspects:

- Both kinds of renewable energy sources will act differently in the different market segments (spot markets, frequency regulation markets and futures' markets) of the energy system, depending on their cost structure (varying shares of marginal and fixed costs) and their predictability.
- They will contribute in different manners to maintaining system stability—being a challenge that cannot only be fulfilled by markets.
- As mainly bioenergy is able to produce simultaneously (and fairly predictable) heat and power, its role in sectoral coupling will differ from the role assigned to variable energy sources.
- Furthermore, biofuel for mobility is an important path but not focused on this paper.

These challenges imply the need of redefinition of the role of bioenergy for the different actors and components of the energy system. In the following chapters, we explain the current legal and factual framework in which bioenergy operates, a method to identify the future role of bioenergy and the findings of the IZES gGmbH regarding the role of bioenergy within the different phases of the energy system transformation. Finally, the possible financing of bioenergy installations will be discussed.

The future role of bioenergy in the electricity sector: a broadened approach to flexibility

In Germany, the energetic use of biomass has seen a rapid increase in the last decade (Fig. 2, first four columns). At present, bioenergy contributes significantly to the production of heat[2] and power and has also seen a growing share in the mobility sector even if this has lessened since 2010. Especially in the biomass-based electricity sector, the increase of new installations in the last 15 years has been a success of the German policy (the German feed-in tariff law, EEG). In the last few years, the average of newly installed production capacity per annum has been between 300–500 MW. Figure 2 represents different scenarios about bioenergy and its shares in the three energy sectors (electricity, heat and mobility).

Currently, there is no universal/official scenario/plan or target for the future share of bioenergy on the different sectors, but discussions on the future role of bioenergy are ongoing. In a study mandated by the German biogas association (Fachverband Biogas), the IZES gGmbH analysed the future contribution of bioenergy to the electricity sector [7].

Before the introduction of the 'flexibility bonus' within the German renewable energy law in 2012 (EEG 2012), which remunerates the installation of additional capacity able to provide more flexible modes of operation, most existing bioenergy installations kept their plant capacity at the same level for the whole year. Installations built before 2012 have been designed and optimised to run constantly. With the newly introduced flexibility bonus, construction companies and installation owners started to experiment with different operation modes, using gas reservoirs, variable feeding of the fermenters and etc.

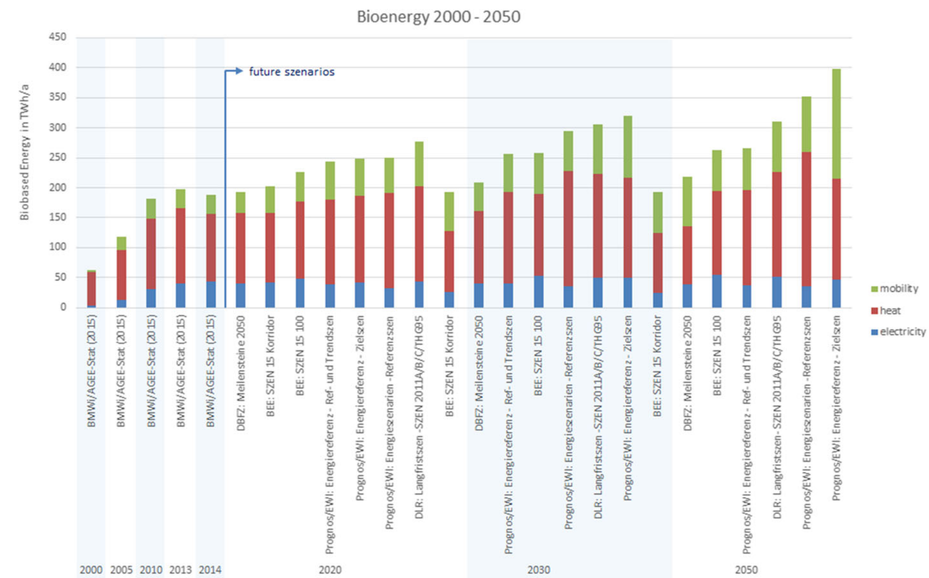

Fig. 2 Recent development and different bioenergy scenarios for mobility, heat and electricity in Germany [14]

Besides these technical aspects, the question of who should profit from this flexibility has been discussed largely in Germany as most biogas plant owners simply sold their flexible production according to spot market prices. These aspects were discussed in [7]. Theoretically, biogas can be used flexibly as natural gas. Furthermore, from a technical point of view, wood is more flexible than coal regarding the partial loads behaviour. This discussion arouses from the underlying question of the short-, middle- and long-term roles of bioenergy in the energy market. Concerning the electricity system, two basic characteristics play an important role in this discussion: the general flexibility and the possibility of highly efficient provision of electricity and heat. Especially, biogas can offer this adjustable flexibility (unlike VRE such as wind or photovoltaic) because of the inherent storing function of biomass and its multifunctional usability. Therefore in the further discussion, biogas is highlighted.

In order to model and analyse the possible costs of the flexibilisation of biogas (depending on the degree of existing and newly transformed capacities), a proper biogas facility database has been established [7] which includes data of existing plants (2014) and a forecast of possible new installations until 2020.

Furthermore, the study distinguishes between the variants of 'complete' and 'partial flexibilisation': Partial flexibilisation as well can allow more flexible operation modes with less capital intensive solutions such as gas or heat storages.

Figure 3 shows the possible capacity gains (in GW) for 16 different cases: Four scenarios have been set up with different degrees of flexibilisation, and these four scenarios have been combined with four different modes of operation:

– Scenario 1: 20% of the existing stock and 50% of new installations exceeding 500 kW are made flexible
– Scenario 2: 20% of the existing stock and 75% of new installations exceeding 150 kW are made flexible
– Scenario 3: 50% of the existing stock and 100% of new installations exceeding 150 kW are made flexible
– Scenario 4: all existing and new biogas capacities are made flexible;
– Operating mode 8S/16E: the installation interrupts or stores its production during 8 h and sells during 16 h (e.g. following specific price patterns or for participation in the tertiary reserve market)
– Operating mode 16S/8E: the installation interrupts or stores its production during 16 h and sells during 8 h (e.g. following specific price patterns or for participation in the tertiary reserve market)
– Operating mode 12S/12E: the installation interrupts or stores its production during 12 h and sells during 12 h (e.g. base-load hours vs. peak hours or for participation in the secondary reserve market)
– Operating mode 10S/4E/6S/4E: the installation interrupts or stores its production during 10 h, sells during 4 h, interrupts or stores during 6 h and sells for another 4 h (selling during the daily price peaks in the morning and in the evening and interrupting from 8 p.m. to 6 a.m. and from 10 a.m. to 4 p.m., adapted to the 'phelix sun peak future').

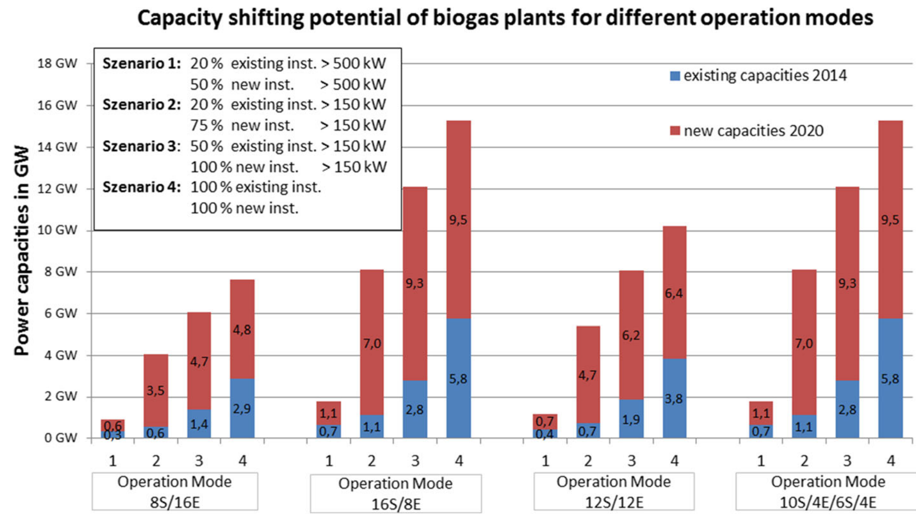

Fig. 3 Potential for capacity shifts in 2020 assuming different degrees of flexibilisation of existing installations (status quo) and possible new capacities with four different modes of operation [7]

There is a maximum capacity shift potential when combining scenario 4 with the operation mode 2 (16S/8P) with 16 GW of capacity shift, slightly followed by the operation mode 4 (10S/4P/6S/4P). From a technical point of view, biogas is thus able to deliver important quantities of capacity shift and therefore contribute to the different needs of the electricity system.

Consequently, the next step in the study has been to ask whose demands can be satisfied with these flexibility potentials as the flexibilisation of the biomass always should preferably be pursued according to the needs of the system transformation.

One priority flexibilisation aim has been identified when analysing the origin of negative prices in the spot market of the EPEXSpot. In order to maintain system security, a minimum power plant capacity must remain in operation in order to deliver instantaneously ancillary services (particularly the primary and secondary reserve). Today, they are delivered by conventional power plants and partly contribute to the formation of negative prices at the day-ahead market of the electricity exchange.

Usually conventional power plant operators market their whole production in advance in the long-term markets if at least they can achieve their marginal costs. Having sold their capacity, they carry out a monetary optimisation in the day-ahead auctions by replacing their own production with renewable energies sold 'unlimited' (which means at the lowest price limit). If the quantity of substitutable conventional production exceeds the production of renewable energies, positive prices occur in the power exchange day-ahead trade. In the opposite case, when the production of renewable energies cannot be substituted completely, negative prices occur. Conventional producers are, either due to the supply of balancing energy or due to reasons of microeconomic optimisation of a single power station, resp. their portfolios, willing to *pay* for electricity to avoid a still more expensive reduction or a complete switching off.

Consequently, current bioenergy power plants should be empowered to replace these conventional must-run capacities by offering and delivering all forms of balancing energy. Accordingly, the legislator should continue to remove tangible obstacles for the use of bioenergy as balancing energy (further shortening of offer periods, approximation of trading dates to the delivery date, further synchronisation of the trading dates of the bulk energy markets and of the balancing energy markets, etc.). In doing so, it should be achieved by appropriate regulations that the bioenergy plants behave less 'spot market price fixed'.

Due to the spot market price-related shift of the production of electricity from biomass, actually, a substitution of fossil electricity is only partly achieved. As Fig. 4 shows, buffering biogas in low-price periods and selling it in high-price periods creates the necessity to produce more electricity from lignite and even less gas-fired electricity. In the end, the ecological effect is rather negative due to a higher share of coal.

Therefore, it seems adapted to pursue a spot market-based operation of bioenergy plants starting from the time where the production of variable renewable energies contributes to more than half of the electricity production. At this time, we can more frequently expect hours in which real surpluses of VRE occur. With VRE surpluses taking place, switching off bioenergy may prevent VRE from being thrown away and thus generate system-wide and environmental benefits.

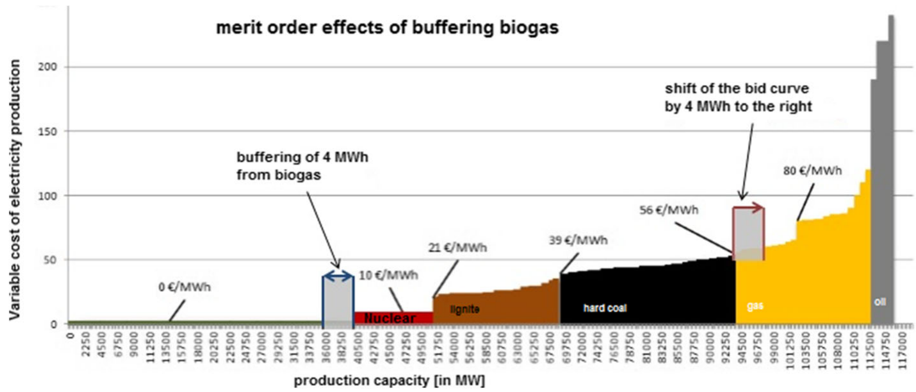

Fig. 4 Exemplary shifting effects by flexible biogas CHP within the merit order of power plants [7]

Regarding the energy system transformation, it seems necessary to pay more attention to the separation of functions of real 'peak load power plants' (especially combined cycle power plants and gas turbines) and the biomass-based CHP plants, whose operation is more linked to the fluctuation and seasonality of the heat demand. Thus, the German legislator should implement measures to check and if necessary, revoke the exceptions concerning minimum percentage of heat recovery of biogas gas plants applied for the direct marketing of their electricity. For the future, it is not desirable that bioenergy plants whose economic calculation is too unilaterally based on incomes resulting from the electricity sector are built. In this context, it should be checked if the minimum proportion of combined heat and power production can be seasonally differentiated if bioenergy plants show a seasonally strong diverging operation. So during the heat period, the heat production level could be considerably higher, whereas in summer months, it could be reduced which would also serve the aims of developing solar thermal and waste heat use combined with thermal storages and heat grids fed by these devices.

It therefore seems that the principal role for biogas plants, besides the provision of highly efficient combined heat and power, should be to provide ancillary grid services as shown in Fig. 5 (i.e. frequency stability, voltage stability and reactive power compensation, delivery of grid losses, re-dispatch, congestion management resp. or black start capacity). Basically, bioenergy plants have the ability to provide these system services.

Developing and marketing these abilities of bioenergy plants seem actually quite important in order to replace the existing must-run capacities by conventional power plants.[3]

Current legislative points of failure concerning bioenergy

As pointed out in Chapter 3, bioenergy has a huge potential to fulfil ancillary grid services. To enable existing installations to fulfil these functions, owners need to have reliable incentives to invest in the refurbishment of their installations. The project 'Biogas quo vadis'[4] analysed the recent development of existing biogas plants in Germany and the incentives for their future perspectives under the current law. Further research should now be done in order to find out whether these results can be adapted for all types of bioenergy plants.

The feed-in tariff law in Germany (EEG) guarantees payments for the electricity fed into grid for 20 years. After this period, the installations should be financed only by selling their electricity (and heat). Figure 6 is demonstrating the challenges if market participants would only rely on the spot market. In 2015, the average price in the wholesale market was around 32 €/MWh. The hourly rates varied between minus 80 and plus 100 €/MWh. Without the market premium, a common biogas installation could only produce several hours per year. The blue line shows the spot market prices, the red and the green line the production costs. The modelled biogas installation has a capacity of 500 kW with benefits from heat sales (green line). A sensitivity analysis was done to demonstrate the price differences in a high price scenario. In this scenario, there are no lignite-fired power stations in operation. Even in this scenario, the average electricity spot market price is only around 56 €/MWh; the maximum EPEX spot prices should be around 150 €/MWh. Taking into account these assumptions, the 500 kW installation would have less than 200 h to cover the production costs—even when deducting its income from heat sales.

Without any further income, the number of existing power plants is expected to decrease. In 2016, a new feed-in tariff law for energy ('EEG 2017', being effective at the beginning of 2017) has been adopted. It contains a new expansion target of 150 MW_{el} for the three years from 2017 to 2019. From 2020 on, an expansion target of 200 MW_{el} is stipulated, thus expanding the existing one

Offered services	Offered goods	Demand (D & neighbouring countries)	‚Market place'
Primary reserve	MW/ MWh	783 MW (AT-CH-D-NL)	www.regel-leistung.net
Secondary reserve	MW/ MWh	Neg: 1919 MW Pos: 1998 MW	Idem
Tertiary reserve	MW/ MWh	Neg: 2801 MW Pos: 2464 MW	idem
Lost energy	MWh	Depends on TSO/ DSO	Auctions of the TSO/ DSO
Reactive power	‚Var' (=W)	?	contracts
Self-contained restart capacity	Depends on the context		contracts
‚Redispatch'	MWh	situational	contracts
‚Countertrading'	MWh	situational	Power exchanges

Fig. 5 Existing ancillary grid services and their main characteristics [5]

(since the EEG 2014) of 100 MW_{el}. These objectives are 'gross' expansion targets which do not form an upper limit but mean that the digression of the feed-in tariffs is more dynamic if more biomass plants are installed than foreseen. These gross targets do not take into account that existing installations may have to be replaced due to the end of the life cycle of the engine or if they are running out of the EEG after 20 years. Figure 7 describes one possible development of biogas capacities until 2035 [5], sketching the gross expansion target of development stipulated by the EEG 2014 of 100 MW_{el}. The installed capacity is higher than the rated capacity, as flexibility requirements in the EEG lead to a less-rated power (nearly one half).

It can be concluded that biogas can play an important role in the future energy system only if biogas capacities can exceed the capped expansion target of 100 MW_{el} per year [5].

Discussion and conclusions

In their recent studies, the authors came to the point that there are currently no further market opportunities for biogas plants in Germany. Besides this, in the last years, electricity generation from wood decreased due to the policy of cascading utilisation of wood with a priority to material usage [9, 10]. Wood burning systems are even less flexible than biogas CHP units. The number of new biogas installations is expected to extend only due to the utilisation of organic waste materials as substrates or small installations based on liquid manure [11]. The consequence of these restrictions may be an important decommissioning of existing biogas or bioenergy plants that can be expected to start in the next decade as shown in Chapter 4. Another study [10] also came to the conclusion that remuneration schemes are insufficient for biogas installation in the future.

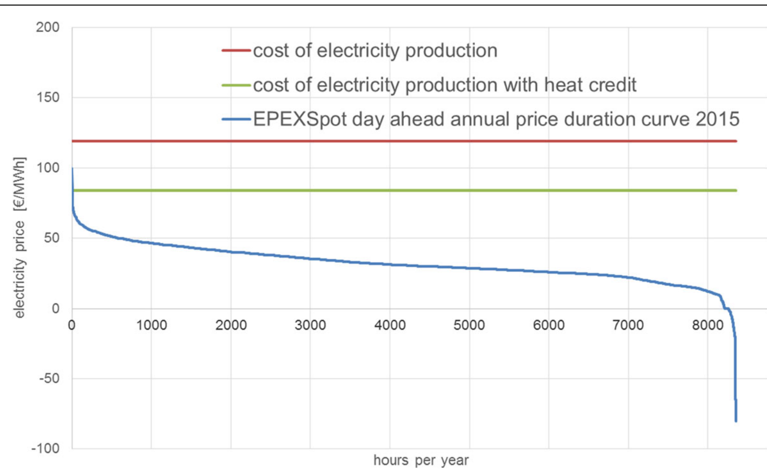

Fig. 6 Example for specific bioenergy production costs and prices on EPEX spot market 2015 [5]

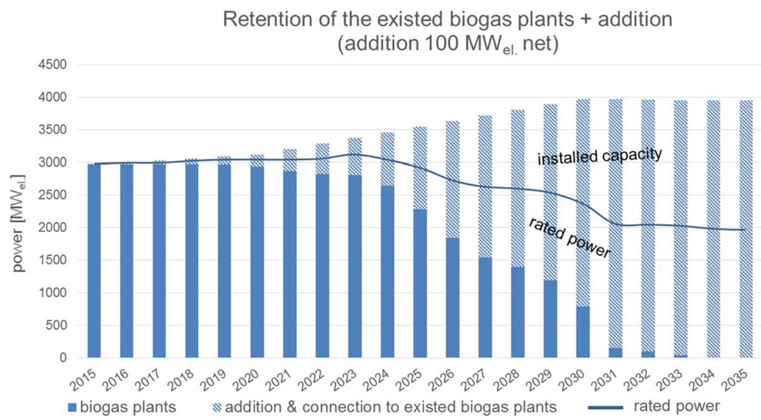

Fig. 7 Capacity development of biogas installations until 2035 as targeted in the EEG 2014 [5]

This could have some influences on the climate change reduction goals in Germany. The authors' calculations [5] assume a yearly increase of 20 Mio. t CO_2 equivalents in the field of electricity if a reduction of biogas installations will take place. Furthermore, there may be rising CO_2 emissions due to the replacement of heat production delivered by bioenergy units being the main supplier of renewable-based district heating systems [5]. Stranded investments of biogas-based district heating grids may take place, even accentuated by recent low oil prices. Thus, both the transition to a renewable electricity system and to a renewable-based heat system proves to be an important challenge [5].

The ability of renewable power plants to replace fossil fuel-based must-run capacities and to cover other needs of a future energy system would be lost.

Suggestions of how to overcome missing financing [7] are displayed in Fig. 8. They focus on the following further positive effects of bioenergy which are currently not rewarded:

– Biogas installations as a nutrient buffer for nitrogen surplus regions (mainly caused by extensive livestock breeding)
– Further incomes from the provision of ancillary services in the electricity system
– Higher incomes from heat supply (induced e.g. by fossil fuel prices taking their negative external effects into account
– Compensation for the GHG reduction of the agricultural and waste treatment sector
– Financial transfer from other sectors like solid waste or wastewater–compensation for positive effects due to climate change mitigation or water protection
– Positive effects on the nature conservation and landscape management

Therefore, the cost-benefit discussion in the field of bioenergy needs to urgently integrate the additional positive effects of bioenergy on other sectors as cited above. In conclusion, further research should focus on effects of all kinds of ancillary services in order to

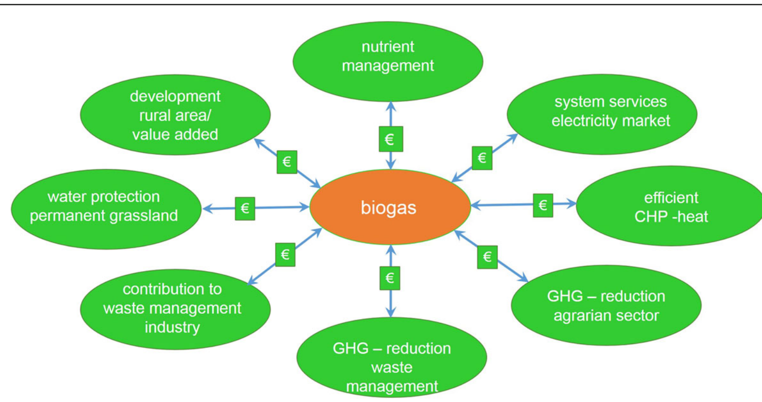

Fig. 8 Possible ways to overcome missing financing in the field of biogas [5]

replace the conventional must-run capacities. This future research should investigate the positive effects of biomass on other economic and societal sectors and how these sectors can contribute to the financing of biomass-based renewable energies. Further important research questions should address the impact of lessening the demand of energy crops on the agricultural markets if the biogas capacity is decreasing as predicted.

Endnotes

[1]As shown in [12], a fundamental redesign of the different markets is necessary to assure re-financing of variable AND flexible renewable-based power plants.

[2]As heat production depends from climatic variations, the absolute values represented in this figure give an (incorrect) expression of a stagnating share of renewable heat.

[3]The opportunities and the constraints of the conventional 'must-run capacities' compensation is currently under review within the project 'Symbiose'. Symbiose is a research project funded by the German Federal Ministry for Economic Affairs and Energy (BMWi), conducted in cooperation of IZES and Fraunhofer IWES. The results are expected by the end of 2016.

[4]Conducted from IZES and IFEU, November 2015–May 2016, funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB).

Abbreviations

BMUB: Bundesministerium für Umwelt, Naturschutz, Bau und Reakorsicherheit; BMWi: Bundesminiserium für Wirtschaft und Energie; CHP: Combined heat and power; CO_2: Carbon dioxide; EEG: Erneuerbare-Energien-Gesetz; EPEX: European Power Exchange; gGmbH: gemeinnützige Gesellschaft mit beschränkter Haftung; GHG: Greenhouse gases; IFEU: Institut für Energie- und Umweltforschung Heidelberg; IWES: Fraunhofer Institut für Windenergie und Energiesystemtechnik; IZES: Institut für Zukunftsenergiesysteme; RE: Renewable energy; VRE: Variable renewable energy

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Authors' contributions

Both authors drafted the different parts of the first version of this manuscript and contributed to revising and finalising this article. Both authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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