Background paper

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Agricultural perspectives on biogas and biorefinery technologies

Grote, U.; Lewandowski, I.; zu Löwenstein, F.; Tappeser, B.; Thrän, D.; Wolperdinger, M.

Note

This background paper summarises significant key statements and discussion points from various workshops held on this topic between March and September 2022 under the leadership of the aforementioned authors and with the participation of external stakeholders. This is not a Bioeconomy Council position paper. Its contents, views and conclusions do not represent recommendations for action or the results of studies carried out by the German Bioeconomy Council, rather they exclusively reflect the contents of the discussions conducted by and with experts.

Summary

There are around 9,700 biogas plants in Germany (Statista Research Department, 2022), most of which can be found in the agricultural sector (German Biogas Association, 2021). These produce about 31.3 TWh of electricity (Research group: Erneuerbare Energien-Statistik, AGEE-Stat am UBA, 2022), and have become a significant source of income for agriculture. Besides contributing to the reduction of greenhouse gas emissions, they can provide a range of other environmental benefits by decreasing emissions from slurry use and the usage of this leftover agricultural material for energy and fertiliser production. However, amendments to the German Renewable Energy Sources Act (EEG) are endangering the economic viability of running agricultural biogas plants. As a result, plant operators need to develop new operating models and possible alternative sources of income that are independent of funding by the EEG. Examples of these include the manufacture of biomethane that can be fed into the natural gas grid or local fuel supply, flexible electricity production or increased heat supply.

Furthermore, public criticism of the increased cultivation of maize within the context of biogas plant expansion is growing, especially since this crop, grown to assist in energy

production, has the potential to compete with food production. It is therefore necessary to examine how the enormous infrastructure of biogas plants in Germany can be developed further, both in terms of a more sustainable supply of raw materials and from a technical standpoint. This will unlock their potential for providing renewable energy, reducing greenhouse gases and supplying farms with their own energy and fertilisers. Future options include, for example, sowing flowering plants, aquacultures (for heat use) or power-to-X processes. What all these have in common is that they can be considered as a possible source of income with agricultural biogas plants.

In addition, integration of the relevant technologies into biorefineries can also be deemed a suitable development. This could be numerous technologies, adapted for use with bio-based raw materials, that result in a range of target products In agriculture, the aim is to install biorefineries on farms or as close to them as possible. This will allow the raw material, which is usually watery and liquid, to be processed on site, thus avoiding the need for costly transportation. Plus, farmers are then able to participate as much as possible in added value, thus creating income opportunities in rural areas. In such instances, the "economy of scale", as it is known in the industrial sector, is replaced by the "economy of numbers" (decentralisation).

1. What specifically do agricultural biogas and biorefinery technologies contribute to achieving land management diversification goals?

Reducing the input dependency of agricultural systems

In essence, biogas and biorefinery technologies reduce the input dependency of agricultural production systems and farms. They do this by:

- enabling agricultural businesses to supply themselves with renewable energies (electricity, heat, fuel)
- closing material and energy cycles. In particular, this can result in a reduced requirement for externally sourced mineral fertilisers. These can either be
    - replaced by digestates or,
    - if biorefineries and biogas plants are integrated into farms, by recycling mineral components – phosphorus (P) and nitrogen (N) in particular – on-site as fertiliser or by selling them off (see NADU https://www.nadu-naturduenger.de; site only available in German)
- crop rotation diversification, which can result in the reduced use of synthetic fertilisers, e.g. if nitrogen is fixed using legumes in the crop rotation (important for organic farms in particular), or

- crop diversity – this reduces the pressure put on farmers by disease and pests, so that fewer plant protection agents and pesticides are required. Integrating them into biorefineries can result in an expansion in the scope of crops used (e.g. fibre, oil, protein crops).

Carbon accumulation in soils

Crop rotation diversification can also enrich the soil with carbon, e.g. if humus-forming and catch crops are integrated.

The targeted application of digestates or biochar on agricultural land can also lead to an increase in long-term carbon fraction retention in the soil. During fermentation, it is mainly the readily available carbon compounds that are decomposed and it is primarily those that are difficult to break down, such as lignin, that remain in the digestates (Hofmann et al., 2015). Indeed, in studies conducted by Chen et al. (2012), the digestates decomposed 2.5 times more slowly in the soil compared to maize stover and yielded a 34% higher carbon fixation.

Enhancing income opportunities in agriculture

Biogas and biorefinery technologies offer income options with higher added value for agriculture. Electricity and heat are sold as refined products instead of biomass. In the future, the expansion of biorefineries will offer additional potential, thanks to a diversified product range consisting of agricultural raw materials with high-value products (e.g. biochar or activated carbon, basic chemicals such as HMF), thus enabling the comprehensive use of all raw material and energy flows.

This is why more and more research into technologies that are suitable for decentralised use close to the farm – i.e. close to the biomass resource – is being carried out.
It is therefore advantageous, both financially and environmentally speaking, if the often very liquid biomass, containing next to no dry matter, can be processed directly, close to the source, eliminating the need for transportation, which can be costly.

Overall, (integrated) biogas and biorefinery technologies can offer opportunities for developing new business models that play their part in the revitalisation and diversification of rural areas.

Biorefineries can be integrated into existing infrastructures and attached to chemical and biological and biotechnological processes for biomass and waste processing, meaning that they constitute the actual implementation of cascade use for primarily material purposes.

Generating energy that conserves resources

Germany's approximately 9,500 rural biogas plants supply about 11% of the country's renewable electricity and save about 20 million tonnes of CO_2 equivalents in the electricity sector, which corresponds to about 10% of the total greenhouse gas emissions averted by renewable energies across all sectors (e.g. electricity, heat, transportation). This quantity must be secured politically in the long term, so the renewable portion of electricity generation is not lost.

In this context, agricultural biogas plants enable synergies to be achieved via the

- use of residual and waste materials for generating energy
- simultaneous use of slurry for generating energy and for reducing nitrogen losses resulting from both its storage and spreading
- recycling of nutrients

Preservation and/or restoration of biodiversity

Potential synergies with biodiversity, in particular by sowing catch crops and flowering plants as well as the opportunity to exploit landscape management materials, may exist within the context of expanded crop rotations and crop spectra.

2. What is the state of biogas and biorefinery technologies? Are they able to realise these goals?

Biogas

Germany has an extraordinarily large infrastructure of biogas plants in rural areas.
We should continue to make meaningful use of them.

The greatest challenge for the continued operation of biogas plants in rural areas is converting the resource base to a low-energy crop or to a biogas-maize resource base. There have been controversial discussions on the extent to which conversion to a predominantly waste-based resource base should be set as a premise for continued operation.

The challenges with digestates, however, are that they are often difficult to ferment in the first place (e.g. due to high lignocellulose content, process inhibition induction, very low or very high dry matter content), have fluctuating material properties and are usually produced in small quantities on a decentralised basis. From a technical view, the existing biogas plants have so far been equipped with stirred tank reactors, which are designed to feed easily fermentable feedstocks as uniformly as possible. There is, therefore, an urgent need to build modular biogas plants that are also equipped with precise process control (sensor and model-based, largely automated) to facilitate the steady control and monitoring of the biogas process with a changed resource base in the future. This technological level has not yet been reached in the biogas plants built to date.

Other major challenges are the changed financial framework conditions – above all due to amended requirements for guaranteed remuneration claims through the EEG. Existing business models are being scrutinised and are undergoing major changes; new business models have only partially been established. As a result, plant operators need to develop new operating models and possible alternative sources of income that are not part of EEG funding. However, the majority of plant operators are still looking for ways to diversify their business models. Examples of these include the manufacture of biomethane that can be fed into the natural gas grid or local fuel supply, flexible production of electricity or increased heat generation. There is increasing interest in and demand for CO_2 credits as part of new business models.

The technological development of biogas plants (automation and digitalisation) is also essential for these new business models to succeed.

Biorefineries

In 2017, there were 224 biorefineries in Europe (Biobased Industries Consortium, 2017), including both rather simple technologies such as biodiesel and bioethanol plants focusing on one main product, and oleochemical or starch, sugar and cellulose processing plants with a wide range of products. Indeed, the word "biorefinery" is not a one-size-fits-all term – numerous technologies exist, each of which can produce a scope of products adapted to the raw material base used.

Consequently, there is a wide range of technical possibilities. However, special, customised machinery for each product stream is required initially. Integration into automated process lines, spanning receipt of materials to processing and packaging, are necessary for this. The complexity of the technologies calls for sufficient expertise among all those involved, at all levels, which is often not available to an adequate degree on farms. This will result in the need for external support to be provided to farms in the future. Other difficulties may also arise in manufacturing various chemicals that, for example, fall under the REACH regulation and other legal provisions. (Comparable to the costs incurred for preventing explosions in biogas plants, which also had to be dealt with initially before production can begin).

These framework conditions make access to these technologies in rural areas more difficult. Biorefineries that produce fertiliser and biochar or fibres as feedstock for the packaging industry are particularly suitable for farms.

Increasing emphasis is being placed on the use of waste (agricultural, industrial, municipal) for the resource base. However, flora such as the cup plant and miscanthus are also becoming increasingly attractive for producing basic substances for fibre manufacture and are already being used full-scale at some locations.

3. What are possible conflicting goals and obstacles to the sustainable implementation of biogas and biorefinery technologies?

The main conflicting goals and obstacles pertain to both biogas plant and biorefinery operation.

Raw material base

Possible conflicting goals can arise from the competing uses of biomass for food production or the generation of energy, and possibly also for material use. The latter is of secondary importance, however, as the quantity required is significantly smaller than in other areas. Nevertheless, a supply of resources that is both reliable in the long term and as consistent in composition as it is high in quality is the greatest challenge for biogas plant and biorefinery operation.

Possible solutions for this could be:

- Switching the feedstock base to waste
- The use of flora that has its own land requirements may only be used in conjunction with the pursuit of other objectives, such as the fulfilment of ecosystem services (e.g. flowering plants, catch crops, paludi biomass, landscape management)
- Growing multi-purpose crops, thereby creating synergies with food production or even recyclables (e.g. fibres and vegetable oils) alongside energy. Maize is a multi-purpose crop that can be used as an energy, fodder and food source. Consequently, the advantage of growing biogas maize is that it can be used immediately as a food crop if required. The same is true for wheat.
- Using land that is not used for food production (marginal land, surplus grassland)
- Contributing to the reduction of competing uses, also on the part of food systems, shifting to more plant-based and, hence, less resource-consuming diets.

When using waste, risks to health and the environment are possible (i.e. contamination with pathogens, antibiotic residue). However, this can partly be solved by technology.

The use of waste materials is potentially less economical than the use of energy and industrial crops, since

- higher demands are placed on plant technology and process control (see current state of technology), which increases expenditure,
- fluctuating composition requires additional treatment steps,
- lower methane yields may reduce revenues.

Raw material trade-off: what is the focus of biogas technology – energy production, a circular economy or a biorefinery system?

Economy of Scale

For biogas plants, the "economy of scale" affects the implementation of a circular economy.

In industrial applications, the competitiveness of biorefineries is often dependent on their size, as their operation is associated with high costs in terms of administrative tasks and requirements, and there are high demands on the infrastructure. A possible solution is the clustering together of several biogas plants that share the skilled labour where maintenance, permits, etc. are concerned.

Unlike the industrial sector, the "economy of scale" in biorefineries can be compensated by the "economy of numbers" in the agricultural sector, with somewhat smaller plants located closer to the farms. The extent to which farmers can afford these biorefineries or whether cooperative models need to be developed, which could be equally helpful in this regard, has been discussed. However, it must be ensured that no further concentrations can develop that could lead to a local oversupply of nutrients and therefore – due to the high costs of transporting nutrients to other regions – to the over-fertilisation of areas close to the biogas plants.

Ecological aspects

As the profitability of agricultural production increases, so does the incentive to intensify production or to achieve high biomass yields. This leads to unproductive but more biodiverse biomass production systems such as wild plant mixtures, which have lower biomass and lower specific methane yields, not being grown. Moreover, the poorer digestibility of this biomass jeopardises technological process reliability.

The carbon balance should be taken into account to ensure the carbon content in the soil does not decrease. This must be counteracted by further improving the return of the biogas digestates to the production areas.

Technical aspects

Biogas

- Expansion and development of storage technologies
- The state of technology and state of knowledge remain insufficient. As a result, the operators were confronted both with constantly changing requirements and targets (e.g. proportion of slurry, retention time, heat use, electricity or gas feed-in, elimination of by-product use, etc.). This required considerable additional investments. Legislation from other sectors also brought considerable need for amendments. Every change is expensive and determines how operations are to be run in the long term. The demand for the most up-to-date knowledge is high, both for the operators and for the advisory services.
- Existing technologies for water management and both recirculation and use of process water are technically complex, expensive and usually require a considerable amount of energy. This means that these methods are too costly and too inefficient for their use to be economically viable.

Biorefineries

- Biorefinery concepts are still in the development phase and not in technical use.

Economic aspects

The bioeconomy requires a transformation of the economic system ("regionalisation" of the economy, "decentralisation"). This also raises the question as to how a sustainable model can become a business model.

Biogas

- Waste-based biogas systems are not competitive enough
- Legal uncertainty and obstacles to approval on the use of waste in the biogas process
- Lack of planning security

Biorefineries

- The long-term availability of raw materials that are, as far as possible, consistent in terms of quality and composition, especially when using by-products and waste, can only be achieved to a limited extent
- Raw material waste is of low quality, meaning that correspondingly more effort is involved in intermediate and end product extraction

- Bio-based products are often not competitive enough compared to fossil-based products. As prices for fossil products rise, new perspectives should be possible here.
- Costs for decentralised, small-scale solutions for processing locally produced biomass (on-farm biorefineries) are high, unless they are built in larger quantities ("economy of numbers")
- Marketing costs increase with the number of products. Close cooperation between the decentralised biorefineries is necessary here.

Social aspects

- Where biogas is concerned, there has been a lack of objective information and public acceptance of bioenergy due to strong negative lobbying by certain groups (energy suppliers, BUND) against the growing production of biogas over the past 20 years
- Supply chains are very long with high overall added value, yet raw material suppliers have not been involved enough so far
- Public awareness must be strengthened, in order to encourage support for domestically produced products and energy, as well as to favour their use over fossil sources. This can also facilitate regional added value.

Additional information

- High licensing requirements are placed on biogas plants
- There is a lack of knowledge institutionalisation, e.g. mechanisms for rewarding additional services such as CO_2 fixation
- Support for innovative business models and fair pricing in connection with CO_2 certificates for agricultural plants is low

Specific projects must be implemented at a local level, and the parties involved must be sufficiently integrated into the planning process. In this respect, the extent to which these parties' strategies already provide for a different use of resources must be taken into account.

4. What are possible recommendations for overcoming these obstacles and for supporting the sustainable use of biogas and biorefinery technologies?

Research and development

- Separation processes and technologies that are "affordable"
- Technology for producing chemicals/substances in the upstream chain (e.g. ensiling)
- Technology for extracting valuable ingredients from the downstream chains
- Water management, recirculation, process water
- Research on automation and substrate preparation (hardly any sensors are available for quality determination and process control) is needed
- Development of "raw material-tolerant" processes for the use of temporally and spatially variable input materials; greater flexibility of biogas plants and biorefineries
- How can the products of future land management systems, which also pursue multiple goals, and the provision of ecological functions (e.g. agroforestry and perennial crops, grassland, flowering and wild plants, paludiculture) be used, or how can future land management systems be designed in a product-oriented way?

Legal framework conditions

EEG

- The EEG must be realigned with a focus on the use of waste for energy, intercropping, making energy supply more flexible
- The EEG must be geared consistently towards adequate support for waste-based biogas systems

Renewable Energy Directive (RED)

- RED III must not cause material use to be inhibited by energy use
- Material use should be treated separately and as a priority

Training

- Promote capacity building and development measures, especially among biogas plant operators and those involved in implementation
- Implement consistent knowledge institutionalisation in control instruments

Establishment of regional networks and structures

- Support the development of regional production and marketing channels, close cooperation between farmers and initial processors

Additional information

- Combining energy production options that promote "energy hosting" is to be seen more broadly than just biogas, i.e. biogas plants are given a new role and new energy mix in and from agriculture
- How do we ensure that incentives are created for the raw material supplier in long supply chains?
- Promote better use of, and emphasis on, the flexibility of biogas plants and biorefineries, i.e. that raw materials can be used for different purposes, depending on the situation (e.g. energy and food)
- Biorefineries that produce fertiliser, fibres and biochar are particularly suitable for farms. Handling chemicals can be more difficult, also for legal reasons.
- Support systems that can perform many functions simultaneously
- Participatory implementation of innovations

Sources

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