Chapter 7

Sustainability of the Biowaste Utilization for Energy Production

Thorsten Ahrens, Silvia Drescher-Hartung and Olga Anne

Additional information is available at the end of the chapter

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Abstract

This article presents strategies for the development and practical modelling of biogas processes under economy market conditions. Herewith, anaerobic digestion results out of practical tests in different scales (lab to pilot) and different substrate mixtures were taken into account. Two lab-scale reactors on the one hand and pilot-scale examinations of chosen substrate mixtures on the other hand led to workable conclusions such as mixture suitability for biogas production, gas amounts and technical demands for full-scale implementation under market economy conditions. A comparison of both laboratory and pilot system performance with a full-scale biogas system has been done; herewith, the suitability of the corresponding practical process upscaling simulation has been proven. On the basis of the results, calculations regarding the necessary full-scale fermenter sizes and the required substrate amounts as well as the disposable (reusable) fermentation residues were made. The conclusion of outputs on biogas technology particularly with regard to the demand-driven production of electricity (500 + 250 kW flexible) as a special request for energy from renewable sources is given. As a further result, a general outlook and estimation for the economical implementation on a common Baltic Sea region country basis have been developed.

Keywords: biowaste, biogas, pilot scale, full scale, circular economy, waste-to-energy, sustainability, process simulation

1. Introduction

The European Union (EU) calls on all parties to the efficient use of energy and accelerates the integration of energy recovery technologies from wastes that emit less carbon dioxide [1].

Biogas production by anaerobic digestion is a well-known method of energy recovery from biomass. Nowadays, such technologies are widely implemented in accordance with the EU policies for green and sustainable energy supply, for example, in all Baltic Sea region countries, but in different percentages. As an example, in Lithuania, mostly sewage sludge was used for biogas production till year 2012. Half of the Lithuanian energy demand in 2009 was covered by fossil fuels, 16% by renewable sources [2]. As different publications of FNR (Fachagentur Nachwachsende Rohstoffe, Germany) show that the anaerobic digestion is well investigated, but due to the technology development, there is need of research, especially in terms of market economy conditions, because funding for such processes will end in the near future [3]. Funding strategies should be taken into account in order to allow the development and pilot implementation of new technologies. In any case, new technologies need to position themselves in market economy, which means that a long-lasting funding (e.g. for more than 20 years) should not be taken into account. In terms of biogas processes, long-lasting funding took place and market demands were not considered in most cases, corresponding solutions for the future technology development shall be addressed in this article. For example, in order to identify substrate potentials (especially from waste materials) for biogas production in connection with suitable operational strategies for different parts of the Baltic Sea region, two EU financed BSR programme research projects were performed—regional mobilizing of sustainable waste-to-energy production (REMOWE) and ABOWE (implementing advanced strategies for biological utilization of waste) [4, 5]. The technological and economic efficiency analyses of the biogas development were fulfilled within above-mentioned projects. Therefore—besides to operational data—costs (investment and operating costs) and expected revenues from the products were considered, because efficiency analyses constitute the basis for the process and evaluation of decision-making process [6]. A standard method for the execution of company evaluations is the calculation of discounted cash flow via assessing the value of future cash flows via discounting to the valuation date and deduction of the initial net investment [7]. The energy demand, which is presented by load profiles in the article, shows the difficulty of the energy management from different renewable energy sources like wind and solar power. From the authors point of view, an adapted feeding and demand-driven operation of biogas plant provides a possibility to solve this problem.

2. Renewable energy production: initial situation

The production of renewable energy currently plays an important role in the European Union and will gain importance in the future. Renewable energy sources are wind power, solar power, hydroelectric power, tidal power, geothermal energy, biomass and renewable parts of waste. Between 2003 and 2013, the production of renewable energy within the European Union increased by 84.4%. Thereby, the most important source was biomass and renewable waste. The renewable electric energy production had a share of 25.4% of the gross electricity consumption in the EU. Here the main growth could be registered in three renewable energy sources, which are wind turbines, solar power and biomass [8]. In Germany, the production of renewable energies had a share of 30% of the gross electricity production; in Lithuania, a rate of 16% is reached. Until 2025 the share, for example, in Germany should be increased up to 40–45% and until 2035 up to 55–60% [9].

2.1. Load profiles vs. renewable energy from wind and solar power

The term load profile relating to electricity describes a detailed listing of the yearly energy consumption or demand [10]. That means the load profile provides a pattern of the electricity usage of one or more and also different customers. Herewith, the current collection will be projected at 15-min intervals. Unless the energy consumption is not being measured directly, there are standard load profiles available, which will be used for forecasting calculations [11]. Based on measured data or standard load profiles, the yearly electricity demand of a certain region or customer group can be determined. An example of an annual load profile is being shown in **Figure 1**. The figure constitutes a simplified version. The curve was straightened and therefore shows no 15-min-pattern.

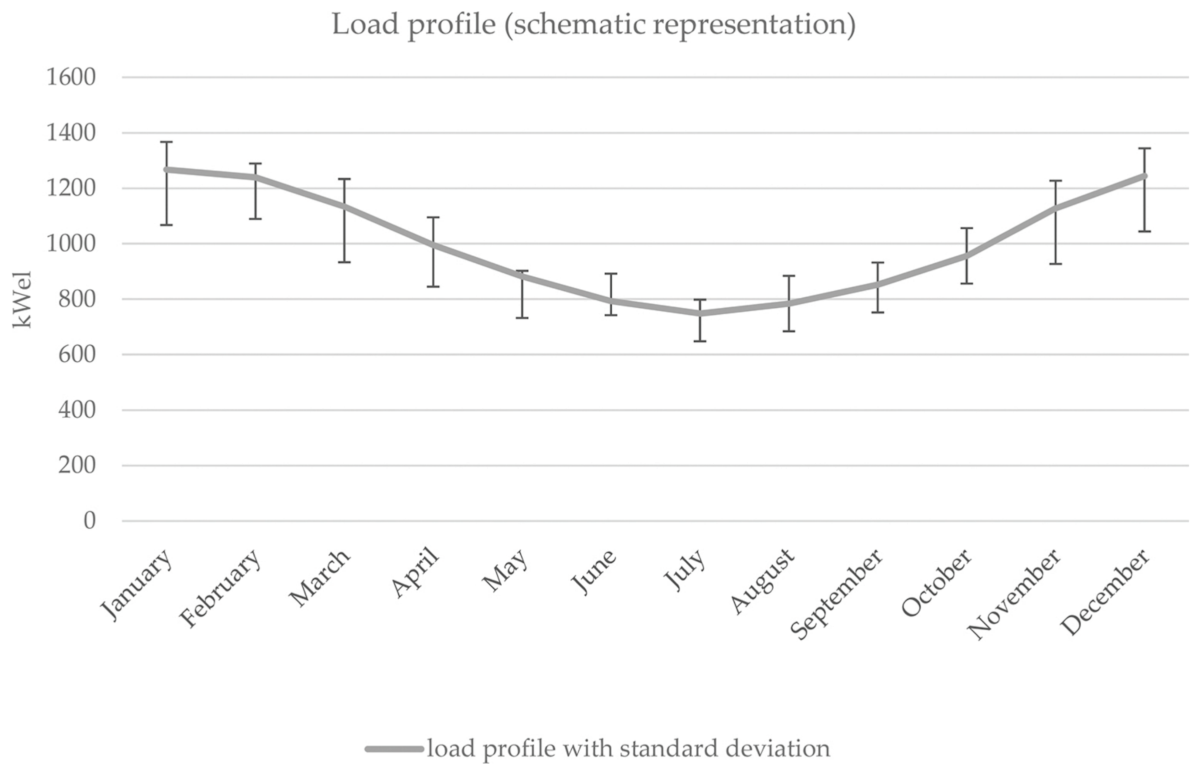

Figure 1. Load profile electricity demand.

As shown in **Figure 1**, the electricity demand is not evenly during the year. In current energy management concepts, the fluctuating demand is being compensated by the quick ramp-up of natural gas power plants [12]. The production of electricity from renewable energy sources had a high growth in between the last year. The relative share of electricity in the total quantity of electricity which was produced from biomass (incl. renewable waste) rose to 17.8%, the share of wind power to 26.5% and the share of solar power to 9.6% [8]. Anyhow wind and solar power are fluctuating producing electricity systems. Energy storage (for wind and solar power) is one of the possibilities to solve this problem [13]. Because of the increasing rate of fluctuating energies, it becomes more important to modify the electricity system, respectively, to find possibilities for energy storage or adapted energy production. **Figure 2** shows in an exemplary presentation how the covered amount of electricity produced by wind and solar power could exemplary look like. Data about the share of these techniques on the total energy demand are herewith being considered in percentage rates.

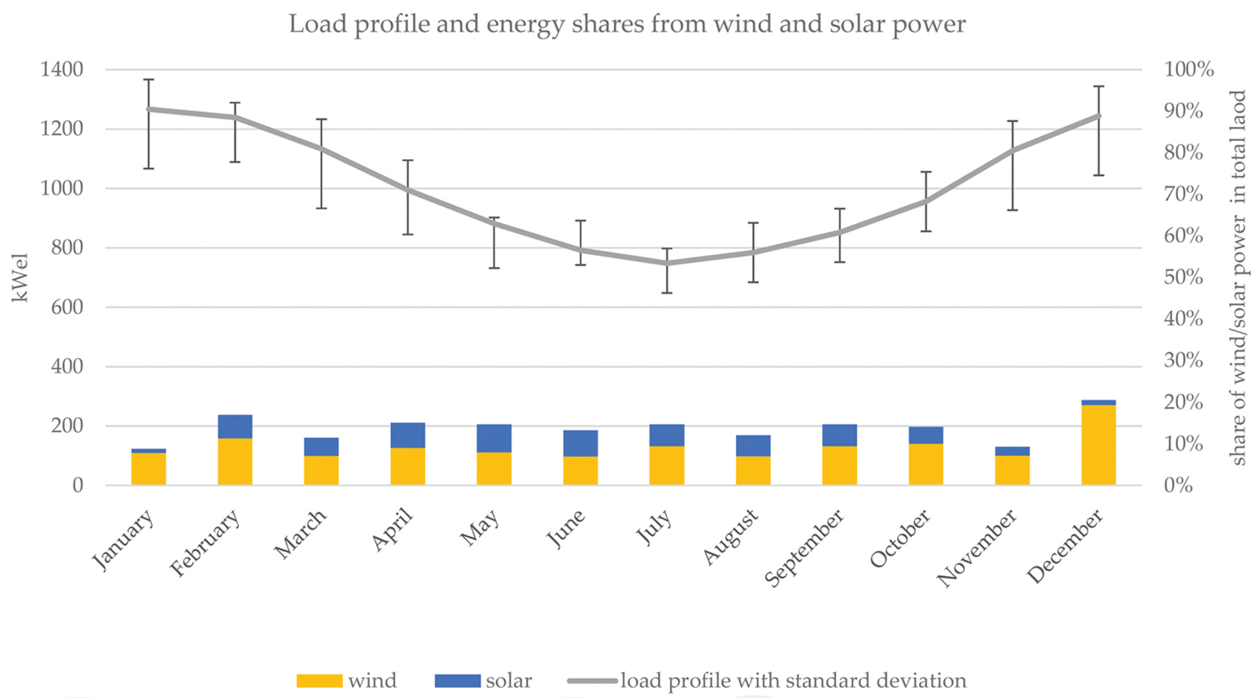

Figure 2. Load profile and energy shares from wind and solar power, data from Refs. [11, 14], adapted.

The annual load profile shows the variations in the electricity demand, which are not consistent. The problem of the electricity from renewable sources becomes obvious as it has been described above. Energy production from wind and solar power cannot be adapted, and it is fluctuating. The operation of biogas plants and production of biogas could be adapted with suitable operational methods, but nowadays the energy production is mostly even at a 24/7 rate. In order to solve the problem of adapted electricity production from renewable sources, there are essentially two possibilities available: (a) to store it or (b) to operate biogas plants adapted to the energy demand. Option (b) means that the production of electricity from biogas provides more features than wind or solar power. The produced biogas or also the produced electricity could be stored for later use. Moreover, a biogas plant provides the option to be operated energy demand oriented. Here the production of electricity depends on the feeding

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quantity, and therefore, an adapted feeding would lead to a demand-adapted production of electricity.

3. Substrate demand for adapted biogas scenarios

For production of biogas, many different substrates are used [3]. Primarily, manure or sewage sludge was used, but the kind of substrates used for biogas production changed in the last years. Many organic materials, for example, by-products in industrial or agricultural processes or also organic fractions from wastes like residual waste or biowaste from households, can be used. Many data concerning new substrates were collected during European-funded projects REMOWE and ABOWE at Ostfalia University [15]. Because some substrates are arising fluctuating and also with changing biogas yields, a targeted substrate management for an adapted operation of biogas plants is required.

3.1. Optimal operation of biogas plants adapted to the annual load profile

Based on load profiles (graph of the variation in the electricity demand of a region/city/single electricity consumer or other), the operation of a biogas plant can be planned and adapted, so that the electricity will be produced demand-based. Load profiles are provided by the power supplier or can be determined by use of standard load profiles (see Chapter 2.1). The substrate amounts, which are necessary for the calculation (see Chapter 7), will be determined on the basis of regional structural data or known arising substrates. As a conclusion, the exact quantity of demanded energy can be determined. Consequently, the biogas plant can be operated according to a well-structured substrate management.

3.2. Substrate management adapted to the annual load profile

Ostfalia University performed extensive studies concerning the energy demand and the adapted operation of biogas plants within several non-published student thesis works, including the consideration of the substrate demand. Herewith, the load profiles of different energy demands were used for the determination of regional-specific load profiles. The results of an exemplary adapted operation are shown in **Figure 3**.

In **Figure 3**, the exemplary adapted feeding of a biogas plant with biowaste and corn is demonstrated. The biowaste, which arises regularly but not evenly and furthermore with different biogas potentials (dependent on the time of year), has to be fed constantly because it cannot be stored for a longer period.

Therefore, energy crops like ensiled corn, which can be stored over a longer period of time, are being used for the additional feeding. The amount of corn, which has to be fed to reach the amount of the energy demand (based on an exemplary load profile), is being calculated in reference to laboratory substrate assessment results in Chapter 4 of the article.

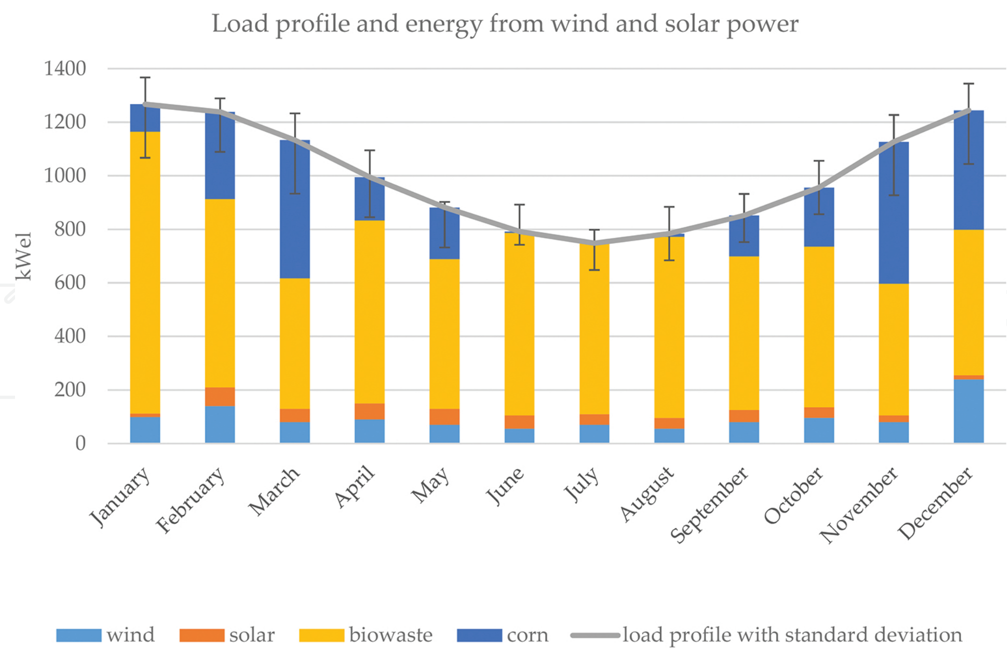

Figure 3. Load profile vs. energy potentials from wind, solar and biomass, data from Refs. [11, 14] and own calculations.

4. Biogas plant operation: from laboratory tests to large-scale plant operation

In order to be able to estimate the gas potentials of pure substrates as well as from substrate mixtures, practical data assessment is required. The following explanations are about samples being exemplary chosen by their availability in the Šilutė region of the country of Lithuania.

Figure 4. Substrates used in Lithuania. Cow manure (top left), distillery leftovers (top middle), algae (top right), food waste (original, mashed, sanitized) (from bottom left to right) [16].

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The Šilutė region is widely settled by farmers mostly cow farms; furthermore, there is a spirit distillery factory which produces considerable amounts of bioethanol process leftovers and residues of food (food waste) from catering business. Other sources for biomass are macro- and microalgae. These have been collected at different locations at the Curonian Lagoon near Klaipeda. The cow manure was delivered by a local farmer, and the distillery leftovers were provided by a local spirit distillery factory. The food waste has been collected in Lithuanian kindergartens.

The substrates are shown in **Figure 4**, and the physical properties are listed in **Table 1**.

Substrate	Methane potential (m_N^3 CH_4/Mg FM)	Methane content (%)	Dry matter content (DM) (%)	Organic dry matter content (oDM) (%)
Food waste	85	57	23.5	22.7
Distillery leftovers	40.5	57	12.3	11.5
Algae, fresh	14.4	55	22.8	14.1
Cow manure	19.3	57	24	10.7

Table 1. Physical properties of the substrates used for the scenario in Lithuania.

4.1. Laboratory tests: batch and continuous

For the determination of anaerobic fermentation data of different substrates, two basic steps have to be done. These are batch fermentation tests to determine the maximum biogas potential and continuous tests to investigate the long-term fermentation behaviour of the tested substrate or substrate mixture. The batch tests are performed in 5-l flasks over a period of 35 days. The vessels for the continuous tests have a volume of 15 l and are being operated constantly over a longer period of time. In **Figures 5** and **6**, batch and continuous fermentation reactors in laboratory scale can be seen.

Figure 5. Batch tests in heating cabinet.

Figure 6. Continuous lab fermenter.

4.2. Pilot-scale digester

The pilot plant used during the research is a 550-l plug flow dry digester that was designed for long-term continuous operation to estimate the biogas potential of various substrates. The digester is situated inside a 20-ft container that is equipped with all necessary laboratorial equipment for daily diagnostic of anaerobic digestion conditions, and thus, this pilot plant is totally mobile (**Figures 7** and **8**).

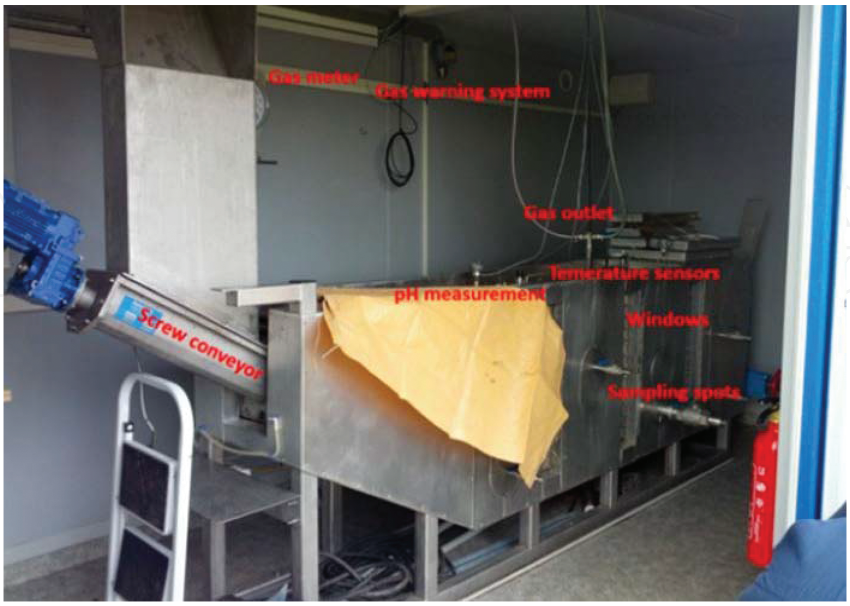

Figure 7. Plug flow dry digestion fermenter with components [16].

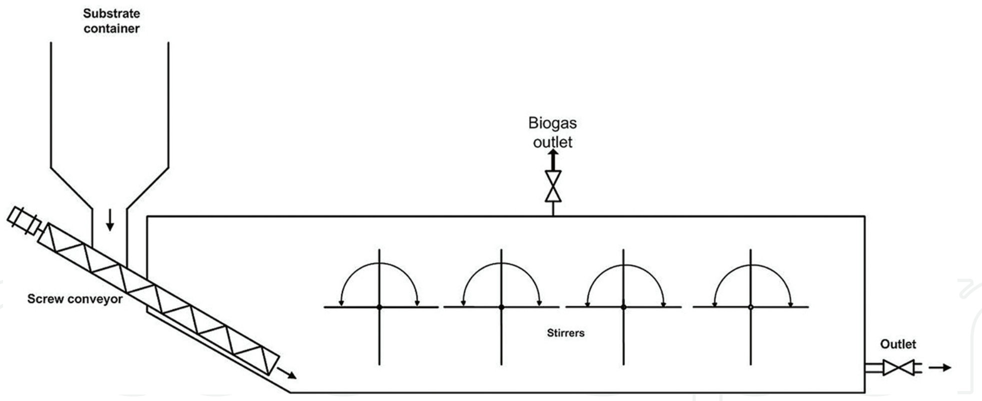

Figure 8. Schematic figure of the pilot plant [17].

Due to its size, real-size material (as for full-scale plants) can be used. This allows the process simulation of full-scale biogas plants.

5. Experimental proof of concept for fermentation strategies

The information obtained from plant operation is compared with the results of a parallel laboratory analysis of the substrates used during the testing period regarding materials and methods. **Figure 9** represents the methane yields of the continuous tests and the expected yields calculated from the batch tests. The results show that these tests correlate to each other. Therefore, the comparability of the continuous tests—relating to the benchmarking of fermentation performances—with the estimated results from previous batch tests is proven [16].

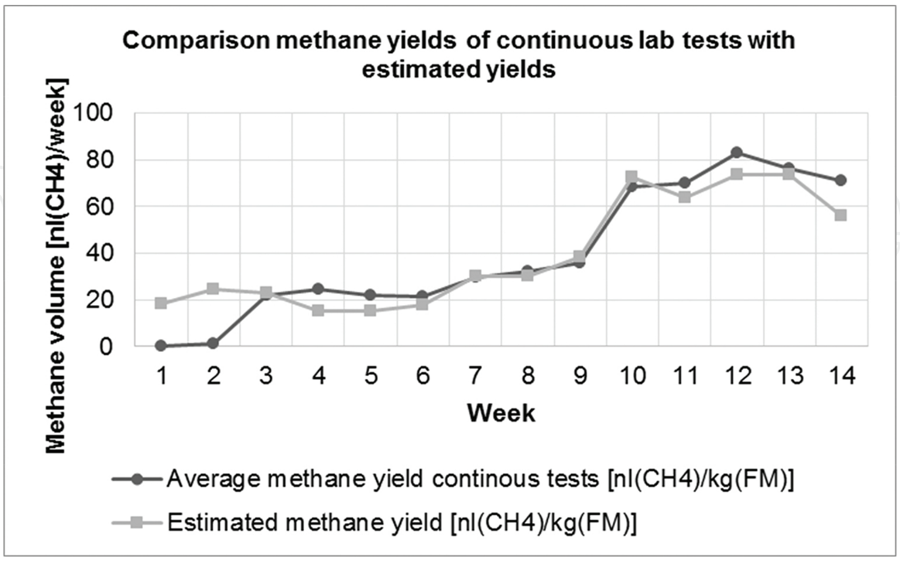

Figure 9. Comparison of methane yields of continuous lab tests with estimated yields calculated from batch tests (substrates: cow manure, food waste, algae, distillery leftovers) [16].

As well as the continuous lab tests, also the measured methane yields from the pilot plant tests correlate to estimated methane yields. The results are shown in **Figure 10**. Accordingly, the comparability of the pilot plant with estimated results from previous performed batch and continuous tests is proven. Because of previous overfeeding, the amount of methane produced in the first 4 weeks is high, but the almost parallel development of the two curves is clearly visible and obvious [16].

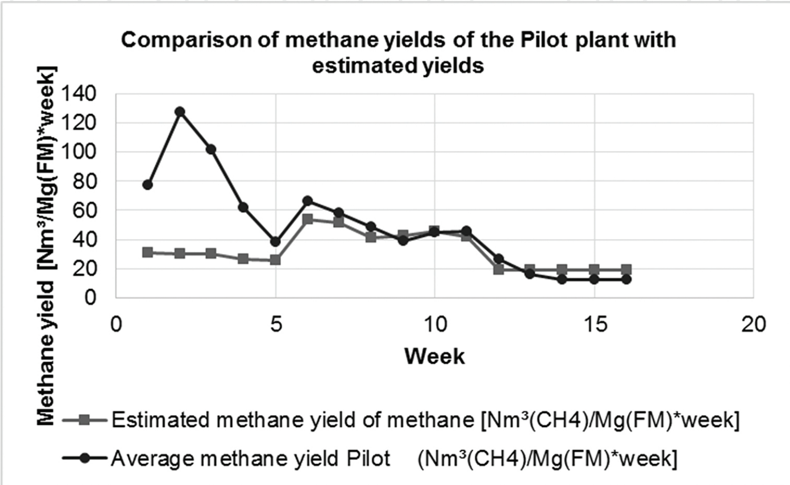

Figure 10. Comparison of methane yields of pilot plant with estimated yields calculated from batch tests (substrates: cow manure, food waste, algae, distillery leftovers).

Finally, the methane yields of the pilot plant were compared with the yields from a German full-scale biogas plant under comparable substrate and operation conditions. As **Figure 11** shows, the comparability of both plants was proven as well. The results of the full-scale plant were thankfully provided by the plant operator (input engineers) and adapted by Bansen [18].

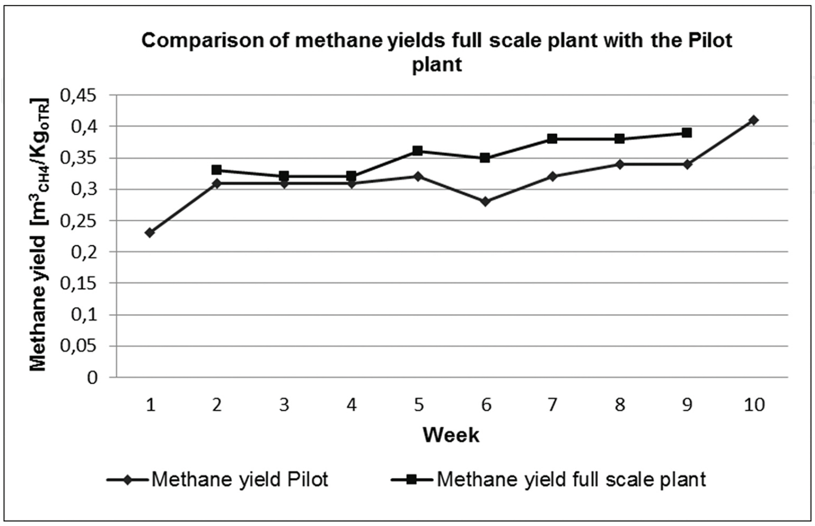

Figure 11. Comparison of methane yields of full-scale plant vs. pilot plant.

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The experimental conditions for the lab-scale as well as pilot-scale tests are shown in **Table 2**.

	Temperature (°C)	Retention time (days)
Continuous lab test	42*	56*
Pilot-scale test	42*/55**	50–333*/40**
Full-scale plant	55	40

*For Lithuanian tests;
**for comparison of pilot-scale with full-scale plant.

Table 2. Experimental conditions of lab-scale, pilot-scale and full-scale tests.

A successful process simulation of the fermentation in pilot scale vs. the full scale has been also obtained by Cavinato [19] biogas production tests in 2010 and by Scano et al. [20] where fruit and vegetable wastes were used. Besides applicable experimental results, an economic analysis showed the possible profitability of the planned biogas project. It is important to emphasize that an improvement in the biogas yield was assessed by the operation of the pilot-scale fermenter, which means that the operation of plant engineering in pilot scale is absolutely suitable for technical and economic simulation and development of upscaling scenarios.

6. Financial implementation of biogas technology under market economy conditions

The implementation of biogas technology without any public funding provides the basis for the following considerations concerning the profitability. Implementing biogas technology requires the assessment of many aspects concerning the economic efficiency. The main financial and economic aspects of biogas plant exploitation include investment costs, plant operating cost and possible revenues achieved by the production and use of biogas, utilization of wastes and use of digestate as fertilizer. The resulting operative cash flow (OCF) calculation is based on the difference between annual revenues and annual expenses as well as investments. The discounted cash flow (DCF), that is, the calculation of future cash flows' present value, was a result of the annual OCF multiplied by a discount factor.

The result for the investor is just the amount of money, which could be received after a period of time. Thereby, the time value of money has to be taken into account [21]. The possible cost factors of biogas plants depend on the different sizes, and noticeable biogas plant characteristics concerning the size of the plant and the substrates, which will be used as input materials, are specified.

6.1. Cost factors

For building the biogas plant, investment costs as well as operational plant costs (both in extracts) have to be considered:

- Investment costs: engineering, permission of the authority (application costs), connection to the public grid, land costs, vehicles, offices and functional units such as substrate delivery and pre-treatment, digester, gas storage, biogas treatment, CHP unit, pumps, piping, digestate storing and others.
- Operational expenses: substrate costs, costs for analysis, process energy, consumables, costs for maintenance and repair, labour costs, land costs and others [3].

In particular, the specific investment costs vary, depending on the size of the biogas plant [22].

For the calculation of average investment costs of biogas plants, key values were determined by referring to investment costs of different German agricultural biogas plants and publications during project ABOWE [4, 16].

The operation of biogas plants with substrates, which require special treatment like municipal solid waste or biowaste, causes additional costs for pre-treatment and other necessary modifications. The use of household biowaste especially demands special treatment such as the sanitation of the material [16]. The hygienisation of biowaste used for anaerobic treatment is regulated by EU hygiene regulation (VO 1774/2002/EG) [23] and country-specific by, amongst others, the German Biowaste Ordinance [24]. Accordingly, biowaste could be sanitized by heating it up to 70°C for a time period of 1 h. Consequently, it has to be taken into account that investment costs for biogas plants with plug flow fermenter and the use of biowaste as substrate are about one-third higher than for the use of renewables [25]. For biowaste or MSW, the garage fermenter system makes biogas production with less pre-treatment of the substrate possible, which potentially reduces the operational as well as the investment costs.

In any case, the specific investment costs tend to decrease with larger plant capacities. When assessing the different types of the investment expenses, it becomes obvious that part of the costs for planning and construction of the biogas plant is personnel expenses. These costs should be considered separately, because, as it was pointed out in project ABOWE, there are considerable variations in different countries [4].

Another point is that some parts of the biogas plant have to be replaced regularly, because certain components such as pumps, stirrers and also the CHP unit have a short operational lifespan. The estimated lifetime of pumps is 4 years and that of CHP units about 6 years [26].

One of the most important aspects when implementing biogas technology is to ensure reliable availability of substrates. Biogas plants demand a continuous supply with substrates. Furthermore, the utilization of the produced energy or the conditioned biogas itself as well as the resulting heat or the electric energy generated by the CHP unit need to be guaranteed.

In addition, it has to be taken into consideration that substrates with a high-energy potential should be used, so that costs and expenses for transport are kept low [4, 16].

Considering further economic aspects, the biogas plant (pumps, stirrer and others) itself demands electrical energy amounting to 5–20% of the total of electrical energy produced by CHP technology [25]. The heat demand of the biogas plant (for the heating of the fermenter), which is about 5–25% [25] (according to FNR even at 28% [22]) of the produced heat, can be covered by the heat of the CHP unit. Here it might be economical to sell all of the energy produced and buy the energy needed from the national energy supplier (depending on the feed-in tariff of the electricity generated) [27].

6.2. Country-specific aspects

For the economic and financial implementation, the different cost items vary according to the country in which the biogas plant shall be built.

The calculation done in the project is based on specific data, which vary according to the relevant countries. Therefore, some prior general considerations are necessary:

- Investment costs: it has to be considered which parts of the plant can most cost-effectively be manufactured in the country in which the plant shall be operated.
- Operational costs: most specific costs depending on the relevant countries; the personnel costs in particular are varying strongly.
- Revenues: the feed-in tariffs for electricity and heat are country-specific, also the price for the sale of digestates [4, 16, 17].

General data were collected with respect to the investment and operational costs of biogas plants in EU developing counties and furthermore with data of plant operators as well as plant construction companies.

Based on all above-mentioned aspects, results of the pilot plant operation in certain EU developing and developed countries, lab tests at Ostfalia University and a numerous collection of data (own investigations, literature sources, data from biogas plant operators), many key values were determined and used for the calculation of the operative cash flows over a period of 20 years. The cumulative discounted cash flow then gives an impression of the profitability of a planned biogas project. Spoken fundamentally, a detailed calculation and estimate of the operative cash flows are only possible by defining real system models. Based on these data (referring to commercial offers) and on the investigation of the economic aspects of a planned biogas plant, detailed cash flow calculations are possible.

7. Full simulation of a practical application: implementation of a biogas plant from energy demand to profitability

For illustration of above-constituted considerations concerning the implementation of biogas technology with no public funding, necessary substrate management and load profile adapted operation a scenario were developed. Substrates mentioned in Chapter 4 were used for a complete implementation scenario of biogas technology in Lithuania.

Herewith, food waste, distillery leftovers and algae serve as basic substrates for the production of biogas during the year. Cow manure is available as additional substrate and will be fed as compensation substrate to get an adapted feeding for the production of the needed electricity.

According to the previously described strategy, the following amounts (in **Table 3**) of substrates and methane potentials were used for further calculations. For the scenario, the size of the biogas plant was chosen with 500 kWel.

Substrate	Methane potential (Nm^3 CH_4/Mg FM)	Quantity used (Mg/a)
Food waste	85	8000
Distillery leftovers	40	5000
Algae, fresh	14	2000
Cow manure	19	10,000

Table 3. Substrates used for an implementation scenario (Ostfalia lab).

Table 3 shows the biogas yields, which arose from batch tests of food waste, distillery leftovers and algae (see Chapter 4.1). Starting from the assumption that the waste is arising constantly with a constant biogas yield (algae occur from April/May to September/October), the electricity production would be evenly because of a constantly daily feeding amount. The load profile, which constitutes the electricity demand, would therefore not be covered (sum of electricity from food waste, distillery leftovers and algae). Consequently, cow manure will be used as additional feeding material, see **Figure 12**.

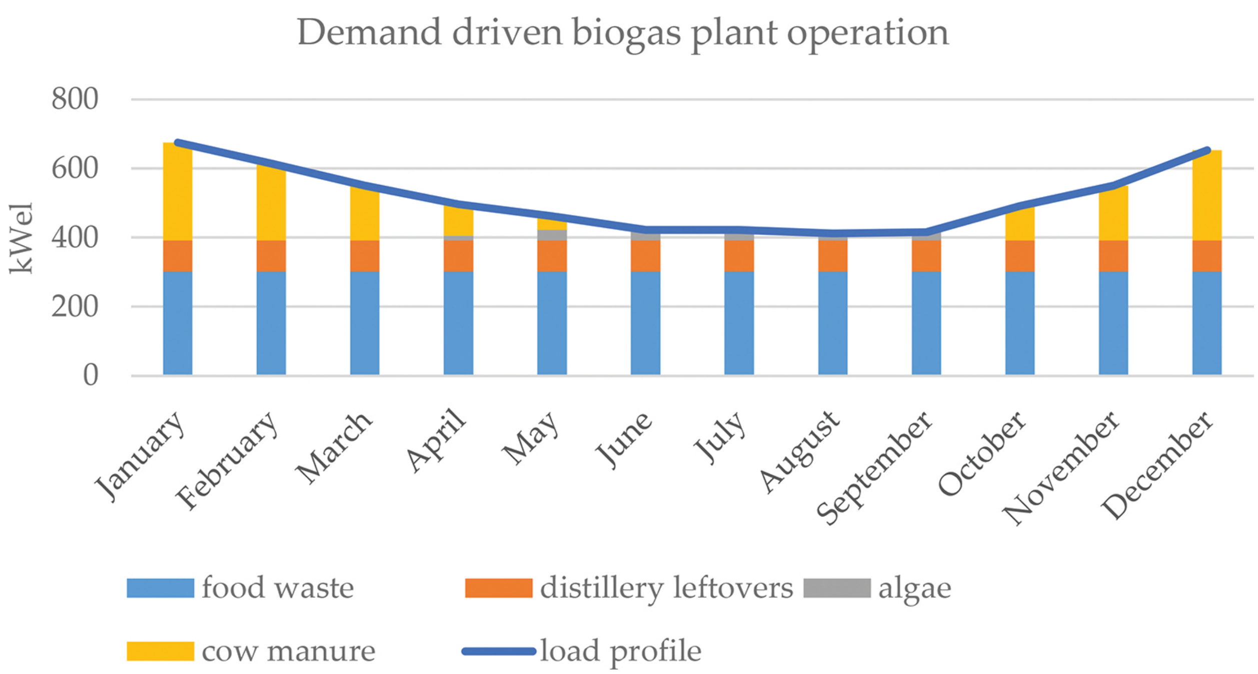

Figure 12. Power from methane production (scenario).

Based on the results of the performed batch tests and the developed scenario, the substrate amounts and mixtures were tested in continuous fermenter tests. The long-term fermentation behaviour is therefore proven, before tests with these substrates will be proceeded in the pilot-scale fermenter. The results of this test procedure lead to the planning of a demand-driven supplied biogas plant by meanings of an adapted production of electricity, no demand for long-time storing capacities and strict avoiding of energy undersupply.

The corresponding calculations were done in reference to basic data, (especially concerning the substrates and feed-in tariffs and other incentives). These data concerning substrate amounts and tariffs are stated by the prospective customer or need to be determined. Therefore, all data are exchangeable and can easily be adapted to other scenarios besides the exemplarily chosen Lithuanian scenario. Assumptions made for the following calculations are summarized in **Table 4**.

	Tariffs (€/Mg)	
	Costs	**Income**
Substrates:	8.66	20
Food waste	–	–
Distillery leftovers		25–50
Algae		
Cow manure		
Digestate		5
Electricity	Public grid: 0.126 (€/kWh_{el}) or less	Feed-in: 0.09 (€/kWh_{el})
Heat		0.04–0.06 (€/kWh_{th}) (by season)
Produced energy	3,929,083 kW_{el}/a and 3,929,083 kW_{th}/a; efficiency rate η = 40%	
Digestate	22,646.55 Mg/a	
Biogas plant: plug flow fermenter system, investment costs plus 30% for waste hygienisation (assumption based on Ref. [25]).		
CHP unit, 1 × 500 kWel, 1 × 250 kWel: production of electricity and heat, each re-invested after 72-month operating time.		
Substrates: food waste, distillery leftovers, fresh algae, cow manure.		
Sale of electricity and heat (minus own demand).		

Table 4. Tariffs and further background assumptions.

The operational strategy resulting from **Figure 12** requires a flexible operation of the biogas plant. Thus, the biogas plant should be operated with two CHP units, one with an installed power of 500 kWel and another with 250 kWel. The 500 kWel system is in continuous operation and the other is operated in modulation and on-demand. In any case, a suitable dimensioned gas storage facility needs to be provided.

With respect to this substrate scenario, an exemplary financial implementation of the biogas system is developed. The results of the corresponding economic calculations are shown in

Figure 13 as a cumulative discounted cash flow curve progression starting with the initial investment costs and cumulating the operative cash flows over a period of 20 years.

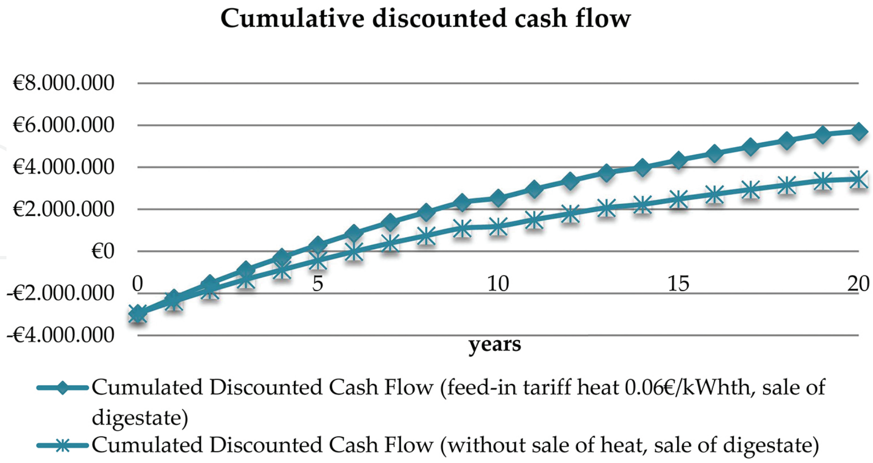

Figure 13. Cumulative discounted cash flow—comparison of two exemplary sale scenarios.

Assuming that the biogas plant operator gets gate fees from the acceptance of waste and all of the produced electricity and heat (minus own heat demand) will be sold, the biogas plant operation reaches the zero line after about 4.5 years. The second curve results in the supposition that the heat could not be sold. Here the zero line would be reached after about 6 years. This example of the variation of just one parameter shows that it is really easy for the user to create scenarios, to vary parameters, to find the most influencing parameters and to get first information about the profitability of a planned project.

The chosen scenario as well as the calculated model biogas plant constitutes a theoretical exemplary situation. The corresponding assumptions are not being meant for a generalized use, because they depend on scenario-specific aspects and were just chosen for the exemplary developed scenario. Nevertheless, all economic influencing variables can easily be changed and adapted to other scenarios and regions, and the resulting impacts are illustrated in the same way as described above. This calculation model provides a good impression of the profitability of a planned biogas implementation project. Therefore, the essential feature of the presented model is a suitable opportunity for easy and rapid profitability calculation for the usual users, respectively, investors such as farmers or rural area authorities.

8. Perspectives towards sustainability and impact to global environmental problems

From the sustainability and circular economy point of view [28], the idea of the biogas production from biowaste is in line with industrial symbiosis mechanism that is essential for achieving social-economic and environmental benefit [29]. Except economic and social aspects that have close relationship and depend on profitability and subsequent improvement in the

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quality of life, the environmental aspects should be discussed as well. LCA is often used as a tool to evaluate a process, service or product impact to the global environmental problems. The method of LCA is described in ISO standards [30] and starts from the finding of the study system boundaries. The magnitude of the environmental impact of the biomass anaerobic digestion and CHP unit depends on numerous factors, such as fermentation conditions (mesophilic, thermophilic), kinds of substrates (cow manure, bioethanol residue, algae, food wastes), biogas yield, energy demand for the own process of digestion and sanitation, transportation, digestate storage and method of utilization and climate condition. The scientific results related to influence of the renewable energy production and transportation processes to global problem, especially greenhouse effect, sometimes differ a lot [31–33]. Nevertheless, there are some common features, which allow determining the main tendency of the above-mentioned processes and products contribution towards sustained environment.

Global warming potential. The main impact of the GHG emissions is expected from biogas combustion at CHP and methane emissions from the storage of the digestate. Anaerobic biomass digestion itself does not pollute environmental air and does not use oxygen/air for biogas production.

Ozone depletion potential. During biogas burning process at the energy production plant, some amount of CFC/HCFC can get in to the air. In addition, the manufacturing of the fermenter and energy plant could cause CFC/HCFC release in the atmosphere.

Photochemical oxidation potential. This kind of impact relates to the secondary methane emission source—emission from the digestate storage.

Acidification potential. Environmental acidification potential expressed as sulphur dioxide equivalent is the biggest for hydrogen sulphide and ammonia and mostly connected with ammonia emissions due to the digestate storage.

Eutrophication potential. Nitrogen and phosphorus compounds contribute to an increased biomass production in aquatic environment, and these results in additional oxygen consumption for biomass decomposition. Release of ammonia from the digestate storage can increase the eutrophication potential.

Abiotic depletion potential. This kind of depletion can be decreased due to the usage of digestates instead of traditional fertilizers. Anaerobic digestion demand of additional energy consumption increases abiotic depletion, but use of traditional fossil fuel for traditional energy production plant does not reduce abiotic depletion as well. The recycling of the fermenter and CHP plant constructions after usage prevents damage for the environmental and resources.

The environmental impact assessment does not take the digestate spreading into consideration because spreading of fertilizers exists in any case, but the method of the spreading can have significant impact to soil acidification and aquatic body eutrophication. The evaluation of environmental aspects of the study shows that biomass anaerobic digestion and CHP system for energy production have savings in global warming and abiotic depletion potentials. Scientific publications [34–36] regarding biomass anaerobic digestion and energy production support present study environmental results and recommendations.

9. Conclusions

9.1. Technical conclusions

Digestion technology adapted for a Lithuanian scenario with lab-scale examination in batch and continuous tests was realized. Four different kind of substrates were applied: cattle manure, bioethanol distillery waste, food waste and Curonian Lagoon algae.

The similarity of the fermentation process in lab-scale, pilot-scale and full-scale plant was shown.

The technological adequateness of biogas technology for substituting fossil energy resources with respect to fluctuating energy demand and fluctuating supply of renewable energy has been demonstrated, and the possibility of demand-driven operation of a biogas plant has been proven.

9.2. Financial-economic conclusions

The financial-economic aspects as the most important part of the chain of waste-to-energy advanced strategy have been confirmed.

The feasibility study based on certain regional data was detected as the most realistic for biogas development benefit for local society and environment.

A detailed perspective into the strategy of digestion for biogas production is given. Starting with energy demand, load profiles and substrate demand, a detailed substrate management has been performed. Based on this, the profitability and thereby financial implementation without any public funding could be considered. Herewith, a special focus is given in the potential implementers' and investors' demands, which shall be enabled to take reliable decisions on technologies for implementing advanced digestion technology as full-scale plants. With the corresponding developed strategies (experimental as well as economical), new possibilities of producing renewable energy can be implemented and fostered in the Baltic Sea region as well as in other regions of the EU.

Author details

Thorsten Ahrens[1*], Silvia Drescher-Hartung[1] and Olga Anne[2]

*Address all correspondence to: th.ahrens@ostfalia.de

1 Institute for Biotechnology and Environmental Engineering, Ostfalia University of Applied Sciences, Wolfenbüttel, Germany

2 Department of Natural Science, Klaipeda University, Klaipeda, Lithuania

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