EXPLOITING POTENTIAL FOR ECONOMIES OF SCALE IN BIOGAS PURIFICATION INFRASTRUCTURE

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Abstract

Biogas has a crucial role as a fossil fuel substitute for future energy system decarbonization. The substitution leads to a reduction of CO_2 emissions compared to natural gas or other fuel utilization. The main usage of biogas in Germany currently is the direct on-site combined heat and power combustion. Changes in support mechanisms for renewable energies require a change in business models. One opportunity is the usage of biogas in other sectors. A purification plant is required for the wider use of biogas in the natural gas grid. It processes and upgrades biogas to a green gas of fossil gas quality.

This paper develops an innovative methodology to identify the optimal purification infrastructure for biogas based on the existing natural gas infrastructure grid and the current location of biogas fermenters. Technology-dependent costs of different purification systems are used to evaluate the optimal size and location of upgrading plants. The minimum size of biogas purification plants typically exceeds the size of the biogas production capacity of one single biogas fermenter. In most cases, a joint usage of purification plants leads to lower costs. The economic effect is reinforced by economies of scale that lead to reduced investment costs with the increasing size of purification installation. Moreover, connection charges to the gas grid can also be reduced with the increasing gas production capacity. Consequently, economics of gas purification depend mainly on the availability of the gas infrastructure and the options of cooperation in the purification process.

The problem can be classified as a location-allocation model. In the latter, algorithms are used to determine an optimal location for one or more facilities within a geographic information system. In this case, the sizing and placing of the biogas purification plants are conducted.

Planning future municipal energy systems is a challenging task for stakeholders. Therefore, systematic approaches that integrate energy models and link them with real data are required. In this context, spatial modeling of renewable energy based on geographic information systems offers an emerging research area that aims to support and improve the planning process of energy systems with high shares of renewable energy. This work contributes to this field by proposing a model for planning communal cooperative energy systems and supporting policy decision-making processes.

Introduction

One possible business model for biogas plants is biogas purification and injection into the natural gas grid. Only a small share of German biogas plant operators make use of this option under the current regulatory and economic framework. Around 8,500 plants process biogas in on-site combined heat and power (CHP) units; by contrast, only 200 biogas plants upgrade biogas to biomethane (biogas upgrading plants) (Daniel-Gromke et al., 2017). Changes in the regulation (Renewable Energy Sources Act) and the coupling of sectors might lead to an inversion of this relationship (Scheftelowitz and Thrän, 2016). Biogas purification to biomethane allows greenhouse gas savings, as fossil fuels are replaced by biomethane. Ecological benefits are even higher if residues, such as manure and organic municipal waste, are used as feedstock. The greenhouse gas saving of biomethane compared to natural gas was calculated at 103 – 148 % due to the indirect effects, for example, through increased recycling of nutrients, which reduces the need for fertilizers (Börjesson, Tufvesson and Lantz, 2010). The main advantage of upgrading biogas to biomethane is the possibility of using an existing infrastructure. This ready-made system can be used for the injection and distribution of biomethane in regions with an existing natural gas grid (Urban, 2013).

The usage of biomethane is more flexible and efficient compared to unpurified biogas. Upgrading biogas to natural gas quality offers a sensible alternative particularly if the heat generated by CHP plants on the site of biogas plants cannot be fully used. An advantage of biomethane as an energy source is its universal applicability. It can be used in at least three possible ways: Off-site CHP generation, fuel replacement in the mobility sector as compressed or liquid natural gas, and in the heat market. The versatility improves the potential revenues for producers (Fischer and Szomszed, 2013).

A purification and distribution infrastructure is needed to maximize the usage of the biogas. Biogas contains different impurities, depending on the composition of the substrate used in the anaerobic digestion process. Biomethane needs to be separated from those impurities before injecting into the gas grid. The main step, in addition to desulphurization and dewatering, is the removal of carbon dioxide (CO_2). This leads to an increased energy density as the biomethane content is increased (Petersson and Wellinger, 2009). The focus of this paper is on the costs for the removal of CO_2 as they have the highest share in the whole process with nearly 80 % of the capital costs of the upgrading infrastructure (Urban, Girod and Lohmann, 2009). The costs of desulfurization, compression, calorific value adjustment and grid connection are not considered in this paper.

The minimum size of biogas upgrading plants (250 m_N^3/h) to be an economically viable business model (Daniel-Gromke et al., 2020) usually exceeds the size of the biogas production capacity of single small biogas fermenters (average biogas production capacity in Germany: 180 m_N^3/h) (BMEL, 2020). The biogas upgrading plants would, therefore, be overdimensioned for many small biogas plants. Depending on the cost of pipeline investment, the joint usage of upgrading plants is expected to lead to lower costs. This effect is reinforced by economies of scale that lead to reduced investment costs with the increasing size of purification installation. Connection charges to the gas grid can also be reduced with increasing gas production capacities. Based on the current biogas plants, the infrastructure can be optimized to ensure cost-effective biogas upgrading.

Several alternative usages of the existing natural gas infrastructure are currently being discussed. In addition to biogas, the production of green hydrogen from renewable electricity is one option. The hydrogen generated can be converted into methane by methanation. The methanation process converts H_2 and CO_2 into CH_4 and H_2O. The process can be performed chemically or biologically (Ghaib, 2017). Methane and carbon dioxide are produced in biogas plants. The CO_2 can be converted directly into methane, for example, with the help of bacteria, by feeding hydrogen into the reactor (Bensmann et al., 2014). The gases are upgraded to biomethane, so that biogas upgrading allows a combined usage of gas infrastructure for all green gases (Staiger and Tanțău, 2020).

Biogas with an average methane concentration of 54 % is produced at decentral biogas plants and then transported to central biogas upgrading plants, both having limited capacities. Green gas (biogas which is upgraded to natural gas quality) with a methane concentration of more than 95 %, as a product of the purification process, is transported through a pipeline and injected into the gas grid (Litvinchev, Mata, Ozuna and Saucedo, 2012). It is usually fed into a medium ($0.1 \text{ bar} < p \leq 1 \text{ bar}$) or high pressure ($1 \text{ bar} < p \leq 100 \text{ bar}$) gas grid because year-round usage can only be guaranteed under certain conditions in a low-pressure infrastructure (Klinski, 2006; Bundesnetzagentur, 2017).

Biogas upgrading is a widely studied topic due to the various utilization options. Since there are different methods for upgrading biogas, the technical and economic aspects of these options are compared (Khan et al., 2017). The various end-use applications and business models resulting from storability and from new potential sales markets due to purification are also comprehensively considered (Budzianowski and Brodackac, 2017). Further studies focus on the greenhouse gas emissions and life cycle analyses of biomethane production (Adelt, Wolf and Vogel, 2011), as well as on the use of different substrates, such as starch and lignocellulosic crops (Frigon and Guiot, 2010) or grass (Korres, Singh, Nizami and Murphy, 2010). The exploitation of economies of scale in the investment costs in upgrading infrastructure through the formation of biogas clusters has also already been identified as a possibility for future cooperation (Dotzauer et al., 2021). In addition, a possible local biogas grid infrastructure was investigated that connects biogas plants in a region to one central purification plant at optimal costs (Havrysh, Nitsenko, Bilan, and Streimikiene, 2018).

This novel approach combines the optimization tools and geographic information for existing biogas fermenters and gas infrastructure to identify optimal investment strategies for biogas purification.

Model Description

This paper develops a methodology to identify the optimal purification infrastructure for biogas. The aim is to minimize the system costs for biogas purification. Size-dependent costs of upgrading systems are used to identify optimal cluster sizes and structures (Khan et al., 2017). There is a trade-off between cost savings by increasing the size of the purification plant and additional costs for extending the biogas pipeline network. The solution delivers the optimal size of the purification infrastructure and the length of the pipeline network.

The problem can be classified as a two-level capacitated facility location problem (CFLP) with two types of facilities, thus, it is a type of hierarchical facility location problem (Ortiz-Astorquiza, Contreras and Laporte, 2017; Irawan and Jones, 2018). The two-level CFLP is an enlargement of the widely studied (one-level) CFLP. It extends the CFLP by considering the cost of transportation from the first to the second facility (Klose, 2000). The classic two-level CFLP is an NP-hard optimization problem, as it represents a generalization of the basic plant location problem, which has been proved to be NP-hard (Krarup and Pruzan, 1983). The problem with two levels being investigated is even more difficult to solve using an exact method (via a solver, such as CPLEX), especially when the size of the problem is relatively large (Irawan and Jones, 2018).

Nomenclature

The following parameters are used:

Index sets:

j	set of biogas clusters = {1, …., j, …., J_{max} }
n	set of biogas plants = {1, …., n, …., N_{max} }

Cost parameters:

C_t	total system costs in €
C_{j_p}	total pipeline costs for biogas cluster j in €
C_{j_u}	total upgrading costs for biogas cluster j in €
$C_{j_{annual}}$	annual costs for upgrading in biogas cluster j in €
EAC_{j_u}	equivalent annual investment costs for biogas cluster j in €
EAC_p	equivalent annual investment costs for pipeline in €/km
a	plant service life in years
i	rate of invest in %
C_0	net present value in €

Geographical parameters:

D_{j1}/ D_{j2}	total pipeline length in cluster j in km for option 1 or 2
$D_{j_{BC}}$	total pipeline length to connect biogas plants in cluster j to upgrading plant in the cluster center in km, option 1
$D_{j_{CG}}$	pipeline length to connect upgrading plant in cluster j to gas grid in km, option 1
$D_{j_{BU}}$	total pipeline length to connect biogas plants in cluster j to upgrading plant in km, option 2
$D_{j_{UG}}$	pipeline length to connect upgrading plant in cluster j to gas grid in km, option 2
bp_{n_x}	longitude/ x value of biogas plant n
bp_{n_y}	latitude/ y value of biogas plant n
c_{j_x}	longitude/ x value of cluster center from cluster j
c_{j_y}	latitude/ y value of cluster center from cluster j
g_{j1_x}/ g_{j2_x}	longitude/ x value of gas grid connection point for cluster j in option 1 or option 2
g_{j1_y}/ g_{j2_y}	latitude/ y value of gas grid connection point for cluster j in option 1 or option 2
u_{j_x}	longitude/ x value of upgrading plant from cluster j in option 2
u_{j_y}	latitude / y value of upgrading plant from cluster j in option 2

Technical parameters:

$Q_{j_{biogas}}$	capacity of biogas upgrading plant in m_N^3/h
$P_{n_{el}}$	installed electrical capacity of CHP at biogas plant n in kW
η_{el}	electrical efficiency of CHP in %
c_{CH_4}	average methane content of biogas in %
HV_{CH_4}	energy content of methane in kWh/m_N^3

Boolean decision variables:

X_{j_n}	biogas plant is part of cluster j
$X_{j_{p1}}$	approximation option 1 (clustering) is used for cluster j
$X_{j_{p2}}$	approximation option 2 (pipeline optimization) is used for cluster j

Existing gas infrastructure

The locations of the biogas plants and the gas grid are known and fixed because the optimal upgrading infrastructure for an existing biogas plant and natural gas infrastructure of a model region is to be investigated. The locations of the biogas upgrading plants and the locations of the biomethane injection into the gas grid have to be defined by the model.

Basic model structure

A two-step Python model is developed to find possible biogas plants for joint upgrading. This qualifies as an NP-hard optimization problem (Krarup and Pruzan, 1983). Possible locations of the upgrading plants are provided to the optimization algorithm to approximate the optimal solution. Two approaches for approximation are considered, which can potentially save the costs of building pipelines. Figure 1 shows the general modeling structure in Python.

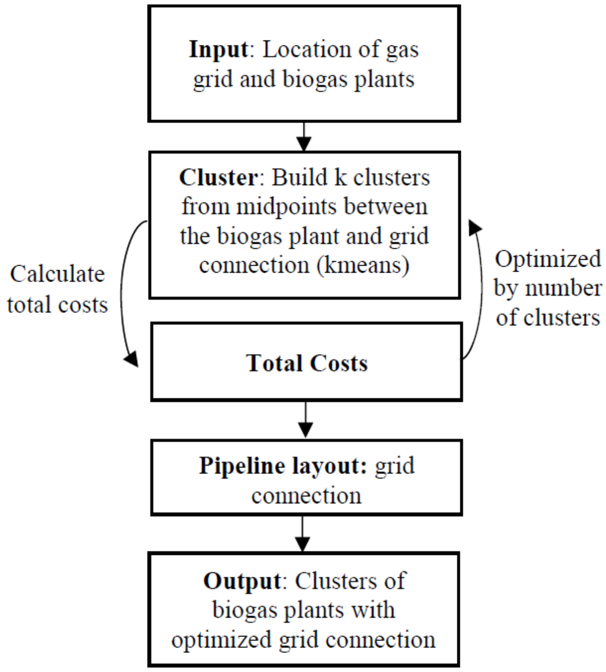

Figure 1. Flowchart of the general model structure

A mathematical model is developed to identify the optimal purification infrastructure for biogas. The objective function is to minimize the system costs, which consist of the sum of the infrastructure costs of all clusters (1).

$$C_t = \min(\sum_j C_{j_p} + \sum_j C_{j_u}) \quad (1)$$

The system costs are composed of the sum of costs for the upgrading plants (2) (annual expenditure – e.g. operating costs, personnel costs, maintenance costs, capital costs – and equivalent annuity of investment costs) and the costs for the pipelines (3) (equivalent annuity of investment costs).

$$C_{j_u} = C_{j_{annual}} + EAC_{j_u} \quad \forall j \quad (2)$$

$$C_{j_p} = EAC_p \cdot \left(D_{j1} \cdot X_{j_{p1}} + D_{j2} \cdot X_{j_{p2}}\right) \quad \forall j \quad (3)$$

The equivalent annual investment costs of the upgrading plant and the pipeline are calculated as follows (4):

$$EAC = \frac{(1+i)^a \cdot i}{(1+i)^a - 1} \cdot C_0 \quad (4)$$

Many models set a fixed capacity in the two-stage CFLP for each potential depot (for example Geoffrion and Bride, 1978; Klose, 1999; Tragantalerngsak, Holt and Rönnqvist, 2000). In practice, the capacity of the depot, in this case the upgrading plant, is also a variable that has to be determined by the model. Thus, the model not only determines the optimal amount of upgrading plants and their location but also their respective optimal capacity. The possible capacity of the upgrading plant is divided into different size categories. The investment costs and the annual costs for upgrading depend on the size of the upgrading plant. The capacity needed can be determined by the amount of biogas produced in a cluster $Q_{j_{biogas}}$, which can be calculated based on the capacities of the CHP installed (5). It is assumed that the operation mode of the biogas plants is continued with the same substrate input. The biogas is used in the upgrading plant instead of the CHP.

$$Q_{j_{biogas}} = \frac{\sum_n P_{n_{el}} \cdot X_{j_n}}{\eta_{el} \cdot c_{CH_4} \cdot HV_{CH_4}} \quad \forall j \quad (5)$$

The final stage is the injection of biomethane into the gas grid. The location of the gas grid is known, but the optimal connection points are identified by the model.

Approximation of upgrading plant location

Two approaches for placing the upgrading plants are developed and implemented into the model since determining a location for the upgrading plant and for the biomethane injection point is an NP-hard problem. In the first step, the midpoint between the biogas plant and the grid connection point is determined using the Shapely object.interterpolate function. It returns a point at the distance required along a LineString (Gillies, 2020). Clusters of biogas plants are formed from this list of centers. The aim is to find possible biogas plants for joint upgrading, which also includes the distance to the gas grid. The sklearn.cluster.kmeans function is used for clustering. K-means optimizes the quadratic deviations from an average, which is used to form a previously known number of k groups from a set of similar objects. The k-means method can also find the center of the cluster created (Pedregosa et al., 2011).
In this first approach, the upgrading plant for the joint upgrading of the biogas cluster is placed at the center of the cluster. The distances of the biogas plants in the cluster to the upgrading plant (6) and from the upgrading plant to the next grid injection point (7) are determined.

$$D_{j_{BC}} = \sum_{n} \left(\sqrt{\left(bp_{n_x} - c_{j_x}\right)^2 + \left(bp_{n_y} - c_{j_y}\right)^2} * X_{j_n} \right) \quad \forall j \quad (6)$$

$$D_{j_{CG}} = \sqrt{\left(c_{j_x} - g_{j1_x}\right)^2 + \left(c_{j_y} - g_{j1_y}\right)^2} \quad \forall j \quad (7)$$

The total length of pipelines for cluster j (8) is calculated by summing the distance $D_{j_{BC}}$ of the biogas plants to the upgrading plant and the distance $D_{j_{CG}}$ from the upgrading plant to the injection point into the gas grid:

$$D_{j1} = D_{j_{BC}} + D_{j_{CG}} \quad \forall j \quad (8)$$

The second strategy to approximate the optimal location is placing the upgrading plants of each cluster at the biogas plant closest to the gas grid. This can potentially save the costs of building pipelines (pipeline optimization). In the first step, the nearest_points function is used to determine the biogas plant closest to the gas grid for each cluster. The distances of the biogas plants in the cluster to the upgrading plant (9) and from the upgrading plant to the nearest grid injection point (10) are then determined.

$$D_{j_{BU}} = \sum_{n} \left(\sqrt{\left(bp_{n_x} - u_{j_x}\right)^2 + \left(bp_{n_y} - u_{j_y}\right)^2} * X_{j_n} \right) \quad \forall j \quad (9)$$

$$D_{j_{UG}} = \sqrt{\left(u_{j_x} - g_{j2_x}\right)^2 + \left(u_{j_y} - g_{j2_y}\right)^2} \quad \forall j \quad (10)$$

The total length of the pipelines in cluster j (11) is the sum of $D_{j_{BU}}$ and $D_{j_{UG}}$:

$$D_{j2} = D_{j_{BU}} + D_{j_{UG}} \quad \forall j \quad (11)$$

The two possible approximations for the placement of the purification plant are shown in Figure 2.

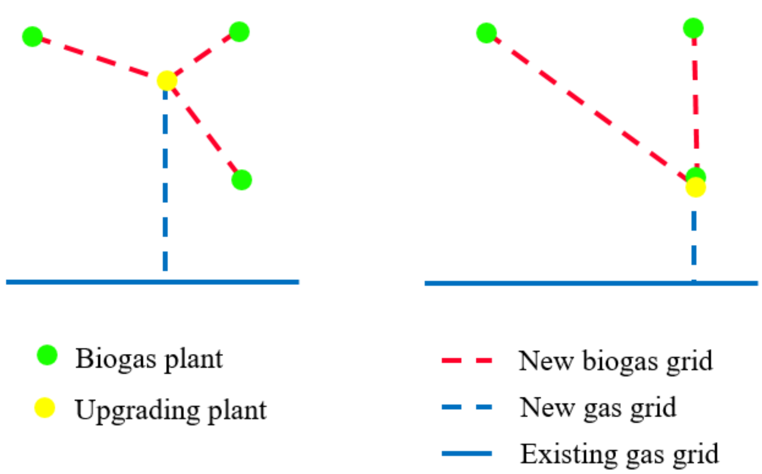

Figure 2. Comparison between approach 1 (clustering) and approach 2 (pipeline optimization)

The cost-optimal infrastructure for each cluster is selected by the model, i.e. the approach with the shorter pipeline length, in order to connect the biogas plants to the upgrading plant and then to connect it to the gas grid. A decision variable is used to determine which approach is selected; exactly one approach of the upgrading infrastructure must be selected for each cluster j (12).

$$X_{j_{p1}} + X_{j_{p2}} = 1 \qquad \forall j \qquad (12)$$

The best solution of the modeling consists of the number of clusters formed, the placement of biogas upgrading plants, the choice of the capacity required for the upgrading plant and the connections to the gas grid. As a result, the optimal upgrading and grid connection infrastructure can be determined for each biogas plant in a region.

Case study and model parameter

The reference region used in the case study is the administrative district of Osnabrück county. There are 90 biogas plants in the region, and none of them currently uses a biogas upgrading plant for upgrading biogas to biomethane. An upgrading infrastructure is created for the existing biogas plants and no further biogas plants are added.

Input parameter

The area is modeled based on the current German biogas system with real data. Several data sources are used (50Hertz Transmission GmbH, Amprion GmbH, TransnetBW GmbH and TenneT TSO GmbH, 2019; Niedersächsisches Ministerium für Umwelt, Energie Bauen und Klimaschutz, 2019; Marktstammdatenregister, 2021). As none of the data sources gives a complete set of the biogas plant inventory within the model region, an aggregation of the different data sets is used, which consists of 90 biogas plants. The largest, smallest and average biogas plant sizes are shown in Table 1.

Table 1: Biogas plants in the administrative district of Osnabrück (50Hertz Transmission GmbH, Amprion GmbH, TransnetBW GmbH and TenneT TSO GmbH, 2019)

	Installed capacity in kW	**Raw biogas volume in m_N^3/h**
Biogas plant with largest installed capacity	**2700**	**730**
Biogas plant with smallest installed capacity	**75**	**20**
Average biogas plant size in the region	**560**	**150**

The geodata of the biogas plants are available as Shapley Points, which process the X and Y coordinates as tuples. The gas grid is available as a Shapely MultiLineString, which is a collection of Shapely LineStrings. A LineString is a line consisting of two or more points (Gillies, 2020). The electrical capacity installed is also used from the set of different sources, so that the sizes required for the biogas upgrading plants can be determined. Furthermore, the existing gas grid in the administrative district of Osnabrück county is used to find connection points to feed in the upgraded biogas. Only gas grids of medium and high pressure levels are considered.

The investment costs and the annual expenditure of the upgrading plants and the costs of the gas pipeline to connect the biogas plants, the biogas upgrading plants and the existing gas grid infrastructure are necessary to determine the costs of biogas upgrading. The latter depend on the volumetric flow rate and are divided into four size categories that are shown in Table 2.

Table 2: Cost components of biogas upgrading plants (Urban, Girod and Lohmann, 2009; Beil et. al., 2019)

Raw biogas capacity in m_N^3/h	**250**	**500**	**1000**	**2000**
Investment costs in 10^3 €	**800**	**936**	**1739**	**2600**
Annual expenditure in 10^3 €/a	**229.3**	**326.5**	**523.1**	**982.4**

According to Urban, Girod and Lohmann (2009), the gas pipeline costs are assumed to be 150 €/m. No distinction is made between biogas and natural gas pipelines. The following assumptions are used to determine the total annual costs for the purification plants and the pipeline costs:

- Plant service life: 15 years
- Calculative annuity interest rate: 6 %
- Electrical efficiency of existing CHPs: η_{el} = 37.5 %
- Energy content of methane: $HV_{CH4} \approx 10\ kWh/m_N^3$
- Average methane content of biogas: $c_{CH4} \approx 54$ %

Results

In a first step, the costs of a single upgrading, i.e. one upgrading plant for each biogas plant with a pipeline to the gas grid, were identified. The model calculated cumulated costs of around 39.87 million euros per year for this approach. The problem is that even the smallest upgrading plants are significantly overdimensioned for many biogas plants. This leads to high costs.

Therefore, a common biogas upgrading plant in the center of a biogas plant cluster defines the first optimization approach for a joint upgrading plant. The optimization of the model achieved the lowest costs with 14 clusters. The costs of this approach are approximately 22.94 million euros per year, which means that the total costs of biogas upgrading to methane were almost halved.

In an extended approach, the model was given two options for placing the biogas upgrading plant. Again, the optimal result was achieved with 14 clusters. The system costs could be further reduced; the cost reduction is caused by a reduction in pipeline costs. The total annual cost in this approach is 22.82 million euros per year. The upgrading plant is placed at the center of the cluster in two-thirds of the clusters, so the variant of the first approach is still the best connection option. Thus, the total annual costs could be reduced only marginally. Figure 3 shows the result of the modeling.

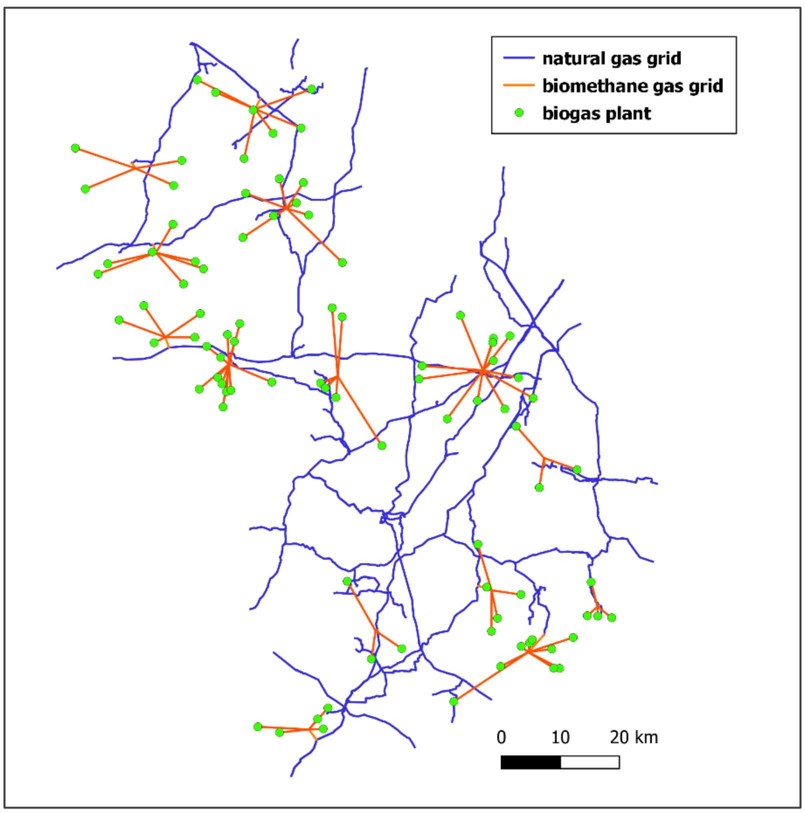

Figure 3. Result of the modeling: Infrastructure to connect the clusters to the gas grid

The results for a varying number of clusters are shown in Figure 4. The costs for biogas upgrading in individual facilities are significantly higher than in the joint operation of biogas upgrading facilities for several biogas plants. By contrast, the pipeline costs for forming fewer clusters are higher than in the models with more clusters. There are some minor up- and downward movements in the graph of the costs for upgrading, meaning that, in some cases, another cluster leads to the same or lower costs for upgrading, although there must be at least one more upgrading plant. This results from the fact that the installed capacity of the purification plants can partly be better utilized with more clusters and an optimal cluster composition.

In summary, the modeling shows that 14 clusters combine the advantages of both extreme approaches. The upgrading costs are reduced by combining the biogas plants into clusters. The advantage of a collaborative upgrading results from the use of the degressive costs of the biogas upgrading plants with increasing size and an adequate use of the plant sizes, so that small biogas plants particularly do not use oversized upgrading plants. In addition, the pipeline costs are optimized through local clusters and the addition of the second approach to place the upgrading plant.

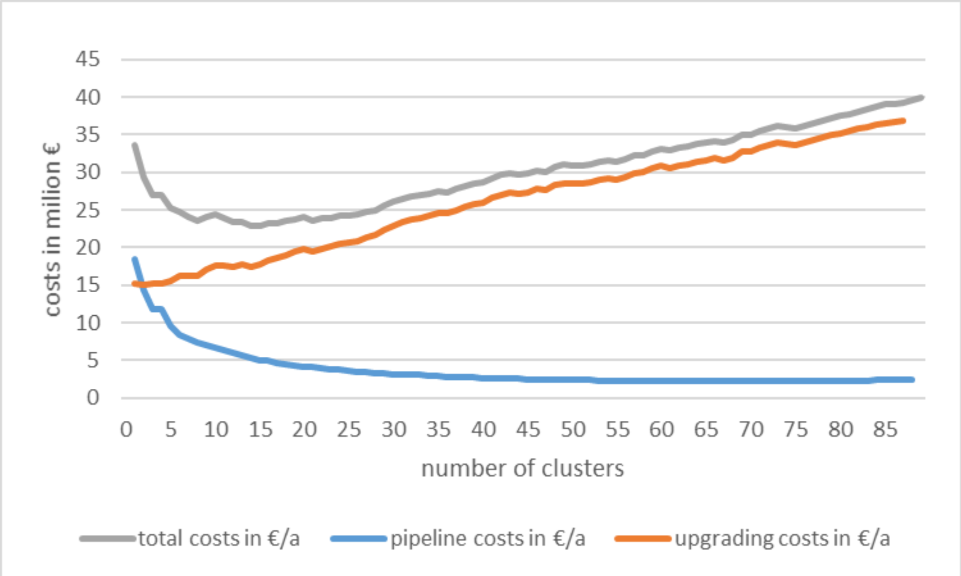

Figure 4. Cost ratio of different cluster options

A significant success of the model is the reduction of system costs as a result of a joint operation of biogas upgrading facilities for biogas plant clusters instead of separate units at each single biogas plant. In particular, the minimum of total costs consisting of pipeline costs and upgrading costs is exploited here. The formation of clusters helps to make use of the spatial proximity of different biogas plants for the cooperation and exploitation of cost degression. The approximation of the optimal solution for placement of the upgrading plant is a good approximation of the optimal solution and avoids the NP-hard problem.

Conclusions and policy recommendation

The economics of gas purification depends mainly on the availability of a gas infrastructure and the possibilities of cooperation in the purification process. The more biogas plants that are consolidated for a combined purification, the more the cost of purification decreases. On the other hand, the cost of the pipeline infrastructure increases with an increasing cluster size. The advantage here, however, is that the costs of the biogas upgrading plant are degressive. Therefore, the aim of optimization is to find the perfect number and arrangement of groups for joint upgrading.

Biomethane is a promising energy source with its various application possibilities, which can contribute to the decarbonization of the energy system and, thus, to the energy transition in various application scenarios. A collaborative approach to upgrading was investigated in this work because the upgrading of biogas to biomethane is currently not yet an economical option, especially for small biogas plants.

A mathematical model was developed to solve a two-level CFLP to determine the optimal location for centralized biogas upgrading facilities. The goal was to minimize system costs, consisting of costs for the upgrading facilities and costs for the pipelines. The model determines the optimal number of clusters and the location of the upgrading plant with its associated capacity and subsequent injection point into the existing gas grid. The results of the innovative model show that the costs of biogas upgrading and injection into the gas grid can be almost halved by joint biogas upgrading plants. Thus, the exploitation of cost degression can lead to the upgrading of biogas to biomethane being an economic business model for significantly more biogas plants in the future.

The modeling is verified with real data; therefore, it is highly relevant for further infrastructure development in regional energy systems. The model developed enables indications and recommendations for regional planning and political decision-making. A flexible adaptation of the model to local requirements of other regions is possible by using publicly available data for modeling. Thus, the model offers the possibility to co-develop the design of energy systems beyond the model region.

The next step for the realization of the joint upgrading would be the examination of the economic efficiency of the projects in detail. In this work, no statement can be made about the economic efficiency of the concept. Furthermore, the actual implementation of joint upgrading depends in reality on various framework conditions, especially on the willingness of the biogas plant operators to participate in a joint upgrading. Similarly, regarding the real world implementation, how and where gas pipelines and upgrading plants can be built, must be examined.

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