EXPLOITING POTENTIAL FOR ECONOMIES OF SCALE IN BIOGAS PURIFICATION INFRASTRUCTURE

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Overview

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 utilization. Currently, the main usage of biogas in Germany is the direct on-site electricity conversion. Change in regulation (Renewable Energy Sources Act) and coupling of sectors require change in business models. For the wide use of biogas in the natural gas grid, a purification plant is required. It cleans and upgrades biogas in order to produce green gas of natural gas quality. This paper develops an innovative methodology to identify the optimal purification infrastructure for biogas.
Technology depended costs of different purification systems are used to evaluate the optimal size of upgrading plants. Minimum size of biogas purification plants exceeds the size of biogas production capacity of single small biogas fermenters. 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 increasing size of purification installation. Connection charges to the gas grid can be reduced as well with increasing gas production capacity.
As a result, economics of gas purification depend mainly on the availability of gas infrastructure and the possibilities of cooperation in the purification process. The problem can be classified as a location-allocation model. In location-allocation models, 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 is 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.

Methods

The problem can be classified as a two-level capacitated facility location problem. 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. From the upgrading plant, the product, green gas with a methane concentration of more than 95 %, is transported through the pipeline and injected into the grid. Since 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 plants and the gas grid are known and fixed. 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. This qualifies as an NP-hard optimization problem.
A two step Python model is developed to find possible biogas plants for joint upgrading. First, possible locations of the upgrading plants are identified. In the next step, an optimization algorithm is used to approximate the optimal solution. Two approaches for approximation are considered. In the first approach, the upgrading plant for the joint upgrading of a biogas cluster is placed at the center of the cluster. The second strategy to approximate the optimal location places the upgrading plant of each cluster at the biogas plant closest to the gas grid. This can potentially save costs of building pipelines.
A mathematical model is developed to identify the optimal purification infrastructure for biogas. The objective function is the minimum of system costs, which includes the sum of the infrastructure costs of all clusters. The system costs are based on the sum of costs of the upgrading plants (annual expenditure and annuity of investment costs) and the costs of the pipelines (annuity of investment costs). The optimal number of clusters and the best approximation option for each cluster are determined by the model. The best solution consists of the number of clusters formed, the placement of the biogas upgrading plants, the choice of the capacity required 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 the region.

Results

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 a first step, the costs of individual upgrading, i.e. an processing plant for each biogas plant with a pipeline to the gas grid, were identified. The problem is that even the smallest upgrading plants are significantly overdimensioned for many biogas plants. This leads to high costs. A common biogas upgrading plant at the center of a biogas plant cluster defines the first modeling approach for a joint upgrading. The system costs of this approach are almost halved, compared to the system costs of individual biogas upgrading. In an extended approach, the model was given two options for the placement of the biogas upgrading plant. This further reduced the system costs. The cost reduction is caused by a reduction in pipeline costs. In three quarters of the clusters, the upgrading plant is placed in the middle of the cluster.
The system costs of different clusters were compared to the optimal solution in order to get an idea of the magnitude of the individual cost components. It is evident that the costs for biogas upgrading in individual facilities are, as expected, 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. In summary, it has become clear that in the model region of the administrative district of Osnabrück, Germany, 14 clusters for the covered 90 biogas plants 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 extended approach to place the upgrading plant.

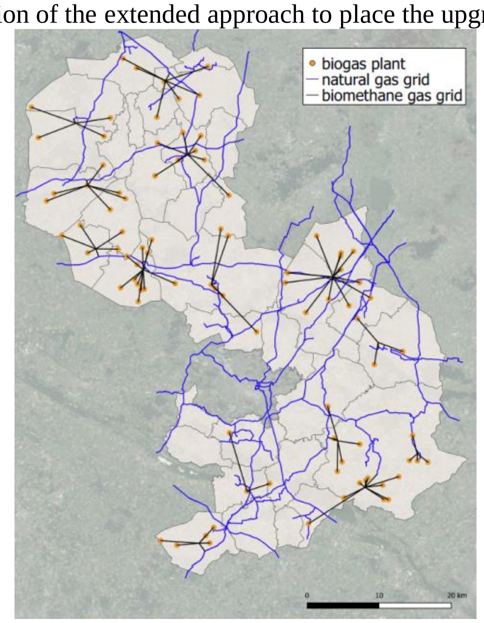

Fig. 1: Result of the modeling: Infrastructure to connect the clusters to the gas grid in the model region Osnabrück

Conclusions

A mathematical model to determine the optimal location for centralized biogas upgrading plants was developed. The aim was to minimize system costs, consisting of costs for the processing plants and costs for the gas pipelines. The model determines the optimal amount of clusters, as well as the location of the processing plant with the associated capacity and the 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 facilities. Since the modeling is verified with real data, it is highly relevant for further infrastructure development in regional energy systems. The developed model enables indications and recommendations for regional planning and political decision making. By using publicly available data for modeling, a flexible adaptation of the model to local requirements of other regions is possible. Thus, the model offers the possibility to co-develop the design of energy systems beyond the model region.

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