Subject no. 5.2: Sustainability assessment and criteria

A tool for analysing, researching and modeling energy efficiency, sustainability and flexibility of biogas chains operating as load balancer within decentralized (smart) energy systems.

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Abstract

Renewable energy is often suggested as a possible solution for reducing greenhouse gas emissions and decreasing dependency on fossil energy sources. The most readily available renewable energy sources in Europe, wind, solar and biomass are dispersed by nature, making them ideally suited for use within Decentralized Energy Systems. Decentralized energy grids can help integrate renewable production, short lived by-products e.g. heat, minimize transport of energy carriers and fuel sources and reduce the dependency on fossils, hence, possibly improving the overall efficiency and sustainability of the energy distribution system. Within these grids balance between local renewable production and local energy demand is an important subject. Currently, fluctuations between demand and production of energy are mainly balanced by input from conventional power stations, which operate on storable fossil energy sources e.g. coal, oil, natural gas and nuclear. Within the long term scope of transition towards a low carbon intensive energy system, sustainable systems must be found which can replace fossil energy sources as load balancer in our energy supply systems.

Decentralised biogas production from co-digestion can become an important player in (future) decentralised smart energy grids. Its flexibility and reasonably steady production throughout the year can make biogas very capable in balancing other more irregular decentralized renewable resources e.g. wind and solar PV and fluctuations in energy demand. Biogas can be transformed into electricity, heat and green gas, which includes most of the energy demand in decentralized energy grids. Green gas is upgraded biogas to natural gas grid quality, ready for injection in the national gas grid. Furthermore, biogas can potentially be stored for longer periods of time. The aforementioned qualities can potentially give biogas a pivotal role in future decentralized renewable energy grids as load balancer. However, maintaining balance between energy demand and supply can be seen as a complex dynamic process, which strives to control several timescales and factors at any given moment. These dynamic factors can range from, short term intermittency in energy demand or production, midterm seasonal fluctuation to long term social and technological developments.

Unfortunately, the sustainability and efficiency of biogas production, operating as load balancer within decentralized energy grids, is not fully understood. Explanation could be, first, currently such energy systems have not yet been commissioned and second, methods and models capable of simulating the aforementioned scenario are lacking. Berglund & Borjesson, 2006, already indicated that biogas production systems are complex to study from a system analysis perspective, as the number of possible biogas system is large due to variety of available raw materials, digestion technologies and field of applications for the digestate and the biogas produced. Unlike wind and solar, biogas is not very abundant, there is only a small amount of renewable biomass available per area for the production of biogas, which also differs per chosen location. Biogas production requires energy inputs partially still supplied by fossils, hidden away in e.g., cultivation, transport, processing, conversion of energy and construction of the various systems. Furthermore, there are multiple biogas production pathways possible, that either upgrade biogas to green gas, produce electricity and heat or use the biogas directly. All the aforementioned variables within the introduction and more make a one size fit all biogas system very difficult to achieve. To find suitable, applications of specific biogas chain operating in decentralised energy system will require some form of optimisation tooling.

From the aforementioned one can conclude that, what is needed is an **optimization tool capable of determining the sustainability and efficiency of biogas production chains operating within a decentralized smart energy system**. The Flexigas project is working towards economic and sustainable integration of biogas into the future national and decentralized energy system (Flexigas, 2013). The main goal is to design a modeling tool, consisting of the dynamic LCA method integrated within a dynamic model. The resulting modeling tool will be capable of integrating biomass availability, energy demand, biogas production and energy production from other renewable sources, such that conclusions can be drawn on the sustainability, efficiency, flexibility and economy of biogas production in the near and far future (2012 to 2050), within local decentralized smart energy grids. The tool can be programmed with average data giving a general overview or it can be programmed with more precise data to give a more specific indication of the performance of biogas pathways. Together with future research the tool can help determine on a general level; if biogas is a suitable renewable energy source and on a more specific level; the tool can help determine how to use the flexibility of biogas most effectively in specific decentralized energy systems.

Two main results are accomplished in this ongoing line of research. First, a new methodology is developed for performing a dynamic LCA. Second a dynamic biogas simulator was developed to incorporate the dynamic LCA method and other functions. In the following section both research lines are explained separately.

The dynamic LCA method: Most Life Cycle Analysis studies focus on single static cases, which do not incorporate dynamic interactions. Therefore, a method is proposed, based on the industrial metabolism concept, capable of determining the sustainability and efficiency of biogas production within a dynamic system. This is achieved by integrating three known methods into one dynamic LCA methods. First, the Material Flow Analysis method is used to simulate the biogas production chain. Second, the Material and Energy Flow Analysis method is used to determine the direct energy and material requirements. Finally, the Life Cycle analysis is used to calculate the indirect material and energy requirements. Complexity in the method is handled with a modular approach that separates the whole system into individual physical processes. Dynamics will be introduced through the use of hourly intervals and relative patterns. One simulation will be the summation of all the static intervals over the cause of one year. The dynamic LCA method will be integrated in a dynamic model that will express resulting dynamic sustainability of biogas production in; first, carbon footprint, second, Energy Returned on Energy Invested and third, EcoPoints.

Dynamic BioGas Simulator: Most simulation software is based on a finely tuned model, which is highly specific and calculates a single set of input parameters. Our approach is to have flexibility in the model, flexibility in the parameters and even flexibility in the components of the model across time. Generating the model dynamically based on the scenario will give us this flexibility. The generated scripts run in Modelica which uses mathematical equations to solve the scenario.

Each part of the LCA method will be represented in the Modelica script which can then be combined together in a dynamic workflow. Leveraging cloud technology, multiple scripts can be generated automatically and run simultaneously with different sets of parameters. The results from the multiple calculations are ranked based on the preferred end result (minimize carbon footprint or maximize returned energy or EcoPoints) and the top10 sets of parameters are selected. The results can then be used to show the best results given different scenario's and compare the scenarios with each other. This allows rapid comparison and evaluation of given models.

Combining the developed Dynamic LCA method with the developed Dynamic BioGas Simulator will result in a faster and better explorable set of results than using a static model with a static simulator. Running thousands of simulations with all kinds of variations is now possible, where time and the dynamics of demand and production can be taken into account. With this combination we have a tool for analysing, researching and modeling energy efficiency, sustainability and flexibility of biogas chains operating as load balancer within decentralized (smart) energy systems. Using the many calculations as mentioned, the reverse process can also be calculated. Given that we want to minimize our environmental impact and carbon footprint or maximize our efficiency, the model can calculate the best combination of applicable input parameters or market conditions to achieve the given. The proposed method and model can expand the current knowledge on carbon footprint, energy efficiency and environmental impact of biogas production within a dynamic energy system. With the gained knowledge advise can be given on the most effective, efficient and sustainable use.

Sources

- Maria Berglundand Pal Borjesson, 2006. Assessment of energy performance in the life-cycle of biogas production. Biomass and Bioenergy 30 (2006) 254–266.
- The Flexigas project 2013, www.flexigas.nl

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Our line of research needs feedback to improve our current vision and trajectory. If possible we like to participate in the poster session and if possible we would also like to present our model through the use of a demonstration setup.