CHAPTER 6

Conclusion and further research
Biogas is a carrier of renewable energy that can contribute to avoid carbon dioxide emission. A great research effort is in place to optimize implementation of biogas based energy systems. Research aims at improving biogas production e.g. improving production of biomass, improving biogas potential by pre-treatment and optimizing the digester configuration. But also research is done on the biogas producer user chain and the role biogas can play in the energy system. There are large differences between the European countries in the quantities of biogas produced and the way biogas is used in heat and power generation or production of green gas. Policies of the European countries with regards to renewable energy and thus to biogas production can be quite different.

In this thesis the focus is on techno-economic modelling of a value chain that includes a dedicated biogas pipeline infrastructure. A model is used to study in what way the use of such an infrastructure influences the costs of energy for the end-user of heat, electricity or green gas. Thereby it aims at answering the main research question formulated as: “To what extent can a biogas infrastructure using pipelines support a viable biogas producer-user chain?”. This was elaborated upon in chapter 2 to chapter 5. In the first of these, a study on green gas production at farm scale is presented. The next two chapters deal with a biogas infrastructure on regional scale. Costs of transport and energy use in a regional biogas grid are evaluated, two lay-outs are discussed. In the regional biogas grid line-pack storage is quantified: the costs of this type of storage and the maximum volume of storage in the grid. In a case study, chapter 5, production of heat and power from biogas collected by a biogas grid in a region is analysed. The scale advantages in CHP and transport costs of biogas in a grid are calculated and these are used to establish the costs of additional electricity and heat. Each of these chapters deals with a sub-question, which was proposed in the introduction. The conclusions with respect to these sub-questions and the main research question are in the next section.

CONCLUSIONS

Sub-question 1: When does decentralized production of biogas and centralized upgrading and injection into the natural gas grid make sense?

Model calculations show that at farm level a large scale centralized digester produces at lower costs as compared to a configuration of decentralized digesters. The difference is 5 €ct and 13 €ct per m³ green gas, for a biogas grid with respectively 2 and 8 digesters that together produce the same quantity of biogas per hour as one centralized digester. For a centralized digester green gas production costs are 62 €ct per m³.

Cooperation of nearby small scale biogas producers is profitable. Instead of investments in several upgrading and injection facilities, combining the efforts reduces costs in spite of the extra investment and operational costs of the biogas grid.

Energy use per m³ green gas is not lower when biogas is produced in decentralized digesters and collected by a biogas grid. Decentralized digestion could be encouraged by legislation, e.g.
environmental arguments limiting the number of transport movements, or requirements with respect of nutrients use. Financial benefits, like subsidies could make up for the difference and encourage the use of decentralized digesters in a biogas grid.

Sub-question 2: **What costs and energy use are associated with biogas transport by dedicated pipelines at regional level?**

Biogas transport in a region is modelled for two types of grid lay-out, a star lay-out and a fishbone lay-out. This to quantify the transport costs and electrical energy needed for this transport. A star lay-out allows for each individual digester to transport the biogas through a single individual pipeline to the end user. In a fishbone lay-out the biogas grid consists of pipeline segments; the biogas from several digesters is collected through relatively smaller pipelines, the ‘branches’, into a larger biogas pipeline. This collecting biogas pipeline, the ‘backbone’, connects to the end user. A fishbone lay-out presumes cooperation between biogas producers, while in a star lay-out they do not need to cooperate in biogas transport.

The range of biogas transport costs in a region are summarized in Table 6.1. Costs of biogas transport in a fishbone lay out are lower than costs of biogas transport in a star lay-out, see Table 1. So cooperation of biogas producers to develop a biogas grid with a fishbone lay-out will lower biogas transport costs. Also larger digesters in a grid induce lower biogas transport costs; biogas transport costs are reduced if several smaller digesters in a region are merged into larger ones.

**Table 6.1:** Range of biogas transport costs in €ct per m³ biogas.

<table>
<thead>
<tr>
<th></th>
<th>Digester scale = 100 m³ h⁻¹</th>
<th>Digester scale = 1800 m³ h⁻¹</th>
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</thead>
<tbody>
<tr>
<td>total area of region (km²)</td>
<td>62</td>
<td>1108</td>
</tr>
<tr>
<td>total biogas production (m³ h⁻¹)</td>
<td>400</td>
<td>7200</td>
</tr>
<tr>
<td>lay-out</td>
<td>star</td>
<td>star</td>
</tr>
<tr>
<td>biogas transport costs (€ct m⁻³)</td>
<td>6.2</td>
<td>45</td>
</tr>
</tbody>
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Energy use per m³ biogas transported increases with the increase of the size of the area of the region, the size of the grid. In a fishbone lay-out larger amounts of biogas have to pass the combined pipeline as compared to a star lay-out. Often the choice of a larger diameter pipeline is financially preferred, rather than increasing the pressure in the grid to facilitate these larger volumes. Therefore direct energy use in a fishbone lay-out is not necessarily higher as compared to a star lay-out. The energy for compression is in the range 0.1 MJ m⁻³ - 0.5 MJ m⁻³, i.e. 0.5% - 2.3% of the higher heating value (HHV) of the biogas.

Sub-question 3: **How much and at what costs can biogas be stored in a regional biogas grid?**

Biogas can be stored in biogas transport pipelines by means of line-pack storage, i.e., a surplus of biogas can be present in pipelines by controlling pressures in the pipelines. The line-pack
storage was modelled for the two grid types introduced above, in order to find storage costs and storage volumes. Line-pack storage does not require additional investments, but storage costs are a result of extra biogas compression costs. Line-pack storage costs thereby depend on the duration of the storage. The model shows that storage costs are roughly between 0.3 €ct m⁻³h⁻¹ and 1.5 €ct m⁻³h⁻¹; line-pack storage costs are specified per hour of storage.

In a grid with small scale digesters, the storage volume is larger, considering the same region size; in small regions the line-pack storage is limited as the total lengths of pipelines is small in that case. In a grid with a fishbone lay-out the line-pack storage volume in a large region is also small; biogas transport pressure is almost the maximal allowable pressure and that condition leaves only room for a small increase in compression.

Other methods of biogas storage are pressureless storage and storage in pressurized pipes. Cost structure differ between the storage methods. While line-pack storage does not require extra investments, pressureless storage and storage in pressurized pipes do. The storage in pressurized pipes also has cycle costs, to charge/discharge the storage. For seasonal storage pressurised pipes are preferred. For short-term storage costs for line pack and pressureless storage are in the same order of magnitude. So line-pack storage is shown to be suitable to accommodate for daily fluctuations of supply and demand.

Sub-question 4: What are potential advantages in heat and power production when biogas is collected from several digesters using dedicated pipelines?

In the case study "West Flanders" a model is used to study scale effects in combined heat and power (CHP) production from biogas. Data from existing digesters were collected. In a model collection of biogas, from 12 agricultural digesters, to a hub by dedicated pipelines is simulated; at this hub the biogas is used to produce heat and power. If heat is not used effectively at a digester site, collection of biogas at a heat sink may improve the overall energy efficiency.

The scale advantage in a CHP results in a higher electrical efficiency. The same supply of biogas to a centralized CHP produces more electrical energy than to decentralized CHPs; so 'additional' electrical energy is generated. Biogas transport costs, as well as negative costs associated with the scale advantage of the CHP, are attributed to this additional energy. Costs of additional electricity are in many cases below 12 €ct kWh⁻¹ when biogas is collected at a digester site. But if biogas is collected at an exocentric site with a small scale digester these costs can be as high as 26 €ct kWh⁻¹. Costs of additional electrical energy are often in the same order of magnitude or lower than costs of electricity generated from biogas at the digester sites. The model showed a potential power increase of 2.4 MW, 9%, when biogas of all 12 digesters is collected at a hub.

If a hub is at a digester site, costs of heat at the hub showed to be lower than 2 €ct kWh⁻¹ assuming an effective heat use of 50%. A central location was selected as a location with potential high heat demand; transport of biogas from one of the 12 digesters to that hub leads to 3.4 MW heat production with costs of 1.95 €ct kWh⁻¹.

If a hub is located close to a heat sink, more renewable energy from a CHP can be used, especially when heat use is low at digester sites. Overall it can be concluded that scale advantages of a larger CHP can be a driver to collect biogas at a hub using a biogas grid.
Main research question: “To what extend can a biogas infrastructure using pipelines support a viable biogas producer-user chain?”.

The model results in the four studies show options of contributions of a biogas pipeline infrastructure to a viable production chain. The quantification of transport costs and line-pack storage costs makes it possible to estimate the impact of implementation of a biogas grid on final energy costs at the end user. Line-pack storage adds to flexibility in the energy system. The collection of biogas at a hub induces scale advantages, with regard to investment and energy efficiency. Environmentally, decentralized biogas production may reduce biomass transport.

OUTLOOK

Natural gas production in the Netherlands.
In the Netherlands the production level of natural gas in the Groningen gas field is under discussion. The government has indicated that the production is to be reduced in coming years from 19.4 Gm³ in 2018-2019 to 12 Gm³ in 2021-2022, lowering further to close to zero in 2030. Green gas from biogas is mentioned as a substitute [1]. This is a result after protest from citizens in the province of Groningen that suffer from by natural gas production induced earthquakes that increase in number and strength, as was published in the international press [2]. The recent speed up of the natural gas reduction scheme has increased attention for the production of biogas, as green gas can replace natural gas. But the volumes produced are small as compared to the volumes of natural gas in the present situation [3].

Energy crops.
Within the Netherlands an ongoing discussion on sustainability of utilization of biomass is taking place. This includes the potential competition of biomass uses in what is often described as a “food versus fuel” discussion. Different opinions and interpretations were within politics and businesses, but also within the scientific community. These differences in interpretation inhibits the constructive development of biomass options. It is suggested that bio-refining of aquatic biomass, e.g. seaweed, could be a promising technology beyond discussion [3]. In some other European countries policies have changed from supporting energy crops to encouraging bio-waste streams as a (co-)substrate, e.g. Germany, Austria and Scandinavia [4, 5]. An Austrian study reveals the impact of feedstock change, from mainly (90%) maize silage to biogenic waste and agricultural residues, on biogas production costs. In general the overall costs increase, as a result of increased logistic costs and higher installation costs, although the costs of biomass itself may be lowered. The author concludes that policies should take these additional costs for alternative feedstocks into account [5].

In our model calculation a substrate with 50% manure and 50% maize is assumed. If bio-waste will replace energy crops as a substrate for digestion, generally this results in lower biogas potential per area, the average area needed for a digester with the same scale increases.
biogas transport model still can be used, but an input parameter has to be adjusted to account for the lower biogas production per km². In chapter 3 the sensitivity of the biogas transport model to this parameter is discussed; table 6.2 of that chapter shows the variation in transport cost as a result of variation in yearly biogas production per km².

**Bio-based economy.**

The concept of a bio-based economy is based on the idea of a fully renewable economy that relies on biomaterial for energy and material use. A ‘pyramid’ illustrates the concept, Figure 6.1. Within the bio-based economy the biomass should first be used for high value materials as pharmaceuticals and fine chemicals, then in nutrition *i.e.* food and feed. Next is the production of bulk chemicals, performance materials and fertilizers. The last stage is use in energy applications, transportation fuel, power and heat. In that way the total economic value of biomass is optimized. This process is summarized as bio-refining in analogy of refining in the fossil industry. As the added value lowers within the cascading, the volume (or mass) of the biomass increases. For the high value materials the biomass volume can be low, while for the energy applications large volumes are available [6]. The use of *e.g.* maize is reserved to the application in nutrition, and not to energy production. Within the bio-based economy concept the type of biomass used in biogas production will change.

![Biomass value pyramid](image)

**Figure 6.1:** Biomass value pyramid, adapted from [6]
The cascading of biomass processing as proposed in the bio-based economy concepts also requires spatial coordination. The logistics along the cascade is not self-evident; probably the processes in the different steps of the cascade are close together, reducing costs of logistics. In the last cascade step, energy production could be production of biogas, while the end user of the biogas may not be at the same site. In that case biogas transport by pipeline is an option to assist completion of the cascade.

**Biogas applications in 2050 in the Netherlands.**

According a report by Warmenhoven et al. the potential of biogas in the Netherlands is estimated to be 510 Mm$^3$, 971 Mm$^3$ and 1092 Mm$^3$ natural gas equivalent in 2020, 2030 and 2050 respectively. In 2050 a strong reduction of energy use and increase of renewable electricity production is foreseen. At that time biogas could play a role as a buffer in electricity production, e.g. for peak load; providing low temperature heat in some specific built environment; as fuel in heavy transport and production of high temperature process heat in industry. Additionally biogas could serve as a feedstock in industry, replacing fossil carbon. The positioning of biogas tends to be in large scale, often industrial, applications [3].

Large scale industrial biogas use needs large amounts of biomass as a substrate. Processing of the biomass in a digester close to the biomass sourcing area reduces the biomass transport effort, while in a regional grid the biogas can be collected from these digesters to an industrial site.

**FURTHER RESEARCH**

In general, other studies could be performed that involve biogas, whereby biogas production and use are spatially separated and when scale advantages are expected within the biogas-producer-user chain.

Research on the biogas producer-user chain including the biogas grid could aim to extend the model with quantification of greenhouse gas emissions and life cycle analysis (LCA). This could include the use of biogas as a source of energy for the production chain itself. Methods for evaluation of greenhouse emissions and LCA are available [e.g. 7, 8].

In a case study the costs of pipelines could be more specific to the location. This could be done using a Geographic Information System (GIS). Weidenaar developed an algorithm that assigns a pipeline route depending on laying costs based on two categories: rural and urban; the algorithm also optimizes pipeline diameter for this route [9].

Green gas production from biogas facilitates the use of the natural gas grid for transport and distribution of energy. In a case study a comparison could be made between two different set ups: On one hand a biogas producer-user chain including a biogas grid and a CHP at a hub, where an end user is located. On the other, a chain where at a hub biogas is collected and
upgraded; green gas is fed into the natural gas grid to be used in a CHP to produce power and heat at an end user. Such a research would contain elements of chapters 2, 3 and 5 of this work.

As the share of intermittent renewable energy sources increases, the proposition of biogas as a source of dispatchable renewable energy suitable for balancing the electricity grid is interesting. Storage of biogas could support flexible production of electricity. It is worthwhile to know to what extent line-pack storage in a biogas grid could serve this goal. A model simulation in a case study, could help to find out how much and at what costs line-pack storage contributes to flexible electricity production from biogas.

The business model of the value chain including a biogas grid needs attention as well. This could aim at identification of all stakeholders that are involved and research on what value can be created by these stakeholders [e.g. 10].
6.1 REFERENCES


[9] Weidenaar, T. Designing the biomethane chain through automated synthesis [Phd thesis]. Enschede, University of Twente; 2014
